# QUATERNARY HISTORY, PALAEO-GEOGRAPHY AND SEDIMENTOLOGY OF THE HUMBER RIVER BASIN AND ADJACENT AREAS

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# QUATERNARY HISTORY, PALAEO-GEOGRAPHY AND SEDIMENTOLOGY OF THE HUMBER RIVER BASIN AND ADJACENT AREAS

by

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A thesis submitted to the School of Graduate
Studies in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Department of Geography
Memorial University of Newfoundland
1998

St. John's
Newfoundland

# <u>Abstract</u>

The Humber River basin in western Newfoundland was completely glaciated during the Quaternary. Glacial erosional features show an early southward ice flow from a source north of the basin that covered the coastal margins in the western part of the basin, including the Harrys River valley. Subsequent regional ice flow was southwestward to northwestward from a dispersal centre on The Topsails. South to southwestward flowing ice from the Long Range Mountains occupied the upper Humber River valley. This flow was confluent with ice from The Topsails flowing northwestward towards Bonne Bay.

Ice retreated from the inner coast about 13 ka. During retreat, ice occupying the Deer Lake Valley dammed a proglacial lake in the adjacent Grand Lake basin to an elevation up to 85 m above present lake levels, as interpreted from strandlines on the west side and deltas on the east. This lake, named glacial Lake Howley, drained through its western end into the Harrys River valley via a well-defined channel. Drainage followed the modern Harrys River valley, reaching the sea in northern St. George's Bay. The lake was lowered by exposure of the South Brook valley outlet, and finally drained catastrophically through a spillway at Junction Brook.

Marine incursion accompanied glacial retreat in the Deer Lake valley. Marine limit at the coast was 60 m asl, based on the elevation of a delta in the Hughes Brook valley. Inland deltas found at the head of Deer Lake and fine-grained sediment exposed within the Deer Lake valley show inundation below 45 m modern elevation. Dated marine macro-fossils in the Humber

Arm and lower Humber River valley, indicate the deltas at the head of Deer Lake formed about 12.5 ka.

# Acknowledgements

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# Chapter 1

# Introduction to the Geography of the Humber River Basin

**Preamble**

This thesis represents the culmination of several years of investigation into the Quaternary history of the Humber River basin area. The work has been sponsored by the Geological Survey of the Newfoundland Department of Mines and Energy, and is part of the ongoing systematic investigation of the Quaternary geology of Newfoundland. Initial research began in 1989 as a reconnaissance project to resolve conflicts in reported interpretations of ice flow history in the upper Humber River basin area. It was apparent that the basin had a complex glacial history, possibly acting as a conduit for ice from dispersal centres on the Long Range Mountains to the north and The Topsails to the east, as well as remnant ice centres on Birchy Ridge. The presence of several large communities in the Humber River valley, with expanding infrastructure and a diverse resource-based local industry, assisted the decision to elevate the initial project into a full-scale mapping programme. Further impetus for doctoral research resulted from recognition of a large inland pro-glacial lake that existed during deglaciation, and the discovery of thick sequences of waterlain muds up to 50 km inland of the present coast. These investigations have significant implications for the Quaternary history of the west coast of Newfoundland. The description of the Quaternary stratigraphy, and resolution of the ice flow history of the Humber River basin, has allowed significant re-interpretation of the deglacial and early Holocene history of

this part of the west Newfoundland coast. It also has broader implications for the Quaternary chrono-stratigraphic framework of Atlantic Canada.

**Location and Access**

The study area extends between 48° 30' and 49°47'N, and from 56° 30' to 57° 54'W, and includes all or parts of 17 1:50 000 scale NTS map sheets, 12A/11, 12, 13, 14, 15; 12H/2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13; and 12B/9 (Figure 1-1). It includes the area defined by the Humber River basin and smaller catchments along the western margin of the basin, including Corner Brook, Hughes Brook, Old Mans Brook, and Goose Arm Brook (Figure 1-2). The Humber River basin covers an area of approximately 4400 km$^2$. The maximum dimensions are 145 km for length, from Little Grand Lake in the south to within 10 km of the coast near St. Paul's Inlet in the north; and 105 km for width, from Corner Brook in the west to Indian River and The Topsails in the east. The Humber River valley occupies the largest part of the basin, subdivided into the upper Humber River occupying that area north of Deer Lake between Birchy Ridge and the Long Range Mountains, and the lower Humber River occupying that area between Deer Lake and the mouth at Corner Brook. Other components of the basin are the Deer Lake valley, Grand Lake valley, and Birchy Lake valley, all occupied by their respective lakes (Figure 1-2). Much of the basin lies below 100 m elevation, and includes a series of interconnected sub-basins that impound several of Newfoundland's major lakes, including Birchy Lake, Deer Lake, Grand Lake, Hinds Lake, Sandy Lake, and Sheffield Lake.

Much of the area is easily accessible by a network of paved and gravel roads. The Trans Canada Highway traverses the central part, and other roads extend from it to the north and south. Well-maintained gravel roads, constructed to support logging operations, cover many of the intervening areas between the

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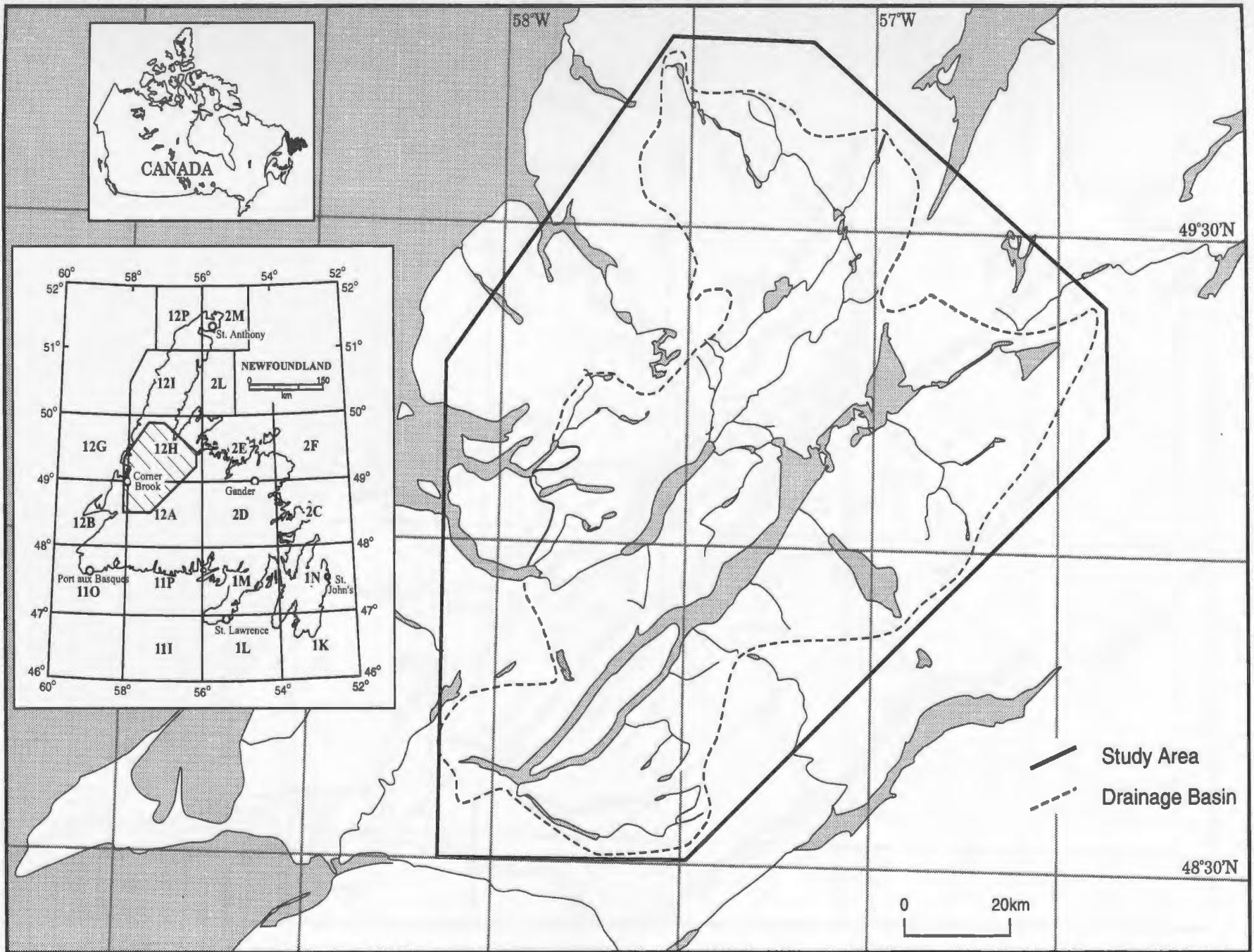
**Figure 1 - 1:** Location of study area.
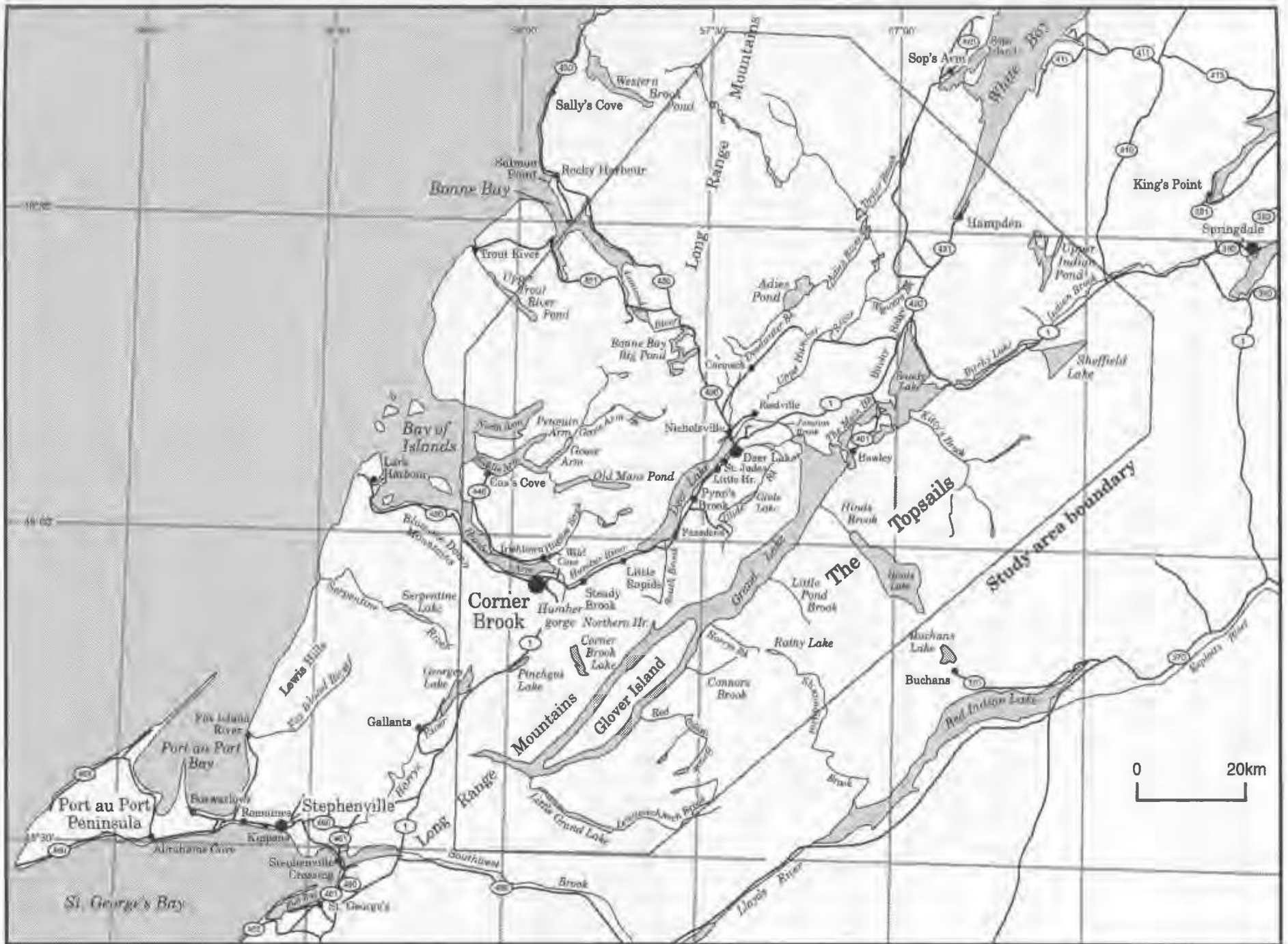
**Figure 1 - 2:** Map of places mentioned in text.

paved roads. The shores of Grand Lake are accessible by boat from Howley and Northern Harbour. Part of The Topsails may be reached by vehicle along the bed of the now-defunct Newfoundland railway. Some areas, such as the summits of the Long Range Mountains, are accessible only by foot or helicopter.

**Early Settlement**

The Humber River valley contains several communities, including Corner Brook, Deer Lake, and Howley (Figure 1-2). The largest is Corner Brook (population 22,500; 1991 estimates) at the mouth of the Humber River. There were no permanent dwellings at the head of the Humber Arm when it was visited by Captain James Cook in 1767. Cook, and his assistant Lt. Michael Lane, mapped part of the Humber River inland to Deer Lake, Sandy Lake and Grand Lake. John Broom of Poole, Dorset established a salmon station in the Corner Brook (originally called Riverhead) area shortly after Cook's visit. The Brake family of Yetminster (Dorset, England) set up a salmon fishery in the 1780's, followed in 1800 by the Bird family of Poole (Dorset). These were presumably the two families mentioned by J.B. Jukes when he visited the area in 1839 in the course of geological investigation (Jukes, 1842). The area was also important for fur-bearing animals. These were originally hunted by Micmacs from Nova Scotia who were landed by the French, and subsequently by British settlers who dislodged the Micmac. The first sawmill was constructed in about 1863, and by the turn of the century the area had developed into a major saw-milling centre harvesting wood from the Deer Lake basin. Expansion of the community resulted from the building of a paper mill in 1925 by the Newfoundland Power and Paper company.

Power is provided for the pulp and paper mill in Corner Brook by the hydro-electric power generating station at the town of Deer Lake. The community

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was established in 1870, originally as a farming settlement, but subsequently to support the mill in Corner Brook. The lake is supposedly named from a herd of caribou which crossed the lake on their annual migration from the Northern Peninsula to the centre of the island (Horwood, 1977). The hydro-electric plant was completed in 1925. It uses the outflow from Grand Lake, the level of which was raised by a dam at Junction Brook. Pulp logs were originally floated down the river, but are now transported by road. Market considerations, infestation of the forests by insects, and the present rate of cutting may affect the long-term viability of the paper mill.

The community of Howley was established as a flag station in 1894 and was named for James P. Howley, Director of the Geological Survey of Newfoundland from 1883 to 1917. It developed as a mining settlement for the nearby mining ventures by Reid Newfoundland Railway Company between 1897 and 1902. Howley contained 13 people in two families in the 1901 census. It became a logging settlement after the 1920's, following establishment of the mill and powerhouse.

An early map of Newfoundland (Figure 1-3) by Cram (1900) shows the communities of Deer Lake, Cormack, Harvey (now Pasadena), and Bay of Islands (now Corner Brook). Birchy Pond (now Birchy Lake) at 125' elevation (38 m) was joined by a narrow channel to Sandy Pond (now Sandy Lake). Sandy Pond was considerably smaller than its modern equivalent, and was joined to Grand Pond (now Grand Lake) at 116' (35 m) by The Main Brook, an 8 mile (13 km) long stream entering Grand Pond near Howley. Howley lay approximately 5 km north of the 1900 shores of Grand Pond. Raising lake levels resulting from construction of the Junction Brook dam enlarged Sandy Lake to include The Main Brook valley and the lowlands northeast of Howley. The dam also produced a slight increase in the
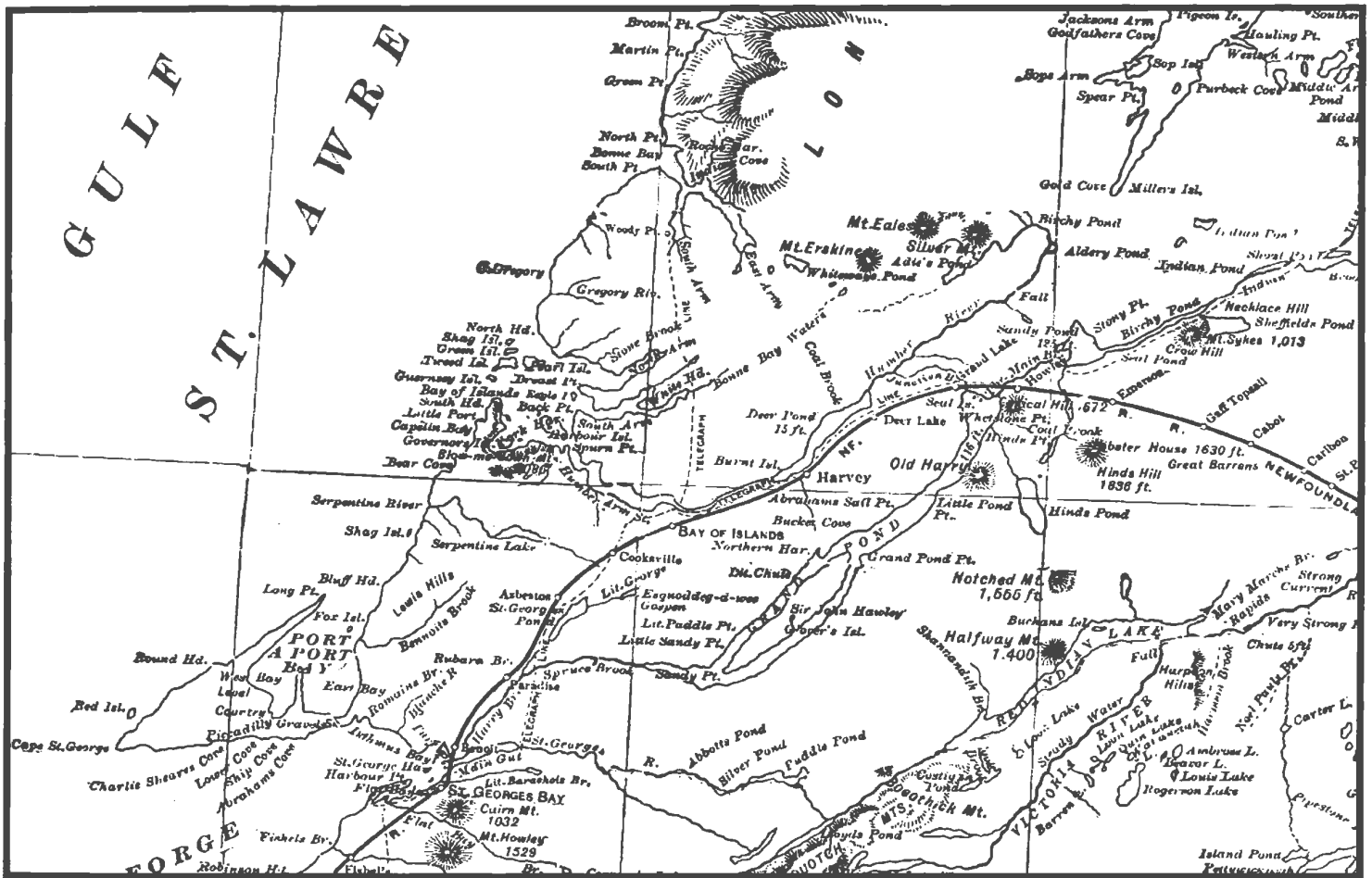
**Figure 1 - 3:** Excerpt from Cram (1900) showing geography of western Newfoundland circa 1900.

surface area of Grand Lake, by inundating the lowlands west of Howley. Although some elevations on the Cram map are accurate, such as Notched Mountain at about 490 m (1600 ft), many are inaccurate (e.g., Mt. Sykes was mapped about 122 m (400 ft) lower than its actual elevation), including the surface elevations of Grand Lake and Birchy/Sandy Lake. Nevertheless, the distribution of land surface features is generally consistent with recently mapped configurations.

## Recent Developments

Corner Brook expanded and diversified to become the major administrative and service centre for the west coast, including Sir Wilfred Grenfell College, which is the west coast campus of Memorial University of Newfoundland. Tourism activity increased since development of the downhill skiing facilities at Marble Mountain, which takes advantage of a heavy and reliable snowfall and the steep slopes flanking the Humber River gorge.

The Deer Lake valley has developed as one of the few agricultural areas in Newfoundland. Strawberries are a major crop on the valley floor, and a strawberry festival is held annually in July or August. Deer Lake is strategically located at the base of the Great Northern Peninsula, and also contains a regional airport. Cormack is a centre for dairy farming.

## Bedrock Geology

An understanding of the bedrock geology of the study area (Figure 1-4) is important to a discussion of the Quaternary history, insofar as it provides data necessary to relate erratic clasts to their sources. Rock types that are visually distinctive and confined to a discrete source area are particularly useful in aiding determination of distances and directions of glacial transport.
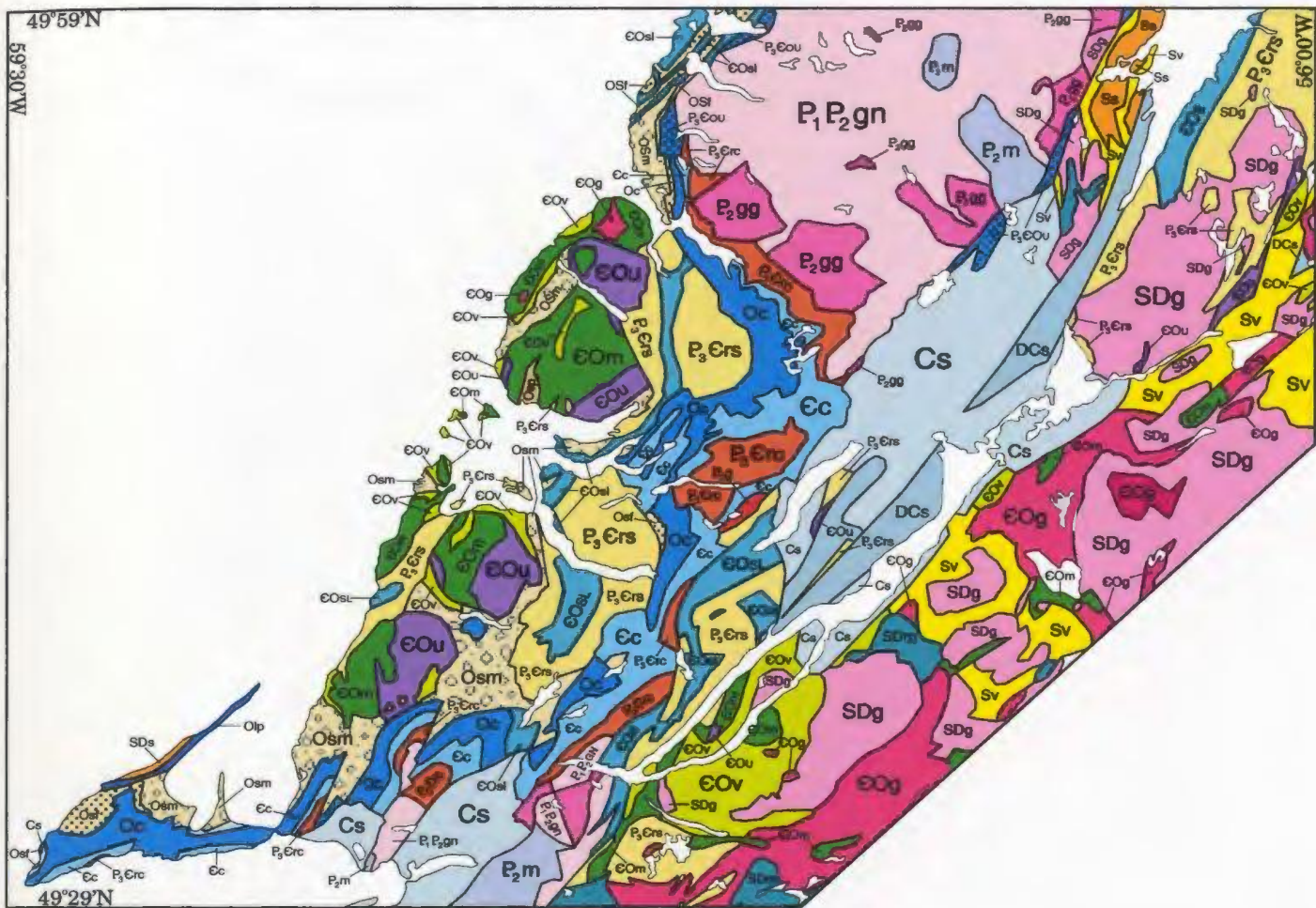
**GEOLOGICAL LEGEND**

**Carboniferous (360 to 286 Ma)**

`Ca` Fluviatile and lacustrine sandstone, siltstone, conglomerate and minor carbonate rocks (Deer Lake Group, Howley Formation)

**Devonian and Carboniferous (408 to 286 Ma)**

`DCs` Fluviatile and lacustrine sandstone, shale, conglomerate and minor carbonate rocks (Anguille Group)

**Silurian and Devonian (438 to 360 Ma)**

`SDs` Shallow marine sandstone, conglomerate, limey shale and thin-bedded limestone.

`SDg` Gabbro-syenite-granite-peralkaline granite intrusive suites and unseparated volcanic rocks

`SDm` Gabbro and diorite intrusions, including minor ultramafic phases

**Silurian (438 to 408 Ma)**

`Sv` Felsic volcanic rocks (includes unseparated sedimentary rocks)

`Ss` Shallow marine and non-marine siliciclastic sedimentary rocks, including sandstone, shale and conglomerate

**Middle Ordovician (480 to 460 Ma)**

`Om` Shallow marine limestone, shale and sandstone

`Osp` Breccia, shale and sandstone

**Early to Middle Ordovician (505 to 460 Ma)**

`Ost` Sandstone and shale turbidites, and carbonate breccia. Some calcareous black shale

`Osm` Shale-matrix melange, containing blocks of ophiolite rocks

`Oc` Limestone and dolostone (St. George Group)

**Cambrian to Middle Ordovician (570 to 460 Ma)**

`€Osl` Continental slope facies sandstone, shale, carbonates, chert, mafic volcanic rocks (includes part of Curling and Mount Musgrave groups)

`€Ov` Submarine volcanic rocks (includes Glover Group)

**Cambrian and Ordovician (570 to 438 Ma)**

`€Og` Granitoid intrusions

`€Om` Mafic intrusions, including granitoid rocks, gabbro and diabase

`€Ou` Ultramafic rocks of ophiolite complexes

**Cambrian (570 to 505 Ma)**

`€c` Marine shelf limestone, dolostone and shale

**Late Proterozoic and Cambrian (900 to 505 Ma)**

`P₃€rc` Rift and transitional shelf facies: non-marine conglomerate, sandstone and mafic volcanic rocks; marine shale, sandstone limestone and dolostone (includes part of Reluctant Head Formation, Old Man's Group)

`P₃€rs` Rift and transitional continental slope facies: sandstone, shale, conglomerate and mafic volcanic rocks (includes part of Curling Group)

**Late Proterozoic to Middle Ordovician (900 to 460 Ma)**

`€Oi` Undivided siliciclastic and carbonate rocks (includes parts of Port au Port and St. George groups)

**Late Proterozoic (900 to 570 Ma)**

`P₃g` Granitoid intrusions

**Early to Middle Proterozoic (>1600 to 900 Ma)**

`P₂gg` Granitoid intrusions

`P₂m` Mafic and anorthositic intrusions

`P₁P₂gn` Granitic gneiss, mafic gneiss and paragneiss

**Figure 1-4:** Bedrock geology of the Humber River basin and surrounding areas (after Colman-Sadd *et al.*, 1990)

The central part of the study area is an interior basin underlain by Carboniferous flat-lying terrestrial, fluvial and lacustrine rocks of the Deer Lake Group (Hyde, 1979, 1984). These consist of red conglomerate, sandstone, and siltstone (North Brook Formation), grading upwards to well-bedded to laminated grey to red siltstone and mudstone, with thin limestone beds (Rocky Brook Formation). Coarse arkosic sandstone, pebble conglomerate, and sandstone (Humber Falls Formation) compose Birchy Ridge, on the eastern margin of the basin.

The northwestern part of the Deer Lake basin is flanked by the Long Range Mountains which are mostly underlain by Proterozoic gneiss and granitic gneiss (Erdmer, 1986; Owen, 1986). Proterozoic medium- to coarse-grained metagabbro crops out northwest of Taylor Brook (Owen, 1986), and a small area of Late Proterozoic to Middle Ordovician quartzite crops out north of Adies Pond (Hyde, 1979). Proterozoic gneiss and granitic gneiss is also found at the western end of Grand Lake.

West of Deer Lake are Cambrian to Ordovician platformal rocks (Williams and Cawood, 1989). These include limestone and dolostone (St. George Group, Port au Port Group, Reluctant Head Formation), and shale, greywacke, and conglomerates (Curling Group, Old Mans Pond Group). Ophiolitic rocks associated with the Humber Arm allochthon, formed during the Taconic orogeny, compose the uplands along the outer coast that form the Lewis Hills, Blow-Me-Down Hills, North Arm Mountain, Table Mountain, and Lookout Hills massifs. Harzburgite, dunite, gabbro, and pillow basalt are the common rock types.

A large area of pssamitic and pelitic schist (Mount Musgrave Group) is exposed along the southwestern margin of the Deer Lake basin, and along the north shore of Grand Lake, east to Northern Harbour. Glover Island and the

adjacent south side of Grand Lake are largely composed of basalt and tuff (Glover Group). Silurian volcanic and intrusive rocks (Whalen and Currie, 1988; Saunders and Smyth, 1990) dominate the area to the east and north, including the east side of Grand Lake, Sandy Lake and White Bay (Figure 1-5). Units of particular interest include one- and two-feldspar granites (i.e., potassium-feldspar (e.g., orthoclase) and/or sodium-feldspar (e.g., albite)), some of which are peralkaline (Topsails Intrusive Suite); flow-banded rhyolite, tuff and basalt (Springdale Group); and gabbro, granodiorite and diorite (Hungry Mountain Complex).

Glacial movement from centres around the Deer Lake basin should be shown by the dispersal pattern of clasts in sediments. Material transported by southward-flowing ice from the Long Range Mountains should contain gneiss and granitic gneiss clasts. Depending on the flow path, sediments may also contain clasts derived from the gabbro near Taylor Brook, the quartzite near Adies Pond, or Devonian intrusive rocks that outcrop outside the Humber River basin, west of Sops Arm, such as the Gull Lake Intrusive Suite or the Devils Room granite.

Dispersal into the Deer Lake basin from The Topsails would, depending on the location of ice dispersal centres, potentially include clasts from a variety of granites, including peralkaline units. In addition, clasts from gabbro, rhyolite, basalt, gneiss, and other intrusive and volcanic rocks could be present.

There is some potential overlap in clast assemblages derived from these two source areas. Clasts derived from units that appear petrographically similar, however, can be differentiated in hand specimen based on their mineralogical composition. For instance, gabbro exposed near Taylor Brook is dominantly a medium- to coarse-grained, mesocratic, pyroxene ± olivine ± amphibole metagabbro (Owen, 1986). In contrast, the gabbro of the Hungry Mountain Complex is a fine- to coarse-grained hornblende gabbro. Gabbro of the Topsail
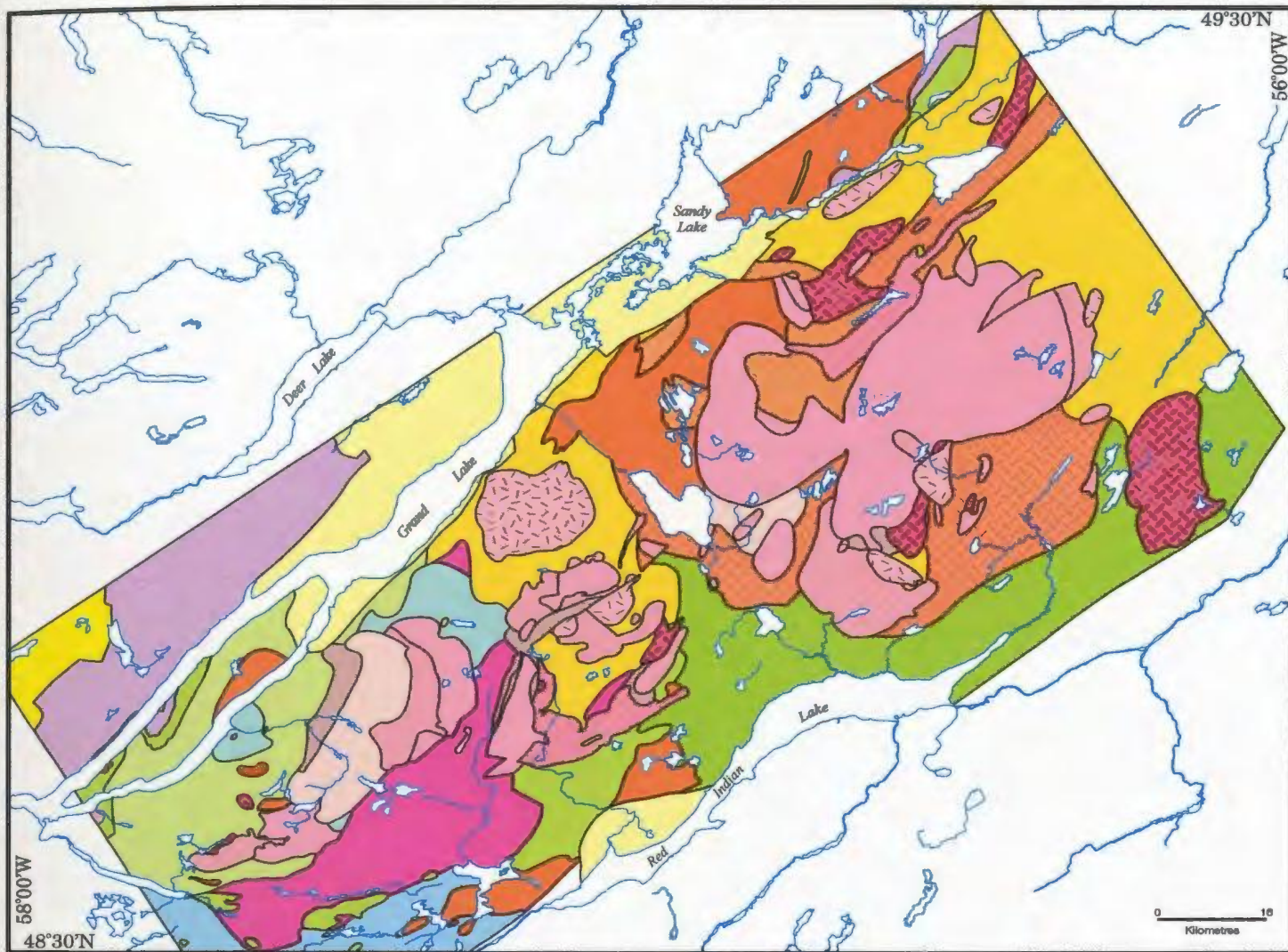
## Legend

**CARBONIFEROUS**

*Clastic sedimentary rocks, including sandstone, siltstone, mudstone, conglomerate and arkose. Forms parts of the Anguille Group, Deer Lake Group, and Howley Formation.*

**SILURIAN**

**TOPSAILS INTRUSIVE SUITE**
*Sq: Quartz-feldspar porphyry (in large part Peralkaline) rhyolite, porphyritic rhyolite, and minor basalt*

*Sm: White to red, fine to medium grained equigranular, one- and two-feldspar granite; minor quartz-feldspar porphyritic granite and aplite*

*Sp: White to red, medium to coarse grained equigranular amphibole sodic pyroxene one-feldspar granite*

*Sg: White to pink, medium to coarse grained biotite amphibole two feldspar granite*

*Ssy: Red, medium grained porphyritic two feldspar, quartz syenite to granite; grey to orange medium to coarse grained gabbro to quartz syenite*

*Sa: Agmatite of mafic to ultramafic blocks in granitic to granodioritic matrix*

**SPRINGDALE GROUP**
*Ss: Red flow banded rhyolite, rhyolite breccia; amygdaloidal and massive subaerial basalt*

**SILURIAN OR ORDOVICIAN**

**RAINY LAKE COMPLEX**
*Fine to coarse grained amphibole-clinopyroxene gabbro, diorite and quartz diorite and amphibole biotite granodiorite*

**ORDOVICIAN**

*Oi: White to red, massive to slightly foliated granite to granodiorite.*

**BUCHANS GROUP**
*OB: Basalt, rhyolite, tuff, diabase and gabbro.*

**GLOVER GROUP (OG)**
*OG: Pillow basalt, massive basalt, agglomerate, diabase, tuff and conglomerate.*

*Os: Platformal sedimentary rocks; includes Table Head Formation and St. George Group.*

*Og: Massive to moderately foliated granodiorite, biotite muscovite and biotite amphibole granite, and minor tonalite, with many small mafic to ultramafic fragments.*

*Ot: White to grey medium to coarse grained hornblende biotite tonalite to diorite, moderately to strongly foliated.*

**HUNGRY MOUNTAIN COMPLEX (Ohm)**
*Ohm: Moderately to strongly foliated hornblende gabbro to granite with many small to large mafic to ultramafic inclusions.*

*Om: Basalt, gabbro, hornblende, pyroxenite, ophiolitic rocks.*

**HADRYNIAN TO LOWER PALEOZOIC**
**FLEUR DE LYS SUBGROUP**
*Hf: Semipelitic schist and psammitic gneiss.*

**Figure 1-5**: Bedrock geology of The Topsails (after Whalen and Currie, 1988)

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Intrusive Suite has elongate clinopyroxene crystals with amphibole rims, euhedral plagioclase, and interstitial K-feldspar (Whalen and Currie, 1988).

Granites found in the igneous terrane west of White Bay also have distinctly different physical properties from those found on The Topsails. In the White Bay area, the Moose Lake pluton is a pink to red, coarse-grained to megacrystic biotite granite (Saunders and Smyth, 1990). The Devils Room granite has pink to white K-feldspar megacrysts up to 25-cm long, with minor quartz (Saunders and Smyth, 1990). In contrast, granites exposed on The Topsails are extremely variable. The Hinds Brook granite, cropping out between Hinds Lake and Sandy Lake, is a white to pink, medium- to coarse-grained biotite-amphibole, K-feldspar, porphyritic two-feldspar granite. Granites of the Topsail Intrusive Suite are white to red, fine- to medium-grained equigranular, biotite ± amphibole, one- or two-feldspar granites, in large part peralkaline. In particular, the granite (Sp) that crops out over a large part of The Topsails from Lewaseechjeech Brook, south of Glover Island, to the vicinity of Sheffield Lake (Figure 1-5) is a peralkaline coarse-grained amphibole granite with prominent quartz grains and a distinctive interstitial habit to the mafic minerals (Whalen and Currie, 1988).

Similarly, distinctive rhyolite clasts can be identified. Rhyolites found in the Natlins Cove Formation (Smyth and Schillereff, 1982), south of Sops Arm, are pink to dark grey, with flow banding defined by opaque minerals, and quartz and feldspar phenocrysts. Rhyolites on The Topsails are assigned to the Springdale Group, which covers a large area extending northeast from Shanuainrit Brook towards White Bay (Figure 1-5). The Springdale Group rhyolites include red, almost structureless rocks with little layering or flow-banding; orange to red units with sparse, small phenocrysts; rhyolites mixed with globules of basalt in a lava flow; breccias; and flow-banded rhyolite dykes (Whalen and Currie, 1988). Table 1-

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1 provides a summary of distinctive rock types and their characteristics.

In addition to the physical differences between individual clasts of gabbro, granite or rhyolite, the character of dispersal trains derived by a single glacial movement from sources in either the Long Range Mountains or The Topsails would be characterised by distinctive assemblages of clasts. Dispersal from The Topsails should be characterised by a wide range of clast types, reflective of the diverse bedrock geology. Long Range Mountain assemblages should be more homogenous, unless ice flow was southward across the volcanic and igneous rocks west of White Bay. Clasts of Carboniferous sediments found outside the Deer Lake basin would reflect dispersal from that source area.

## Physiography

The area of Newfoundland above sea level has been subject to subaerial erosion processes for the last 245 million years (since the deposition of Carboniferous sediments in the basins of western Newfoundland). The province has endured repeated cycles of denudation and subsequent uplift, most recently in association with Quaternary glaciations. The physiography of the province thus has erosional surfaces modified by more recent glacial and post-glacial processes.

The western part of the study area is dominated by the Long Range Mountains (Figure 1-6), part of the Atlantic Uplands of Goldthwait (1924) and Bostock (1970). They extend from the southwest tip of Newfoundland along the Great Northern Peninsula to 51° N. They are characterised by flat-topped peaks, with a maximum elevation of 814 m asl in the Lewis Hills. Elevations decrease to the north and south, although peaks reach up to 500 m asl in the far southwest. The upland plateau surfaces are commonly flat, featureless, deeply weathered surfaces with wide valleys and gentle slopes. The upper surfaces have been interpreted

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**Table 1-1:** Rock types used in clast dispersal studies, and their physical characteristics. Nomenclature in brackets corresponds to that used on Figure 1-5.

| Rock unit | Area found | Texture | Colour | Rock type | Main minerals | Distinctive features |
|---|---|---|---|---|---|---|
| Hungry Mountain Complex (Ohm) | Around Hinds Lake, extending northeast to Sheffield Lake | Fine to coarse | Dark | Gabbro | Hornblende | Moderately to strongly foliated; one of few gabbro outcrops in area |
| Springdale Group (Ssf) | Northward on The Topsails, from Lewaseechjeech Brook | Fine | Red | Rhyolite | | Flow banded; one of few rhyolite areas |
| Rainy Lake Complex (SOrl) | Around Rainy Lake | Fine to coarse | Dark | Gabbro | Amphibole, clinopyroxene | Mildly saussuritized |
| Topsails Intrusive Suite (Sqa) | West of Hinds Lake, west of Sheffield Lake | | Orange to green | Porphyry | Quartz, feldspar, peralkaline minerals (e.g., aegerine, arfvedsonite, aenigmatite) | Colour, porphyritic, peralkaline |
| Oib (Hinds Brook granite) | North of Hinds Lake toward Sandy Lake | Medium to coarse | White to pink | Granite | Biotite, amphibole, K-feldspar | K-feldspar porphyritic, contains 2 feldspars |
| Hf (Mount Musgrave Group) | West side of basin | Fine to medium | Dark grey | Schist / psammite | Mica, quartz | Only micaceous schist in area |
| Deer Lake Group | Deer Lake basin | Fine to coarse | Red | Sandstone | | Only source of red sandstone in area |
| Deer Lake Group | Deer Lake basin | Fine | Red | Siltstone | | Only source of red siltstone in area |
| Devils Room granite | West of Sops Arm | Coarse | Pink | Granite | Quartz, plagioclase, biotite | Euhedral K-feldspar megacrysts |

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| Rock unit | Area found | Texture | Colour | Rock type | Main minerals | Distinctive features |
|---|---|---|---|---|---|---|
| Gull Lake Intrusive suite | West of White Bay | Fine | Dark | Gabbro | Amphibole, plagioclase | |
| Gull Lake intrusive suite (Moose Lake granite) | West of White Bay | Coarse | Pink to red | Granite | K-feldspar, plagioclase, quartz | Massive, contains microcline megacrysts |
| Grenville basement | Long Range Mountains | Fine to medium | Pink to grey | Gneiss, granite gneiss | Quartz, feldspar | Foliated rock, generally confined to north and south margins of area |
| Carbonate | West part of area | Fine | Various | Limestone, dolomite | Carbonates | Confined to west part of area |
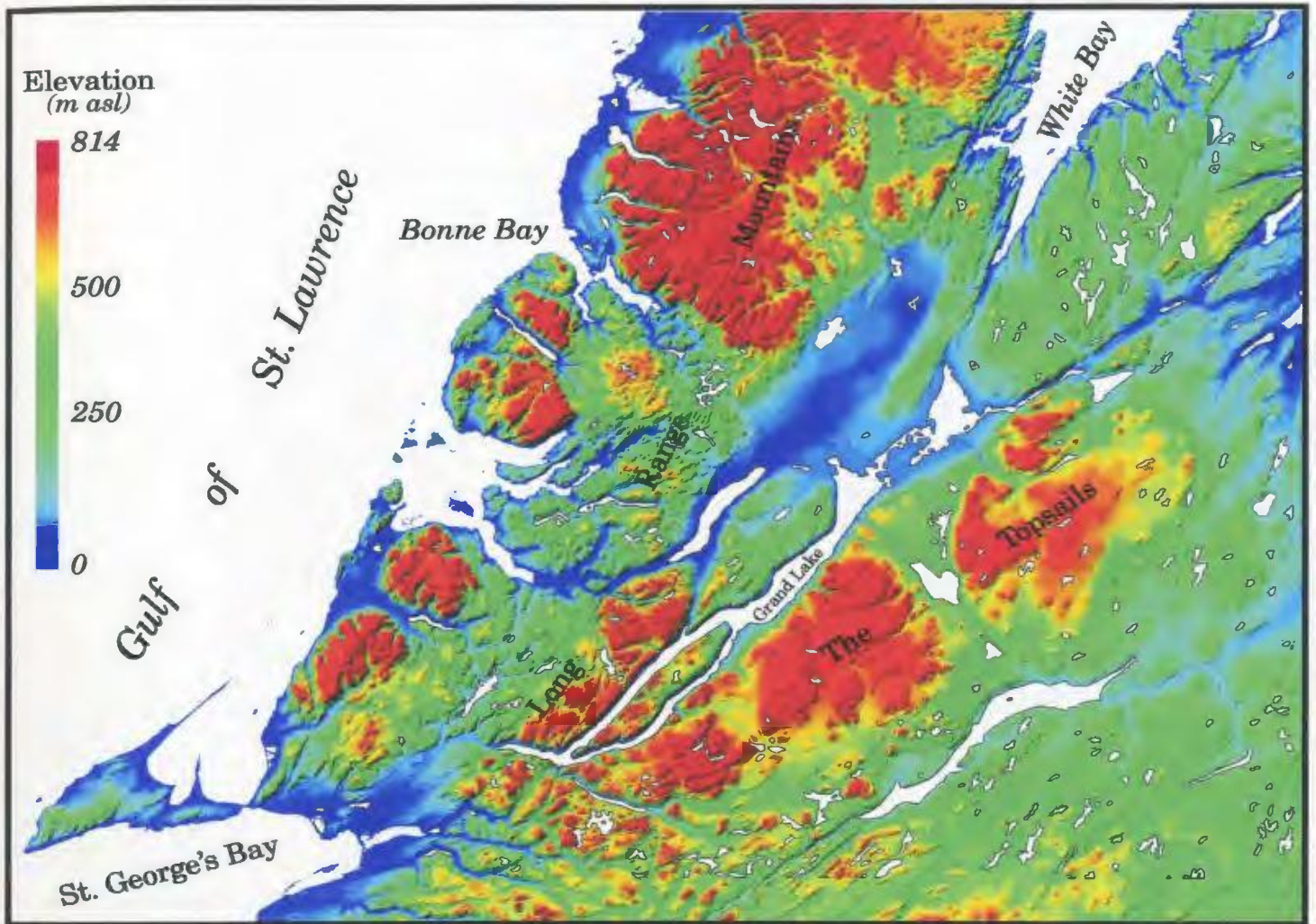
**Figure 1-6:** Shaded relief map of the Humber River basin and surrounding areas. A graduated fill from blue to red has been used to illustrate relief, from lowlands to highlands, respectively. The maximum elevation on the map is 814 m asl, in the Lewis Hills. Refer to Figure 1-2 for place names.

to represent uplifted erosional surfaces or peneplains (Twenhofel and MacClintock, 1940; Brookes, 1974; Rogerson, 1981; Grant, 1987). Erosional surfaces were identified at three elevations on the west coast, all of which tilt up towards the northwest, probably as a result of differential uplift (Twenhofel and MacClintock, 1940).

The upper surface is the Long Range Peneplain. It encompasses surfaces at about 600-650 m asl in the Long Range Mountains, dipping eastward to The Topsails, east of Grand Lake, where it is represented by four erosional remnants. These are the Gaff Topsail (573 m asl), Main Topsail (555 m asl), Mizzen Topsail (537 m asl) and Fore Topsail (491 m asl). Higher peaks in the Long Range Mountains, such as in the Lewis Hills (814 m asl), Gros Morne (806 m asl), and Round Hill in the Blow-me-down Mountains (762 m asl) may also be erosional remnants (Rogerson, 1981). The intermediate surface is the High Valley Peneplain. It is represented by broad, upland valleys at 520 m asl in the Long Range Mountains, dipping down to 400 m asl over much of the plateau surface of The Topsails. The lower surface, the Lawrence Peneplain, is represented by flat-topped spurs in the Long Range Mountains at about 300 m asl, such as Table Mountain near Stephenville and the broad lowland on the southern part of The Topsails north of Red Indian Lake.

The age of the erosional surfaces is problematic. Brookes (1974) suggested they are pre-Quaternary, probably formed during the Mesozoic or early Cenozoic. The surfaces truncate all rock types, and are overlain only by a thin, discontinuous veneer of Quaternary sediment. Kerr (1994) noted that the commonly observed yellow and yellow-green granites are surface alteration products of a primary green granite. The weathering is the result of alteration of potassium-feldspar crystals and extends to a depth of up to 10 m. Granite blocks quarried for

construction about 100 years ago have a less than 1 mm-thick weathering rind, and many granite surfaces are striated.

The Long Range Mountains are only breached in two places along their length. At the southwestern end of Grand Lake, a broad valley (up to 1500 m wide) extends to Harrys Brook (Figure 1-7). The valley is locally flat-bottomed, and contains numerous exposures of sand and gravel. Modern drainage shows a poorly defined watershed at about 122 m asl in the vicinity of Gallants Junction on the Trans Canada Highway. To the east, Grand Lake Brook flows south through a narrow valley east of Georges Lake, to the area of the watershed where it turns east and flows through a 5000 m long channel into Grand Lake. The lower reach of this channel is incised through Quaternary sediment, and has a gradient of 1:95, compared to a 1:206 gradient upstream. West of the watershed, Ahwachenjeech Brook flows into Harrys River through a sinuous channel. Palaeo-drainage was from Grand Lake southwestward into Harrys Brook, as indicated by the well-defined sinuous, flat-bottomed channel, 170 to 400 m wide, extending 11.5 km from the incised lower reaches of modern Grand Lake Brook to Harrys River valley (Figure 1-7). Drainage into Harrys River may also have been through Moose Pond, which shows a palaeo-channel at its southwest end.

The second breach of the Long Range Mountains is by the Humber River east of Corner Brook (Figure 1-2). The Humber River drains most of the study area. The main channel is 125 km long, and drains through a broad, marshy lowland north of Deer Lake, from its headwaters in the southern part of the Long Range Mountains. It flows into the Humber Arm at Corner Brook through a narrow gorge. The gorge is 4000 m long, and extends 200 m above sea level. It is 700 m wide at plateau level, narrowing to a 300 m wide channel at river level. River gradient through the gorge is about 1:1000. The Humber River gorge does not have
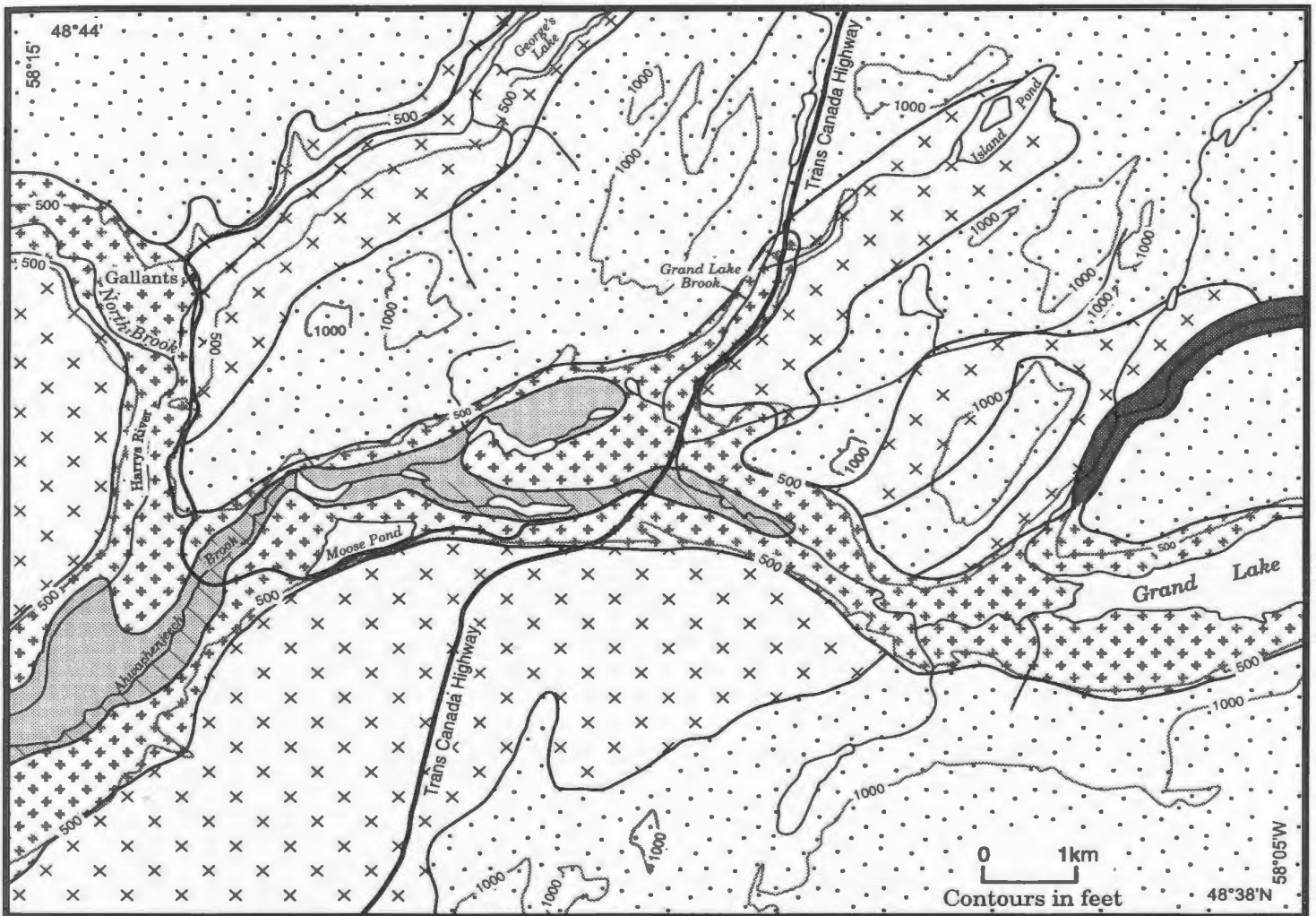
**Figure 1-7:** Geography of the western end of Grand Lake.

the cubic-parabolic shape typical of glaciated valleys (Sugden and John, 1976; Drewry, 1986) (Figure 1-8), suggesting it was largely produced by fluvial action. In contrast, the Wild Cove valley to the north has a cross-sectional profile closer to a parabola, and was likely glacially carved.

The modern drainage basin has an area of about 4400 $km^2$, and includes northeast - southwest oriented lowlands occupied by Deer Lake (elevation 5 m asl), and Grand Lake - Sandy Lake - Birchy Lake (elevation 82 m asl). Brookes (1970a) suggested that the Humber River gorge was cut since deglaciation and that the pre-glacial Humber River basin drainage was towards White Bay, citing differential isostatic rebound across the basin as evidence. It is unclear how the preglacial Humber River could have reached White Bay, but it must presumably have breached Birchy Ridge. No field evidence was found to support this contention.

The Humber River gorge appears to be structurally controlled. The lower part of Humber River valley is fault controlled (Cawood and Van Gool, 1992), and consists of Late Proterozoic to Lower Cambrian psammite overlain by Lower Cambrian carbonate rocks (Williams and Cawood, 1989). Sub-surface water movement may initially have occurred along the contact, shown by the presence of cave structures and calcite veining indicative of previous open flow (Ian Knight, Department of Mines and Energy, personal communication, 1996). Timing of the formation of the gorge is highly speculative, but there is no direct evidence that it was entirely cut post-glacially.

The Humber River basin contains several large lakes. Grand Lake (surface elevation 87 m asl) and Deer Lake (surface elevation 5 m asl) are two of the largest water bodies in Newfoundland, with surface areas of 66800 ha and 5698 ha, respectively (Figure 1-2). Both trend northeast-southwest, and are structurally
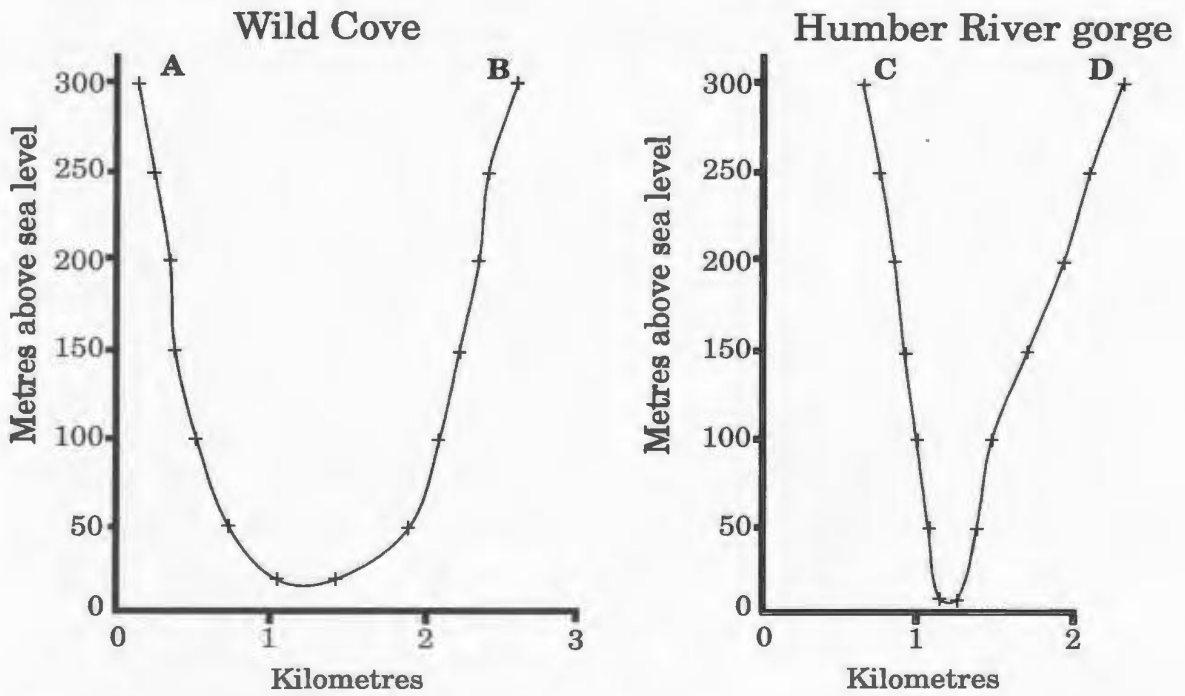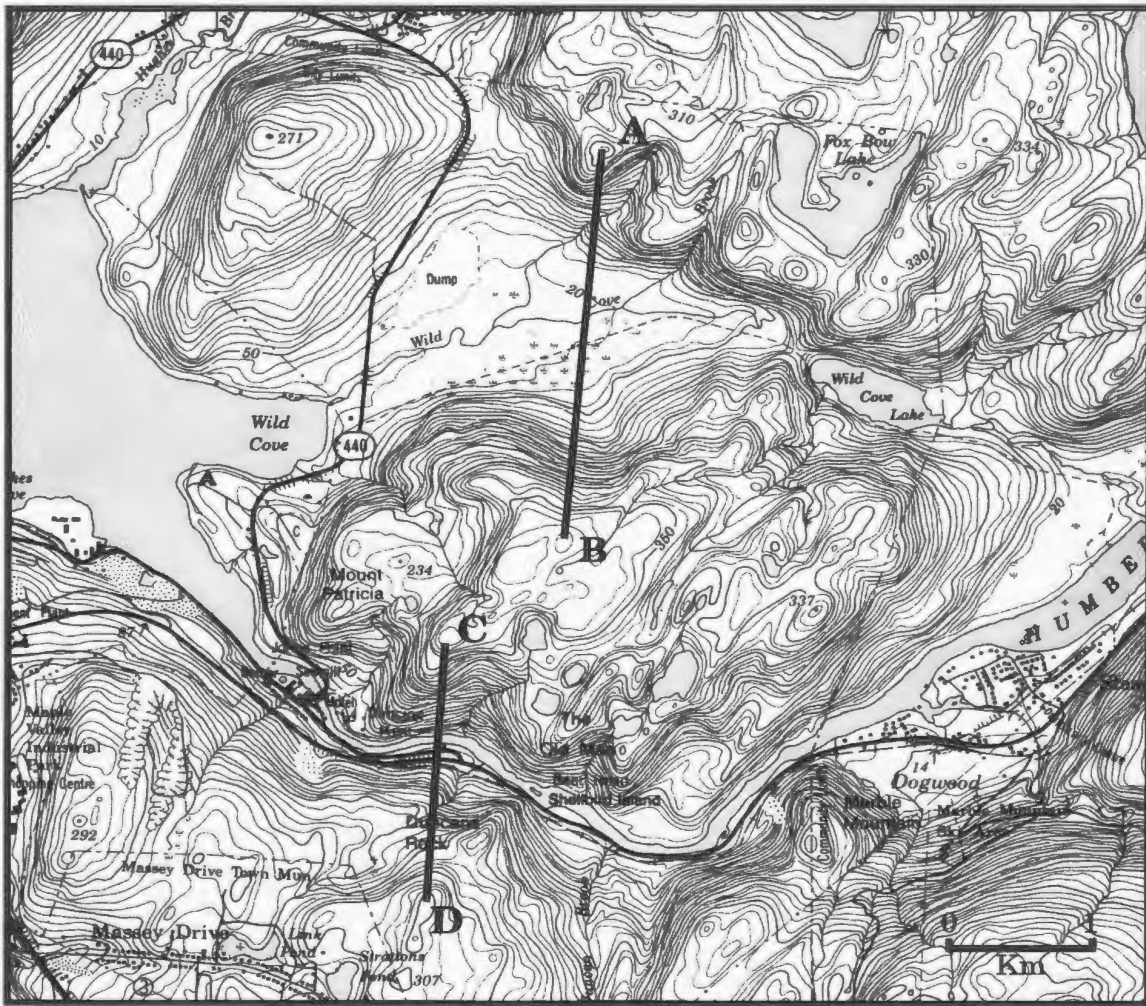
**Figure 1-8:** Cross profiles of the Wild Cove valley and Humber River gorge, showing differences in morphology. Vertical exaggeration on profiles x25.

controlled, Deer Lake by the Humber syncline (Hyde, 1979) and Grand Lake by the Grand Lake Fault (Hyde, 1979; Whalen and Currie, 1988). Grand Lake contains a large island, occupying the southern half of the lake. Glover Island is 39 km long and 6.5 km wide, dominated by sheer cliffs up to 460 m high on all shorelines, except for the northeast shore. The origin of Glover Island is unclear, although Brookes (1970a) speculates the island represents the interfluve between northeast flowing stream channels that were overdeepened by glaciers.

The depth and bathymetry of both Grand Lake and Deer Lake are largely unknown. Jukes (1842) reported depths "greater than 3 fishing lines tied together" or greater than 100 fathoms (183 m) at the south end of Glover Island on Grand Lake. Murray (1882) reported two soundings on Grand Lake, one near Old Harry Mountain at 145 fathoms (265 m) and one south of Glover Island at greater than 184 fathoms (337 m). The surface elevation of Grand Lake was artificially raised by 8.5 m to the level of Birchy Lake, following completion of a dam at Junction Brook in 1925. The dam eliminated the stream (The Main Brook) between Grand Lake and Birchy Lake, and enlarged Sandy Lake. Soundings from Deer Lake indicate Deer Lake has a maximum depth of 95 m (Seabrook, 1962), although the reported survey was incomplete due to equipment malfunction. The surface elevation of Hinds Lake (309 m asl) was raised about 10 m by dam construction in 1980. Other large lakes in the Humber River basin are Sheffield Lake, Adies Pond and Old Mans Pond (Figure 1-2). Each of these has a surface area of greater than 1000 ha.

**Climate**

There are few climate recording stations on the west coast, and only two within the Humber River basin, at Corner Brook and Deer Lake. Table 1-2 presents data from these stations, along with data from Stephenville to the southwest of the

basin.

Three distinct climatic zones cover the study area, the West Coast, Central lowlands, and Western hills and mountains (Banfield, 1981), defined by a combination of latitudinal (48° 30' to 49° 47'N) and altitudinal (0 to 800 m asl) variations.

The West Coast and Central lowlands include the coast between St. George's Bay and Bonne Bay, and the Deer Lake lowlands. This area has better defined seasons than most other areas of the province. Annual sea-level precipitation is about 1300-1400 mm, increasing rapidly to the south and with elevation. Winters are cold and snowy. Corner Brook receives about 400 cm of snow at sea level. Orographic effects increase snowfall, and the ski resort at Marble Mountain commonly receives in excess of 550 cm annual snowfall. In contrast, the Humber River valley is afforded some protection by coastal highlands from snow-laden airstreams crossing the Gulf of St. Lawrence, and has about 250 cm annual snowfall. Spring is commonly well-defined, with an absence of fog and occasional föhn conditions during westerlies. Summers are sunny and moderately warm, with maximum temperatures up to 30°C in sheltered areas. Prevailing winds are southwesterly, parallel to the orientation of Deer Lake and Grand Lake. This contributes to the high (5.0 - 7.9 ms$^{-1}$) mean annual wind velocity at Deer Lake (Banfield, 1981).

The Western hills and mountains are cooler, have longer winters and more precipitation than the adjacent lowlands. Annual precipitation is up to 2000 mm, with continuous snow cover from December to April (Banfield, 1981). Winters are cold, with periods below -20°C, and a February average of about -9°C. Summers are cool, with frequent periods of low cloud.

**Table 1-2:** Climate data for selected stations within or adjacent to the Humber River basin (data from Banfield, 1981, 1993). na = data not available.

| | | Stephenville | Corner Brook | Deer Lake |
|---|---|---|---|---|
| **Radiation** | | | | |
| $(MJ/m^2 day)$ | Direct solar | 5.32 | na | 5.11 |
| | Diffuse solar | 5.96 | na | 5.83 |
| | Global | 11.25 | na | 10.90 |
| **Sunshine (hrs)** | | | | |
| | Yearly average | 1429 | na | na |
| **Temp (°C)** | | | | |
| | Jan. mean max | -1.6 | -1.9 | -2.7 |
| | Jan. mean min | -8 | -8.6 | -10.4 |
| | July mean max | 19.7 | 21.6 | 22.1 |
| | July mean min | 12.1 | 12.2 | 10.7 |
| **Ppt (mm)** | | | | |
| | Jan-Apr mean | 326 | 364 | na |
| | May-Sept mean | 442 | 394 | na |
| | Oct-Dec mean | 325 | 358 | na |
| **Snowfall** | | | | |
| | Av annual days | 92 | 96 | 57 |
| | % of total ppt | 30 | 36 | 27 |

## Palaeoenvironments, modern flora and soils

Vegetation recolonization in southwest Newfoundland following deglaciation can be identified from a pollen record from Southwest Brook Lake (48°28'N, 57°59'W; 145 m asl) (Anderson and Lewis, 1992; Anderson and Macpherson, 1994). The site records a basal radiocarbon date of 11.5 ka. Initial colonization was by a shrub-dominated tundra assemblage of willow (*Salix*), birch (*Betula*), juniper (*Juniperus*) and heaths (Ericales), plus herbs (e.g., sage (*Artemesia*) and sedges (Cyperaceae)). Climatic amelioration continued until ~ 11.0 ka, at which time there was a reversion to cooler conditions that lasted until ~ 10.0 ka. At Southwest Brook Lake, this event is shown in the sediment core by an increase in mineral lake sediment with organic content dropping to as low as 1% (Anderson and Macpherson, 1994). The pollen record shows a rapid decline in shrub pollen during this cool phase in preference to a herb pollen assemblage, dominated by Cyperaceae, mountain sorrel (*Oxyria digyna*), and *Artemesia*. Anderson and Macpherson (1994) relate this period of climatic cooling to the Younger Dryas (Broecker *et al.*, 1988; Wright, 1989; Dansgaard *et al.*, 1993; Taylor *et al.*, 1993; Peteet, 1995).

Morphological and palaeoecological evidence of Younger Dryas cooling is found in Newfoundland. Morphological evidence includes the moraines at Ten Mile Lake dated at 11 ka (Grant, 1969a), and fossil ice wedge casts (Brookes, 1971; Eyles, 1977; Liverman *et al.*, in review). Palaeoecological evidence includes pollen data from numerous sites in northern and western Newfoundland (e.g., Macpherson and Anderson, 1985; Anderson and Lewis, 1992; Anderson and Macpherson, 1994), and diatom evidence from eastern Newfoundland (Wolfe and Butler, 1994).

Other periods of post-glacial climatic cooling are recorded in the Maritime

provinces, both pre- and post-Younger Dryas (Rawlence, 1988, 1992; Anderson and Lewis, 1992; Levesque *et al.*, 1993; Wilson *et al.*, 1993). In Newfoundland, evidence of the Killarney Oscillation between 11.2 and 10.9 ka (Levesque *et al.*, 1993) is suggested by a reduction in sediment organic content at Southwest Brook Lake (Anderson and Macpherson, 1994). A period of intense cooling at ~9.6 ka is interpreted from an abrupt decline in the spruce population on the west coast (Anderson and Macpherson, 1994). This cooling phase may be associated with the release of meltwater into the Gulf of St. Lawrence from the drainage of glacial Lake Agassiz (Anderson and Lewis, 1992; Teller and Kehew, 1994; Teller, 1995). At Southwest Brook Lake, the end of the post-glacial cooling episode at ~8.5 ka is marked by an increase in spruce, tree birch and fir pollen, and the development of a boreal forest assemblage that includes the major components of the modern vegetation.

The period following 8.0 ka is characterised by increased summer warmth and longer growing seasons (Macpherson, 1995). This is indicated by a gradual expansion of tree birch, and the arrival of black ash (*Fraxinus nigra*) recorded in cores from southwest and interior Newfoundland. Increased charcoal concentrations, derived from fire, found in many cores also indicates increased summer warmth. Climate continued to warm until the Hypsithermal, about 6.0 ka. This period is marked by expansion of red and white pine (*Pinus resinosa* and *Pinus strobus*) beyond modern limits, e.g., at Leading Tickles on the north coast of Newfoundland (Macpherson, 1995), and by a decrease in shrub birch, increased balsam fir, and increased sphagnum, indicating higher moisture levels. Mean summer temperatures were likely up to 1.5 °C warmer than present during the Hypsithermal (Macpherson, 1995).

After about 4.0 ka there was a slight decrease in mean annual maximum

temperatures, indicated by the migration from the coast of red pine. Similarly, the length of the growing season was shortened, as shown by the expansion of spruce at the expense of birch, and relative moisture increased, as indicated by increased fir. Increasing moisture and decreasing temperatures also resulted in accelerated paludification, indicated by the cluster of basal bog dates following 4 ka (Davis, 1984, 1993).

Most of the study area is presently within the Boreal Forest vegetation zone (Rowe, 1972), except for the summits of the Long Range Mountains where elevation and exposure produce a Forest Tundra vegetation zone. The summits of the Long Range Mountains support only alpine heath (Ericaceae), sedge (Cyperaceae), and willow (*Salix* sp.). Heaths include Labrador tea (*Ledum groenlandicum*), blueberry (*Vaccinium* sp.), and rhodora (*Rhododendron canadense*), whereas sedges include rock sedge (*Carex rupestris*), and mountain avens (*Dryas integrifolia*). Balsam fir (*Abies balsamea*) is the dominant tree on the west coast. Black and white spruce (*Picea mariana* and *Picea glauca*, respectively) populations increase northward, in response to changing climatic and soil conditions. In exposed locations, trees are dwarfed and commonly form impenetrable thickets of "tuckamore" (krummholz). Common tree types within tuckamore include white spruce (*Picea glauca*), larch (*Larix laricina*), and green or mountain alder (*Alnus crispa*).

The lowlands and valleys have a longer growing season than upland areas, with 1200 degree-days above 5°C compared with less than 1000 degree days in the north (Banfield 1981, 1993). Areas of increased summer warmth are found at the heads of major coastal inlets, the most northerly of which, Bonne Bay, forms the present northern limit of the red maple (*Acer rubrum*), black ash (*Fraxinus nigra*) and white pine (*Pinus strobus*). Yellow birch (*Betula alleghaniensis*) and red pine

(*Pinus resinosa*) reach their northern limit in the Deer Lake basin.

Coastal areas dominated by limestone bedrock, such as Table Mountain near Stephenville, also contain several rare plant species including Slightly-Ciliate Aster (*Aster ciliolatus*), Cymbalaria Ragwort (*Senecio cymbalaria*), Arctic Pyrola (*Pyrola grandiflora*) and Mignonette-leaved Ragwort (*Senecio resedifolius*).

Wetlands are common in western Newfoundland. They develop in response to perhumid climatic conditions, where rainfall is high, temperatures are cool and, consequently, rates of evaporation are low. Domed bog, basin bog and slope fen are found in the study area (Wells and Pollett, 1983). Slope fen is common in the Humber River basin where wetlands receive nutrients from groundwater or seepage water from upslope, as well as from atmospheric sources such as rain and snow. Surface water movement and small streams are present in many fens.

Fens are more nutrient rich and less acidic than bogs. Fens are distinguished from bogs by plant species such as Newfoundland dwarf birch (*Betula michauxii*), northern honeysuckle (*Lonicera villosa*), northeastern rose (*Rosa nitida*), and shrubby cinquefoil (*Potentilla fruticosa*), with some *Sphagnum* mosses. Peats range in thickness from 0.5 m to 2.0 m. Ombrotrophic domed bogs and basin bogs are found on the Long Range Mountain uplands. Bogs are poor in nutrients and generally acidic, receiving their nutrients mostly from precipitation. Vegetation consists primarily of *Sphagnum* mosses (especially *Sphagnum fuscum*), and shrubs such as Labrador tea (*Ledum groenlandicum*), black huckleberry (*Gaylussacia baccata*), dwarf huckleberry (*Gaylussacia dumosa*), and sheep laurel (*Kalmia angustifolia*). Peat thicknesses range from 1.0 to 12 m.

Soil types are mostly podzols (humo-ferric and ferro-humic). Small areas of brunisols and gleysols are found throughout the area, as well as organic soils developed on wetlands. Button (1983), Kirby (1988) and Kirby *et al.* (1992) provide

details on the distribution and characteristics of soils found within the area.

## Fauna

The animals on the Island of Newfoundland are a combination of indigenous and introduced species. There are 14 indigenous terrestrial mammal species, eleven of which represent subspecies restricted to the Island: American beaver (*Castor canadensis caecator*), meadow vole (*Microtus pennsylvanicus terraenovae*), muskrat (*Ondata zibethicus obscurus*), lynx (*Lynx lynx subsolanus*), red fox (*Vulpes vulpes deletrix*), American black bear (*Ursus americanus hamiltoni*), otter (*Lutra canadensis degener*), arctic hare (*Lepus arcticus bangsii*), caribou (*Rangifer tarandus terraenovae*), wolf (*Canis lupus beothucus*) and American marten (*Martes americana atrata*). Of these, the marten population has declined drastically, largely due to a reduction in habitat. The pine marten is the only terrestrial mammal to have special protected status in Newfoundland. The wolf has been extirpated from Newfoundland. The last shooting of a wolf was near Daniel's Harbour in 1920, although there were other wolf sightings on the west coast until the early 1930's. Other mammals are protected under the Wildlife Act, which only permits hunting of larger mammals during defined periods. The other indigenous mammals are ermine (*Mustella erminea*), little brown bat (*Myotis lucifugus*), and Keen bat (*Myotis keenii*).

In addition, twelve mammals have been introduced, including snowshoe hare (*Lepus americanus*), masked shrew (*Sorex cinereus*), arctic fox (*Alopex lagopus*) and moose (*Alces alces*). Moose were successfully introduced into the Howley area in 1904, following an earlier attempt in 1878, and now number about 200,000.

Polar bears (*Ursus maritimus*) are rare visitors to the west coast in the spring, arriving on ice floes from Labrador. Similarly, arctic fox (*Alopex lagopus*) also visits

the Island on ice floes, although others have been released from defunct fox-farming ventures. A more recent colonizer is the coyote (*Canis latrans*). They are thought to have originally ventured across the ice from the mainland in the mid-1980's, and have been steadily increasing their range since then. Rare, but reliable, sightings have also been made of cougars (*Felis concolor*) to the east of the field area.

## Previous Work

### Overviews

There are several reviews of literature dealing with the Quaternary geology of Newfoundland, the most thorough of which is provided by Grant (1989a). Prest (1970), Tucker (1976) and Rogerson (1981, 1982) provided earlier general overviews, and Prest *et al.* (1968) and Dyke and Prest (1987) discussed Newfoundland's position in relation to the Laurentide ice sheet. Brookes (1982) presented a detailed essay on the history of studies into the Quaternary geology of Newfoundland.

The following discussion will initially focus on general issues concerning areas surrounding the basin, including the west, north and southwest coasts, and the Red Indian Lake basin. A review of these areas is critical to discussions of Quaternary events within the Humber River basin through their effects on ice thickness and extent, ice flow directions, and time of deglaciation. Finally, work specifically completed in the Humber River basin will be considered.

### Quaternary history of the West Coast

More has been written about the Quaternary history of the west coast than any other part of the province. In part this is due to well-exposed and continuous Quaternary outcrop around St. George's Bay, and the diverse ecology and physiography along the west coast, although ease of access and natural scenic

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attractiveness are contributing factors.

Role of Labrador ice

The proximity of the Island of Newfoundland to Labrador has prompted considerable debate over potential invasion of the Island by the Laurentide ice sheet during the Wisconsinan. Murray (1882) assumed that the Island was covered by ice moving down the Gulf of St. Lawrence, crossing the Island in an east to northeast direction. He also recognized the development of local ice masses during deglaciation, as did Kerr (1870). Fairchild (1918), based on limited field observation including those recorded by Tyrrell (in Fairchild, 1918, p. 227-228), and relying heavily on data subsequently published by Daly (1921), concluded that there was no physical evidence (striations) to suggest coverage by Labrador ice. Instead, crustal warping patterns on the west coast implied invasion of Labrador ice. Raised marine features increase in elevation northwestward, along the Great Northern Peninsula, leading Daly (1902, 1921) and Flint (1940) to conclude that ice thickened towards Labrador, and that at least the west coast of the island had been covered by ice from Labrador. MacClintock and Twenhofel (1940) and Tanner (1940) shared a similar view to Flint, although only southward directed striations on the Port au Port Peninsula were cited as direct evidence (MacClintock and Twenhofel, 1940). These authors supposed that radial flowing ice from a Newfoundland ice centre during deglaciation removed all evidence of the Labrador phase elsewhere. It was argued that Labrador ice covered the whole of the island during the Wisconsinan maximum, possibly extending out as far as the Grand Banks (MacClintock and Twenhofel, 1940). During waning stages, radial flowing glaciers developed on highland centres, and obliterated all evidence of earlier phases of flow (MacClintock and Twenhofel, 1940). Betz (1939) observed striations oriented southeastward in the Canada Bay area, and Cooper (1937)

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recorded striations showing southward ice flow at Bluff Head near Port au Port Peninsula (Figure 1-2). Both these observations were used as evidence for invasion of at least part of the island by Labrador ice.

Direct evidence of invasion of Labrador ice onto Newfoundland was found at the tip of the Great Northern Peninsula, where Cooper (1937) first identified erratics from Labrador and associated southwest striations. Grant (1969b, 1972, 1977a, 1987, 1992) provided detailed evidence that the Laurentide ice sheet covered the tip of the Great Northern Peninsula, north of a line between Margaret Bay and Canada Bay, up to an elevation of about 300 m asl, above which local island-based glaciation was dominant (Figure 1-9). There have been no erratics from Labrador found within the Humber River basin.

Nunataks on the west coast?

Following the general acceptance of the glacial theory to explain surface features on the island, replacing the previously held diluvial view (e.g., Milne, 1874, 1876), the early workers on the west coast (e.g., Murray, 1882; Bell, 1884) were concerned with identifying evidence for glaciation. Bell (1884) considered that "...the glaciation appears to have been from the centre towards the sea on all sides" (p. 37). Murray (1882) found limited evidence for glacial coverage on summits of the Long Range Mountains and coastal highlands such as the Anguille Mountains (southern St. George's Bay), Blow-Me-Down Mountain and Lewis Hills (Figure 1-2). Twenhofel (1912) proposed that the Long Range Mountains were completely covered by glaciers, based on the distribution of striations on upland peaks. Coleman (1926) challenged this view, instead suggesting that many of the high plateaux were unglaciated during the Late Wisconsinan, and possibly had never been glaciated. Evidence included the lack of glacial features such as erratics and striations, and weathered surfaces. Coleman (1926) argued that The Topsails,

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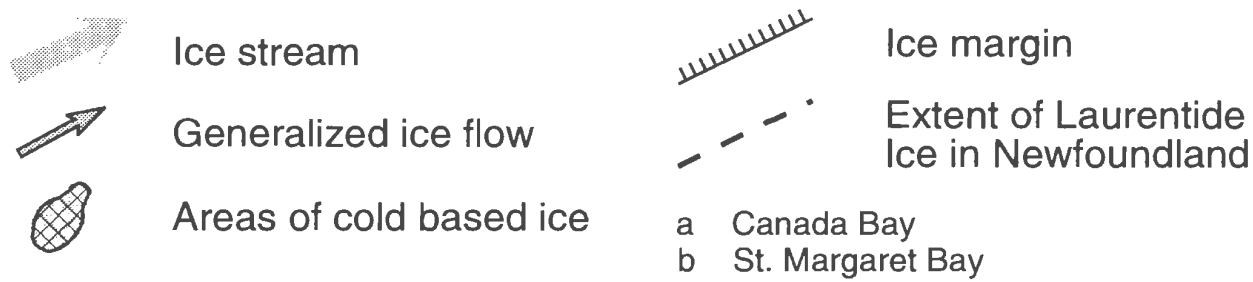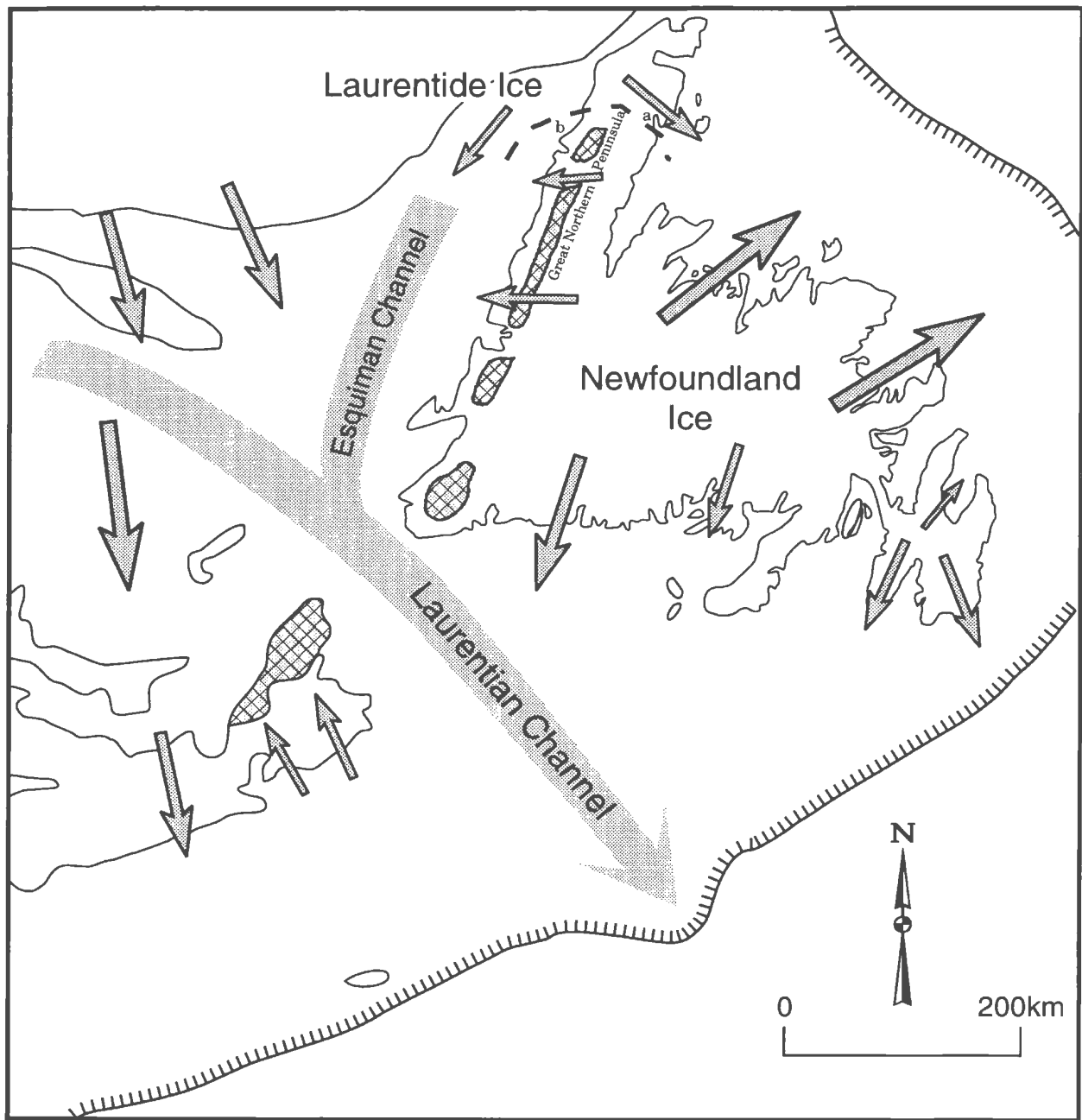
**Figure 1-9:** Extent of Laurentide ice in western Newfoundland (after Grant, 1987a).

and the high peaks of the Long Range Mountains north from Port aux Basques, showed evidence of glaciations of pre-Wisconsinan (Kansan or Jerseyan) age. The tops of the southern Long Range Mountains and Blow-Me-Down mountain in the Bay of Islands showed no evidence of glaciation, and Coleman (1926) concluded that these areas were never glaciated. Antevs (1922) in his compilation of the extent of Pleistocene glaciations, derived from work by Coleman (1926) and Lundberg (1929), designated a large part of the Long Range Mountains on the Northern Peninsula as ice-free during Pleistocene glaciations, although suggesting that the southern part of the Long Range Mountains were ice covered.

There are two conflicting views of glacial coverage on the west coast of Newfoundland. The 'minimum' argument contends that hilltops remained ice free during periods of glacial activity at lower levels, suggesting a restricted extent of ice. The 'maximum' view argues that the hilltops were covered by glaciers, and that ice extent was well beyond the modern coast. Landforms such as tors and felsenmeer found on coastal highlands therefore may have survived coverage by Late Wisconsinan glaciers. Important contributions come from Baffin Island (Sugden and Watts, 1977) and the Torngat Mountains (Gangloff, 1983), where it was demonstrated that tors and felsenmeer survived Laurentide Ice cover, and where incipient tafoni have developed during the Holocene. Ives (1978) provided a detailed history of the 'minimum' versus 'maximum' debate.

Apart from geologic evidence, Coleman (1926) cited corroborative biological data from Fernald (1911, 1925) to support the minimum view. Based on the distribution of vascular plant species in upland areas, Fernald (1911, 1925, 1930) concluded that these areas must have remained ice free and acted as refugia, at least during the Wisconsinan. Some of these plant species are now only found outside Newfoundland in the Rocky Mountains or northeast Asia. The concept of

refugia was supported by Lindroth (1963), who noted the preferred distribution of flightless beetles on the west coast (e.g., *Agonum bicolor*, *Carabus taedatus*, and *Bembidon morulum*). Belland (1981, 1987) came to a similar conclusion based on the distribution of mosses, and Roberts (1993) argued for refugia to explain the distribution of rare plants on serpentinized rocks of the Tablelands. Liverman and Batterson (1995) and Bell *et al.* (1997) also considered the possibility of refugia to explain the distribution of land snails (*Cepaea* sp.) in discussions of exposures of cliff-top loess at Salmon Point, near Rocky Harbour.

The indigenous mammal population in Newfoundland may lend support to the refugia concept. All the subspecies prefer open grassland/tundra conditions. The province lacks mammal species such as porcupine (*Erethizon dorsatum*), skunk (*Mephitis mephitis*) and white-tailed deer (*Odecoileus virginianus*) that are common on the adjacent mainland, which have an affinity for woodland habitats, although they are also found on western prairies. Böcher (1963) introduced the concept of 'half-nunataks', referring to barren slopes below ice covered hilltops, to explain the phytogeography of Greenland. This may be a suitable explanation for accommodating the geological and biological evidence in Newfoundland.

Rogers *et al.* (1990, 1991) postulated the concept of a refugia on the Grand Banks off Newfoundland to explain the isolate character of the now-extinct Beothuk language. However, this would suppose the Beothuk were present on Newfoundland before the last glacial event, and that the Grand Banks were subaerially exposed during the late Wisconsinan. Piper *et al.* (1990) demonstrated that at least parts of the Grand Banks were ice-free during a sea level lowstand of 110-120 m by identifying leached sediments developed through soil formation, a conclusion supported by Segall *et al.* (1987). Nevertheless, environmental conditions would likely have been harsh, and no evidence of preglacial human

occupation has thus far been found.

The concept of west coast nunataks was disputed by Wynne-Edwards (1937, 1939) who argued the glacial climate was too harsh for plant survival, and rare plant distribution is better correlated with soil conditions related to underlying bedrock rather than Wisconsinan nunataks. Instead, Wynne-Edwards (1939) suggested that plants existed in areas marginal to the ice sheets, perhaps on the Labrador seaboard, or in areas to the south and west of Newfoundland.

Following 1960 the minimum viewpoint was favoured again, initially based on work in Baffin Island (e.g., Boyer and Pheasant, 1974; Miller and Dyke, 1974) and northern Labrador (e.g., Løken, 1962; Ives 1960, 1978). The arguments were extended to the island by Grant (1969a, 1976, 1977a, 1977b, 1989a) and Brookes (1970a, 1977a). This 'minimum' viewpoint of Late Wisconsinan ice is largely dependent on the recognition of distinct weathering zones in the Long Range Mountains, Torngat Mountains and on Baffin Island, and equating them with periods of decreasing glacial extent. Weathering zones in Newfoundland were first described by Coleman (1926).

In Newfoundland, Grant (1977a) identified three weathering zones in the area of Gros Morne National Park. The highest zone (Weathering Zone 3) is characterised by an intensely altered surface, where weathering has removed most signs of glacial activity. Grant (1989a) estimated this surface to represent oxygen isotope stage 12 (about 430 ka BP) on geomorphic grounds, and its potential correlation with the offshore record (c.f. Alam and Piper, 1977). Below Zone 3 is an area of modified surfaces (Weathering Zone 2), with morphology clearly related to glacial activity. Grant (1989a) estimated the age of this surface to represent oxygen isotope stage 6 (about 140 ka), based on correlation with glacial deposition in the Gulf of St. Lawrence (Alam et al., 1983). Weathering Zone 1 has the youngest

evidence of glacial activity, and is correlated to the Late Wisconsinan. Brookes (1977b) noted a similar arrangement of weathering zones in the Anguille and southern Long Range Mountains, and observed that several of the summits of the southern Long Range Mountains showed no evidence of glaciation, and hence were probably unglaciated. Coleman (1926) made similar observations in the Blow-Me-Down Mountains in the Bay of Islands.

Proposed Late-Wisconsinan nunataks in Gros Morne National Park, such as Gros Morne Mountain and Big Level, were recently re-examined by cosmogenic radionuclide analysis of the $^{10}$Be and $^{26}$Al contents of quartz from veins and pegmatite dykes (Gosse and Grant, 1993; Gosse et al., 1993). For those areas sampled, data indicate coverage by Wisconsinan ice, probably within the last 50,000 years. This work suggests a cold-based ice cap, with complete plateau ice cover. This point of view contends that the intensity of the features in the weathering zones does not necessarily correspond to the elapsed time since they were last glaciated. This hypothesis suggests that cold-based ice overlies areas where these weathering features persisted - the supposition being that basal freezing would have protected (not destroyed) the surface weathering features. Cold-based ice has been proposed as an explanation for the preservation of blockfields and patterned ground (e.g., Falconer, 1966; Gellatly et al., 1988) and pre-Late Wisconsinan landscapes (e.g., England, 1987; Dyke, 1993; McCarroll and Nesje, 1993; Kleman, 1992, 1994) beneath Late Wisconsinan or recent ice masses.

The debate between complete plateau coverage and Late Wisconsinan nunataks remains unresolved. Cosmogenic radionuclide analysis provides quantifiable data showing those areas sampled were ice covered during the Late Wisconsinan. However, it does not imply that other coastal highlands, such as the southern Long Range Mountains and Anguille Mountains, were also ice covered

during the last glacial. The elevation, and remoteness of these areas from the ice dispersal centres affecting Gros Morne requires a separate examination of each region. Furthermore, biological anomalies remain unexplained.

### North coast and Exploits River valley areas

A watershed at 104 m asl separates Birchy Lake from the Indian River valley which drains into Notre Dame Bay (Figure 1-2), and a watershed at 145 m asl separates the Humber River basin from drainage into White Bay.

The northeastern margin of the Humber River basin includes the area between White Bay and Notre Dame Bay, defined by the Baie Verte Peninsula. Grant (1977a, 1989a) suggested the northern parts of the peninsula were unglaciated, although Macpherson and Anderson (1985) noted that radiocarbon dates from the area suggest deglaciation at about 13.5 ka.

Detailed striation mapping by St. Croix and Taylor (1991) was used to reconstruct glacial flow patterns. They show that at the Late Wisconsinan maximum, ice flow northeast from an ice centre on The Topsails was deflected eastward by ice from the Long Range Mountains that occupied Notre Dame Bay. During deglaciation, the Baie Verte Peninsula hosted remnant ice centres from which ice flowed radially outward (Grant, 1974), including a probable southward flow towards the Indian Brook valley (Liverman, 1992).

Radiocarbon dating on marine molluscs from muds underlying ice contact deltas along the coast provide minimum dates for deglaciation. Tucker (1974a) dated a 75 m-delta at Springdale at 12.0 ka. Scott *et al.* (1991) demonstrated earlier deglaciation based on a radiocarbon date of 12.5 ka from marine shells located 10 km inland of the Springdale delta.

The Late Wisconsinan maximum northeastward ice flow that affected the

north coast originated from a source in The Topsails, identified by detailed striation and clast provenance studies (Vanderveer and Sparkes, 1982; Sparkes, 1985, 1987; Klassen, 1994; Klassen and Murton, 1996). This flow affected much of the Red Indian Lake - Exploits River valley area (Figure 1-2). The Topsails were also the source of southward flowing ice that crossed Red Indian Lake, during both the Early and Late Wisconsinan (Sparkes, 1985), separated by a glacial lake phase that occupied the Red Indian Lake basin up to 59 m above the present level of the lake (Vanderveer and Sparkes, 1982; Mihychuk, 1985). Individual ice flow events were correlated with tills exposed in mine workings near Buchans (Vanderveer and Sparkes, 1982).

### Southwest coast of Newfoundland

Southwest Newfoundland was deglaciated before much of the rest of the Island. Radiocarbon dates on marine shells above glacial diamictons around St. George's Bay found at Robinsons (13,500 ± 210 BP, GSC-1200), Rope Cove (13,700 ± 340 BP, GSC-2942) and Abrahams Cove (13,700 ± 230 BP, GSC-1074) support early deglaciation (Brookes, 1974; Anderson and Macpherson, 1994).

The Humber River basin is connected to southwestern Newfoundland through palaeo-drainage of Grand Lake into the Harrys River valley. Grant (1991) mapped a pro-glacial channel extending southwest from Grand Lake entering St. George's Bay near Stephenville Crossing. Brookes (1974) speculated that ice retreated up the Harrys River valley, and into the Grand Lake basin, presumably forming the channel through proglacial meltwater activity.

Southwestern Newfoundland is one of the few areas of extensive coastal exposures of Quaternary sediment with a complex stratigraphy. MacClintock and Twenhofel (1940) described a sequence of sediments, interpreted as showing a

lower regional till (St. George's River Drift), overlain by glacio-isostatic marine onlap sediments (St. George's Bay Delta), and a local re-advance till (Robinsons Head Drift). MacClintock and Twenhofel (1940) suggested that ice flow was coastward from the interior, based on the distribution of striations, during the St. George's River Drift stage. MacClintock and Twenhofel (1940) found little evidence of Labrador ice, although they did not discount its influence.

Brookes (1969, 1970a, 1970b, 1974, 1977a, 1977b) accepted this tripartite stratigraphy and provided further details on the areal extent, character, and relation of the stratigraphy to post-glacial relative sea level. The St. George's River Drift overlies bedrock, and outcrops in many places around St. George's Bay. It is a compact greyish pink to grey till, and is commonly overlain by delta bottomsets and foresets of the Bay St. George delta that was deposited in the sea up to about 43 m asl. The delta formed about 13.5 ka based on radiocarbon dating of marine molluscs found within the delta (Brookes, 1987; Grant, 1989a). An exception occurs from Stephenville to west of Romaines Brook, where marine overlap was delayed until sea level regressed to 30 (±) m elevation. This delay was thought to be the result of a reactivation of the ice-front, termed the Robinsons Head readvance by MacClintock and Twenhofel (1940). Brookes mapped this re-advance as extending from near Romaines Brook in the north to near Highlands in the south, reaching the coast as several lobes. The Robinsons Head readvance was dated at about 12.6 ka, based on a single date from marine shells found within a sand bed interstratified in kame gravels at Kippens (Brookes, 1977a). Ice subsequently retreated up the Harrys River valley into the Grand Lake basin, its course marked by subaerial glaciofluvial sediments and eskers (Brookes, 1970a). Deglaciation of this part of Newfoundland was, therefore, thought to have occurred sometime after 12.6 ka.

## Quaternary history of the Humber River valley

The first documented descriptions of the Humber River valley are those of Jukes (1842), reporting on expeditions he made through Newfoundland in 1839. Although he was influenced by the diluvial theory, Jukes (1842: 337) observed 'that fragments of rock, frequently of great size have been removed from their original position in all directions for a few miles' . His descriptions of the Humber River valley include terrain as far north as the rapids upstream of the confluence with Junction Brook. Jukes (1842) described a 'lump of good coal six inches thick' from the bed of a stream (Coal Brook) at the head of Grand Lake, that had first been reported by a Micmac some years before. The discovery of coal in this area became the impetus for further exploration from the mid-1860's to the early 1900's by Alexander Murray and James Howley of the Geological Survey of Newfoundland (Murray, 1866; Murray and Howley, 1918). Although this work provides little information on the Quaternary geology of the area, drill data give some indication of overburden thicknesses. Murray (1882) supposed that ice invaded the island during the last glacial, and moved generally northeastward through the Humber Arm into Deer Lake, and from St. George's Bay through Grand Lake. Here, the ice masses merged to eventually flow out into Notre Dame Bay. The orientations of Deer Lake and Grand Lake were cited as supporting evidence.

Coleman (1926) noted a 'blue bowlder clay' in the Humbermouth to Curling area close to modern sea level, deposited by ice moving seaward from the Humber Valley. A fossiliferous sediment at 43 m asl between two units interpreted as tills at Curling, was inferred by Coleman (1926) to represent an interglacial deposit. Striations oriented east - west along the Humber Arm were consistent with westward flow, but northwest-southeast directed striations at higher elevations were attributed to either a northwestward flow unconfined by the valley below, or

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southeastward moving ice flow from a Labrador centred ice mass.

MacClintock and Twenhofel (1940) noted the large accumulations of sediment at the head of Grand Lake (observed earlier by Murray, 1866), and suggested they were moraines formed during a stillstand or readvance, termed the Kittys Brook moraine stage. MacClintock and Twenhofel (1940) also noted the large delta at the mouth of the Humber River, at about 46 - 48 m asl (150 - 157 feet), and suggested that these and all other marine deposits in the area, including the 'interglacial' deposit identified by Coleman (1926), were of late-glacial age.

Lundqvist (1965) examined the eastern part of the study area, and concluded that The Topsails were a dispersal centre. Subsequently, the area was overridden by ice flow from the main Wisconsinan centre in the Long Range Mountains. Rhythmically bedded sediments were observed in the eastern part of the canal between Birchy Lake and Indian Brook. The sediments were interpreted as ice-marginal glaciolacustrine deposits.

Grant (1973) completed preliminary mapping of parts of the Humber River basin. The data were subsequently compiled into a 1:250,000 scale surficial geology map (Grant, 1989b).

There are three published interpretations of ice flow history for the upper Humber River basin, from Rogerson (1979), Vanderveer (1981) and Batterson and Taylor (1990). Rogerson (1979) was the first to comment directly on ice flow directions in the upper Humber River basin (Figure 1-10a), as a component of a project primarily concerned with defining the dispersal patterns of high-grade uranium boulders found in the Wigwam Brook area. Rogerson (1979), largely on the basis of till fabrics and regional observations, produced a speculative ice flow map for the Humber River basin. It shows a regional ice flow northward through the upper Humber River valley out into White Bay, followed by topographically-

controlled flow off Birchy Ridge and the Long Range Mountains into the basin.

Vanderveer (1981) used striations, till fabrics, and topographic evidence to present a glacial chronology consisting of three separate ice movements (Figure 1-10b), each correlated with a distinctive till unit. The first event, correlated to a red, clay-rich till at the base of the Quaternary stratigraphy, originated from a centre to the northeast, overtopping parts of the Long Range Mountains and Birchy Ridge. This event was pre-Late Wisconsinan in age. The second event was an eastward to southeastward ice flow that covered the northeast part of the basin, and deposited a sandy, pinkish grey till over the red clay till. The two tills are, in places, separated by a sand and gravel unit, interpreted to be of interglacial or interstadial age (Vanderveer and Sparkes, 1982). During the Late Wisconsinan, ice advanced south to southwestward down the upper Humber River valley. Vanderveer and Sparkes (1982) suggested this flow was responsible for creating the major landforms in the area, including a series of drumlinoid-ridges, recessional moraines and meltwater channels, as well as depositing a locally extensive immature and poorly comminuted till of local provenance.

Batterson and Taylor (1990) suggested that two ice flow events affected the area (Figure 1-10c). The first was a regional, west to northwestward flow from a centre in The Topsails, interpreted from striations and clast provenance data. The second ice flow event was a local, southwestward flow confined to the upper Humber River valley, and recognised on the basis of striations and surface landforms. Batterson and Taylor (1990) suggested that a large proglacial lake may have occupied the Grand Lake-Deer Lake-Sandy Lake-Birchy Lake basins during deglaciation.

Previously collected data on the Quaternary geology of the Humber River basin was, therefore, fragmentary, and conclusions commonly contradictory. A

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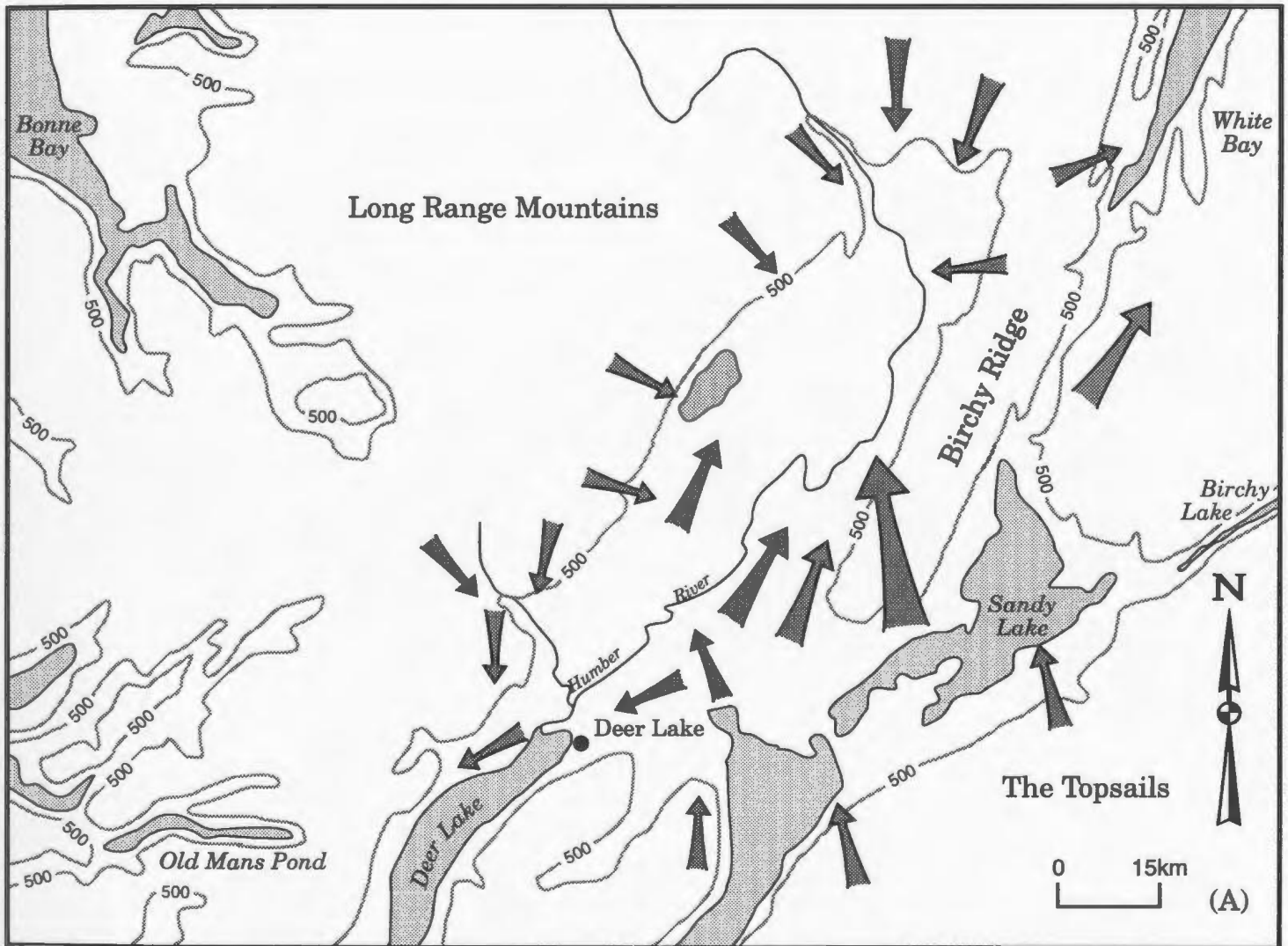
**Figure 1- 10:** Previously published maps of the ice flow history of the Humber River basin : A) after Rogerson, 1977; B) after Vanderveer, 1977; C) after Batterson and Taylor, 1989.
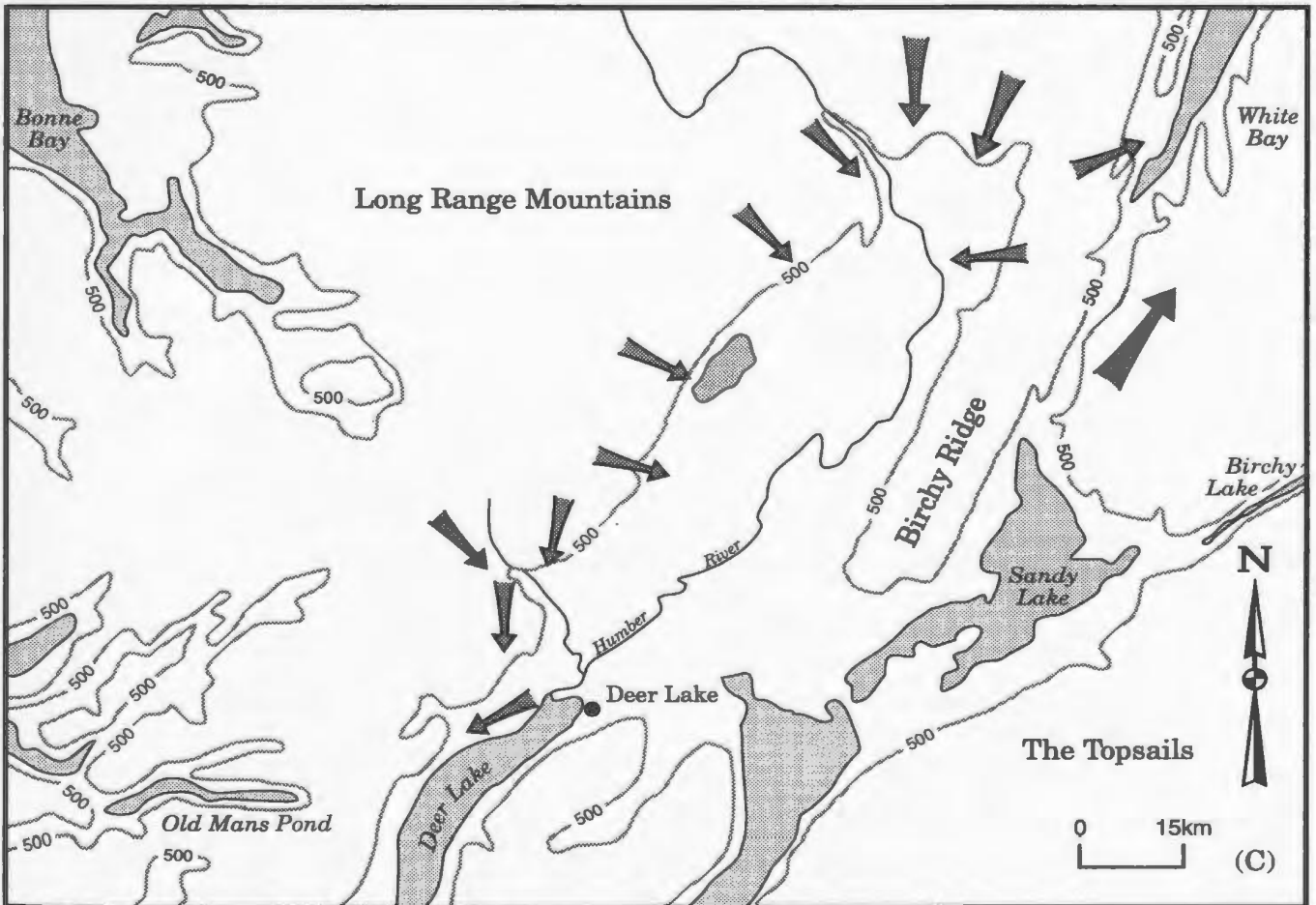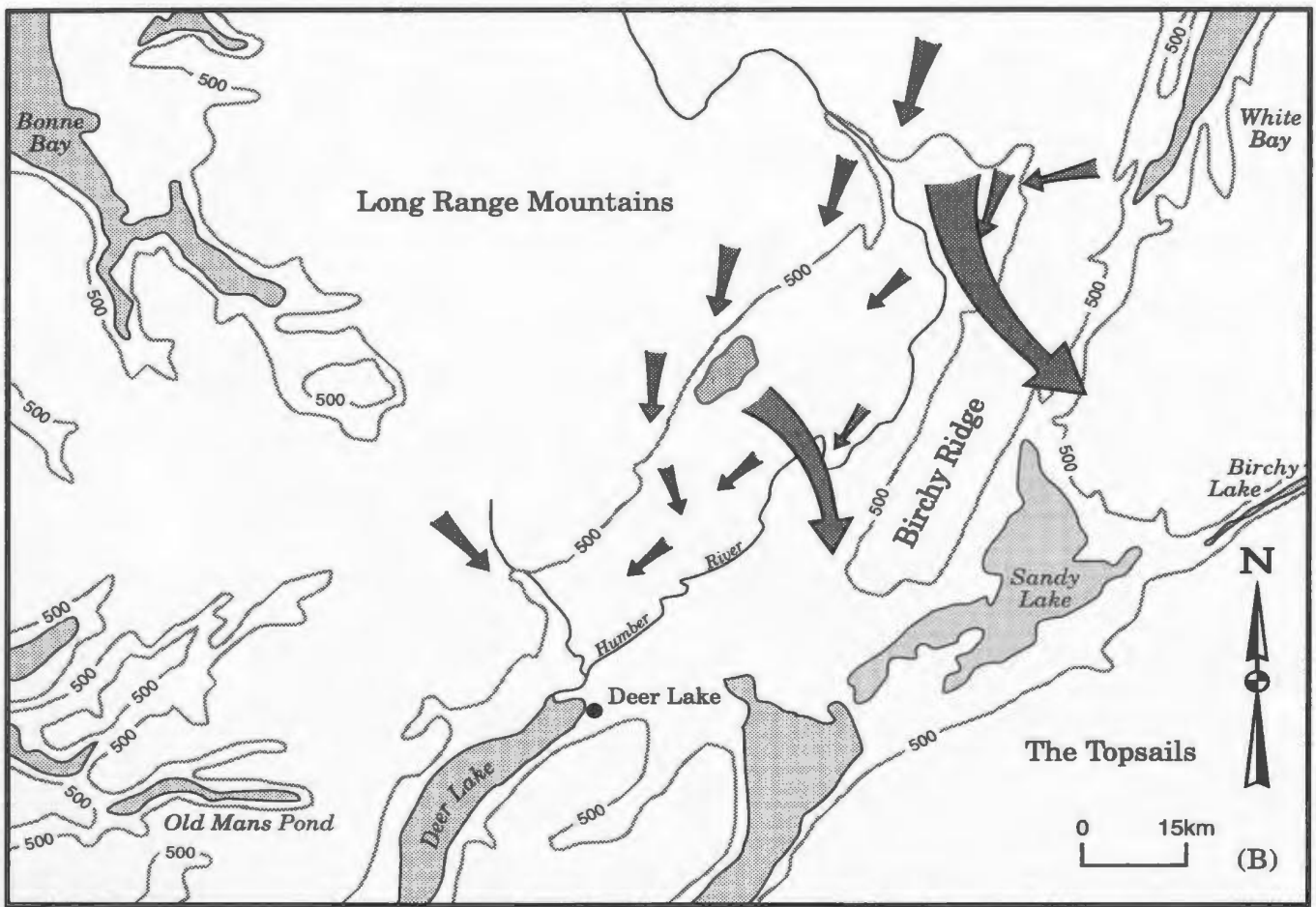
clear ice flow history and stratigraphic framework had not been established. In some areas, such as Birchy Ridge, researchers had recognised mutually contradictory ice flow patterns. Although ice dispersal centres were identified in the Long Range Mountains and The Topsails, the number, timing, and extent of advances from these sources was poorly documented. Despite the volume of study, a detailed systematic regional analysis of the Quaternary history of the Humber River basin was lacking.

**Sea Level History**

Investigation of Quaternary sea level change in Newfoundland can be subdivided into three separate periods. The first was the identification and description of raised marine features before the turn of the century. Observations were point specific, with little or no attempt to integrate data or define regional patterns. The second period involved more systematic observations and integration of data during the next 70 years. This promoted regional analysis and the production of isobase maps, many of which showed similar patterns. The third, and current period, developed in conjunction with the increasing knowledge of the rheology of the earth's crust in response to loading by ice sheets. In particular, the concept that the relative sea level history of areas marginal to waning ice sheets are dominated by the effects of forebulge migration produced an increasing discussion of local, as opposed to regional, relative sea level history.

The concept of raised sea level was first noted by Jukes (1842) who, in describing clays found in the Exploits River valley, suggested that it was ..'highly probable that the country once stood at a lower level; that the arm of the sea formerly extended much farther up....' (p. 339). Jukes (1842) also reported marine shell fragments about 10 m asl at Ship Cove, St. George's Bay, although he was

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unsure whether they were emplaced by higher sea level or by birds. Murray (1882) expanded the observations of raised marine features to the Baie Verte Peninsula, where he found shells near the Terra Nova mine site and at Tilt Cove, and to the Bonne Bay - Port au Port area. Murray (1882) also conjectured that Newfoundland was depressed 150 metres (500 feet) from crustal deformation induced by mainland ice. This would have drowned the area between St. George's Bay and Hall' s Bay through the Grand Lake - Indian Brook area, leaving the Northern Peninsula as an island.

DeGeer (1892) constructed the first map showing isobases over Newfoundland, based on limited field data (Figure 1-11a). His map showed the zero isobase traversing the south and west coasts of the island, with a distinct bulge over the island, suggesting an influence on crustal depression from local Newfoundland ice. Fairchild (1918) showed a much more prominent dome over Newfoundland, with the zero isobase far south of the Island (Figure 1-11b), and maximum uplift of more than 180 m (600 ft). Based on observations around the coast, Daly (1921) concluded that the zero isobase crossed the west coast in the vicinity of Robinsons Head and extended out through the centre of Bonavista Bay (Figure 1-11c), but did not speculate on the isobase configuration in the centre of the Island. Daly (1934) showed parallel isobases crossing the Island, suggesting no local ice cap influence on their pattern (Figure 1-11d). Flint (1940) similarly showed no deformation in the shape of isobases crossing the Island (Figure 1-11e), using this as evidence to support the theory that the island was invaded by ice from Labrador, and that ice caps on Newfoundland had little impact on crustal deformation. Farrand and Gajda (1962) show a similar pattern. Flint (1940) however, identified a discontinuous wave-cut bench on the west coast, rising northward from 0 m near Stephenville to over 75 m asl at St. Anthony, termed the

Bay of Islands surface. Flint (1940) suggested this surface resulted from a stillstand or readvance of Labrador ice, although Grant (1994a) speculated that it may relate to the Ten-Mile Lake readvance phase from piedmont glaciers in the Long Range Mountains.

Grant (1980) showed isobases curving towards the interior of the Island, in response to local ice centres, a pattern extended by Rogerson (1982) to show a central dome over the Red Indian Lake area (Figure 1-11f). In scant recognition of this central dome, Grant (1987) shows interior curving isobases (Figure 1-11g).

Apart from Flint (1940), there has been recognition of the effect of interior Newfoundland ice centres on isobase patterns, combined with the major influence of the Laurentide ice sheet on regional trends. The lack of raised marine features in the interior, and debate on late Wisconsinan ice extent, and by implication ice thickness, makes construction of isobases away from coastal areas speculative.

Although Daly (1921) speculated on the rheology of the earth's crust, and discussed the concept of a migrating forebulge, the lack of dating control and data points meant that relative sea level (RSL) curves could not be determined. Walcott (1970, 1972) demonstrated that the effects of loading of ice sheets on the earth's crust affected areas well removed from those areas underlain by ice sheets.

The major effect on RSL throughout the Holocene in Newfoundland is due to forebulge migration as a result of glacio-isostasy, with relatively little influence from eustatic changes (Liverman, 1994). The eustatic component is a function of water added or subtracted to ocean basins through the inception and growth of ice sheets, and the subsequent release of sequestered meltwater during waning stages. Sea level rose rapidly at the end of the last glacial, as water held in ice sheets was released to the oceans. It is uncertain whether this release was smooth and monotonic as suggested by Ruddiman (1987), or involved step-wise release

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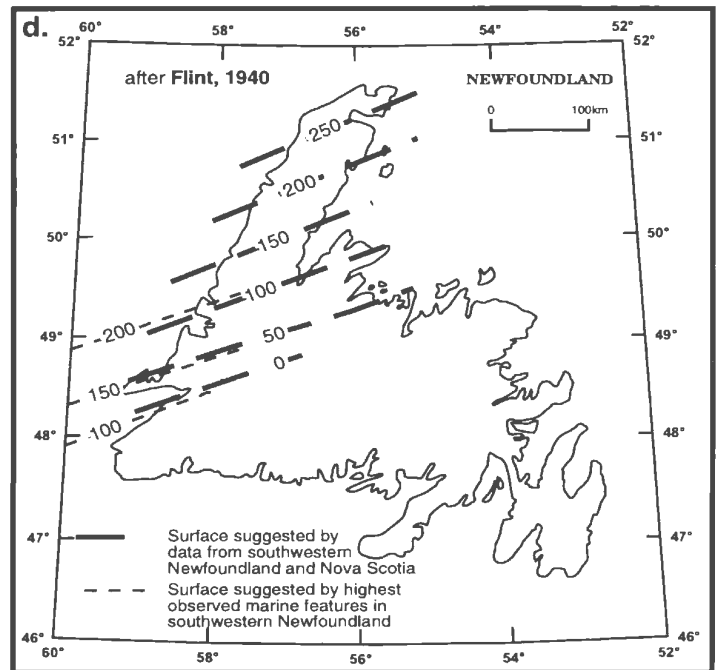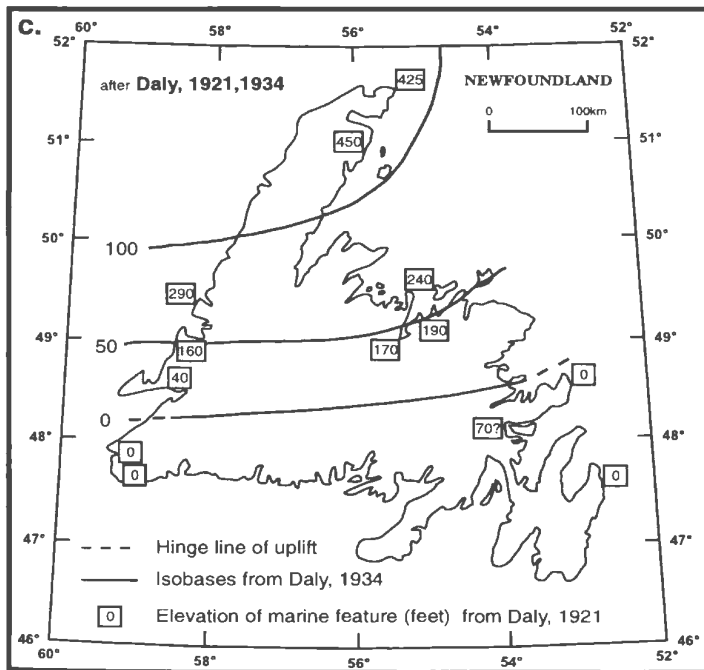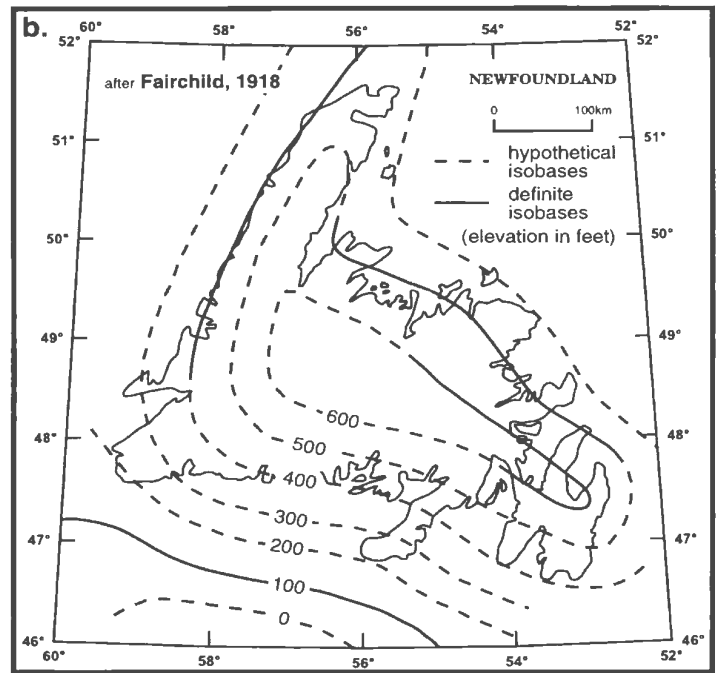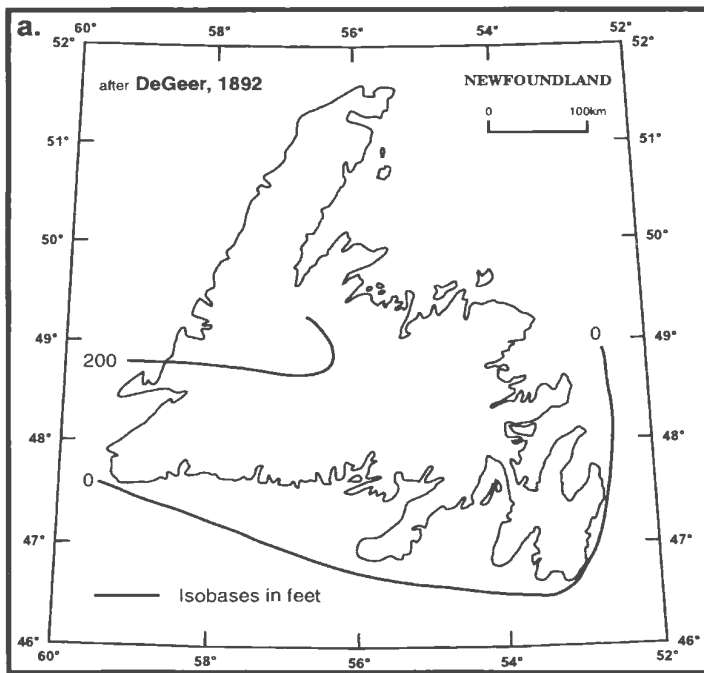
**Figure 1 - 11**: Previously published isobase maps of Newfoundland.

e. after **Fernald and Gagda, 1962** — NEWFOUNDLAND

Isobases (definite)
(isobases in feet)

f. after **Rogerson, 1982** — NEWFOUNDLAND

Isobase (metres)
Tentative isobase trend

g. after **Grant, 1987** — NEWFOUNDLAND

Isobases (definite)
(elevation in metres)

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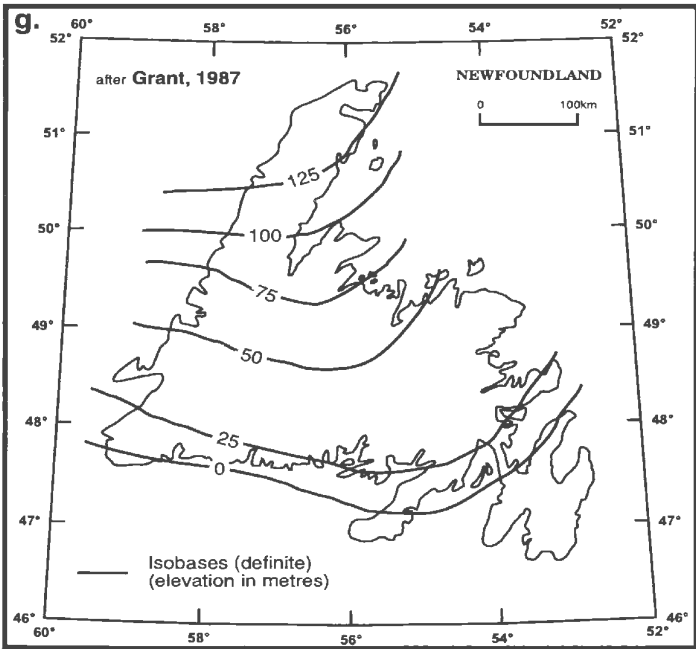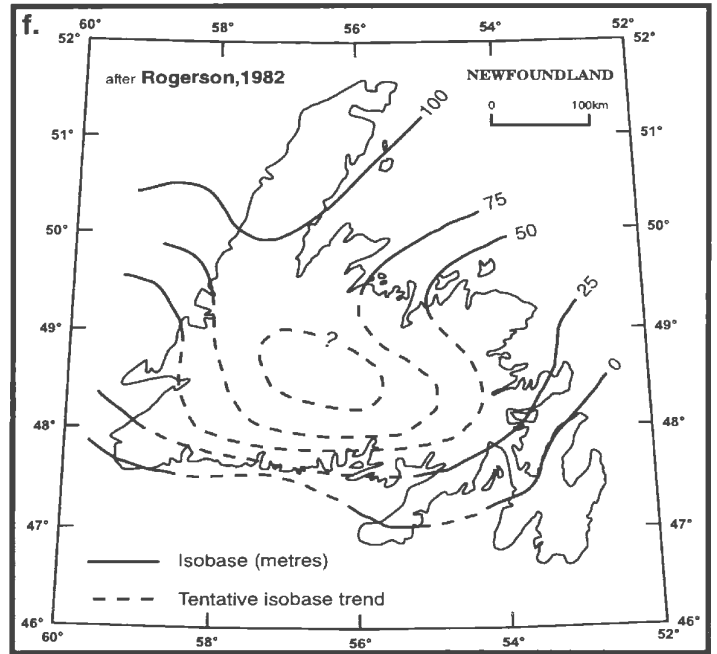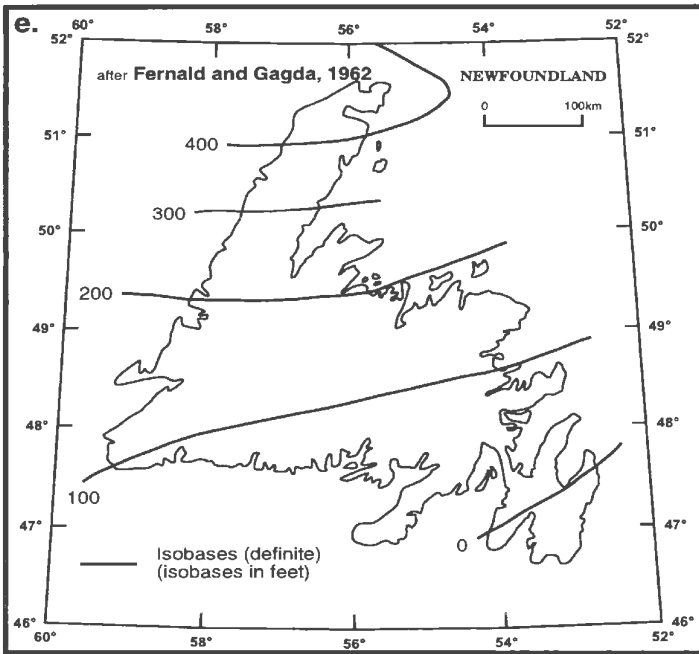
punctuated by intervals of rapid rise such as described by Fairbanks (1989) from Barbados coral reef records, or consisted of periods of rapid rises of about 0.2 metres as a result of catastrophic outburst floods from the waning Laurentide ice sheet (Shaw, 1989; Blanchon and Shaw, 1993) separated by periods of little change. Regardless, sea level has continued to rise in some places and fall in others, with a difference of over 100 m (Lambeck, 1990). The larger changes are in areas underlain by, or proximal to, Late Pleistocene ice sheets, and result from continued isostatic adjustment of the crust as a result of ice sheet loading or non-uniform meltwater distribution. Large parts of the continental shelf off the west (Scotian Shelf), and south and east (Grand Banks) coasts of Newfoundland were exposed during the Pleistocene as a result of sea level lowering of 90 to 120 m (Piper *et al.*, 1990).

Newfoundland was peripheral to the Laurentide ice sheet and was influenced by the forebulge produced by crustal loading to the north. The forebulge or peripheral bulge (Walcott, 1972; Peltier, 1974, 1996) is produced by the lateral displacement of viscous mantle caused by crustal depression from ice sheet loading. During depression this bulge migrates outward causing an RSL rise. Following wastage of the ice, this bulge migrates back towards the centre of the depression in response to the isostatic disequilibrium, causing a local RSL fall. The position of sites relative to the passage of the forebulge produces distinctive RSL curves (Figure 1-12). At point A, the forebulge has not yet passed and the RSL history shows continuously falling sea levels. This pattern characterizes areas beneath the Laurentide ice sheet, and corresponds to zone 1 (glaciated zone) of Clark *et al.* (1978) and Clark (1980), where isostatic adjustment has overwhelmed eustatic response. These curves are consistent in form with those reported from Labrador (e.g., Clark and Fitzhugh, 1992). At point B, the passage of the forebulge

is marked by falling sea levels as the forebulge approaches, followed by rising sea levels as it passes. Point C shows an initial period of falling RSL followed by a rise to the present, and D experiences a steady rise in RSL. Both points C and D should have no geomorphic features showing higher sea level above present. Within the areas defined by the Type A curves the record of falling RSL can be found both onshore (deltas, marine shells) or offshore (deep water to shallow water fossil assemblages from cores). Evidence of previous RSL changes in Type B and C areas can be found by freshwater to marine transitions in terrestrial settings (e.g., salt marshes) or in near-shore basins with a well-defined sill. No terrestrial evidence for Type D areas should be found in the onshore or inter-tidal record.

Quinlan and Beaumont (1981) used these curve types to develop models of RSL history with different ice mass configurations, using an earth model similar to that of Peltier and Andrews (1976). Two separate ice models were used. A 'maximum' model has ice extending out to the modern coast around most of the island, and is similar to that used by Peltier and Andrews (1976). A 'minimum' model, derived from Grant (1977a), has thin ice only reaching the inner coast. Both models showed increasing ice thickness towards the north-northeast reflecting the increasing effect of Laurentide ice. Each of these models allowed subdivision of the Island into distinct zones defined by the RSL curves described above. It was assumed that deglaciation was from an isostatically balanced earth at 18 ka, and ice and water loading was averaged over 1° by 1° grids. The models were then compared to known RSL curves, with the conclusion that the RSL history was best explained by a model falling between the minimum and maximum ice models. In a subsequent paper, Quinlan and Beaumont (1982) used the RSL record to reconstruct past ice configurations for Atlantic Canada. Their conclusions supported the presence of an ice dome on the north shore of the Gulf of St.
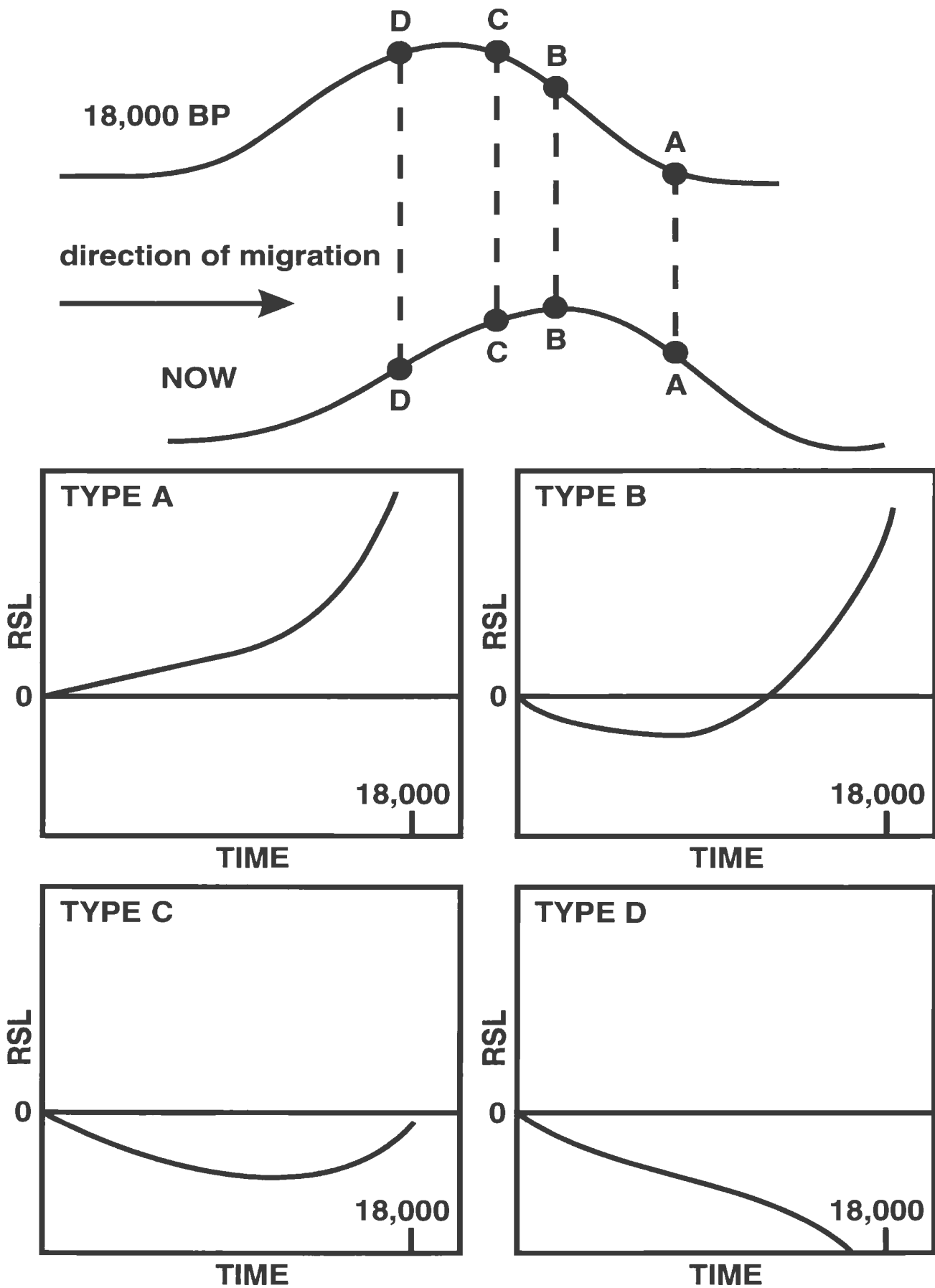
**Figure 1 - 12:** Forebulge migration and resultant relative sea level curves (after Quinlan and Beaumont, 1981).

Lawrence, suggested by a free-air gravity anomaly over the area, and limited ice in the Gulf of St. Lawrence. Despite some minor modifications (e.g., Scott *et al.*, 1987) the models proposed by Quinlan and Beaumont (1981, 1982) for Atlantic Canada have remained largely unchallenged until recently.

In western Newfoundland, RSL curves are only available from the Northern Peninsula (Grant, 1977a, 1992, 1994a, 1994b); and St. George's Bay - Port au Port area (Brookes, 1977a; Brookes *et al.*, 1985; Forbes *et al.*, 1993). The Northern Peninsula curves (Figure 1-13) from sites north of St. Barbe, such as L'anse aux Meadows are generally Type A, and show continual emergence of the coast from marine limit. Grant (1992, 1994a) however, speculates that brief periods of submergence may have occurred in the last 3000 years, and Liverman (1994) suggests the tip of the Great Northern Peninsula may show a modified Type B curve, marking the transition between coastlines showing Type A and Type B curves. Curves derived from south of St. Barbe, such as at Port au Choix, are Type B, although the amount of emergence from below 0 m asl is minimal. Grant (1987, 1989a) showed northward increasing marine limit from 75 m asl at Bonne Bay to 135 m at the tip of the Northern Peninsula. Marine limit in the Bay of Islands is shown at 50-75 m asl, although Brookes (1974) had previously suggested a limit of less than 50 m asl.

The St. George's Bay curve is of Type B. It shows emergence of the coast from a marine limit of about 45 m asl (Brookes, 1987; Grant, 1987), followed by a transition from emergence to submergence. The timing of this transition was initially placed at about 11.5 ka (Brookes, 1977a). Brookes *et al.* (1985) refined this curve based on radiocarbon dated marine shells, foraminifera and pollen, and showed the emergence-submergence transition occurred about 9.5 ± 0.3 ka. A further iteration from Forbes *et al.* (1993), using additional radiocarbon dates and

geomorphic data, demonstrated that the transition had occurred about 11.7 ka, with a -15 m low stand at about 10 ka and relative sea level returning to near present at about 5.5 ka (Figure 1-12). Shaw and Forbes (1995) subsequently redefined the postglacial sea level lowstand at 25-30 m for St. George's Bay, decreasing to 0 m just north of Bonne Bay. Humber Arm had a lowstand at about 6 m below present mean sea level. The timing of the lowstand was relatively late (~6.5 ka) at the northern limit, and early (~9.5 ka) in the southwest.

Liverman (1994) used all available radiocarbon dates on marine fossils to redefine the RSL history of the Island. The presence of *in situ* marine shells shows that the relative sea level was higher than present when the shells were deposited. Areas characterised by Type A curves should therefore have a range of radiocarbon dates from deglaciation to present (assuming no selective sampling), whereas Type B curve areas should record only dates within a certain range, excluding the time when submergence occurred. The results showed that most of the Island is characterised by a Type B curve. The exceptions are the tip of the Northern Peninsula, which shows a Type A curve involving either continual emergence or a modified Type B curve with an emergence-submergence-emergence oscillation, as proposed by Grant (1994a, 1994b) and Liverman (1994); and the easternmost Avalon Peninsula, which may show a single Type C curve. Similarly, the nearshore parts of the Scotian Shelf and Grand Banks record Type C curves, and the outer margins record Type D curves (Piper *et al.*, 1990). Liverman (1994) also showed that there was an earlier and more rapid sea level transgression than predicted by Quinlan and Beaumont (1982).

Shaw *et al.* (1995) conducted an offshore survey in the Humber Arm and adjacent fjords. The survey included a collection of a sediment core, taken from beneath 92 m of water midway across the Humber Arm between Giles Point and
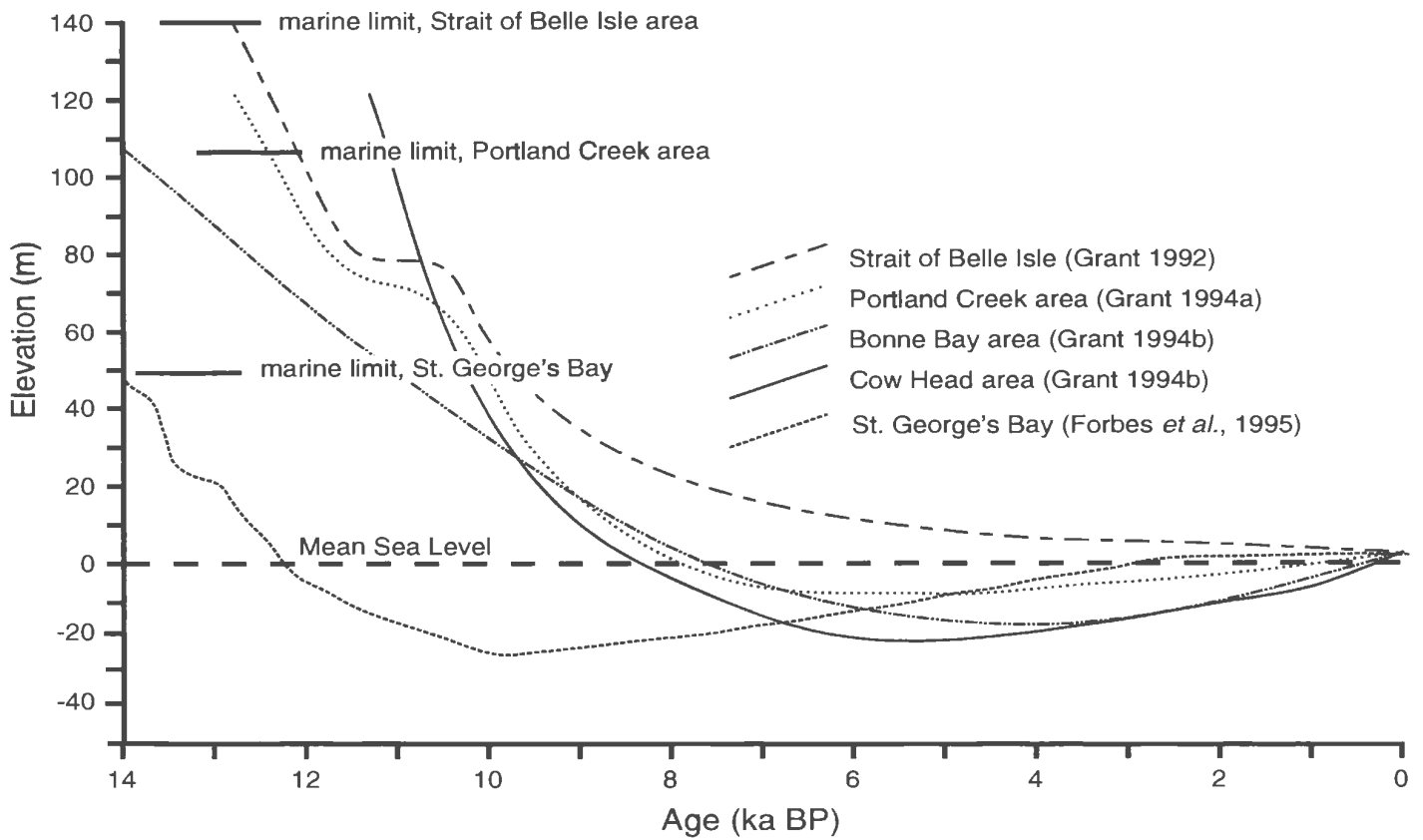
**Figure 1 - 13:** Previously published relative sea level curves for western Newfoundland.

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Meadows Point (48°58.9'N, 58°03.1'W). The core shows at least 102 cm of reddish brown 'buttery clay', overlain by 7 cm of muddy gravelly sand, and 50 cm of silty clay, the upper 25 cm of which is bioturbated. The muddy gravelly sand contained fragments of a marine bivalve, with a corrected age of 5,360±60 BP (Beta 81980), and was tentatively interpreted to be related to the post-glacial lowstand (Shaw *et al.*, 1995). Table 1-3 shows grain size and foraminifera data from this core. They show the reddish brown buttery clay (mean 10.2-10.3ø) has a consistent grain size in at least the bottom 60 cm of the core. Foraminifera diversity and concentration are low below 80 cm, showing less than 5 species. One sample was barren (100 cm depth). Foraminifera species include *Cassidulina reniforme* and *Elphidium excavatum*. Both have a wide range of temperature and salinity tolerances, and are commonly the first to appear following deglaciation (Vilks *et al.*, 1989; MacLean *et al.*, 1992; Scott *et al.*, 1984). Foraminifera species change up-core to those indicative of warmer and more saline water conditions (e.g., *Adercotryma glomerata* and *Islandiella helenae*).

### Use of radiocarbon dates

The establishment of a chronology for western Newfoundland, and other areas, is dependent on radiocarbon dating marine or terrestrial organic material. Notwithstanding discussion of the validity of individual dates with regard to potential errors, a topic recently addressed by Macpherson (1996), two other factors need to be considered.

The inherent uncertainties in $^{14}$C activity (Lowe and Walker, 1984) mean that radiocarbon age calculation is reported as a bell-curve distribution, with the date representing the mean determination, and the error bar (±) representing one standard deviation about the mean. There is thus a 1 in 3 probability that the actual

**Table 1-3:** Grain size characteristics, and number of foraminifera species in a short core from the Humber Arm, taken from Shaw *et al.* (1995).

| Depth (cm) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Mean (ø) | S.D. (ø) | Foraminifera (species) |
|------------|-----------|----------|----------|----------|----------|----------|------------------------|
| 2-4 | 0.04 | 8.58 | 49.98 | 42.4 | 7.7 | 2.5 | 20 |
| 44-46 | 0.51 | 15.34 | 43.78 | 40.37 | 7.3 | 3.0 | 13 |
| 50-54 | 11.87 | 32.24 | 30.42 | 25.47 | 4.8 | 4.4 | 20 |
| 62-64 | 0.0 | 3.61 | 27.92 | 68.48 | 9.3 | 2.6 | 9 |
| 98-100 | 0.0 | 0.54 | 14.09 | 85.36 | 10.2 | 2.1 | 3 |
| 118-120 | 0.0 | 0.99 | 12.54 | 86.47 | 10.3 | 2.0 | 4 |
| 138-140 | 0.0 | 1.07 | 14.69 | 84.23 | 10.2 | 2.0 | 3 |
| 153-155 | 0.0 | 0.62 | 13.99 | 85.39 | 10.3 | 2.1 | 3 |

age of a sample falls outside the range of the mean ± 1 standard deviation. Reported ages should consider the statistical basis, e.g., a date of 12.6 ± 0.3 ka (12.3 to 12.9 ka) is statistically similar to 13.1 ± 0.3 ka (12.8 to 13.4 ka) because the error ranges overlap.

A second consideration is the effect of $^{14}$C plateaux. These are periods of several hundred years duration of constant radiocarbon age, identified in lacustrine (Ammann and Lotter, 1989; Lotter, 1991; Lotter *et al.*, 1992) and marine environments (Broecker *et al.*, 1988). They are likely the result of decreased levels of $^{14}$C in the atmosphere, possibly associated with meltwater events in the North Atlantic (Edwards *et al.*, 1993). Radiocarbon plateaux have been identified at 12.8 - 12.6 ka and 10.0 ka (Ammann and Lotter, 1989), and at 9.5 ka (Becker *et al.*, 1991; Lotter, 1991), and prevent precise dating during the Older Dryas, Bølling, Younger Dryas and Preboreal biozones.

Radiocarbon dates presented in this thesis are in years before present (BP). Shell dates from the Geological Survey of Canada (GSC) laboratory are normalized to $\delta^{13}$C=0% PDB, to correct dates for the age of seawater. Samples from other laboratories are normalized to $\delta^{13}$C=-25% PDB, meaning that GSC dates are about 410 years younger than would be reported from the same sample by another laboratory. A correction of 410 years has been applied to all non-GSC ages.

## Methodology

### Field Observation

Field work largely was conducted over a 3-year period between 1990 and 1993. During this period over 650 bedrock and Quaternary sediment exposures were examined. Bedrock exposures were examined for ice flow indicators, mainly striations. Appendix A provides a complete listing of those sites at which ice flow

indicators were identified, and Chapter 4 provides a discussion of the results.

Quaternary sediment exposures were described from natural (lake shoreline, riverbank) or cultural (gravel pits, road cuts, backhoe pits) features. Each exposure was described, as summarized in Appendix A. Detailed notes are available through the Geological Survey, Department of Mines and Energy, St. John's. Clast fabrics were taken, as described below, and sediment samples collected for laboratory analysis, including Munsell colour (Munsell Colour, 1988), and grain-size analysis (detailed below). Munsell colours presented in this thesis are moist colours taken from fresh exposures, unless otherwise stated. Fine-grained sediments were collected for micro-faunal examination, and for geochemical analysis.

The surface elevation of features was determined either using a topographic map or with an altimeter. Determinations from topographic maps with a 10 metre contour interval are considered accurate to ± 5 m, whereas those from altimeter measurements are ± 2 m. Altimeter measurements were related to mean sea level or lake levels, or to vertical control stations distributed through the field area (Geodetic Survey of Canada, 1978).

### Geophysical Survey

A geophysical survey of Deer Lake was planned to examine the morphology and stratigraphy, initially of Deer Lake, and subsequently of the northern Grand Lake basin. The survey was designed to utilize a Datasonics SPR-1200 Bubble Pulser, and echo sounder. However, a combination of poor weather during the scheduled survey period and mechanical failure, prevented completion of the survey.

## Laboratory and Office Methods

a) Grain size analysis

The textural analyses were completed in the Geological Survey laboratory in St. John's. Matrix samples (finer than 2 mm/-1ø) were split to provide a 100-150 gram sample, and wet sieved through a 4ø (63 µm) sieve. The retained fraction was oven dried and sieved through a nest of 6 stainless steel sieves (-1ø to 4ø) following the standard procedures outlined by Bowles (1978). The finer than 4ø fraction was analysed using a Coulter Counter Model TAII-L. This resistance pulse analyzer determines the number and size of particles suspended in a conductive liquid as it is forced through a small aperture, by monitoring an electrical current that also passes through the aperture from two electrodes on either side of the aperture. The particle size is determined from the change in electrical resistance, that has a magnitude proportional to the particle volume, as a particle passes through the aperture. Results are provided at 0.33ø intervals for 2 aperture sizes, 100µm and 200µm. Duplicate samples were incorporated into the grain size analyses to test the reproducibility of results, and control samples were regularly used to calibrate the instrumentation. Syvitski *et al.* (1991) report on a comparative study between laboratories, including the one at the Newfoundland Geological Survey, in which they concluded the laboratory provided consistent and accurate results.

A program developed by Liverman (Department of Mines and Energy, unpublished) combines data from the coarse sieving and the Coulter Counter. Data were plotted as cumulative curves using log-probability axes, from which proportions of each major Wentworth clast size were determined. In addition, standard statistical parameters were derived for each grain size analysis, including graphic mean and inclusive graphic standard deviation (Folk and Ward, 1957). Other potential statistical measures, such as skewness and kurtosis, that were

designed for characterization of sand-dominated systems are not generally considered useful for analysis of diamictons, silts and clays (Ahlbrandt and Fryberger, 1982; Ehrlich, 1983). Data are provided in Appendix A, and discussed in Chapters 2, 3, and 4.

b) Fabric analysis

At a given site, three-dimensional clast fabrics (trend and plunge) were measured on 25 elongate pebbles with a length-breath ratio of greater than 3:2. Fabric measurements were taken from a small area (less than $1m^2$), remote from both observable contacts and large boulders. Results were plotted on a stereogram and analyzed using the Stereo™ software package for the Apple Macintosh microcomputer (MacEachran, 1990). In each case, eigenvector analysis was completed using the technique of Mark (1973) and Dowdeswell and Sharp (1986). Normalized eigenvalues ($S_i$) indicate the strength of individual eigenvectors, that represent the amount of clustering within the data. The $S_1$ eigenvalue is associated with the eigenvector $V_1$ that gives the direction of maximum clustering. The eigenvector $V_3$ (eigenvalue $S_3$) is the direction of minimum clustering. Randomness testing shows that for 25 pebble samples $S_1$ values of greater than 0.46 and $S_3$ values of less than 0.21 are significantly different from random distributions at the 95% confidence level (Anderson and Stephens, 1972; Woodcock and Naylor, 1983)

c) Boron geochemistry

Sediment geochemistry, particularly analysis of boron, has been used as a palaeo-environmental indicator of conditions during deposition of fine-grained sediments (Shimp et al., 1969; Catto et al., 1981; Mosser, 1983).

Boron was analysed by prompt-gamma neutron activation at the Chemex

laboratory in Vancouver. Detection limit was 5 p.p.m., and standards and controls of known value were incorporated within the data set.

d) Microfaunal examination

A preliminary assessment of microfaunal content of fine-grained sediments was achieved by examination of randomly selected sub-samples of sieved $2\emptyset$ to $4\emptyset$ fractions. Samples from Goose Arm, the lower Humber River valley and the shores of Grand Lake were selected for examination. Samples were disaggregated in water, and passed through a $4\emptyset$ sieve to remove the silt-clay fraction. Residue was air dried and sieved through a bank of $2\emptyset$, $3\emptyset$ and $4\emptyset$ sieves. Individual size fractions were examined under a petrographic microscope, and foraminifera tests identified to the species level, where possible, by Dr. Chris Pereira of the Geological Survey, Department of Mines and Energy.

## Statement of Problem

The Humber River basin is an inland basin situated between two possible Late Wisconsinan ice dispersal centres, one on the Long Range Mountains and the other on The Topsails. The existing literature concerning the glacial history for the area is generally confusing and contradictory, with the individual influences of the two dispersal centres and other possible centres being poorly defined.

The modern Humber River basin is almost isolated from the coast by the Long Range Mountains, except for a breach through the gorge near Corner Brook. The lower parts of the basin, below 50 m asl, lie below the post-glacial marine limit for this part of the west coast postulated by Brookes (1974). These lower areas could, therefore, have been inundated by the sea during deglaciation. Existing relative sea level data suggest that either the ice model or the earth response model

proposed by Quinlan and Beaumont (1981, 1982) require modification. The lack of a well-constrained glacial history used in the original models suggests the ice model may require refinement. The 'maximum' model had ice extending only to the outer coast. Thicker and/or more extensive ice over the Island may be required to explain the distribution of RSL curves found in the existing data.

Jukes (1842) suggested that the area is topographically suited to the development of a large inland lake, which would have included Grand Lake, Deer Lake and the Indian River valley. Preliminary work by Batterson and Taylor (1990) supported this contention. The existence of a large lake during deglaciation would provide an alternate deglacial model for the area to those proposed by Prest *et al.* (1968), Dyke and Prest (1987), and Grant (1989a). They suggested a gradual retreat from the coast towards remnant centres on west coast highlands, beginning about 14000 - 13000 years BP.

The principal objective of this thesis is to develop a hypothesis that describes both the glacial and post-glacial history, and the palaeo-geography of the landscape in the Humber River basin and surrounding areas. This objective has been accomplished by completing the following tasks:

1. Mapping of the distribution of Quaternary sediments, landforms, and features;

2. Description of their geomorphic characteristics, sedimentological and other physical properties; and

3. Recognition and assessment of indicators of ice flow direction.

The hypothesis developed is tested against existing descriptions of the late-Pleistocene history of the area and Holocene relative sea level change.

## Use of Recent Publications

Various components of this thesis have been published, either as progress reports for the Geological Survey, Department of Mines and Energy (Batterson and Vatcher, 1992a; Batterson and McGrath, 1993; Batterson and Taylor, 1994; Batterson and Janes, 1997), as journal publications (Batterson *et al.*, 1993, 1995a), or in conference proceedings (Batterson, 1997). These contributions were derived from thesis research and arguments found within them are discussed within this thesis. Differences in interpretation exist between these contributions and this thesis. In all cases this thesis supersedes earlier work.

## Organization

Apart from the Introductory chapter, this thesis is divided into 7 additional chapters.

Chapter 2 considers the surficial geology of the research area. The distribution and characteristics of sediments and features found are discussed, exclusive of the regional implications to the Quaternary history.

Chapter 3 discusses the characteristics, genesis, and stratigraphy of diamictons found across the Humber River basin. The chapter emphasizes discussion of diamicton exposures that provide evidence for the range of depositional environments encountered.

Chapter 4 provides a detailed description and interpretation of deglacial and post-glacial sediments, emphasizing those exposures across the Humber River basin showing the range of depositional environments found. Interpretation of genetic environments, and their application to similar sediments is discussed. Stratigraphic relationships throughout the basin are also discussed.

Chapter 5 considers ice flow history, based on erosional (striations) and

depositional (clast provenance, clast fabrics, landforms) data. A summary of the ice flow history is provided.

Chapter 6 describes the sea level history for that part of the basin below marine limit. This chapter discusses radiocarbon dates collected during research, and their application to constructing a relative sea level curve for the Humber Arm area.

Chapter 7 integrates the data presented in the mapping, sediment description and ice flow history chapters into a series of hypotheses that describe the glacial and post-glacial history of the Humber River basin. Individual hypotheses are tested against field data, and previous hypotheses are also discussed. The implications of proposed hypotheses to the published regional reconstructions, some of which include areas outside the Humber River basin, are also discussed.

Chapter 8 summarizes the major findings, and also discusses other areas of potential research.

Three Appendices provide site (including location, description, grain size), overburden thickness, and clast provenance data.

# Chapter 2

# Terrain Units and Surficial Geology of the Humber River Basin

**Introduction**

A surficial geology map of the study area (Figure 2-1) summarizes data derived through a process of preliminary aerial photograph interpretation, followed by field work and subsequent reinterpretation. Aerial photography was primarily 1:50,000 scale black and white photographs, although areas of thick drift cover around Grand Lake, and between Reidville and Corner Brook were also examined from 1:12,500 scale colour photographs. Ground verification assisted with the classification of mapping polygons.

The surficial geology was classified using a sediment-landform approach. The classification scheme is similar to that used by Fulton *et al.* (1975), Grant (1973) and Vanderveer (1975), and is suited to areas with physiographic diversity and a wide variety of sediment types, plus Quaternary erosional and depositional landforms. The legend has a genetic category that describes the sediment type (e.g., glacial, fluvial, colluvial), and a morphology category that describes the surface expression (e.g., veneer, hummocky, fan). Most map units contain more than one genetic and/or morphological type. To accommodate this, units are subdivided by decreasing dominance. For example, Tv/Rc means that the area is dominantly a veneer of till, with a lesser area of bedrock concealed by a mat of vegetation and/or soil. Up to three genetic subdivisions can be shown, with a combination of slashes (/ or //) or hyphens (-) being used to indicate

relative proportions. In the map presented, polygons are coloured based on the dominant sediment type, and thus several polygons are commonly combined and shown as a single colour. The map does not take into account differences in texture, colour, or structure that may be found within sediments of the same genetic origin.

Surficial geology maps were initially digitized at 1:50,000, combined with the Caris Geographic Information System, and output as colour maps. The enclosed map is largely derived from 1:50,000 surficial geology maps (Batterson, 1992, 1994a, 1994b, 1994c).

**Previous mapping**

Previous mapping of all or parts of the Humber River basin (Brookes, 1970a; Grant, 1973, 1989b, 1991; Liverman *et al.*, 1991; Sparkes, 1985, 1987; Vanderveer, 1987) was reviewed following completion of aerial photograph interpretation and field work. Although there are broad similarities between previous mapping and the present surficial interpretation, there are also significant differences. For instance, areas mapped by Grant (1989b) along the eastern shore of Grand Lake as thick till containing moraines are interpreted here as glaciolacustrine fan deposits, composed mostly of sand and gravel, on the basis of field investigations. The lowlands on the northwest shore of Deer Lake mapped as thick till eroded by meltwater channels by Grant (1989b) and Vanderveer (1987) are mapped here as fluvial sand and gravel. Similarly, areas mapped as till ridges in the Cormack area by Vanderveer (1987) are defined here as till eroded by meltwater channels. Better access, and the increased exposure recently available in many areas, has allowed an improved interpretation over previous ones.

## Quaternary sediment thickness

Figure 2-2 shows an isopach map for the Humber River basin. It was constructed from 902 data points, generated from a variety of sources, including water well data (67), drill core data from mineral exploration (141), site assessments for buildings and infrastructure development (53), highway construction (9), and field observations by the author (632). A listing of data sources, apart from field sites, is recorded in Appendix B.

Drilling and construction data commonly extends to bedrock, and therefore provides accurate data on Quaternary sediment thicknesses. Drill logs include descriptions of sediment type, although these may be unreliable. Golder Associates (1983) for instance, reported up to 120 m of "till" in the Steady Brook area. Examination of samples collected by the Department of Works, Services and Transportation from drilling in the same area during highway reconstruction showed the sediment to be silty clay.

Drilling as part of mineral exploration programs was restricted to several small areas. Wigwam Brook in the upper Humber River valley was the site of exploration for uranium in the late 1970's and early 1980's (Hyde, 1984). Over 80 drill holes were placed within a 10 km$^2$ area. Similarly, diamond drilling in support of gold exploration in the Kettle Pond area at the southern end of Glover Island provided data from 30 boreholes. Several drill holes were reported in the area north of Sandy Lake, and along the east shore of Grand Lake. The latter was the site of the earliest drilling in the Humber River basin. Two drill holes were sunk in the Kelvin Brook area in 1879 in support of coal exploration (Murray and Howley, 1881). The precise location of these drill holes is uncertain because

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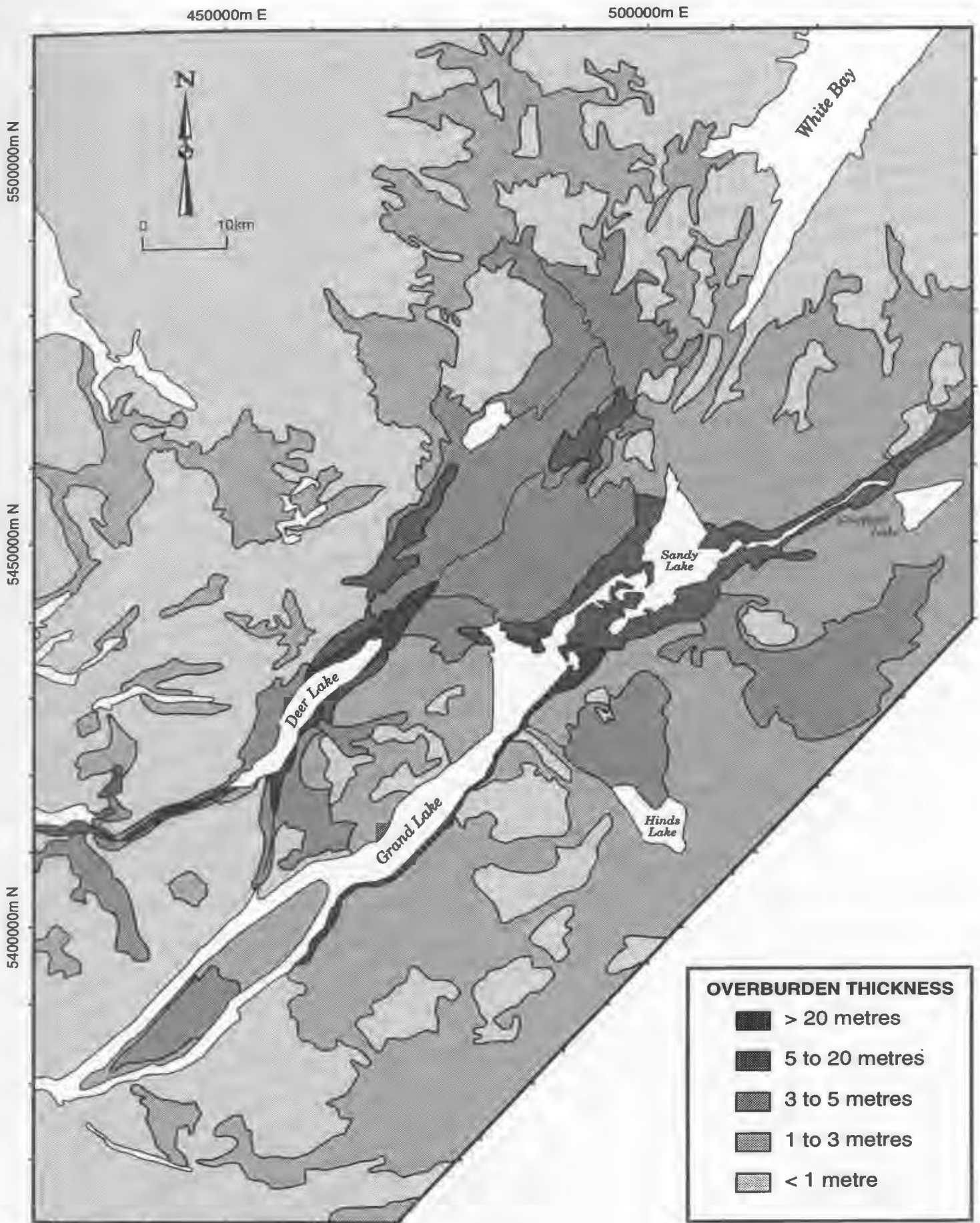
**Figure 2 - 2:** Isopach map of the Humber River basin.

descriptions refer to distances upstream from the lake, which has subsequently been changed by the dam at Junction Brook. Further drilling was completed in the same area in 1893 (Murray and Howley, 1918).

Following 1983 legislation, water well records must be submitted to the Provincial Government. Data compilations (Department of Environment, 1995) provide accurate location and overburden thickness data. Water wells are mainly restricted to communities, so data are therefore confined to the Humber River valley.

Field observations record exposure thicknesses. Bedrock is commonly not observed in test pits, and consequently most field observations must be considered as minimum depths of overburden. Areas of exposed bedrock were mapped from aerial photographs.

Field observations and borehole data have been individually measured, and are therefore accurate to within ± 0.5 m. Areas interpreted from aerial photographs as bedrock or bedrock concealed by vegetation are considered accurate indications of the lack of overburden. Areas in which underlying rock structure is identified from aerial photographs (i.e., areas of veneer) show overburden thicknesses of less than 2-3 m. Areas from which no bedrock structure is seen, and which are not adjacent to measured observations show overburden greater than 3 m. Data points are not evenly distributed across the study area, and the isopach boundaries are therefore approximate.

Much of the Humber River basin is characterised by thin overburden cover (less than 5 m). The Long Range Mountains west of the Humber River valley and south of Corner Brook are bedrock dominated, with generally thin (less than 1-2 m) and discontinuous overburden. Other large areas of bedrock exposure are Birchy Ridge, the western shore of Grand Lake, and parts of The

Topsails south of Hinds Brook. Small areas of bedrock exposure are scattered through the basin, mostly restricted to highlands.

The major valleys contain areas of thick Quaternary sediment. The Humber River valley between Reidville and Corner Brook contains thick successions. Thicknesses of more than 60 m of sand, silt and clay are reported from Deer Lake airport (Environment Canada, 1980), and in excess of 120 m of sediment was recorded at Steady Brook (Golder Associates, 1983). Successions greater than 20 m in thickness are found at Humber Village (30 m), Little Rapids (30 m), Pasadena (85 m), Pynn's Brook (62 m), St. Judes (76 m) and Reidville (25 m) (Figure 1-2). The consistent thickness found in these drill holes suggests a sediment-filled depression extending from at least as far north as Reidville to the modern coast. Offshore in the Humber Arm, Shaw *et al.* (1995) reported combined water depth and sediment thickness exceeding 115 m. There are no drill core records from the Humber River gorge, but extension of the data from Steady Brook to Humbermouth suggests the presence of a deep (up to 100 m?), and narrow (less than 200 m wide in places) channel. The extent of the depression north of Reidville is uncertain. Bedrock is exposed in the river bed at Harrimans Steady (about 20 m asl), 8 km upstream of Reidville, with an adjacent 15 m high sand and gravel terrace. Surficial aerial photograph mapping suggests sediment thickness is generally less than 10 m upstream of this point.

An area of relatively thick sediment is found in a 150 m to 1200 m wide belt along the eastern shore of Grand Lake, extending south from Howley to Connors Brook, and possibly beyond (Figure 1-2). Lakeshore exposures are up to 30 m high, and Murray and Howley (1918) reported 35 m of overburden near Howley. Similarly, the north shore of Grand Lake also has sediment exposures in excess of 30 m high. Sediment thickness below the floor of the modern lake is

unknown. No seismic data are available for the Grand Lake basin. The depth of Grand Lake itself is unknown, although it is believed to extend far below modern sea level (see Chapter 1). The western shore of Grand Lake is bedrock dominated.

Other areas of relatively thick Quaternary sediment are found in the western foothills of Birchy Ridge, the Cormack area, the Old Mans Pond valley, Hinds Brook valley, and Birchy Lake valley (Figure 1-2). The Birchy Ridge foothills have been subject to intensive uranium exploration. Drilling near Wigwam Brook commonly encountered more than 10 m of overburden (see Appendix B). Sediment thickness generally decreases both west and east of Wigwam Brook. The Cormack area, on the western edge of the upper Humber River valley has water well data showing sediment thickness of at least 10 m, and locally as much as 40 m. Bedrock exposures are more common westward towards the Long Range Mountains, although numerous rock ridges are also found in areas northeast of Cormack. The Old Mans Pond, Hinds Brook and Birchy Lake valley areas contain relatively thick (5-10 m) sediment, largely confined to the valley sides. Bedrock exposures in these areas are rare, commonly exposed during road construction or in stream cuts.

Areas between bedrock dominated highlands and sediment filled river valleys have 0 to 5 m of sediment, an assessment based on the numerous bedrock outcrops exposed through these areas. These intermediate areas characterize 60-70% of the Humber River basin.


## Surficial Units

### Bedrock (R or Rc)

Exposed bedrock and bedrock concealed by a thin mat of soil and/or vegetation together compose about 34% of the Humber River basin. The largest

regions are the Long Range Mountain uplands, west of the Humber River valley; the area west of the South Brook valley, and parts of Birchy Ridge; Glide Lake highlands; and The Topsails south of Hinds Brook. Areas underlain by Carboniferous strata contain rare bedrock exposures.

In some parts, bedrock structure controls surface relief features (Figure 2-3). In the Carboniferous Deer Lake basin, Hyde (1982) recognised numerous north-south to northeast-southwest-trending anticlines and synclines within the Humber Falls and Rocky Brook Formations in the Humber River valley, and in the Saltwater Cove Formation on Birchy Ridge. The largest of these is the Humber Syncline, extending along the axis of the Humber River valley from the head of Deer Lake to near Adies Pond. Elongate hills on the Glide Lake highlands are also coincident with the location of isoclinal folds (Hyde, 1982).

The orientation of bedrock ridges and coastal valleys, such as Goose Arm, Penguin Arm and North Arm follow fold or thrust axes within carbonate bedrock (Williams and Cawood, 1989; Knight, 1994). In particular, the Goose Arm, Sugar Loaves, and Raglan Head anticlines, the Middle Arm and Sugar Loaves synclines, and the Goose Arm, Reluctant Head and Alder Steady (Figure 2-3) thrusts are all aligned roughly northeast-southwest (Knight, 1994). Bedrock ridges in the carbonate rocks south of Corner Brook commonly define the trend of north-south oriented folds (Knight, 1995). Large areas of The Topsails plateau in the east of the study area are underlain by granitoid rocks and lack the fold structures characteristic of the sedimentary rocks to the west. Some valleys are fault guided, notably the Hinds Brook valley (Whalen and Currie, 1988). The prominent erosional remnants found on The Topsails - the Fore, Main, and Mizzen Topsail - are likely bedrock controlled features. Kerr (1994) suggests that,
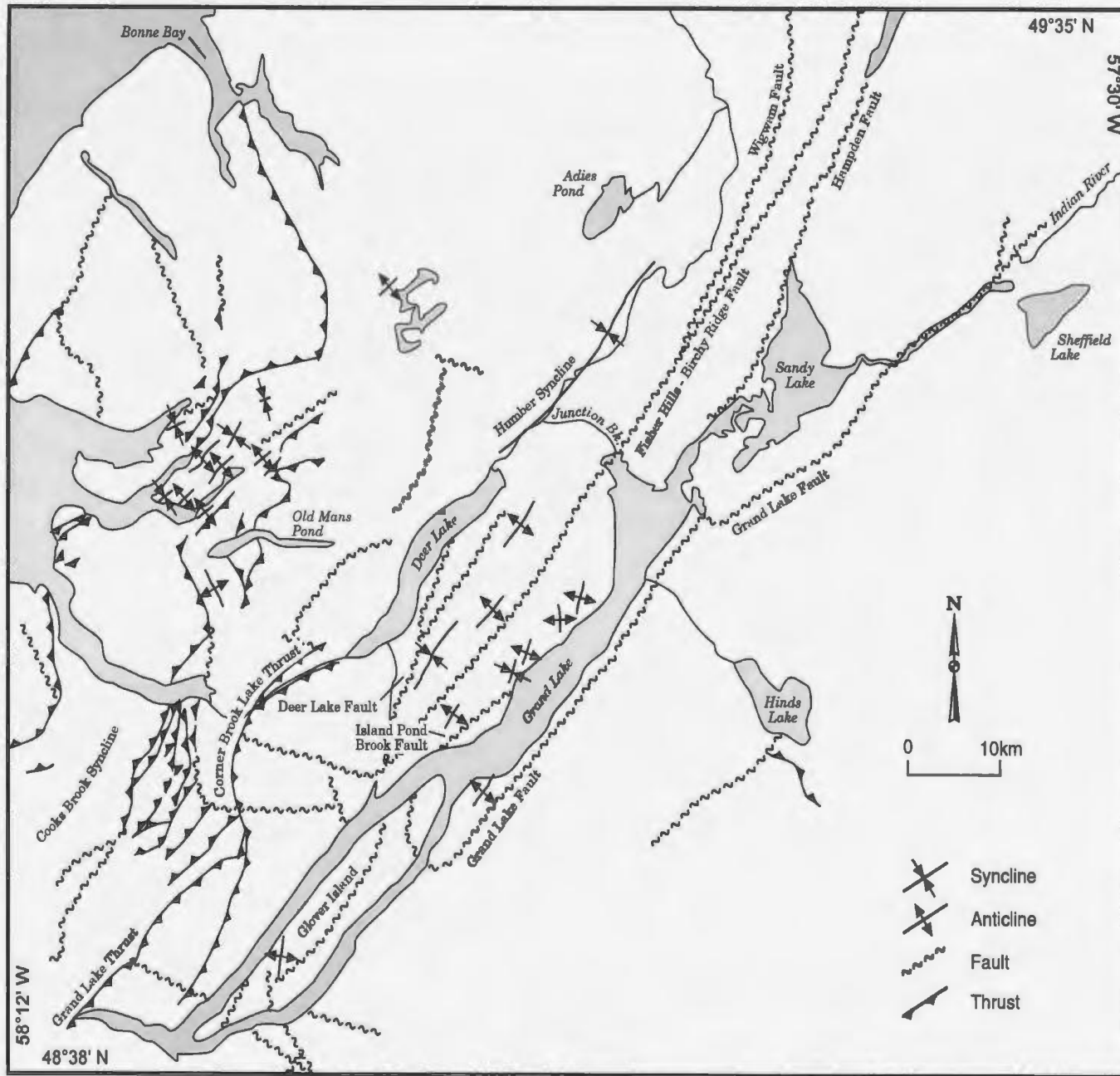
**Figure 2 - 3:** Bedrock control on surface geology.

although there is no lithological contrast with surrounding rocks, the lack of joints oriented perpendicular to glacial flow on the remnants may have impeded erosion.

### Diamicton (Tv, Tr, Te, Th)

General Comment

The surficial geology of the Humber River basin contains large areas described as diamicton. Diamicton is a sediment with a wide range of grain sizes (Flint *et al.*, 1960; Dreimanis, 1988). It is a descriptive term that carries no genetic implication. Diamictons that are demonstrably deposited by glaciers are tills. The term till has, however, commonly been used as a lithological descriptor rather than genetic. Surficial maps produced by the Geological Survey of Canada, and provincial agencies are examples of this approach, which is a pragmatic view considering multiple users, commonly with a limited scientific background. Published maps of the Humber River basin by the author adopt this approach.

Determination of the depositional environment is critical during interpretation of section descriptions. In Newfoundland, the revision of the number of Late Wisconsinan glacial advances on the southern Avalon Peninsula was based on stratigraphic re-interpretation (Rogerson and Tucker, 1972; Eyles and Slatt, 1977). Similarly, in the southern St. George's Bay area, Liverman and Bell (1996) demonstrated that sediments previously interpreted as representing glacial advance and readvance, separated by a delta-building phase, could have been entirely deposited within an ice-contact glaciomarine environment. Elsewhere in Canada, the ongoing debate on the interpretation of sediments within the Scarborough Bluffs between those arguing for diamictons to be interpreted as tills (e.g., Karrow, 1967, 1984, 1989; Karrow *et al.*, 1984; Dreimanis,

1982; Sharpe and Barnett, 1985), and those who invoke a proglacial lake depositional environment (e.g., Eyles and Eyles, 1983, 1984; Eyles *et al.*, 1983a; Eyles and Westgate, 1987) has significant implications on the number and timing of glacial episodes within the Great Lakes basin.

Application of the term diamicton is appropriate for discussion of the regional distribution of sediments, where the genesis cannot be unequivocally determined. This is the approach taken on terminology in the remainder of the discussion. The exceptions are those cases, such as landforms, where an environmental link can be made.

### Areal Distribution

Diamicton is the most common surface unit across the Humber River basin, comprising 44% of the surficial geology (Figure 2-1). It is found throughout the basin area, with the exception of the main valleys, such as lower Humber River, Deer Lake valley, upper Humber River (adjacent to the main channel), Grand Lake valley, Grand Lake - Sandy Lake lowland, Hinds Brook, Goose Brook and Kitty's Brook valleys, and the Birchy Lake valley. Within each of these areas, however, diamicton may be found underlying younger surface sediments.

Diamicton in the Humber River basin is generally thin (0-3 m). The thickest assemblages, exceeding 10 m, are present in the upper Humber River valley in areas underlain by soft Carboniferous bedrock. Diamicton thicker than 5 m is also found in the Corner Brook area overlying shale bedrock, in the South Brook valley, and adjacent to Hinds Lake.

### Physical Characteristics

Many of the characteristics of diamictons within the field area, especially

colour, texture and clast provenance are largely controlled by the composition of the underlying bedrock.

a) Grain size

No complete grain size analyses of any diamicton was undertaken during the course of this study, due to the impracticalities and statistical difficulties of characterizing coarse sediment containing boulders up to 50 cm diameter (Gale and Hoare, 1992). However, Ricketts (1993) provided data on 38 diamicton samples from an aggregate resources inventory (Table 2-1). They show that diamictons in the Humber River basin are generally coarse, with matrix content between 25-65% of total grain size by weight.

A total of 282 grain size determinations were made on diamicton matrix samples from the thesis area. Figure 2-4 shows a grain size envelope for diamictons found throughout the basin. They show a wide range of curves, reflecting the diverse bedrock geology of the area. The relative proportions of sand (-1 to 4ø), silt (4 to 8ø) and clay (finer than 8ø) are plotted on a ternary diagram (Figure 2-5). The figure shows most diamictons in the study have a sand to silty sand matrix, using the subdivisions of Shepard (1954). The mean grain size proportions are 66% sand, 28% silt and 6% clay. Table 2-2 provides a summary of matrix statistics. Diamictons are very poorly sorted to extremely poorly sorted, ranging from standard deviation (s.d.) 2.14ø to 5.65ø, with an average of 3.55ø. The low silt-clay component is reflected by the mean grain size that ranges from granule gravel (-1.8ø) to medium silt (5.9ø), with an average in the medium sand (1.4ø) fraction. The mean grain size value of -1.8ø is an artifact of the graphing process that interpolates data into the coarse fractions. Of the 282 diamicton exposures sampled only 40 had a silt-clay content greater than 50%, with only 5 recording silt-clay fractions greater than 70%. Of these, three were
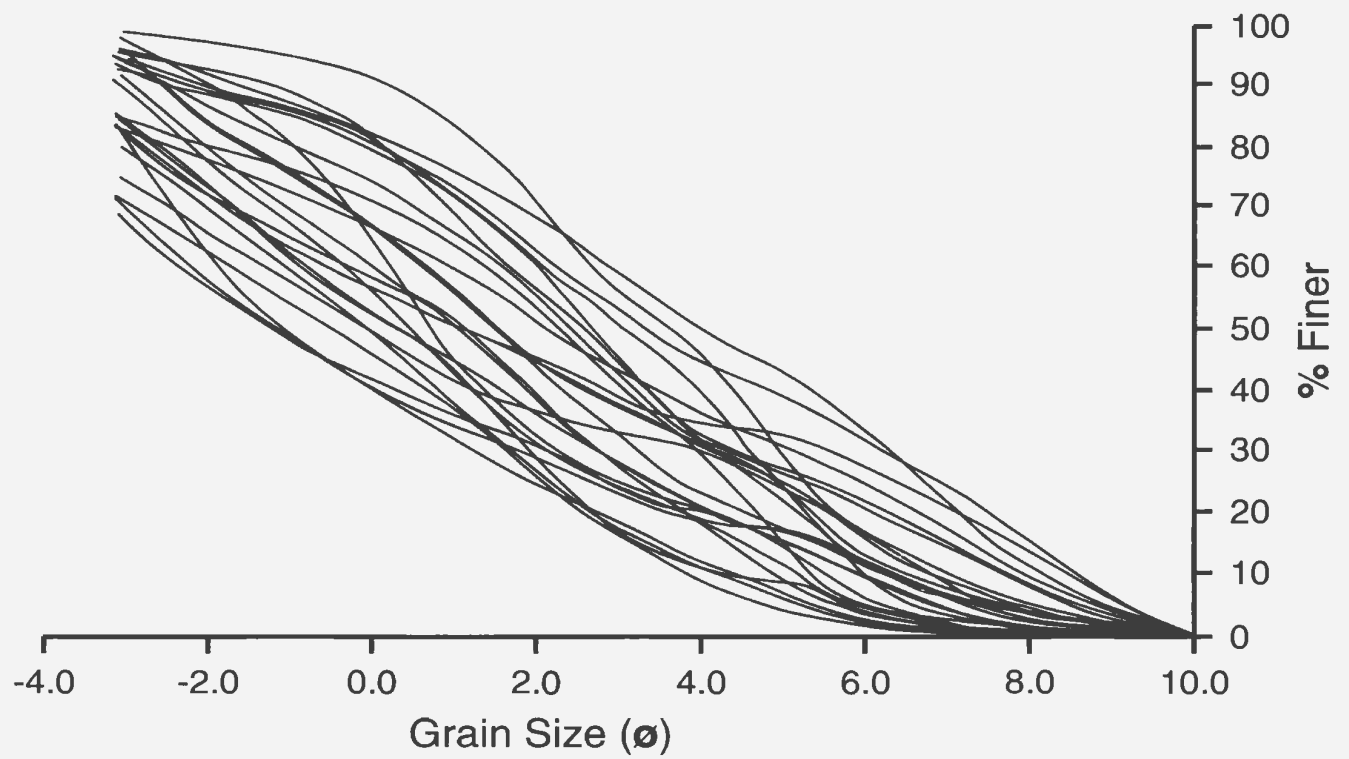
**Figure 2 - 4**: Grain-size envelope for diamictons within the study area. These curves are representative of the total of 282 grain size determinations.

**Table 2-1**: Grain size analysis of diamicton samples from the Humber River basin, including mean and standard deviation (S.D.). Data from the Aggregate Resources database (Ricketts, 1993).

| NTS sheet | sample | % gravel (-1σ to >6σ) | % sand (-1σ to 4σ) | % silt-clay (< 4σ) |
|---|---|---|---|---|
| 12H03 | 783464 | 53.1 | 37.8 | 9.1 |
| 12H03 | 783466 | 52.0 | 43.2 | 4.9 |
| 12H03 | 783463 | 67.3 | 28.4 | 4.3 |
| 12H03 | 784000 | 64.4 | 27.7 | 7.6 |
| 12H03 | 784002 | 44.5 | 42.1 | 13.3 |
| 12H03 | 784003 | 32.7 | 46.1 | 21.2 |
| 12H04 | 783977 | 40.8 | 47.7 | 11.5 |
| 12H04 | 783978 | 39.0 | 55.0 | 6.0 |
| 12H04 | 783979 | 42.9 | 47.2 | 9.9 |
| 12H05 | 770701 | 61.3 | 32.1 | 6.6 |
| 12H05 | 770702 | 58.4 | 37.8 | 3.9 |
| 12H05 | 770708 | 74.0 | 23.5 | 2.5 |
| 12H05 | 783882 | 54.3 | 34.1 | 11.6 |
| 12H05 | 783884 | 33.6 | 50.1 | 16.3 |
| 12H05 | 783886 | 45.3 | 35.1 | 19.6 |
| 12H05 | 813102 | 53.3 | 41.2 | 5.6 |
| 12H06 | 783936 | 41.4 | 42.9 | 15.7 |
| 12H06 | 783962 | 48.1 | 41.4 | 10.6 |
| 12H06 | 784011 | 51.9 | 43.3 | 4.8 |
| 12H06 | 784013 | 47.6 | 30.7 | 21.7 |
| 12H06 | 784014 | 78.6 | 19.9 | 1.4 |
| 12H06 | 803188 | 58.9 | 35.1 | 5.9 |
| 12H06 | 803343 | 66.0 | 33.0 | 1.0 |
| 12H07 | 782410 | 50.5 | 31.7 | 17.8 |
| 12H07 | 782413 | 59.5 | 26.1 | 14.3 |
| 12H07 | 782415 | 44.4 | 43.8 | 11.8 |
| 12H07 | 782417 | 62.7 | 29.1 | 8.1 |
| 12H07 | 782421 | 49.5 | 41.6 | 8.9 |
| 12H07 | 782423 | 64.7 | 32.2 | 3.0 |
| 12H07 | 782424 | 66.6 | 29.6 | 3.9 |
| 12H07 | 782436 | 65.9 | 22.1 | 12.0 |
| 12H07 | 782445 | 45.3 | 50.4 | 4.3 |
| 12H07 | 782451 | 52.7 | 39.0 | 8.3 |
| 12H07 | 782462 | 54.6 | 37.8 | 7.6 |
| 12H07 | 782464 | 45.9 | 43.3 | 10.8 |
| 12H07 | 782466 | 59.5 | 32.0 | 8.5 |
| 12H07 | 782467 | 50.8 | 42.2 | 7.0 |
| 12H07 | 782470 | 64.2 | 32.0 | 3.8 |
| | | | | |
| | Mean | 53.8 | 37.1 | 9.1 |
| | S.D. | 10.7 | 8.4 | 5.4 |
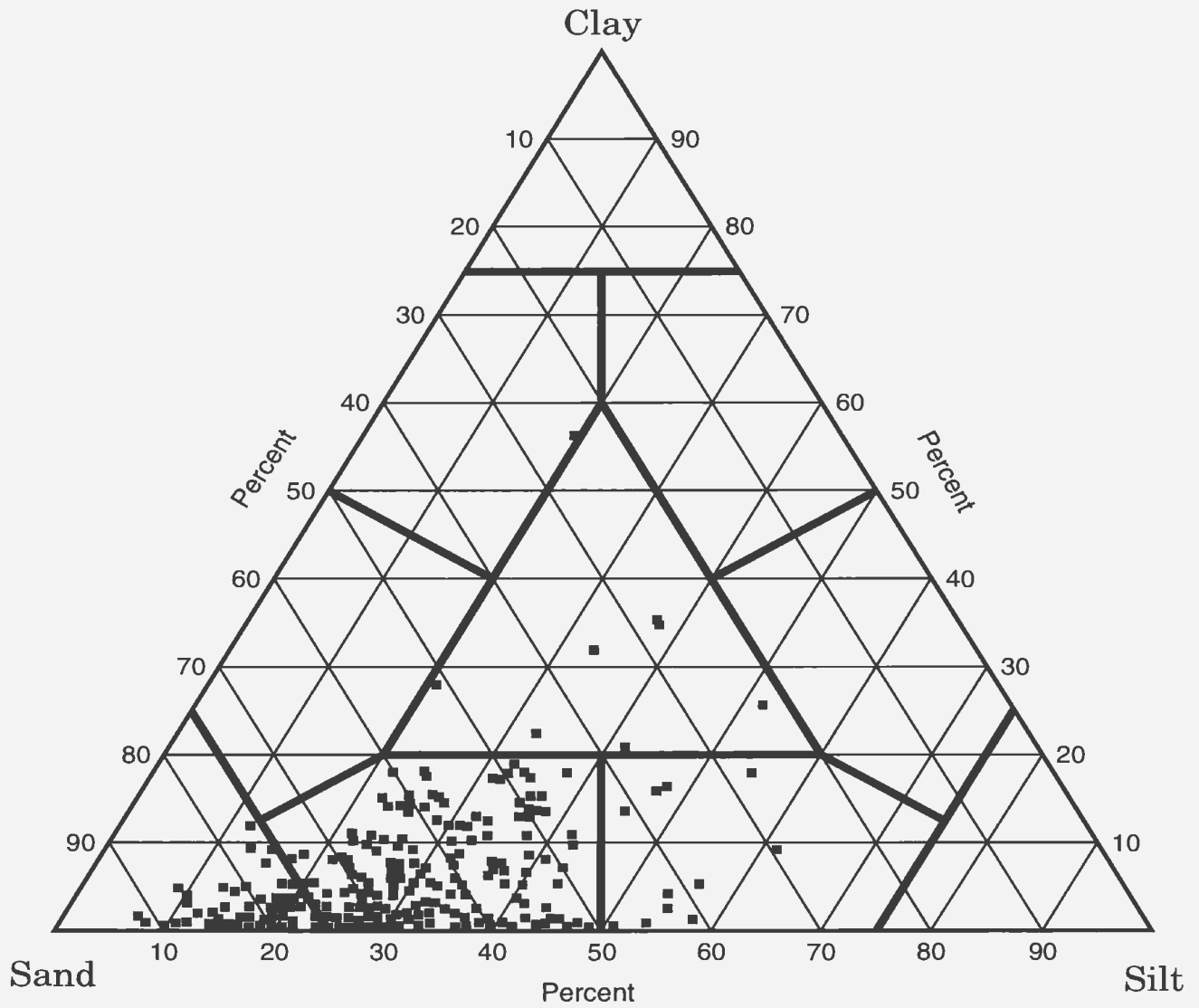
**Figure 2 - 5:** Ternary diagram of diamicton matrix for all 282 grain size determinations. Thick lines represent the grain size subdivisions of Shepard (1954).

**Table 2-2:** Mean, range and standard deviation of diamicton matrix samples (n=282).

| Sediment | Mean % | High % | Low % | Std. Dev. |
|---|---|---|---|---|
| | | | | |
| Sand | 66.4 | 95.8 | 23.0 | 12.1 |
| Silt | 28.0 | 61.3 | 4.2 | 9.9 |
| Clay | 5.5 | 56.4 | 0 | 6.8 |

found in the Humber River valley (Humber River gorge, Pynn's Brook, and Wigwam Brook), and two on the east side of Birchy Ridge. In each case adjacent diamicton exposures recorded a considerably smaller silt-clay component.

Figure 2-6 shows the distribution of mean grain sizes across the study area overlain on a simplified bedrock geology map. Although data are concentrated in the central part of the Humber River basin, some general trends are evident. Those diamictons with a mean grain size finer than 3ø generally are found overlying soft Carboniferous bedrock, or over the limestone terrain directly west of the Carboniferous basin. Some fine-grained diamictons also are found overlying schist in the South Brook valley, although areas of schist bedrock both west and east of the valley are overlain by coarse textured diamictons. Coarser grained diamictons (coarser than 2ø) are found along the shores of Grand Lake, on The Topsails, and overlying gneiss bedrock west of the upper Humber River basin. These bedrock types are generally coarse textured. Although bedrock texture is commonly similar to the texture of overlying diamictons, there are some exceptions. The Upper Humber River basin west of Birchy Ridge, for example, is underlain by soft Carboniferous sandstone and siltstone (Hyde, 1979). Diamictons in this area, however, are relatively coarse grained, and are thus likely not derived from the underlying bedrock. Similarly, Carboniferous sediments underlie the Glide Lake area between Deer Lake and Grand Lake, but are overlain by relatively coarse grained diamictons. In each of these cases, the clast content contains low proportions of the underlying bedrock (see Chapter 3).

### b) Colour

Diamicton colour is an important field descriptor. Colour carries no genetic implication, although it has been used in stratigraphic interpretation and
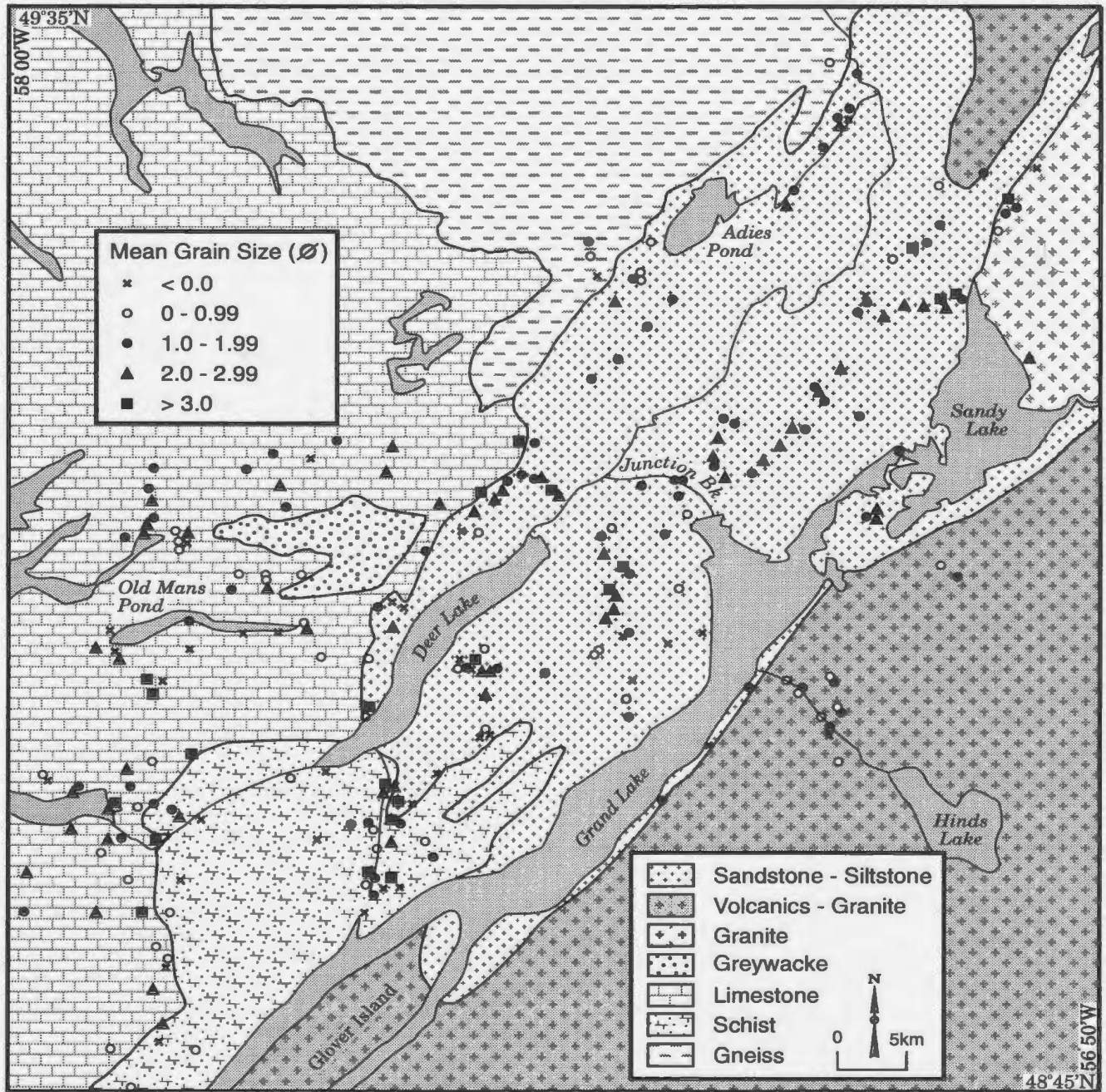
**Figure 2-6:** Mean grain size of diamictons overlain on a simplified bedrock geology map.

correlation (e.g., Stalker, 1984; Eschman and Mickelson, 1986; Matsch and Schneider, 1986). Matrix colour is largely controlled by grain size, mineralogy, and post-depositional weathering. Matrix colour is expected to be variable in an area such as the Humber River basin where there are abrupt lateral changes in bedrock geology. Kirby (1988) noted the wide local variation in diamicton colour during soil mapping in the area. Table 2-3 shows the variations in diamicton colour found during field mapping, in relation to the underlying bedrock geology.

### Surface Expression

Diamicton is most commonly exposed as a surface veneer (less than 2 m) over bedrock, with surface expression controlled by the underlying bedrock structure (Figure 2-1). In the upper Humber River valley diamicton is found as a veneer over northeast-southwest oriented bedrock ridges. Many of these features had been previously interpreted as till ridges (e.g., Vanderveer, 1981, 1987; Grant, 1989b).

Diamicton ridges are rare across the basin. Several are found in the Goose Pond area. They are northwest-southeast oriented linear ridges up to 1500 m long, 400 m wide, and less than 10 m high. A single diamicton ridge is located in the Hampden River valley, south of Rushy Pond. It is oriented approximately north-south, about 400 m long, 250 m wide and 20 m high, with an asymmetric long-profile, steeper and shorter on the south side. Diamicton thicker than 3 m is found in a south-southwestward (190°) oriented, 1600 m long, 400 m wide and 15-20 m high ridge in the Mary Ann Brook valley at the southwest end of Birchy Ridge. The orientation of the ridge is similar to isoclinal bedrock features mapped by Hyde (1979), although no bedrock was found along the ridge.

**Table 2-3**: Diamicton colours across the Humber River basin, using the Munsell Colour Chart System (Munsell Color, 1988). All samples are taken from freshly cleaned exposures.

| Geographic area | Bedrock geology | Moist colour | Dry colour |
|---|---|---|---|
| Long Range Mountains, west of upper Humber River valley | Gneiss, granitic gneiss | dark greyish brown (10YR 4/2) | light greyish brown (10YR 6/2) |
| Upper Humber River valley | Red, green, grey sandstone, siltstone, conglomerate | dark brown to reddish brown (10YR 3/3 to 5YR 4/3) | light grey to light reddish brown (10YR 7/1 to 5YR 6/3) |
| Birchy Ridge | Grey sandstone and siltstone | dark greyish brown to very dark greyish brown (2.5Y 4/2 to 10YR 3/2) | grey to light brownish grey (2.5Y 6/0 to 2.5Y 6/2) |
| East of Birchy Ridge | Grey to red sandstone, siltstone. Granite | dark greyish brown to very dark greyish brown (10YR 4/2 to 2.5Y 3/2) | light grey to light brownish grey (10YR 7/2 to 10YR 6/2) |
| Hinds Lake area | Granite, granodiorite, rhyolite, gabbro | very dark to dark greyish brown (10YR 3/2 to 10YR 4/2) | light grey to light brownish grey (10YR 7/2 to 10YR 6/2) |
| Highlands east of Glide Lake | Grey sandstone, siltstone | dark brown to very dark greyish brown (10YR 3/3 to 10YR 3/2) | pale brown to light brownish grey (10YR 6/3 to 10YR 6/2) |
| West of Glide Lake and Humber River valley | Red to grey sandstone, siltstone, shale | grey-brown (2.5Y 5/2) to dark reddish-brown (5YR 3/3) | very pale-brown (10YR 7/3) to light reddish brown (5YR 6/3) |
| Highlands west of Deer Lake - sandstone-rich | Red to grey sandstone, siltstone, conglomerate | reddish brown (5YR 4/3) | light reddish brown (7.5YR 6/4) |
| Highlands west of Deer Lake-limestone-rich | Limestone and dolomite | dark greyish brown (2.5Y 4/2) | light brownish grey (2.5Y 6/2) |
| Highlands south of Corner Brook | Limestone, dolomite, marble, shale | light olive brown (2.5Y 5/4) to dark yellowish brown (10YR 4/4) | light grey (2.5Y 7/2) |
| Old Mans Pond area | Limestone, dolomite, shale | olive (5Y 5/3) to dark greyish-brown (2.5Y 4/2) | light yellowish-brown (2.5Y 6/4) to pale yellow (5Y 7/3) |

A group of crag-and-tail hills was mapped in the Long Range Mountains west of Deadwater Brook (Figure 2-1). The ridges are less than 500 m long, 50 m wide and 10 m high. They are oriented west-northwestward (azimuth 280°).

Minor moraine ridges are found in four locations across the study area. In the un-named valley directly south of Blue Grass Brook, a series of small ridges are oriented perpendicular to the valley axis. Similar features are found in the Island Pond Brook valley, east of South Brook. Minor moraine ridges oriented south-southwest to north-northeast are found southwest of Junction Brook, and east-west oriented moraines are found near Adies Pond. Only the features near Junction Brook were examined in detail. They are 100-200 m long, 30-50 m wide and less than 3 m high. They are composed of sandy diamicton, with a fine sand matrix containing numerous thin, coarse-sand lenses. Clast types are varied and include granites, porphyry, sandstone and siltstone. The granites are similar to those found on The Topsails (units Sm, Oib, Oic of Whalen and Currie, 1988). Clast fabric is weak ($S_1$=0.55, $S_3$=0.17).

Larger moraines are found in the Chain Lakes - Kitty's Brook area of The Topsails. Moraines are oriented southeast-northwest, perpendicular to the orientation of the valley, up to 1600 m long and 12 m high, with crests up to 300 m apart. Moraines have either symmetrical cross profiles or are steeper on southwest-facing slopes. Tucker (1974b) showed the features to be composed of till, with a preferred clast orientation parallel to the ridge long-axis, and suggested they may have originally been drumlins formed by an ice flow towards White Bay, but subsequently modified by flow down the Chain Lakes valley towards Sheffield Lake. Tucker (1974b) suggested the ridges were originally formed in the Early Wisconsinan, although no supporting data were presented.

Hummocks composed of diamicton are found in the upper Humber River valley, northeast of Adies Pond; in the Goose Pond to Hinds Lake area; and on the high plateau (~520 m) east of Goose Pond; with smaller areas identified in the Corner Brook lake valley, and south of Pinchgut Lake.

Hummocks are commonly 50-75 m in diameter and up to 10 m high. In the upper Humber River and Grand Lake areas, hummocks occur over areas exceeding 5 km$^2$, whereas those south of Corner Brook are confined to small groups of features. The hummocks are best viewed on aerial photographs where they are surrounded by wetlands. A hummock dissected by a road west of Adies River shows three superimposed diamictons ranging from dark reddish brown (5YR 3/3) to dark yellowish brown (10YR 3/4) to very dark grey (5YR 3/1). The lower two diamictons are broadly similar in texture, with a very poorly sorted (s.d. 3.45ø), silty sand matrix (79% sand, 19% silt, 2% clay). The upper diamicton has a siltier matrix (65.7% sand, 34.3% silt), and fewer red sandstone clasts than underlying units. A feature near Corner Brook Lake, dissected by a logging road, was composed of a very poorly sorted (2.99ø s.d.), matrix-supported, sandy diamicton (83% sand, 14% silt, 3% clay; mean 0.75ø), containing numerous irregular-shaped sand lenses throughout the unit. Clasts are of local provenance, up to 2 m diameter, with a poor clast fabric ($S_1$=0.51, $S_3$=0.12). Hummocks east of Grand Lake were not examined.

Areas of eroded diamicton surfaces are common across the study area. On the west side of the upper Humber River valley near Cormack, numerous meltwater channels are eroded through the surface diamicton (Figure 2-7). The channels are commonly 1500 to 3000 m long, although those occupied by modern streams, such as Rocky Brook, Middle Branch, and East Branch, are in excess of

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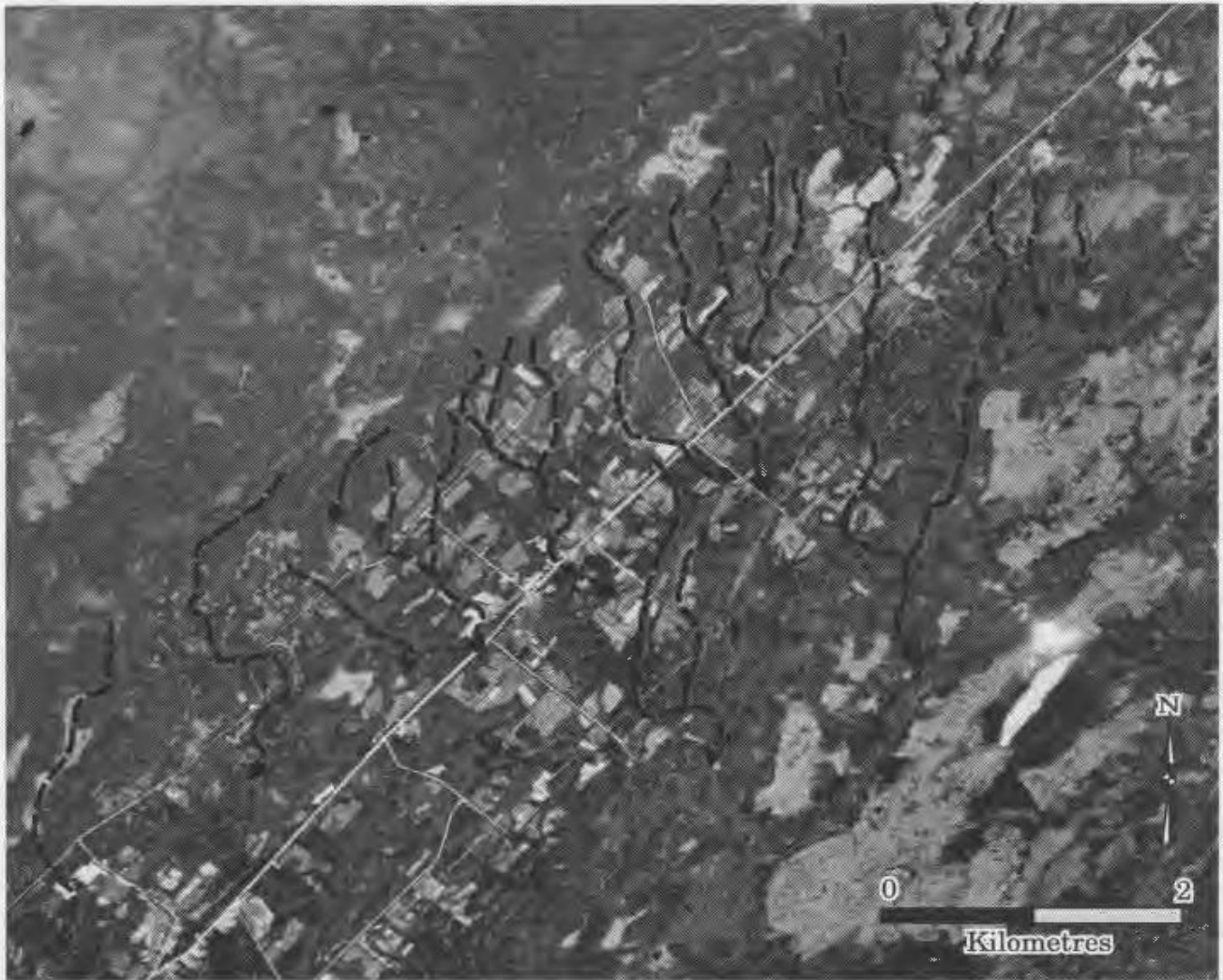
**Figure 2-7:** Meltwater channels in the Cormack area. Most channels extend from the foot slopes of the Long Range Mountains which form the western edge of the Humber River valley. The distribution pattern of the channels show the progressive retreat of ice up the valley towards the northeast (Photograph A20004 - 174 reproduced with permission of the Newfoundland Department of Natural Resources).

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10 km long. Channels are generally less than 100 m wide and 5 to 20 m deep, with a steep-sided, flat-bottomed, symmetrical to asymmetrical cross profile. They are oriented oblique to the valley axis, extending south-southeastward from the basin margins into the valley. Channel gradient varies between 1:40 and 1:95, and no gradient reversals were noted on any of the meltwater channels examined. This suggests that each channel was successively abandoned during northeastward retreat of ice along the Humber River valley. Many palaeo-meltwater channels are presently occupied by seasonal streams.

The Hinds Brook valley contains several large steep-sided, flat-bottomed meltwater channels. They are 1100-2600 m long, 200 m wide and up to 25 m deep; and are arcuate down-slope and down valley. Channel gradients are steep, 1:28 to 1:43, with the heads of channels becoming successively lower in elevation eastward up the valley, from 390 to 340 m asl. Only the easternmost channel extends to modern Hinds Brook (Figure 2-8). The channels were ice marginal or sub-marginal, formed by a glacier retreating up the Hinds Brook valley towards The Topsails plateau. Numerous small channels are found on the south side of the valley. They are short (less than 500 m), steep (1:3) features.

Numerous meltwater channels are found in the northwest slopes of The Topsails, overlooking Sandy Lake. Some of the channels are sub-parallel to the slope, particularly in the Goose Brook area, between Goose Brook and Kelvin Brook, and east of Goose Pond. The features are interpreted as ice marginal or sub-marginal channels formed between the hillside and ice in the valley. Other channels are oriented normal to the slope, and are interpreted as proglacial channels developed from wasting ice on the highlands.

Other areas of eroded diamicton occur on the flanks of Birchy Ridge, in the South Brook valley, in the Humber Canal area, in the Glide Lake valley and

**Figure 2-8:** Vertical aerial photograph of meltwater channels on the north side of the Hinds Brook valley. These show progressive eastward retreat of ice up the valley. (Photograph A20004 - 69 reproduced with permission of the Newfoundland Department of Natural Resources).

around Sheffield Lake. Numerous isolated channels are also found scattered across the area. In most cases, channels are 200-1000 m long and oriented perpendicular to the slope, with gradients between 1:10 and 1:100. They are indicative of wasting ice farther upslope.

### Glaciofluvial (G, Ge, Gh, Gr, Gv)

Glaciofluvial sediments and features are those derived from fluvial processes dominated by a glacial input, and may occur proximal to a glacier or in meltwater channels some distance from the ice front. Glaciofluvial deposits differ from non-glacial fluvial deposits in that glaciers affect input of sediments and water from fluctuating ice margins, buried ice blocks, and highly seasonal, diurnal and weather dependent variations in discharge (Ashley *et al.*, 1985). In recently glaciated areas, glaciofluvial sediments can be distinguished from non-glacial fluvial sediments by the distribution of sediment, sediment texture and sorting, presence of collapse features, and associated structures. Coarse-grained, poorly-sorted fluvial sediments that are apparently unrelated to modern fluvial activity, e.g., within an 'underfit' valley or with no modern fluvial source, are likely to be glacially-related. Fluvial sediments containing high angled cross-beds (>30°) or faulting may be related to deposition adjacent to an ice mass. Similarly, fluvial sediments showing abrupt lateral and vertical variations in grain size may be related to a glaciofluvial source. A glaciofluvial origin is also indicated by the presence of large boulders within fluvial sediment beyond the competence of any adjacent modern fluvial source.

Distribution

Sediments interpreted as glaciofluvial compose about 6% of surficial

sediment (Figure 2-1). They are common within the upper Humber River valley, and in valleys feeding into the Grand Lake and Birchy Lake valleys. In particular, the South Brook, Glide Brook, Humber River and Junction Brook valleys flowing into Deer Lake; the Kitty's Brook, Kelvin Brook, Hinds Brook, Little Pond Brook, and Red Indian Brook valleys along the eastern shore of Grand Lake; the Voyins Brook and Sheffield Brook valleys flowing into Birchy Lake, and the Indian Brook valley to the east, all contain glaciofluvial sediments. Small areas are also found within the Hughes Brook and Goose Arm Brook valleys. Glaciofluvial sediments are relatively rare over the highlands west of Deer Lake, and over the southern extension of the Grenville inlier west of the upper Humber River valley.

### Thickness

There is little data on the thickness of glaciofluvial sediments. Drill core data (see Appendix B) from Reidville show 25 m of sediment, and 50 m of sand and gravel reported from the Rocky Brook valley at Cormack (Department of Environment, 1995). Murray and Howley (1881, 1918) reported at least 29 m of sand and gravel from the Kelvin Brook area near Howley.

In many places, glaciofluvial sediment forms a veneer over diamicton or bedrock. Along the Rocky Brook valley, south of the Cormack Road, glaciofluvial sand and gravel is observed as a 2 m thick veneer over diamicton. Similarly, glaciofluvial veneers were found in the Hinds Brook valley (Appendix A).

### Grain-size

Texture of glaciofluvial sediment is a function of discharge, distance from source, length of system, position within system, bedrock geology and other factors. Although within-system variation can be described and interpreted (e.g.,

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Boothroyd and Nummedal, 1978; Smith, 1985), the listing of grain-size data from adjacent systems taken on a random sampling pattern, serves only to describe the range of grain-sizes encountered. Where examined, glaciofluvial sediments are composed of varying proportions of sand and gravel (~30-70% gravel, Ricketts, 1993), with less than 5% silt-clay.

Matrix texture from 64 glaciofluvial samples shows mostly sand matrices (average 91.2%), with a mean grain size of -0.17ø (very coarse sand). There are small proportions of silt (average 7.6%) and clay (average 1.2%). Appendix A contains a complete data listing.

### Sedimentary structures

Most glaciofluvial sediments consist of poorly to well-sorted gravel, containing subrounded to rounded clasts up to boulder size, with a medium- to coarse-sand matrix. The sediments commonly contain steeply dipping (45-60°), trough cross-bedded, medium- to coarse-sand and gravel, and numerous randomly distributed, moderately sorted, fine- to coarse-sand lenses. The lenses are irregular shaped and commonly fine upwards. Chapter 4 provides detailed descriptions of sediment.

### Surface Expression
#### Eskers

Eskers are found at several places (Figure 2-1) (Grant, 1989b; Vanderveer and Sparkes, 1982). A prominent ridge up to 15 m high and 50 m wide extends 4000 m from Deadwater Brook to Adies Pond (Plate 2-1). Where exposed the sediment is gravelly sand (80% sand) with a poorly sorted, fine to medium sand matrix. Open work granule gravel and coarse sand lenses are common. Clasts are

**Plate 2-1:**
An esker ridge near Adies Pond looking northward. The esker is 50 m wide, 15 m high and extends 4000 m from Deadwater Brook to Adies Pond. The esker shows that northward-retreating ice occupied the upper Humber River valley during deglaciation.

rounded to sub-rounded, and are derived from the underlying Carboniferous sandstone bedrock and from gneiss within the Long Range Mountains. The top of the esker is commonly gravel-rich. The esker is dissected in several places by meltwater channels.

Several smaller esker ridges are found on the north side of Deadwater Brook, each oriented northeast-southwest. Within the upper Humber River valley, another discontinuous esker ridge is found on the east side of Adies River. Vanderveer and Sparkes (1982) also mapped an esker in the Wigwam Brook area, trending northeast-southwest.

Eskers were also mapped in the Grand Lake basin. The valleys entering Little Grand Lake both contain eskers, as does the Red Indian Brook valley further north. The largest esker extends from near the northwest shore of Hinds Lake, through the un-named valley south of the Blue Grass Brook valley towards Grand Lake. All the eskers are sinuous and trend east-west. Similarly, a small esker southeast of Howley is oriented east-west, although an esker mapped north of Blow Hard Point on the north shore of Grand Lake is oriented northeast-southwest. Grant (1989b) mapped several north-south oriented eskers on the Grand Lake shore at the head of Junction Brook. A number of poorly exposed hummocks composed of sand and gravel were found in this area.

Eskers are not present on the highlands west of Deer Lake or on the Grenville inlier to the west of the upper Humber River valley.


Kames

A kame was mapped at the head of the Blue Grass Brook valley near Hinds Lake (site 92100, Appendix A). It is a hummock about 50 m diameter and about 15 m high. A 5 m-high section was exposed during construction of a

logging road, although much of the exposure was obscured by slumping. The sediment is a clast-supported, sandy boulder gravel, with a medium- to coarse-sand matrix (10% matrix). Clasts are subrounded, ranging from granules to boulders, with the largest clast about 80 cm in diameter. Approximately 40% of the clasts are greater than 5 cm diameter. Clast rock types are dominated by locally derived rhyolite and granite. No bedding was observed.

A group of hummocks near Howley are also mapped as kames. They are approximately circular to irregular in shape, 20 to 200 m diameter, commonly with a bouldery surface, and up to 10 m high. They are composed of matrix-supported gravelly sand, with a sand matrix and less than 5% silt-clay. A single grain size analysis shows a very poorly-sorted sediment (s.d. 2.42ø), 97.5% sand and 2.5% silt, with a mean grain size of -1.58ø (site 92016; Appendix A). Sediment is generally structureless, and clast types are dominated by locally derived granites. Clast fabric is moderate, girdle ($S_1=0.66$, $S_3=0.05$), showing a preferred clast orientation towards about 345°. Glaciofluvial hummocks were also found in groups in the lowlands east of Junction Brook.

### Eroded glaciofluvial sediment

Meltwater erosion channels cut into pre-deposited material are common in valleys containing glaciofluvial sediment, and indicate the rapid variations in discharge, and rapidly shifting stream channels common in proglacial fluvial environments. Channels in these areas are commonly short (less than 100 m), with gradients determined by the valley in which they are found.

### Discussion

The distribution of the glaciofluvial features described here is generally

similar to that mapped by Grant (1989b). The distribution of meltwater channels provides some data on the location of areas of ice wastage. The lack of meltwater channels over the highlands west of Deer Lake, and in the southern part of the Grenville inlier suggests that ice retreated rapidly from these areas, and did not waste *in situ*. In contrast, the numerous meltwater channels on The Topsails plateau show this to be an area of ice disintegration. There is a radial pattern to meltwater channels that extend from The Topsails plateau into the Hinds Brook and Kelvin Brook valleys, and into the Sandy Lake-Grand Lake basins from the 340 m asl plateau between Goose Pond and Hinds Lake. The presence of meltwater channels parallel to the slope between this plateau surface and the higher level at about 520 m asl to the east of Goose Pond, suggests that ice remained on the lower plateau as the slopes to the upper plateau became ice free.

The radial pattern of meltwater channels also suggests that wasting ice covered the southern end of Birchy Ridge; the highlands between the Glide Lake and Deer Lake valleys, overlooking the South Brook valley; and The Topsails southwest of Hinds Brook.

### Glacio-lacustrine and Lacustrine (L, Lt, Lr)

Sediments and features produced within bodies of standing water were identified at elevations above the proposed marine limit for the area. Those which are not related to modern lakes have been interpreted as glaciolacustrine. The sedimentary assemblages are discussed in greater detail in Chapter 4. Glacio-lacustrine and lacustrine deposits comprise about 1% of the study area (Figure 2-1), and may be subdivided into shoreline features (strandlines and deltas), and proximal and distal sediments.

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Distribution

Features and sediments related to higher water levels have been found in the South Brook, Grand Lake, and Birchy Lake valleys.

Features mapped as strandlines are found along on the western shore of Grand Lake. They occur as discontinuous, flat benches backed by a steep bluff. The bases of the bluffs commonly have a concentration of boulders. The most clearly defined strandlines are on the east side of Thirty-ninth Brook valley, about 350 m inland from Grand Lake (Table 2-4). Here, three strandlines at 141 m, 153 m and 176 m asl are separated by 2 well-defined bluffs (Plate 2-2). Each strandline was eroded into a diamicton-covered slope, and shows a concentration of boulders (mostly sub-rounded granites from The Topsails to the east), presumably derived from the slope itself. The uppermost terrace is eroded by a channel, the lower part of which is truncated by a ridge that extends across the entire channel. A small test-pit dug in this ridge shows the sediment as a dark greyish brown (2.5Y 4/2), clast-supported (30% matrix) sandy gravel with a poorly-sorted (s.d. 3.74ø), silty sand matrix (83.1% sand, 16.1% silt, 0.8% clay). Clasts are sub-rounded to sub-angular, granule to boulders. On the basis of its position across the channel, and sediment composition, this feature is interpreted as a beach ridge.

Several other areas showing strandlines were found north of the Thirty-ninth Brook valley (Table 2-5). North of Wetstone Point, strandlines were noted at 57 m, 62 m and 85 m above lake level, or 144 m, 149 m and 172 m asl respectively (sites 93026, 93083; Appendix A). East of Johnsons Pond, strandlines were found at 49 m and 56 m above lake level (site 93027; Appendix A). In each case, and at Thirty-ninth Brook, strandlines were coincident with areas of blown-down trees. The relationship between these blow-downs and strandline

**Table 2-4:** Features associated with higher water levels along Grand Lake, in the lower Thirty-ninth Brook valley. Elevations represent the mean of three separate altimeter determinations.

| Feature | Latitude (°N) | Longitude (°W) | Height (m) | Width (m) | Height above Grand Lake (m) | Elevation (m asl) |
|---|---|---|---|---|---|---|
| Strandline | 49°01.3′ | 57°21.8′ | | | 53.5 ± 1.5 | 140.5 |
| Scarp | | | 6.5 ± 1 | | | |
| Terrace | | | | approx. 75 | | |
| Strandline | 49°01.3′ | 57°21.8′ | | | 66 ± 1 | 153 |
| Scarp | | | 16 ± 1 | | | |
| Terrace | | | | approx. 150 | | |
| Strandline ? | 49°01.4′ | 57°21.8′ | | | 88.5 | 175.5 |

**Plate 2-2:**
Oblique aerial photograph showing strandlines along hillside adjacent to the Thirty-ninth Brook valley. Three levels are found, at 145 m, 153 m and 176 m asl. The strandlines were produced by a proglacial lake that occupied the Grand Lake valley during deglaciation.

**Table 2-5:** Features associated with higher water levels along the west side of Grand Lake. All measurements are by altimeter, and are considered accurate to within ± 2 m.

| Site | Location | Latitude (°N) | Longitude (°W) | Elevation (m asl) | Comments |
|------|----------|---------------|----------------|-------------------|----------|
| 93014 | Thirty-Ninth Brook | 49°01.3′ | 57°21.8′ | 174 | Front of terrace at 170 m asl. Boulders at base. Diamicton hillside. |
| 93014 | Thirty-Ninth Brook | 49°01.3′ | 57°21.8′ | 153 | Front of terrace at 147 m. 17 m bluff behind terrace. |
| 93014 | Thirty-Ninth Brook | 49°01.3′ | 57°21.8′ | 140 | Front of terrace 135 m. 7 m bluff behind terrace. |
| 93016 | Island Pond Brook | 48°56.4′ | 57°28.7′ | 137 | Front of terrace 137 m. 21 m bluff behind terrace. |
| 93026 | Just north of Wetstone Point | 49°04.4′ | 57°16.4′ | 171.5 | 14 m bluff behind terrace. Boulders common at base of terrace. |
| 93026 | Just north of Wetstone Point | 49°04.4′ | 57°16.4′ | 143.5 | Boulders common at base of terrace. 6 m bluff behind terrace. Front of terrace 139.5 m. Minor slope break at 168 m. |
| 93027 | East of Johnsons Pond | 49°05.9′ | 57°16.2′ | 143 | 7.5 m bluff behind terrace. Boulders at base of slope. |
| 93027 | East of Johnsons Pond | 49°05.9′ | 57°16.2′ | 136 | Possible terrace. |
| 93033 | North of Wetstone Point | 49°04.8′ | 57°16.2′ | 149 | 7.5 m bluff behind terrace. Boulders at base of slope. Other minor breaks of slope at 126 m, and 179.5 m. |

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development, if any, is unclear.

Strandlines were not found on the east side of Grand Lake. Instead, well-defined, flat-topped deltas were noted (Table 2-6), at the mouth of Hinds Brook (118 and 157 m asl), north of Grindstone Point (144 m asl), Little Pond Brook (140 m asl), Harrys Brook (144 m asl), south of Grand Pond Point (145 m asl), Connors Brook (130 m asl), and at Lewaseechjeech Brook (128 m asl) (Plate 2-3). Exposures within these features commonly show interbedded sand and gravel dipping towards Grand Lake at 20-30°. North of Hinds Brook, deltas are commonly fan-shaped. They are interpreted as deltas based on descriptions of sediment exposures, which are more fully discussed in Chapter 4.

The South Brook valley also contains deltas. Two deltas were found at about 135 m asl; one between Whitefish Creek and Carp Creek, and the other south of Salmon Creek. A delta was identified on the west side of the valley south of the transmission line at 145 m asl, and a large flat-topped feature was found on the opposite side of the valley with a surface elevation of 150 m asl. A small delta, with a surface elevation of 150 m asl, was also identified near Northern Harbour. Each of these features was flat-topped and showed interbedded sand and gravel dipping into the valley.

### Sediments

Sediments associated with the deltas identified above were generally sand and gravel. They are described in detail in Chapter 4. Generally, sediments are sandy gravel, with about 57% gravel, 42% sand, and 1% silt-clay (mean of 4 samples, Ricketts, personal communication, 1995). Matrix components are generally very poorly-sorted (s.d. 2.56ø) sand, with 95% sand, 5% silt and <1% clay (mean of 10 samples), and a mean grain size of -1ø.

**Table 2-6:** Deltas formed in higher water levels, above marine limit defined for the Humber River basin. Elevations are from altimeter (± 2 m) or topographic maps (± 5 m).

| Site | Location | Latitude (°N) | Longitude (°W) | Elevation (m asl) | Comments |
|---|---|---|---|---|---|
| 93032 | Hinds Brook | 49°04.8' | 57°12.5' | 118 | Front edge of delta 114 m. Well developed surface. |
| | Lewaseechjeech Brook | 48°38.4' | 57°56.7' | 128 | Topographic map. Unvisited. |
| | Connors Brook | 48°49.4' | 57°32.9' | 130 | Topographic map. Unvisited. |
| | Grand Lake | 49°06.0' | 57°11.0' | 129-141 | Fan deltas. Tops difficult to determine. Poorly exposed. |
| 89006 | South Brook | 48°58.5' | 57°37.2' | 134 | Abandoned gravel pit. Contains fossil ice wedges. |
| | 2 km south of Grand Pond Point | 48°51.9' | 57°30.9' | 135 | Topographic map. Unvisited. |
| 91235 | South Brook | 48°57.5' | 57°37.2' | 135 | West side of valley. Abandoned gravel pit. |
| 93030 | Little Pond Brook | 48°57.8' | 57°20.3' | 140 | Delta surface continues on north side of brook. |
| 93017 | Harrys Brook | 48°54.0' | 57°25.6' | 144 | Delta front at 129 m. 32 m bluff behind delta. Bluff mostly gravels. |
| 93031 | North of Grindstone Point | 49°00.8' | 57°16.5' | 144 | Front edge of delta at 134 m. |
| 91232 | South Brook | 48°57.4' | 57°36.3' | 145 | East side of river. Dissected by channels. |
| 91087 | Northern Harbour | 48°53.9' | 57°38.1' | 150 | Top of 20 m terrace. |
| 93032 | Hinds Brook | 49°04.8' | 57°12.5' | 157 | Delta surface highly dissected by channels |
| 93111 | Birchy Lake | 49°16.9' | 56°47.3' | 210 | Possible delta. No internal structure noted. |
| | Kitty's Brook | 49°09.9' | 56°51.1' | 250 | Tucker, 1974b |

**Plate 2-3:**
Oblique aerial photograph of a raised delta at the mouth of Little Pond Brook on the east side of Grand Lake. Two main levels are seen, at 145 m and 136 m asl. This delta, and others along the east side of Grand Lake were produced at the margin of a proglacial lake that occupied the valley during deglaciation of the Humber River basin.

Sections commonly show interbedded fine and medium sand, laterally grading to interbedded sandy gravel and gravely sand. The interbedded sands are well-sorted, and planar-bedded, with beds extending laterally in excess of 5 m. Pebbles are rare and do not deform surrounding beds. In the deltas adjacent to Grand Lake, beds dip toward the lake at 10 to 15°. The interbedded gravelly sand and sandy gravel have 10-50% sand matrix. Clasts are commonly sub-rounded, composed of local rock types, and are less than 5 cm diameter. Beds dip toward Grand Lake at 20-25°.

Grand Lake and Sandy Lake contain several modern lacustrine features. Recurved spits are found at the mouths of Blue Grass Brook and Hinds Brook (Plate 2-4). The Hinds Brook spit is 800 m long. It is anchored to the north shore of Hinds Brook from where it extends 450 m northwest into the lake before curving 350 m towards the north. An area of flats occupies the foreshore northeast of the spit. The spit is composed of sand and gravel. A separate spit is found on the south side of Hinds Brook, although it is smaller (200 m long) than that on the north shore. The Blue Grass Brook spit is smaller, extending 150 m northeastward from the lakeward edge of the delta on the south side of the brook. The spits indicate northward shoreline transport of sediment. Baymouth bars were identified in 4 places: 800 m north of Blue Grass Brook, 900 m south of Alder Brook, at the mouth of Coal Brook, and 600 m west of Blow Hard Point. The latter two locations were not vegetated. A small tombolo was noted at the southern end of Sandy Lake, east of Howley.

All these features have developed since the level of Grand Lake was raised in 1929. The features were formed by wave transport, produced by dominant southwesterly winds that are funneled along the lake. Referring to Grand Lake, Jukes (1842) commented that "..there was often a tide in the pond after a high

**Plate 2-4:**
A recurved spit at the mouth of Hinds Brook, looking northward towards Howley. This is a recent feature formed subsequent to the raising of the lake in 1925. Fan-deltas produced at the margins of a proglacial lake that occupied the Grand Lake valley during deglaciation are seen to the north of the spit.

wind. This is no doubt caused by the banking up of the water at one end from the pressure of the wind." (p. 147). Strong southwesterly winds are also common along Deer Lake (Banfield, 1981), oriented in the same direction as Grand Lake. Wind velocities along Grand Lake are enhanced by the steep, high valley sidewalls.


### Marine (M, Mt, Mf)

Marine sediments are those deposited on, or seaward of, modern or palaeo-coastlines. Marine sediments comprise about 1% of the surface geology, and are subdivided into littoral and sublittoral features and deposits.


Distribution

Areas mapped as marine are found along the modern coast, and in the lower reaches of the Humber River basin below about 60 m asl (Figure 2-1).


Thickness

Although surface exposures are generally poor, commonly showing less than 3 m of sediment, evidence from drill logs shows that the thickest sediment in the basin is found in the lower part of the Humber River valley, occupying a depression up to 100 m below modern sea level. This basin is filled mostly with silt-clay or sand (Appendix B).


Surface Expression

Littoral features include marine terraces and deltas composed of sand and gravel. Brookes (1974) suggested marine limit in the Humber Arm/Bay of Islands area was 49 m asl, based on the elevation of deltas at Corner Brook and Cox's

Cove. Recognition of a marine delta in the Hughes Brook valley, however, discussed in detail in Chapter 4, demonstrates that marine limit was at about 60 m asl. Marine features have not been recognised above this elevation in the western parts of the Humber River basin. Marine deltas and terraces are recognised below 60 m asl in the Humber Arm, Goose Arm, Penguin Arm and Humber River valley areas (Table 2-7).

At the head of the Humber Arm raised deltas are found in the Hughes Brook valley (60 m asl), at the head of the Wild Cove valley (50 m asl), and in the Humbermouth area (51 m asl). The features were identified on the basis of morphology, showing flat tops with steep fronts on the seaward side. Internal structure revealed during gravel extraction operations showed beds of sand and gravel dipping steeply towards the coast, interpreted as foreset beds (Plate 2-5).

Brookes (1974) described the delta at Humbermouth as extending on both sides of the Humber Arm. The delta was interpreted as ice-contact based on the presence of ice-contact sediments and lodgement till interbedded with the delta sediments. The sections from which descriptions were made no longer exist. The Mount Patricia cemetery occupies much of the remaining delta surface on the north side of Humber Arm. The position of the feature at the mouth of a long valley, and the extension of the delta on both sides of the Humber Arm suggests that an ice-contact origin is likely.

An ice-contact delta is found at the mouth of Deer Lake, below which the Humber River valley narrows (Plate 2-6). The valley is only 1300 m wide at this point, compared to a width of 7200 m 4 km upstream. The delta is flat-topped with a surface elevation of about 45 ± 2 m (altimeter estimate). It extends on both sides of the Humber River, and is dissected both by the modern river and by a 250 m wide and 30 m deep channel on the south side, part of which is now

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**Plate 2-5:**
The internal structure of a raised delta at Pynn's Brook showing foreset
and topset bedding. The surface elevation of the delta is 33 m asl, and was
produced during postglacial marine inundation of the Deer Lake valley. A
delta with a similar elevation is found at Pasadena.

**Table 2-7:** Deltas formed below proposed marine limit in the lower Humber River valley. Deltas were identified primarily on the basis of morphology. Internal sedimentary structure was examined where exposed. Additional data are listed in Appendix A.

| Site | Location | Latitude (° N) | Longitude (° W) | Elevation (m asl) | Comments |
|---|---|---|---|---|---|
| 91103 | Pynn's Brook | 49°05.3' | 57°32.5' | 33 | Abandoned gravel pit. |
| 91069 | Pasadena | 49°00.6' | 57°36.8' | 33 | Community built on delta surface. |
| 93030 | Hughes Brook | 48°59.8' | 57°53.3' | 43 | Abandoned gravel pit. Mostly obscured by slumping. |
| 92108 | Little Harbour | 49°08.3' | 57°28.5' | 44 | Abandoned gravel pit. |
| 93008 | Junction Brook | 49°13.0' | 57°20.1' | 45 | Abandoned gravel pit. Mostly sloped. |
| 91187 | Little Rapids | 48°59.7' | 57°42.5' | 45 | Abandoned gravel pit. Fan delta. |
| 91190 | West end Deer Lake | 49°00.0' | 57°42.4' | 46 | Delta largely removed for highway upgrading. |
| 91144 | East of North Brook | 49°09.6' | 57°31.4' | 47 | Abandoned gravel pit. |
| 92027 | Nicholsville | 49°11.5' | 57°27.4' | 48 | Abandoned gravel pit. |
| 91219 | Wild Cove | 48°58.4' | 57°52.1' | 50 | Reading from top of fan. |
| | Humbermouth | 48°57.8' | 57°53.4' | 51 | Site of Mount Patricia cemetery. |
| 91029 | Hughes Brook | 49°00.2' | 57°52.6' | 58 | Possible delta in community. Some surface stripping. |
| 91173 | Hughes Brook | 49°01.8' | 57°51.2' | 59 | Abandoned gravel pit. Some surface stripping. |
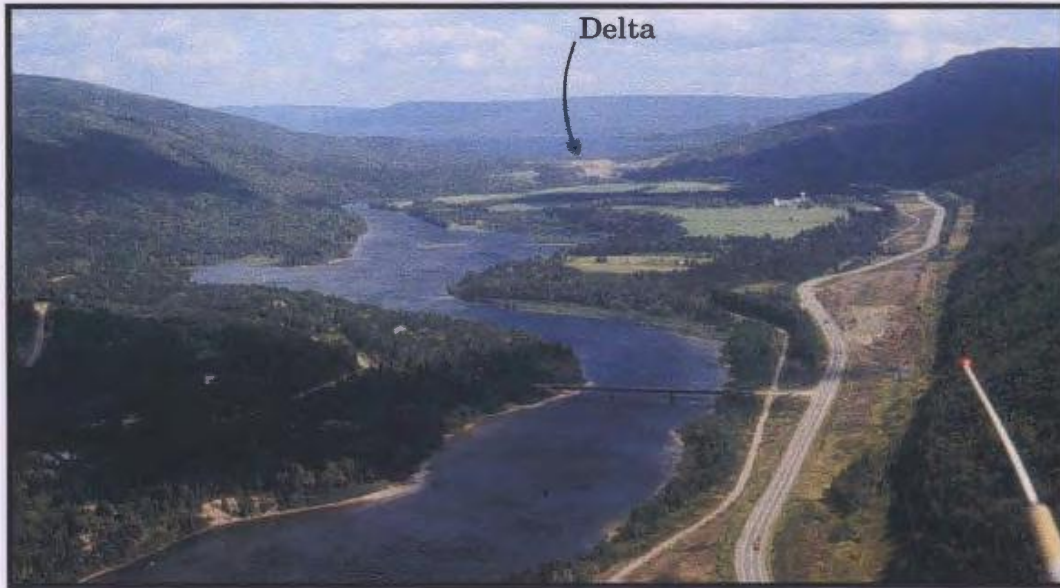
Delta

**Plate 2-6:**
An oblique aerial photograph of the lower Humber River valley looking
northeastward. In the middle background is the ice-contact delta at the
mouth of Deer Lake, with a surface elevation of 45 m asl. This was formed
during retreat of ice up the valley and is associated with marine
inundation.

occupied by Round Pond. The south side of this channel is flanked by bedrock. Road construction in 1993-1994 revealed interbedded sand and pebbly sand. Medium- to fine-sand beds were 1 to 3 cm thick, moderately-sorted, and ungraded to normally graded. Pebbly sand beds were 5 to 10 cm thick, poorly sorted, with a medium- to coarse-sand matrix with granules and pebbles up to 3 cm diameter. Beds dipped about 24° towards 060°, indicating flow down the modern valley. The sediments are interpreted as having been deposited in a delta. The position of the feature at the mouth of Deer Lake, extending across the valley, with a steep upstream face, and foreset beds indicating palaeo-flow down the valley, suggests the delta was an ice-contact deposit. Incision of the delta presumably occurred as the Humber River became re-established in the lower reaches of the valley during periods of isostatic uplift in the early Holocene. The exposures have been sloped and seeded following construction.

Features interpreted as deltas based on their surface morphology and internal structure are also found at Pasadena (33 m asl) and Pynn's Brook (33 m asl) (Batterson and Vatcher, 1992a), and at Little Rapids (45 m asl), Little Harbour (44 m asl) and Nicholsville (48 m asl). In all cases, the features have steep fronts, but grade upstream to glaciofluvial or fluvial systems.

Terraces interpreted as marine are found in several locations near, and adjacent to, the modern coast (Table 2-8). They are identified by morphology, showing a flat to gently inclined surface with a well-defined frontal escarpment. The terraces are locally continuous over hundreds to thousands of metres. Prominent terraces front the Humbermouth delta, extending from Prince Edward Park to Wild Cove at about 33 m asl, and along the lower Hughes Brook valley at about 20 m asl. In Goose Arm, a terrace was identified at 21 m asl. Other terraces were identified adjacent to modern Deer Lake. Terraces at 21-22 m asl were

**Table 2-8:** Location and elevation of terraces found adjacent to the modern coast, or adjacent to modern Deer Lake.

| Site | Location | Latitude (°N) | Longitude (°W) | Elevation (m asl) | Comments |
|------|----------|---------------|----------------|-------------------|----------|
| 91019 | Wild Cove | 48°59.0′ | 57°54.5′ | 20 | Top of terrace bluff. Approximate elevation. |
| 92161 | Goose Arm | 49°10.9′ | 57°51.3′ | 21 | Top terrace bluff. |
| | Pynn's Brook | 49°06.6′ | 57°31.5′ | 21 | |
| | North side Deer Lake | 49°06.5′ | 57°35.5′ | 22 | Beach ridge about 2 m high and 12 m wide. Continuous along hillside. |
| | North side Deer Lake | 49°06.5′ | 57°35.5′ | 28 | Possible shoreline |
| 91010 | Humbermouth | 48°58.0′ | 57°53.7′ | 33 | Prince Edward Park area. |
| 91009 | Dawe's Pit | 48°57.3′ | 57°53.2′ | 35 | Top of gravel pit. |
| | Pynn's Brook | 49°06.6′ | 57°31.5′ | 36 | Top of 14 m bluff. |
| | South Brook | 49°00.9′ | 57°37.3′ | 36 | Top of 5 m beach ridge |
| | North side Deer Lake | 49°06.5′ | 57°35.6′ | 38 | Shoreline. Distinct slope break |
| | Pynn's Brook | 49°06.5′ | 57°31.5′ | 40 | Top of 4 m bluff. |
| | Hughes Brook | 49°00.1′ | 57°52.6′ | 55 | Base of terrace. 11 m bluff behind |
| 91008 | Humbermouth | 48°57.0′ | 57°52.5′ | 61 | Top of terrace. |
| | Hughes Brook | 49°00.1′ | 57°52.6′ | 66 | Top of terrace |

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found on the south side of Deer Lake near Pynn's Brook, and the north side near Eighth Brook. Terraces at 36 m and 40 m asl were also found at Pynn's Brook, and at 28 m and 38 m asl near Eighth Brook. Grant (1973, 1989b) also noted the features along Deer Lake.

### Sediments

Sediments identified as marine are those found below the marine limit of 60 m asl, and/or associated with marine features. They include littoral sand and gravel deposited adjacent to the modern coast as beach-ridges or a discontinuous veneer of sediment over bedrock or diamicton. They are found within a narrow belt along the shores of Humber Arm, Penguin Arm, Goose Arm and North Arm. Littoral sediments may also be found in raised marine terraces or deltas, as described earlier.

Rhythmically bedded silt and clay is found within the Humber River valley at elevations below about 50 m asl, commonly capped by a thin veneer of sand and/or gravel. Silt and clay beds are interpreted as sublittoral marine deposits, based on their continuity inland from the coast, palaeontology, and association with marine features, as discussed more fully in Chapter 5. They are commonly light reddish brown to reddish brown (5YR 6/3, dry to 5YR 4/3, moist) clayey silt to silty clay. Mean grain size determinations from twenty-one (21) exposures show 11% sand (range 0.6 to 35.3%), 62% silt (range 27.2 to 91.5%), and 27% clay (range 1.5 to 67.2%), with a mean grain size of 6.3ø (fine silt). Spatial textural trends were not evident through the valley.

### Fluvial (A)

Fluvial sediments are those deposited postglacially by rivers. Fluvial

sediments are defined by their position relative to modern stream channels (i.e., they occur within the modern flood plain), and by their stratigraphic position (e.g., occurring above sediments identified as post-glacial marine muds). However, the transition from sediments deposited within a fluvial system fed by glacial meltwater, to a system with no glacial input is difficult to define (Ashley *et al.*, 1985). Fluvial sediments comprise about 3% of the surficial sediment in the study area (Figure 2-1), and range from gravel to silt.

### Distribution

Postglacial fluvial sediments are common adjacent to the modern Humber River valley, particularly in the lower reaches below Deer Lake. They are also mapped in the Kitty's Brook, Deadwater Brook, Rocky Brook, South Brook, Otter Brook and Hughes Brook valleys, as well as in small valleys scattered across the area.

### Thickness

Fluvial sediments are commonly found as a veneer over marine muds, diamicton or bedrock. A drill hole log from Humber Village in the lower Humber River valley recorded 4 m of sand overlying clay (see Appendix B). Elsewhere across the basin, fluvial sediments are less than 3 m, and commonly less than 1 m thick.

### Sediment type

Fluvial sediments commonly are well-sorted fine- to coarse-sand, to poorly-sorted sand and gravel. Near Little Rapids, adjacent to the Humber River, a 3 m exposure shows planar cross-stratified, well-sorted fine- to medium-sand

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overlying marine mud. Planar-tabular cross-bedding indicates deposition by current flow down the modern valley. Some sections show low-amplitude ripples formed under low flow conditions.

In contrast, sections within the Humber River gorge exposed during road construction in 1991 have a succession of a basal unit of planar bedded, moderately- to well-sorted, medium- to fine-sand, with occasional ripples with 10 to 15 cm wavelength and 1.5 cm amplitude. These sands are overlain by 50 to 100 cm of planar-bedded, clast-supported pebble gravel. Clasts are subrounded, of mixed rock types, and have a 2- to 3- mm-surface coating of reddish-brown silty clay. Overlying this gravel unit is poorly-sorted, planar-bedded sandy gravel that have a fine- to medium-sand matrix. The unit commonly contains ovoid, open-work gravel lenses. The sediments within the Humber River gorge suggest increased current flow, probably related to constriction of the valley within the lower reaches. To the east of the Humber River gorge the valley is wide, and gravelly sediments are less common.

### Surface Expression

Fluvial terraces are found adjacent to the modern upper Humber River, and its tributaries, particularly Rocky Brook (Table 2-9). Lower terraces are commonly continuous for more than 10 km, and are graded to the modern channel, with a gradient of about 1:750 in the lower reaches below Harrimans Steady, and about 1:450 between Harrimans Steady and Big Falls. Higher terraces are commonly discontinuous, and no gradient was measured.

Seventeen observations were made on four terrace levels in the Rocky Brook and upper Humber River near Reidville. They showed terraces at 43.5 ± 0.5 m (2 observations); 36.0 ± 1 m (2 observations), 28.0 ± 2 m (4 observations), and

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**Table 2-9:** Terraces found adjacent to modern upper Humber River. All elevations are altimeter and are considered accurate to ± 2 m.

| Location | Latitude (°N) | Longitude (°W) | Elevation (m asl) | Comments |
|---|---|---|---|---|
| Rocky Brook | 49°12.4' | 57°26.2 | 10 | 5 m terrace bluff. Base of bluff. |
| Rocky Brook | 49°12.4' | 57°26.2 | 15 | Top of bluff |
| Rocky Brook | 49°12.4' | 57°26.4' | 23 | 14 m terrace bluff. Base of bluff. |
| Reidville | 49°13.4' | 57°24.5' | 23 | Top of bluff |
| Rocky Brook | 49°12.2' | 57°26.3' | 23 | Top of bluff |
| East Reidville | 49°14.6' | 57°22.0' | 23 | Top of bluff |
| East Reidville | 49°14.2' | 57°22.4' | 24 | Top of bluff |
| Reidville | 49°13.6' | 57°23.8' | 24 | Base of bluff. 6 m terrace height. |
| East Reidville | 49°13.8' | 57°22.7' | 24 | Top of bluff. |
| Reidville | 49°13.4' | 57°24.0' | 27 | Top of bluff |
| Rocky Brook | 49°12.8' | 57°25.9' | 28 | Top of bluff (delta?) |
| Reidville | 49°13.6' | 57°23.3' | 28 | Top of bluff. Near Community Park. |
| Reidville | 49°13.9' | 57°23.9' | 30 | Top of bluff. By ball field. |
| Near Reidville | 49°13.1' | 57°25.2' | 35 | Top of bluff |
| Rocky Brook | 49°12.4' | 57°26.4' | 37 | Top of bluff |
| Rocky Brook | 49°12.3' | 57°26.6' | 43 | Top of bluff |
| Reidville | 49°13.7' | 57°23.8' | 44 | Top of bluff |

23.5 ± 0.5 m (7 observations), plus single observations at 10 m and 15 m asl. Lower terraces are graded parallel to the modern river, whereas upper terrace gradient was not measurable.


### Organic (O)

The Humber River basin contains large areas of wetland, which comprise 9% of the surface cover (Figure 2-1).


Distribution

Wells and Pollett (1983) mapped the distribution of wetland types. The upper Humber River valley contains domed bog and slope fen, where they comprise approximately 20% of the valley floor. Both eccentric and concentric types of domed bog are found, with surface slopes 1:100 to 1:150, and with a concentric pattern of pools. The wetlands are ombrotrophic, compared to the minerotrophic slope fens that are found on 1:20 to 1:4 slopes. Slope fens are found throughout the Deer Lake basin and lower Humber River valley, being especially common in areas underlain by limestone bedrock. These are less acid and the most nutrient-rich of fens in Newfoundland. Basin bogs are common on The Topsails, characterised by treeless areas of peat with generally flat surfaces and rare pools. In each of these areas, wetlands have developed over an underlying diamicton surface or bedrock. Wetland areas adjacent to the modern coast are commonly underlain by marine sediments. Large areas of organic terrain are uncommon west of the Deer Lake valley and over the Grenville inlier west of the upper Humber River, although these areas contain small patches of basin and slope bog.

Thickness

Domed bogs are up to 10 m thick, whereas basin bogs and slope fens are generally shallow accumulations, rarely exceeding 2 m thick.

### Colluvium (C, Cf, Ca)

Colluvial sediments are deposited at the base of slopes through a combination of falling (free-fall or rolling), sliding or flowing. Colluvium comprises about 2% of surface sediment (Figure 2-1).

Distribution

Colluvial aprons are commonly found along the sidewalls of oversteepened glacial valleys, such as Old Mans Pond, Hinds Brook, along Goose Arm, Penguin Arm and North Arm, the west shore of Grand Lake, north shore of Glover Island, through the Humber gorge, and in the Birchy Lake valley.

Colluvial fans form at the mouth of gullies fed by landslides and avalanches. Numerous fresh scars show these processes to be active. Historically, landslide and avalanche events have affected the Humber River valley, occasionally with fatal results (Batterson *et al.*, 1995b). Small-scale landslides occur in poorly consolidated sediment. Recent examples are in the Humber River gorge (blocking the Trans Canada Highway in 1985), along the banks of West Rocky Brook near Cormack (resulting from stream undercutting in 1993), and along Riverside Drive in Corner Brook (initiated by highway construction, in 1994).

Areas of colluvium from sliding or flowing by solifluction or gelifluction processes are found in highland areas, though generally not as mappable units.

Diamicton covered slopes south of Old Mans Pond likely consist of resedimented diamicton.

### Thickness

Colluvial deposits thicken downslope, and are likely up to 5 m thick at the base.

### Sediment

Colluvial deposits are commonly coarse-grained gravel and sand. Larger talus slopes show a typical downslope increase in grain size (e.g., Clayton, 1972). No samples were taken from colluvial deposits.

# Chapter 3

# <u>Glacial Sediments and Stratigraphy</u>

**Introduction**

Surficial mapping of the Humber River basin shows most of the area is covered with diamicton, with lesser amounts of glaciofluvial, marine and glaciolacustrine sediments. These sediments are exposed in hand-dug test pits, stream and road cuts and from gravel pits. Most of these exposures were small (less than 1 m thick), and from these only basic descriptions could be derived. The general characteristics of sediments were described in Chapter 2. Larger exposures were mostly found at gravel pit operations, which by their nature are ephemeral features of the landscape, and at river sections produced by undercutting of banks.

Sediment exposures are scattered throughout the basin, rarely exceeding 100 metres in lateral extent. Larger sections are preferentially described as they contain better exposures of sediment units, allow examination of lateral extent, and more than one stratigraphic unit commonly is exposed. As a consequence some areas, and/or sediment types, may be over-represented compared to others. Broad areal sediment distributions were described in Chapter 2. Examination of over 400 hand dug and backhoe test pits from across the basin has ensured that no major sediment types were omitted.

Sediment types are discussed in stratigraphic order, commencing with glacial sediments. Proglacial and non-glacial (Holocene) sediments are discussed in Chapter 5.

The purpose of this chapter is to describe and interpret the larger exposures of glacial sediment found across the basin, discuss stratigraphy, determine genetic environments, and to correlate, where possible, individual exposures.

## Glacial Sediments and Landforms

### Background

Till is a sediment that was transported and subsequently deposited by or from glacier ice, with little or no sorting by water (Dreimanis, 1982). Tills are subdivided into primary tills (ortho-tills) and their re-sedimented secondary products (allo-tills). Primary tills are released directly from glacier ice, whereas secondary tills are remobilized by mass movement processes or by settling through a water column subsequent to their release from the glacier (Ashley *et al.*, 1985). However, primary and secondary tills are so intimately related that it may be difficult to separate them in any meaningful manner (Dreimanis and Lundqvist, 1984). Drewry (1986) suggested that the term till is no longer applicable as an indicator of genesis, and that it should be replaced by non-genetic terminology, such as 'diamict'. This term was originally defined as diamicton by Flint *et al.* (1961), later resurrected by Eyles *et al.* (1983b) and Miall (1983). Environmental interpretation would append a prefix, e.g., glacial diamicton.

Dreimanis and Lundqvist (1984) suggested there are three conditions common to all tills: they consist of glacially transported debris; they have a

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close spatial relationship to glaciers, either being deposited by or from them; and sorting by water is minimal or absent. The usefulness of this proposal lies in the conceptualization of the term till, rather than developing any criteria for the differentiation of till-types or distinguishing tills from other, similar-looking sediments. Sediments that resemble tills are found in other depositional settings, such as sediment gravity flows in marine or terrestrial environments (e.g., Schermerhorn, 1974; Shultz, 1984; Spalletti *et al.*, 1989), diamictons deposited by ice rafting (e.g., Ovenshine, 1970; Gravenor *et al.*, 1984; Domack and Lawson, 1985), and volcanic environments (e.g., Mills, 1984; Car and Ayres, 1991; Smith and Lowe, 1991). Oberbeck *et al.* (1993) described Precambrian diamictites produced by meteor impacts. This highlights the need for a clear understanding of the genetic and physical differences not only between different glacial environments, but also between glacial and non-glacial diamictons.

### Primary (ortho-) tills

These include lodgement till and deformation till that are produced by actively sliding glaciers; and melt-out till and sublimation till that are deposited in a passive environment.

Lodgement till is defined as a sediment "deposited by plastering of glacial debris from the sliding base of a moving glacier by pressure melting and (or) other mechanical processes." (Dreimanis, 1988, p.43). Many of the characteristics of these tills have been well described in the literature, including clast 'traffic jams' (Åmark, 1980), boulder pavements (Humlum, 1981; Hicock, 1991), and faceted and bullet-shaped clasts (Boulton, 1978; Kruger, 1984). Dreimanis (1988) provides a detailed summary. The direct

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contact of the ice with the substrate during lodgement produces several structures. Sole marks are formed by dragging clasts through a deformable bed (Shaw, 1982). Till fills the resulting grooves producing spoon-shaped ridges at the base of the lodgement till bed. Subglacial deforming beds also exhibit sub-horizontal jointing or fissility, characterised by shingled, cross-cutting till units. Fissility represents minor failure planes beneath the ice, caused by loading stress (Boulton, 1971; Eyles, 1993), or as a result of brittle deformation (Hart, 1995). The sliding and internal deformation during lodgement means that unlithified intraclasts are absent from lodgement tills, although Kruger (1979) recognized smudges consisting of nearly horizontal bands of substrate material that may be the deformational remnant of intraclasts. There is little water involved in the deposition of lodgement tills and therefore they do not contain sorted strata.

The pressure exerted on the substrate by the overriding glacier can, in certain circumstances, drag the till forward as an internally deforming mass. This process was first recognised by Geikie (1863), and the depositional product was named deformation till by Elson (1961). Deformation tills are defined as "... weak rock or unconsolidated sediment that has been detached from its source, the primary sedimentary structures distorted or destroyed, and some foreign material admixed." (Elson, 1989, p.85). Deformation tills consist of remoulded subglacial till that can be incorporated *en masse* into the overlying ice or bulldozed in front of the ice (e.g., Boulton, 1986). They therefore form a continuum with lodgement and melt-out tills, and here are considered to be a primary till.

Finer, impermeable, clast-poor till will be more susceptible to deformation than coarser, permeable, clast-rich till (Boulton and Hindmarsh,

1987; Hart and Boulton, 1991). In the Great Lakes basin, where glaciers have advanced over lacustrine sediments, tills have high silt-clay contents (commonly in excess of 60%). Hicock and Dreimanis (1992) identified three layers of a deforming bed, with associated sedimentary structures: an upper ductile layer, a brittle-ductile layer, and a lower brittle layer. These three layers are also referred to as A, B1, B2 (Boulton, 1987), M, Q?, H? (Menzies, 1989) and homogenous, sheared, overturned (Hart and Boulton, 1991) layers. Deformation tills are internally complex, resulting from rapid deposition. Each layer may have distinct physical properties. They may contain structures generated by drag of the over-riding ice, such as folds (isoclinal, hook or chevron folds) and boudins (Hart and Boulton, 1991; Hicock and Dreimanis, 1992). They may contain rafts of unlithified substrate, some of which may show evidence of rolling or attenuation (Hicock and Dreimanis, 1992) or they may contain delicate structures formed in pressure shadows protected from the bulk of deformation by the presence of a clast (Hart and Boulton, 1991). Hart (1994) suggests decreasing fabric strength from rigid to deforming bed situations, and between thin deforming and thick beds.

In contrast to the active sliding required for the deposition of both lodgement and deformation till, melt-out till "... is deposited by a slow release of glacial debris from ice that is not sliding or deforming internally." (Dreimanis, 1988, p.45). Melt-out tills form subglacially or supraglacially, and because transport is generally passive, melt-out tills may inherit properties from transport and the melt-out process (Shaw, 1977, 1979, 1982, 1983, 1987; Lawson, 1979; Haldorsen, 1981; Haldorsen and Shaw, 1982; Dreimanis, 1988). During deposition of melt-out tills, large quantities of meltwater are expelled from the debris-rich basal layers of the ice. Sorted beds are common in melt-

out tills, either draping clasts or truncating against clasts. Some are formed by the scouring of turbulent water in micro-channels (millimetres thick) beneath a clast as it is let down onto the till surface. Small cavities (millimetres thick) open and close quickly at the base of the ice, into which sorted sediments are deposited (Haldorsen and Shaw, 1982). The sorted sediments may be cross-laminated, plane-bedded or graded (Ashley *et al.*, 1985). Larger cavities (centimetres to tens of centimetres) also exist. Material commonly founders into these cavities from above and the sides producing diapiric structures. The passivity of the melt-out process means that unlithified clasts are preserved in melt-out tills (Shaw, 1982, 1987).

Sublimation tills are restricted to areas such as Antarctica, with long term extremes of aridity and cold. They are an end-member of supraglacial melt-out till formed by the sublimation of debris-rich ice (Dreimanis, 1988; Shaw, 1988).


### Secondary (allo-) tills

Secondary tills are resedimented primary tills. Some workers suggest that the lack of direct influence of glacial action precludes their inclusion as tills (e.g., Lawson, 1979, 1988), although others (e.g., Dreimanis and Lundqvist, 1984; Dreimanis, 1988) consider this approach too restrictive. The proximity of many of these resedimented deposits to glaciers, and requirement of a glacial slope down which sediment moves, seems to be sufficient reason to include resedimented tills as glacigenic. Allo-tills are formed by the action of gravity, either by transporting sediment down a slope (the glacier, either subglacially into a cavity, supraglacially or ice-marginally) as glacigenic sediment flows, or by movement through a water column of insufficient depth to cause much

sorting (e.g., undermelt diamictons (Gravenor *et al.*, 1984), and subaqueous basal till (Link and Gostin, 1981)).

Hartshorn (1958), Boulton (1968, 1971, 1972), Eyles (1979), and Lawson (1979, 1981, 1988) described glacigenic mass movement deposits (flow tills, solifluction tills, sediment gravity flow deposits, ice-slope colluvium, glacigenic mass-flow deposits). They are found in supraglacial or ice marginal positions where sediment is concentrated on the surface by ablation and compressive flow, or subglacially within cavities as lee-side tills or cavity fill. Sediment moves down-slope, through a combination of free-fall, collapse, slide, slump or flow processes and commonly produces structureless, internally disturbed, or chaotically structured diamictons.

The most commonly preserved mass movement diamicton is that produced by sediment gravity flow (Lawson, 1988). These diamictons form a continuum of sediment types depending on water content. With low water contents, cohesive deposits may form in which many of the features of the source material are preserved, whereas at high water contents, shear strength is low and the sediment is supported by flow turbulence, as a turbidity current. Sediment gravity flows can be deposited within standing water, along the grounding line of a tidewater glacier (Powell, 1981, 1984; Molnia, 1983), or in a glaciolacustrine environment (Rust, 1977; Ashley, 1988).

Sediment gravity flows produce a wide range of sedimentary structures dependent on the type of flow. The structures found in glacigenic sediment gravity flows are identical to those produced in non-glacial environments, because the process of emplacement is primarily the same. Structures related to sediment movement include boudinage structures, compressional and tensional fractures, load structures in the lower parts of the flow, and a

general downslope thickening. Sediment gravity flow deposits may also show crude inverse grading of clast sizes. On a glacier surface this down-slope movement of material is continuous as material is added to slopes by ablation. Flow deposits are commonly buried or partly eroded by subsequent flows, or interstratified with sorted sediments, when flow is into ponds on the ice surface. These processes commonly produce a complex stratigraphy.

### Discussion

Till is a highly variable sediment. Given its diverse genesis, either primary or secondary, it has no single diagnostic characteristic. Grain size in tills is a function of material entrained by the glacier. Some tills are composed largely of sorted sediments, e.g., Kalix till (Lundqvist, 1977). Some tills are clast-supported, and stony, whereas others are clay-rich with few boulders, such as the deformation tills of southern Ontario (Hicock and Dreimanis, 1992). Some tills are non-stratified, whereas others show either faint lamination (such as the Catfish Creek Till; Dreimanis, 1982) or are stratified (such as the Sveg till; Shaw, 1979). There may be grain size differences between melt-out and lodgement tills found within an individual section. Less abrasion and greater winnowing by meltwater during melt-out means they are commonly coarser than lodgement tills produced from the same ice. Striated clasts are generally produced by subglacial transport, although Blackwelder (1930) reports randomly distributed striae from clasts in non-glacial debris flows. Kruger (1979) suggested that consistently oriented striations on the upper surfaces of clasts were a characteristic of lodgement tills, as a result of continued abrasion following deposition. Hicock and Dreimanis (1992) noted the multiple crossing striae on clasts in deformation

tills, and suggested this is the result of rotation of the clasts during the deformation process.

Clast fabric is an important characteristic of diamictons. Pioneering work by Holmes (1941) and Harrison (1957) describing clast fabric in tills has been followed by statistical (e.g., Mark, 1974; Woodcock, 1977), and graphical approaches (e.g., Woodcock, 1977; Rappol, 1985; Benn, 1995) designed to characterize clast fabric within individual depositional environments (e.g., Dowdeswell and Sharp, 1986; Clark and Hansel, 1989; Hicock, 1992; Hart, 1994; Hicock *et al.*, 1996).

Woodcock (1977) developed a descriptive terminology of fabric shape (Figure 3-1). Two parameters define fabric shape. A strength parameter C, where,

$$C = \ln (S_1/S_2)$$

and which ranges from weak (C less than 1) to strong (C greater than 3). The strength of the fabric increases away from the origin. A shape parameter K, where

$$K = \frac{\ln (S_1/S_2)}{\ln (S_2/S_3)} \quad \text{(after Woodcock, 1977)}$$

ranges from cluster (K greater than 1) to girdle (K less than 1). The value K=1 defines the separation of girdle from cluster fabrics.

Data from different genetic environments, including modern glacigenic, is presented in Figure 3-2, as a conventional two-axis plot of $S_1$ versus $S_3$. The cluster-girdle transition is indicated, and fabric strength

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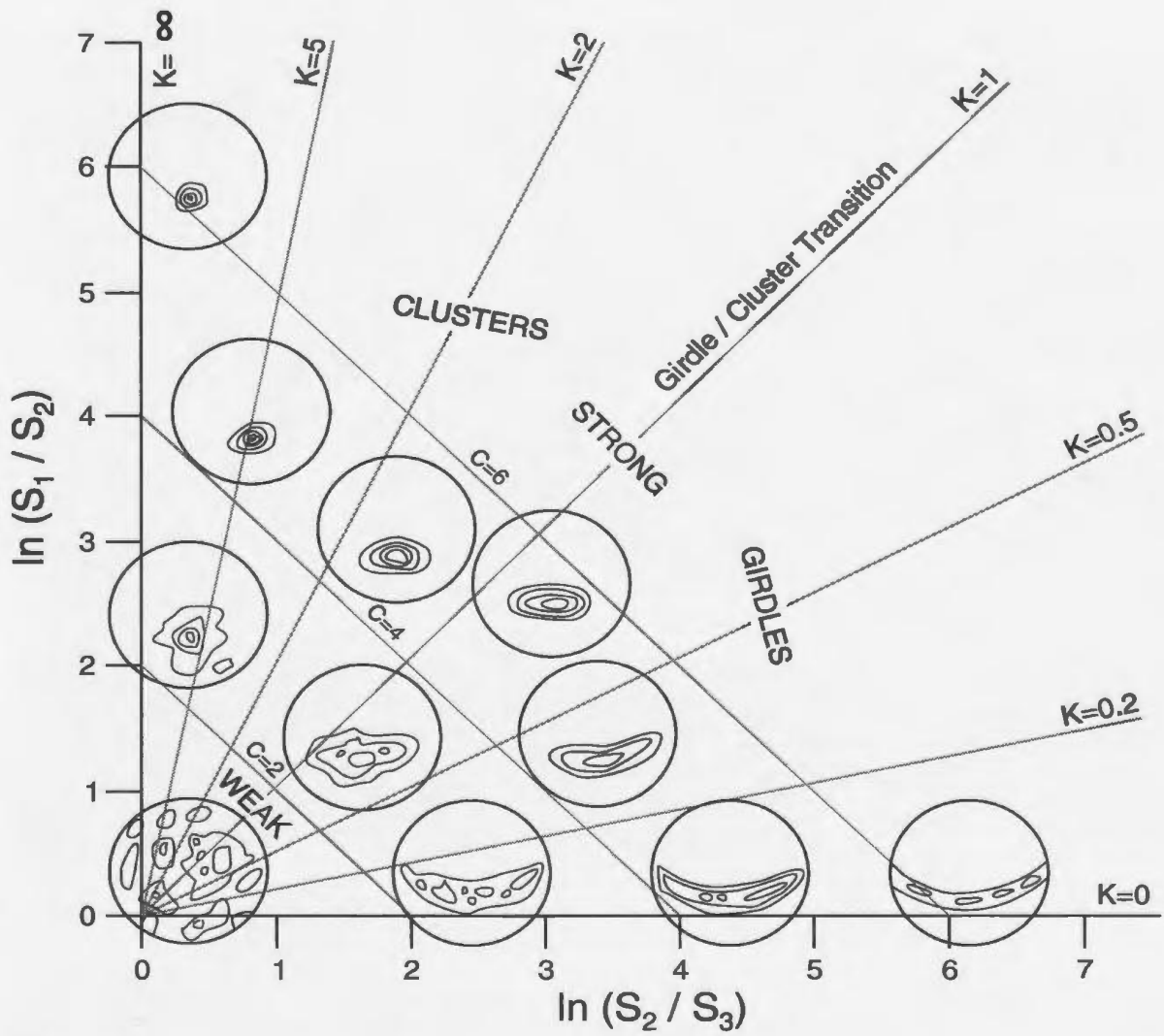
**Figure 3 - 1:** Description of fabric shape (after Woodcock, 1977).
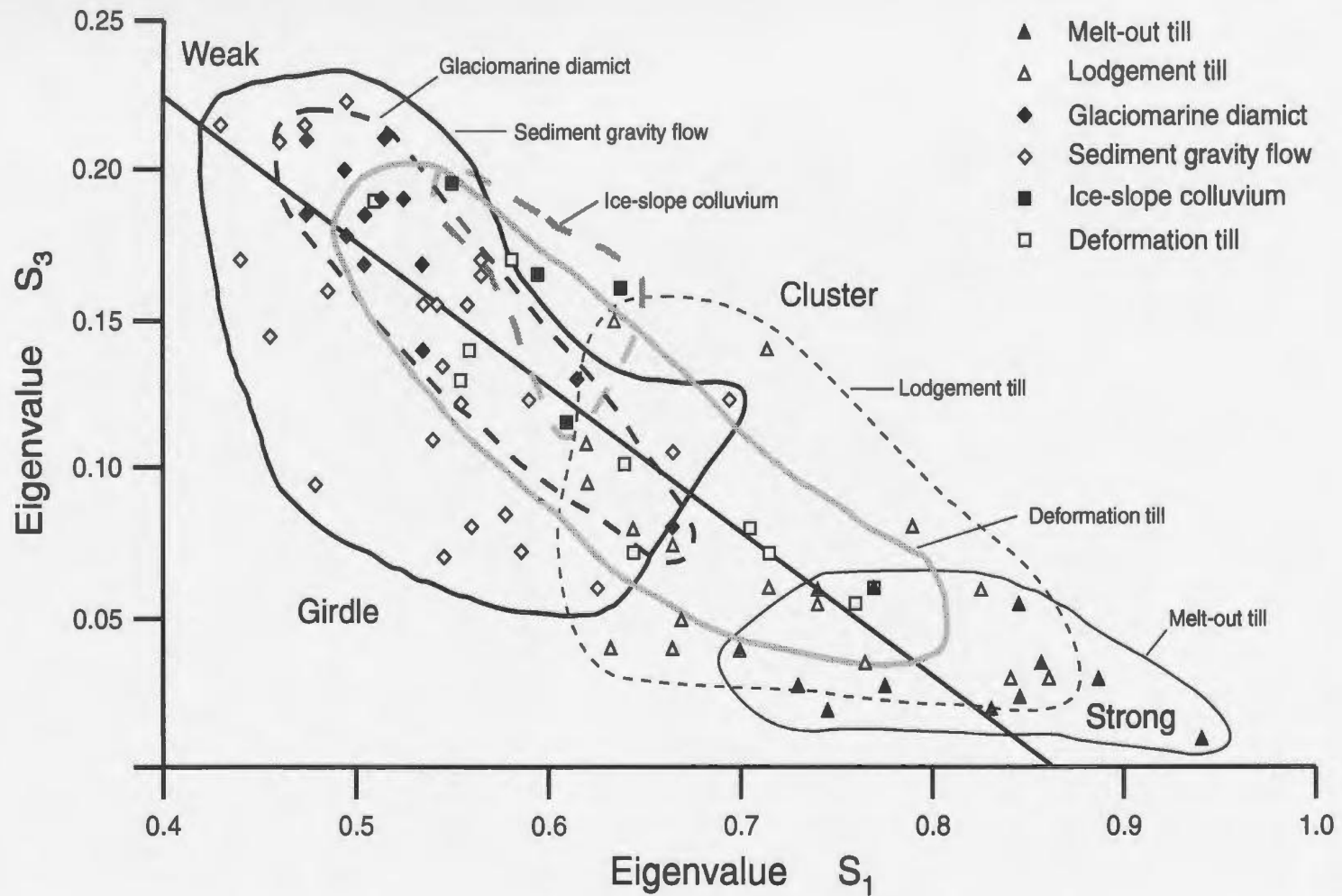
**Figure 3- 2:** Plot of $S_1$ versus $S_3$ eigenvalues from diamictons deposited in different depositional environments.
Sources: Shaw (1982), Hicock (1992), Lawson (1979), Dowdeswell and Sharp (1986), Hart (1994), Hart and Roberts (1994), Domack and Lawson (1985), Hicock and Lawson (1996).

increases towards the right. Using the terminology of Woodcock (1977), the diagram shows that melt-out tills have a tendency to have high strength cluster fabrics, although some girdle fabrics are found. Lodgement tills are characterised by moderate to high strength cluster to girdle fabrics.

Deformation tills have a range of fabric shapes from low strength, girdle ($S_1$=0.53, $S_3$=0.12), intermediate strength ($S_1$=0.69, $S_3$=0.08), to high strength, cluster fabrics ($S_1$=0.77, $S_3$=0.06) (Hart, 1994). Glacigenic subaerial sediment gravity flow deposits show commonly moderate to low strength girdle fabrics with some clusters (Lawson, 1979; Dowdeswell and Sharp, 1986; Hart, 1994). Clast fabrics of glacigenic sediment flows resemble those reported from non-glacial debris flows (e.g., Van Loon, 1983; Mills, 1984; Shultz, 1984). Mills (1984) found that clast fabrics from the Mount St. Helens lahar deposits had an upflow dip, and a greater tendency for transverse fabrics and higher dips than glacigenic flows (Lawson, 1979).

Few studies have been completed on the clast fabric of glaciomarine diamictons, formed as either proximal sediment gravity flows, distal underflows, or undermelt diamictons. Undermelt diamictons have generally low strength cluster to girdle fabrics ($S_1$=0.54, $S_3$=0.15; Hart and Roberts, 1994), but with a large proportion of clasts dipping at high angles (Dreimanis, 1982; Gravenor et al., 1984; Domack and Lawson, 1985). These high angles result from reorientation of clasts as they drop through the water column.

In both melt-out and lodgement tills, the high frequency of clast interactions at the base of a sliding glacier produces an alignment of elongate clasts, although clast dips may be higher in lodgement tills than in melt-out tills due to settling of clasts in the horizontal plane during melt-out. Clast long axes in melt-out and lodgement till may be parallel or transverse to the

direction of ice movement determined from independent sources (c.f.,

Krumbein, 1939; Elson, 1957; Harrison, 1957; Virkkala, 1960; Flint 1961;

Boulton, 1970; Mickelson, 1971; Price, 1973; Drake, 1974; Mills, 1977; Lawson,

1979; Shaw, 1982; Rappol, 1985; Dowdeswell and Sharp, 1986; Dreimanis, 1988;

Hicock and Dreimanis, 1989). These tills commonly have an $S_1$ value greater

than 0.6 (Figure 3-2).

Identifying a diamicton as a till can only be accomplished by multiple

criteria, including both sedimentological properties, and stratigraphic and

regional considerations. The lateral and vertical association with other

sediments is commonly a key to assigning diamictons to a glacial or non-

glacial environment. Individually, any potential indicator may be unreliable

(e.g., grain size, striated clasts, compaction, and stratification). Sedimentary

structures and clast fabric in combination with other parameters, however,

may be used to suggest a genetic origin. Commonly, this is achieved by

eliminating unlikely processes, and allowing a most-probable interpretation

to be made.


## Diamicton exposures in the Humber River valley

### General comments

The distribution and general characteristics of diamictons within the

Humber valley were described within Chapter 2. Two hundred and seventy-

seven diamicton exposures were examined across the field area. Most of these

were small roadside exposures or test pits, from which few sedimentary

structures could be seen. Fabric analysis was not attempted in these small pits.

Larger exposures were found in scattered aggregate pits, natural river

exposures, or were created in backhoe test pits. The diamictons in these exposures were described, clast fabrics recorded, and matrix and pebble contents sampled. Some sections of greater lateral extent, or distinctive character, were described in detail.

### Clast fabric

Clast fabric analysis was conducted on 173 diamicton exposures across the area. Figure 3-3 presents a clast fabric data plot using the method of Woodcock (1977). It shows most diamictons have moderate strength, cluster to girdle fabrics. Highly clustered or girdled fabrics (i.e., C > 3) are poorly represented (27 of 173). A plot of $S_1$ (maximum) and $S_3$ (minimum) eigenvalues is also presented (Figure 3-4). Fabric envelopes generated from data presented in Figure 3-2 are superimposed on the diagram. It shows that most samples (119 of 173) have $S_1$ values greater than 0.6. Of these, 46 are girdle fabrics. Fabrics with $S_1$ values > 0.8 are clustered, whereas those with an $S_1$ value < 0.6 are dominantly girdle shapes.

Strongly oriented clast fabrics are not consistent with deposition from sediment gravity flow or glaciomarine processes, and are more compatible with a subglacial depositional environment. This relationship is strengthened by comparison of the preferred trend of clast fabrics with ice flow patterns derived from independent sources. For those fabrics with an $S_1$ value > 0.6, 94 of 119 clast fabrics showed similar trends to ice flow directions. This is discussed more fully in Chapter 5.
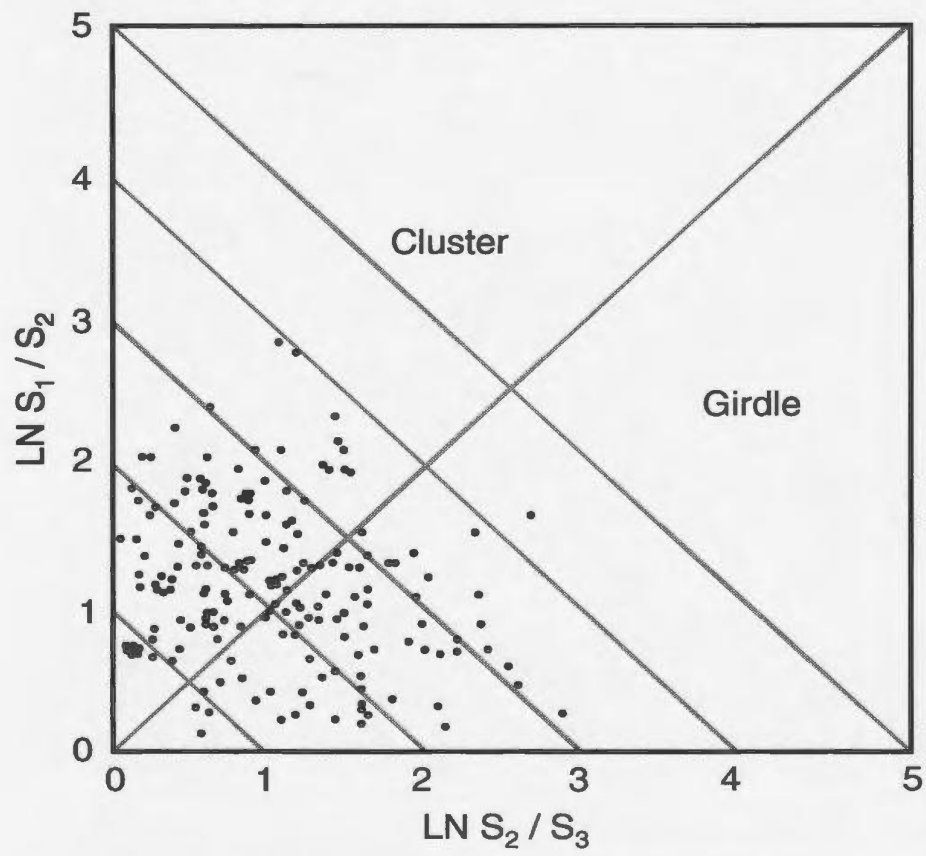
**Figure 3 - 3:** Shapes of clast fabrics from diamictons within the Humber River basin.
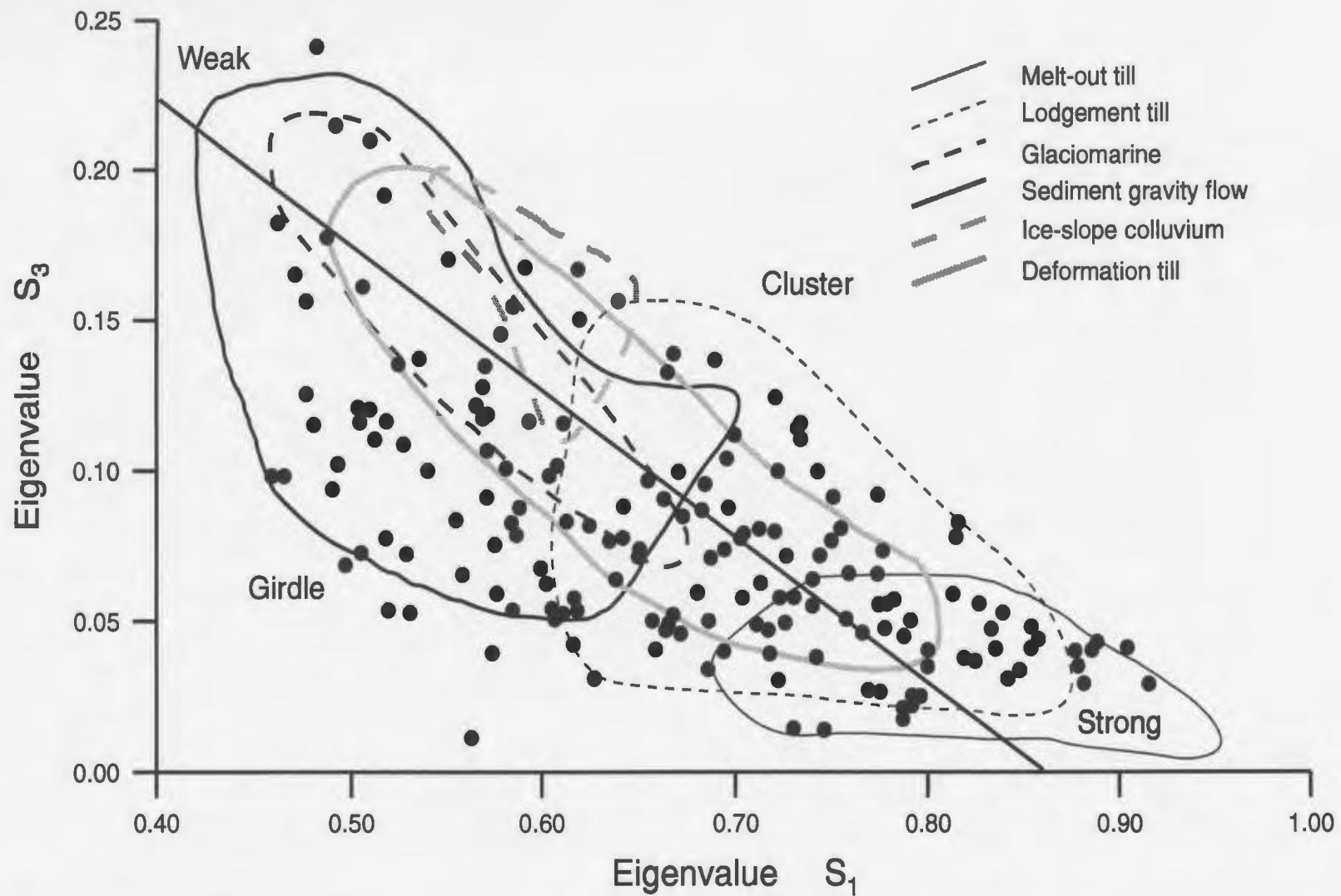
**Figure 3 - 4:** Plot of $S_1$ versus $S_3$ eigenvalues from diamicton fabrics within the Humber River basin. Fabric envelopes are from data presented in Figure 3-2.

## Sedimentary structures

Most diamictons exposed across the research area are homogenous, and lack obvious sedimentary structures. Of those containing structural features sub-horizontal fissility is the most common. Steeply dipping clastic dykes, and clast pavements are found in rare exposures. Sections at the Pasadena dump, near Hinds Lake, and Rocky Brook contain examples of these features. These are described and interpreted in more detail in the following pages.

## Section Descriptions

Exposures of diamicton are scattered throughout the Humber River basin, commonly overlying bedrock. No attempt is made to describe and interpret all individual sections, given the repetitive nature of sediment characteristics encountered. The approach adopted here is to describe either unusual outcrops or those representative of a group of diamicton exposures with similar characteristics, and deposited in a similar depositional environment.

### 1. Rocky Brook: An overconsolidated basal till

Rocky Brook, a tributary of the Humber River, has its headwaters in the foothills of the Long Range Mountains north of the community of Deer Lake. The middle reaches of Rocky Brook flow through a gorge cut through Carboniferous sandstone, and the lower 2.5 km is eroded through Quaternary sediment. A small diamicton unit (Figure 3-5) is exposed near the bridge on the Reidville road (site 92009; Appendix A).
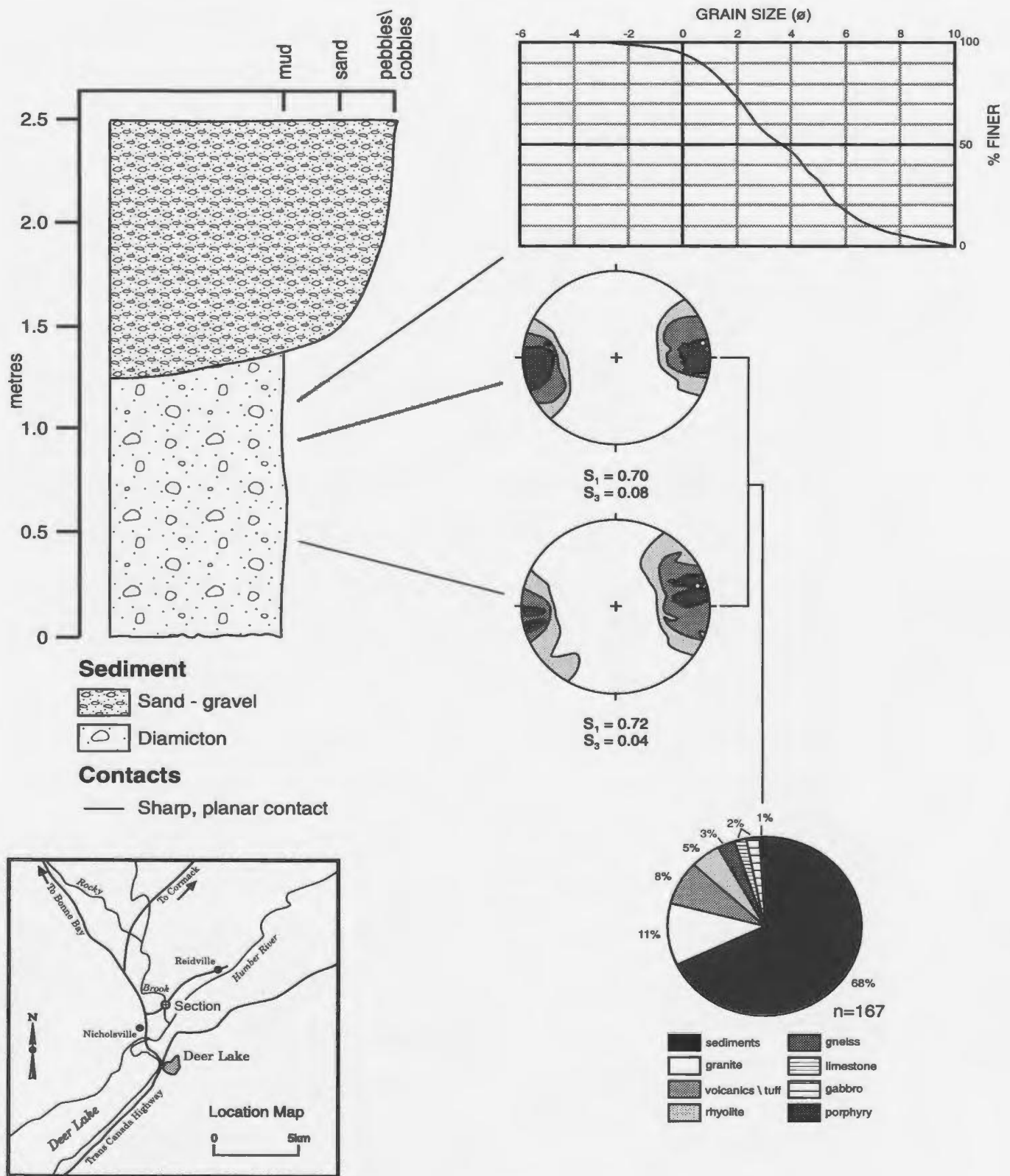
**Figure 3 - 5:** Stratigraphy of the diamicton exposure at Rocky Brook.

Description

The diamicton is exposed on both sides of the river laterally for about 100 m. It is best examined when the river is low. The unit extends about 1 m above modal river level, and is of unknown thickness. It is a reddish brown (2.5YR 3/4, moist), very compact diamicton. Two samples (924003, 924004; Appendix A) have a very poorly-sorted (s.d. 2.45ø and 2.14ø), silty-sand matrix, with a mean matrix composition of 63% sand, 34% silt and 3% clay. Clasts are generally granules to cobbles, although rare clasts greater than 50 cm diameter are found. Many of the clasts are striated. A total of 167 clasts were identified from two samples. Clasts are mostly sandstone and siltstone (63%), with granite (11%), acid volcanics (7%), rhyolite (5%) and gneiss (3%), and minor amounts of limestone (2%), quartzite - quartz pebbles (4%), gabbro (2%), quartz pebbles (2%), quartz feldspar porphyry (2%), and tuff (1%) (Figure 3-5). Two fabrics, one taken from the north and one from the south side of the river, show strong $S_1$ eigenvalues (0.72 and 0.70), and low $S_3$ (0.04 and 0.08), respectively. The preferred trend of both fabrics is toward 075° (Figure 3-5). Vanderveer noted similar results from an exposure on the north bank ($S_1$ = 0.74, $S_3$ = 0.05) (unpublished data). The diamicton is very compact, and fractures in sheets parallel with the river bank. A 30 cm-long, single-clast thick, sub-horizontal concentration of cobble-shaped clasts was noted about 100 cm below contact with overlying sediment. A thin veneer of reddish brown silt-clay is found in the casts beneath clasts.

The diamicton is overlain above a sharp, planar contact by a 1 to 1.5 m-thick, clast-supported boulder gravel. It has a coarse-sand to granule gravel matrix, and subrounded to rounded clasts of mixed rock types, up to 1.5 m in diameter.

Interpretation

The diamicton is interpreted as a primary subglacial till. The strongly oriented clast fabrics with low $S_3$ eigenvalues are typical of subglacial deposition, and plot within the lodgement/melt-out till envelope described in Figure 3-4. The fabric trend is also similar to regional striae directions, indicating glacial flow into the Deer Lake basin from the east. Siltstone and sandstone clasts are locally derived from the underlying Rocky Brook Formation, or adjacent Humber Falls or North Brook formations. Crushing of these rock types would produce the reddish brown matrix colour. Exotic clasts are derived from bedrock located in directions consistent with palaeo-ice flow. The rhyolite clasts are commonly flow banded, and are likely derived from the Springdale Group, which crops out on The Topsails (Figure 1-4). Granite (units Oid and Sm) and quartz-feldspar porphyry (Sq) clasts are likely derived from The Topsails (Figure 1-5). Other rock types such as gabbro, tuff, and acid volcanics also crop out on The Topsails. Limestone clasts may be derived from the Rocky Brook Formation or North Brook Formation, both of which have minor limestone constituents (Hyde, 1979). Similarly, the striated clasts suggest a subglacial depositional environment.

The lateral concentration of clasts is a clast pavement. These have been well documented, and form as the result of clast collisions from ploughing on the lodgement surface (Boulton, 1976; Boulton and Paul, 1976; Kruger, 1979; Åmark, 1980; Clark and Hansel, 1989).

The spalling of the till in fractures parallel with the river banks are interpreted as structures due to release of pressure. Sladen and Wrigley (1983) consider such fractures to be caused by a reduction in shear strength due to the removal of a supporting load, in this case due to fluvial erosion. Babcock

(1977) and Catto (1984) described jointing in Quaternary sediment caused by valley cutting. Similar cases of instability are also associated with cutting exposures through lodgement till during road construction (e.g., Cocksedge, 1983). In Newfoundland, examples of failure due to loss of lateral support have been cited in bedrock along glacially overdeepened fjords (Grant, 1987). An alternative interpretation is that the fractures represent fissility, as described by Muller (1983), Ashley *et al.* (1985) and others. However, fissility is commonly defined by subhorizontal pseudo-beds. As such, the orientation should be similar on both sides of the river, and be aligned approximately normal to the vertical exposure face. The near-vertical trend of the fractures is incompatible with fissility. Fissility should persist throughout the deposit, but the Rocky Brook till becomes less fractured further into the bank. This suggests that cracking is ongoing as a result of the loss of lateral support.

The till at Rocky Brook has been previously interpreted as representing ice flow southward down the Humber River valley (Vanderveer and Sparkes, 1982). This interpretation was based on the presence of the gabbro clasts, considered to be derived from the Gull Lake intrusive suite, west of White Bay. However, gabbro is also found on The Topsails, within the Rainy Lake Complex, Hungry Mountain Complex, unit Om, and in the Buchans Group (Figure 1-4). The identification of granites and other rock types compatible with a source on The Topsails suggests westward glacial transport. The previous interpretation is therefore rejected.

The section at Rocky Brook is the only known exposure of this compact diamicton, although Vanderveer and Sparkes (1982) cite unreferenced drill-core data from the upper Humber River valley to suggest the Rocky Brook till is pre-Late Wisconsinan, based on stratigraphic position overlying bedrock. A

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review of existing data neither supports nor refutes this hypothesis. Pre-Late Wisconsinan tills from elsewhere in Atlantic Canada, such as the Halten Till (Stea and Fowler, 1979), McCarron Till (Stea *et al.*, 1985) or Lawrencetown Till (Grant, 1975) were identified on the basis of oxidation, induration or overlying non-glacial sediments containing macro- or micro-fossils dated to pre-Late Wisconsinan age. The Rocky Brook till is indurated, but is unoxidised and undated. In the absence of corroborative data the age of this unit remains uncertain.

The boulder gravel overlying the Rocky Brook till is interpreted as a postglacial fluvial deposit, as indicated by the stratigraphic position of the unit, the position of the unit adjacent to the modern stream channel, and its sedimentological characteristics. The section is directly downstream of a confined gorge, at a point where the stream likely lost its competence to transport large clasts. Clasts of similar dimension are observed during periods of low flow in the base of the modern stream channel.


### 2. Hinds Lake dam - subglacial melt-out till

The area adjacent to the Hinds Lake dam is generally sediment-covered (1-5 m), with rare bedrock exposures (Bajzak *et al.*, 1977; Whalen and Currie, 1988). It has numerous small borrow pits developed during dam construction. Regional ice flow indicators show an early flow to the northwest (320°), followed by a later southwest (250°) flow (see Chapter 4).


Description

A borrow pit (site 92195; Appendix A) on the north side of the Hinds Brook valley exposes two sandy diamictons (Figure 3-6). The basal diamicton

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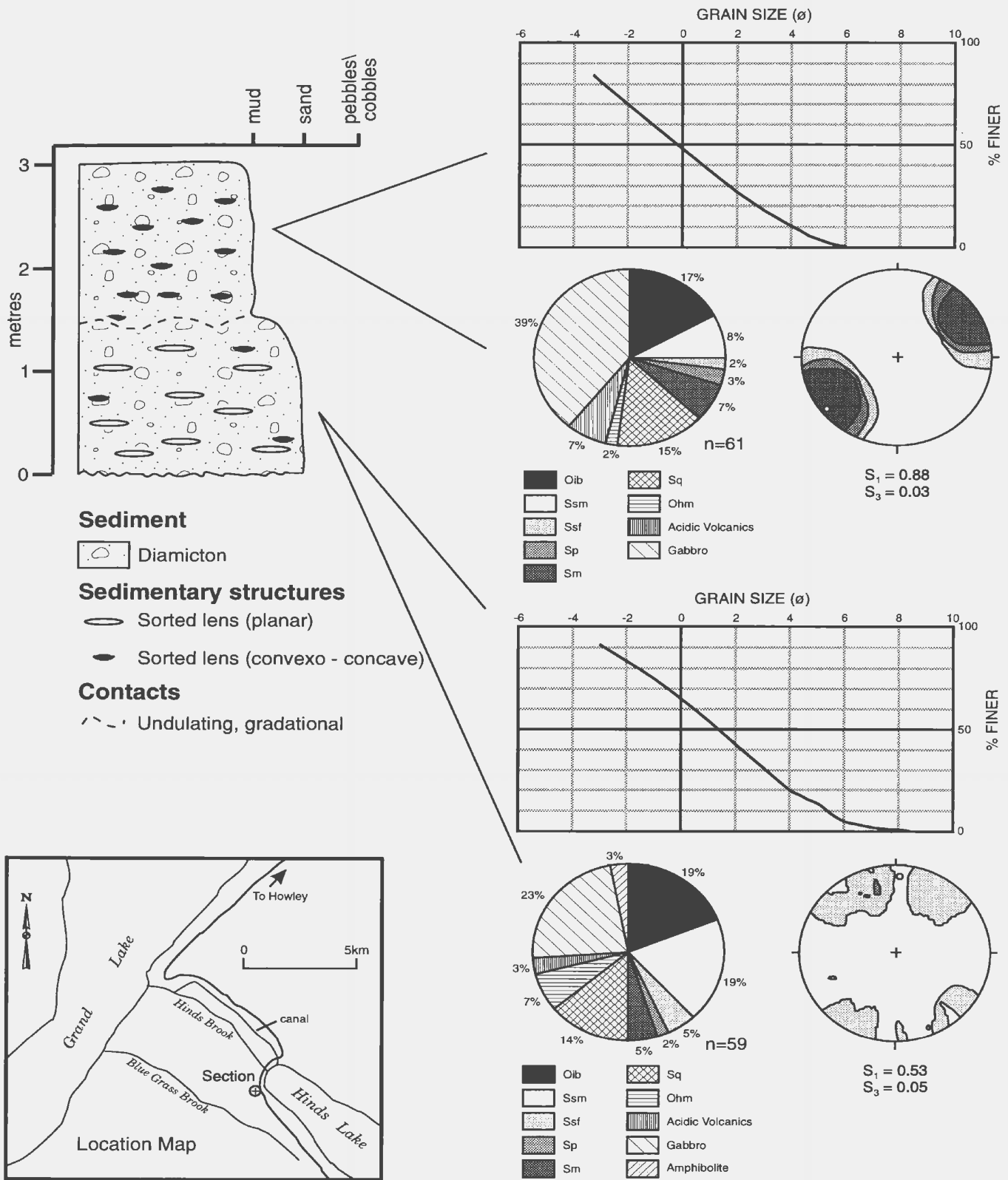
**Figure 3 - 6:** Stratigraphy of a diamicton exposure near Hinds Lake dam.

has a minimum thickness of 1.5 m. It is matrix-supported (40% matrix), very dark greyish brown (10YR 3/2, moist) to light brownish grey (10YR 6/2, dry), with a very poorly-sorted (s.d. 3.03ø) silty sand (73.7% sand, 26.2% silt, 0.1% clay) matrix and a mean grain size of 1.17ø. Clasts are subrounded to subangular, granules to boulders, up to 40 cm diameter. They are commonly covered by silt on their upper surfaces and have clean lower surfaces. Rock types include gabbro (30%), granite (25%), basalt (19%), porphyry (14%), and minor amphibolite (3%), rhyolite (3%) and acid volcanic (2%). The diamicton has a weak girdle fabric ($S_1$=0.53, $S_3$=0.05). Distributed throughout the unit are small (8 cm lateral extent and 2 cm thick), sub-horizontal lenses composed of moderately to well-sorted, fine- to medium-sand, and containing rare trough cross bedding. Sorted medium- to fine-sand lenses also occur beneath clasts, the lateral dimensions of which are restricted to clast dimensions.

The lower diamicton is overlain by 1.5 m of a very dark brownish grey (10YR 3/2, moist) to pale brown (10YR 6/3, dry) sediment (Figure 3-6), with a very poorly-sorted (s.d. 3.07ø) sand matrix (82.3% sand, 17.7% silt, 0% clay), and a mean grain size of -0.06ø. Clasts are subangular to subrounded, granules to boulders, up to 60 cm diameter. They commonly have silt covered upper and clean lower surfaces. Clast types are dominated by gabbro (42%), granite (26%), and porphyritic rhyolite (15%), with minor basalt (8%), acid volcanic (7%) and rhyolite clasts (1%). Aphanitic clasts were commonly striated. The unit has a strong, clustered clast fabric ($S_1$=0.88, $S_3$=0.03), with a preferred clast orientation towards 238°. Most clasts have low plunges (15/25 < 10°). The unit contains numerous convexo-concave and planar lenses of moderately to well-sorted fine- to medium-sand. The lenses are crudely bedded, although not graded. Some lenses are found on the north to west side of larger clasts, and

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have a ribbon-shaped plan view. The maximum thickness of the lenses was controlled by the clast diameter. The lenses pinched out laterally, toward the west. The lenses contained crudely bedded sand, with beds dipping 10-15° northward to westward. Other small (less than 2 cm lateral extent by 1 cm thick), subhorizontal, planar lenses of moderately to well-sorted, fine- to medium-sand were found throughout the diamicton. Sorted lenses are found beneath clasts, the dimensions of which are controlled by the clast dimensions.

Interpretation

The upper unit is interpreted as a subglacial melt-out till. It has a strong clast fabric, showing a well oriented, clustered distribution that is typical of subglacial deposition (Lawson, 1979; Dowdeswell and Sharp, 1986; Dreimanis, 1988; Hart, 1994). The preferred trend of clasts is similar to the regional ice flow derived from striations, i.e., southwestward. The low plunge of many clasts is also common in melt-out, produced by the settling of clasts in the horizontal plane during melt-out (Lawson, 1979; Shaw, 1983; Ashley et al., 1985; Dreimanis, 1988). The lower till has a weaker clast fabric, and may have been deposited by debris flow.

The clast rock types are consistent with transport from the northeast. The site is underlain by Hinds Brook granite (Figure 1-5), from which most of the granite clasts are derived. Other granitic clasts originate from the Topsails Intrusive Suite (units Sp and Sm). The gabbro may be from the Hungry Mountain Complex, and the basalt from the Springdale Group both of which are found in outcrop adjacent to the site. Porphyritic rhyolite is found within

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the Topsails Intrusive suite (unit Sq) and the Springdale Group. All of these clast types indicate southwestward glacial transport.

The lenses indicate sorting by water, and the crude bedding suggests current flow. This is supported by the low silt-clay content, produced by winnowing of fines. Such sedimentary features are uncommon in lodgement tills. Shaw (1982, 1983) and Haldorsen and Shaw (1982) described sorted layers, formed as the result of meltwater flow during the melt-out process. Intra-till sorted lenses are distributed throughout the exposure. Lenses form in subglacial cavities that are abandoned relatively quickly (Haldorsen and Shaw, 1982). Convex-concave sorted lenses are scour features caused by turbulent flow beneath clasts suspended from overlying melting ice (Shaw, 1983). The lenses extend beyond the confines of the overlying clast and are commonly part of laterally continuous beds. They are syndepositional features. The presence of a thin layer of silt covering the upper surfaces of clasts and a thin sorted, medium- to coarse-sand to granule layer beneath has not been described by previous authors. It is a common feature of many diamictons in Newfoundland. Several hypotheses exist for the formation of the sorted layers:

1. They represent boulder scours formed in melt-out tills (Shaw, 1983). This is rejected because boulder scour features commonly are traced laterally beyond the confines of the clast. The sorting described above is confined to beneath the clast. Similarly, this model does not explain the upper silt layer.

2. They are 'perched clasts' and represent fines protected from erosion (by water?) by the overlying clasts (Fisher, 1989). This is rejected because the features described above are not associated with other features suggestive of erosion. Moreover, it does not explain the silt cap.

3. They are secondary features resultant from the downward percolation of water during the Holocene. This suggestion is neither accepted nor rejected. No evidence was found, such as organic matter, that may demonstrate downward percolation of water. This may suggest that this process occurred shortly after deposition, where there was little or no surface soil profile. The silty sand matrix common in diamictons suggests downward migration of water may be continuous, and may result in minor turbulence beneath clasts, and deposition above.

Sedimentary features exposed near the Hinds Brook dam are compatible with deposition in a subglacial environment through a process of melt-out. Other potential genetic environments, such as sediment gravity flow are rejected. The strong clast fabric is not compatible with sediment gravity flow deposits, that commonly have weak cluster to girdle fabrics (Figure 3-2). The low plunge angles of clasts are uncommon in sediment gravity flows (c.f., Lawson, 1979). Similarly, the presence of numerous sorted lenses does not support a debris flow origin for the sediment.

### 3: Goose Arm - two diamictons

This site is located along the Goose Arm road north of Old Mans Pond (site 92147; Appendix A). It is a 4 m roadside exposure, cut into a hillside with a slope angle of about 17°. The exposure consists of a minimum of 2 m of diamicton dominated by limestone clasts, overlain by a 2 m sandy diamicton containing numerous exotic clasts (Figure 3-7).
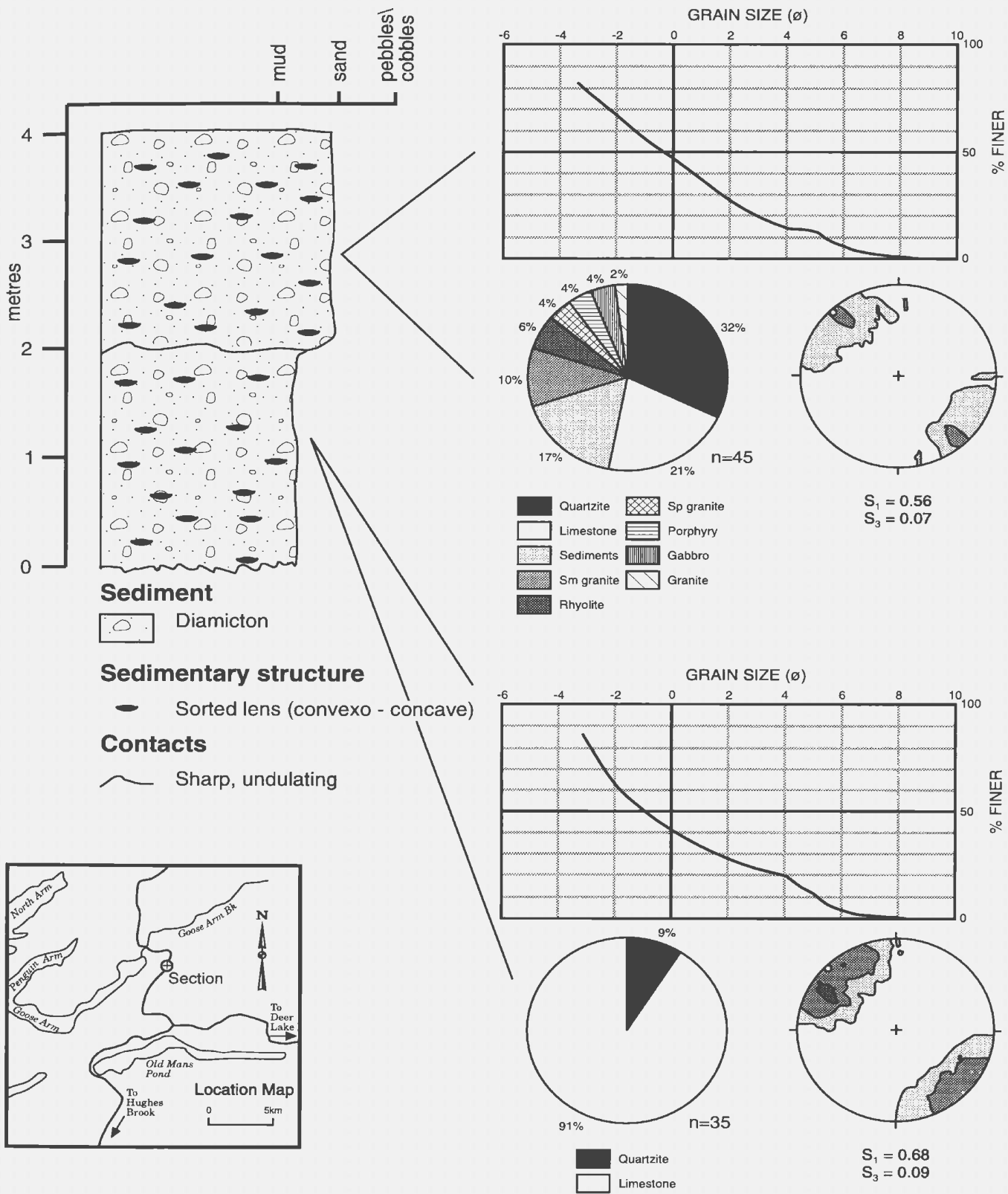
**Figure 3 - 7:** Stratigraphy of a roadside exposure near Goose Arm.

Description

The lower diamicton is compact, and greyish brown (2.5Y 5/2, moist) to light grey (10YR 7/2, dry). It has a very poorly-sorted (s.d. 3.45ø), silty sand matrix, composed of 61% sand, 39% silt, and <1% clay, with a mean grain size of 0.3ø. The unit is generally structureless, although medium- to coarse-sand lenses and rare open worked granule gravel lenses are found beneath clasts, within dimensions equal to the diameter of the clast. The upper surfaces of clasts are commonly silt covered, and lower surfaces are clean. The diamicton is clast-rich (~70% clasts). Clasts are angular to sub-angular, granules to boulders, with the largest clast about 70 cm diameter. Limestone (89%), with minor quartzite (9%) and dolomite (2%) dominate the clast rock types. Clast fabric is of moderate strength ($S_1$=0.68, $S_3$=0.09) and clustered, with a preferred clast orientation trending northwest.

Overlying a sharp, undulating contact is a loose, dark greyish brown (2.5Y 4/2, moist) to light brownish grey (10YR 6/2, dry) diamicton. The matrix is a very poorly-sorted (s.d. 3.42ø), silty sand composed of 74% sand, 24% silt, 2% clay, with a mean grain size of -0.07ø. The unit generally is structureless, except for small lenses of medium- to coarse-sand and occasional open-work granule gravel lenses found beneath clasts. The texture of the lense coarsens in relation to increasing clast size. Larger lenses are normally graded. Clasts are subangular, granule to boulder sized, with the largest clast about 50 cm diameter. Quartzite (32%) and limestone (22%) are the major clast rock types, but they also include granite (10%), sandstone (10%), rhyolite (6%), gabbro (4%), porphyry (4%), shale (4%), and siltstone (2%). Clast fabric is weak, with a girdle distribution ($S_1$=0.56; $S_3$=0.07). Clasts are rarely striated.

Interpretation

The lower diamicton is interpreted as a basal till. This is indicated by the moderately oriented clustered fabric, and the preferred clast orientation parallel to regional ice flow directions determined from striation data. The till is locally derived, with angular clasts from the underlying Port au Port Group (Knight, 1994), and is similar to 'immature' tills described by Croot and Sims (1996).

The overlying diamicton is interpreted as a secondary till, possibly deposited by debris flow. It contains more far-travelled material than the lower diamicton. The granite clasts are derived from the Topsail Intrusive Suite (units Sp, Sm, Sq). The rhyolites are flow banded and have their source in the Springdale Group, and gabbro is found within several rock units on The Topsails (Hungry Mountain complex, Rainy Lake Group, unit Om). Transport from The Topsails has crossed the Deer Lake basin, incorporating red Carboniferous sandstone clasts. Derivation of clasts from The Topsails and the Deer Lake basin is consistent with the regional trend of ice movement, and thus the sediment is glacial in origin. The weak, girdle fabric does not support primary subglacial deposition (c.f., Lawson, 1979; Dowdeswell and Sharp, 1986; Dreimanis, 1988), and the sandy matrix (75% sand) suggests winnowing of silt and clay. Winnowing is also suggested by the sorted layers beneath larger clasts, and may have been post-depositional or syn-depositional, as discussed above. The unit is located on a hillside, and thus downslope movement under the influence of gravity is likely.

<u>4. Pasadena dump - complex stratigraphy</u>

On the west side of the road to Northern Harbour along the west side of the South Brook valley, 100 m north of the gate to the Pasadena dump is an abandoned gravel pit (Plate 3-1). The pit face is oriented north-south, and is about 8 m high, including the lower colluviated 2 m. The upper surface of the pit face is about 65 m asl. The face exposes three diamicton units (site 91094; Appendix A) (Figure 3-8).

Description

The lower unit is at least 2 m thick. It is a dark brownish grey (10YR 4/2, moist) to pink (7.5YR 7/4, dry), matrix-supported (~ 60% matrix) diamicton. It has an extremely poorly-sorted (s.d. 4.24ø), silty sand matrix with a mean matrix composition of 66% sand, 25% silt and 9% clay (n=2). The unit is compact, and generally structureless. Clasts are subrounded to subangular, generally granule to cobble size with the largest clast size 30 cm in diameter. Clast surfaces commonly are striated. Two clast fabrics were completed on the diamicton from similar stratigraphic positions, separated laterally by 10 m. Both are strongly oriented and weakly clustered (Table 3-1), with the direction of preferred orientation towards the northwest. Sandstone (48%), siltstone (26%), and arkose (15%) dominated clast rock types. Minor amounts of schist (5%), quartz feldspar porphyry (3%), and conglomerate (3%) are also present.

Overlying an undulating, gradational contact extending 60 cm vertically is a 1.5 m-thick diamicton. It is olive grey (5Y 4/2, moist) to light brownish grey (2.5Y 6/2, dry), compact, and matrix-supported (~60% matrix) (Figure 3-8). It has an extremely poorly-sorted (s.d. 4.08ø), silty sand matrix, composed of 57% sand, 31% silt and 12% clay. Clasts are subangular to

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**Plate 3-1:**
A general view of the Pasadena dump exposure. Three diamicton units are exposed at this site, all deposited during the Late-Wisconsinan. A clastic dyke is seen to the left of the upper person, and a wedge of sand and gravel is seen to the right.
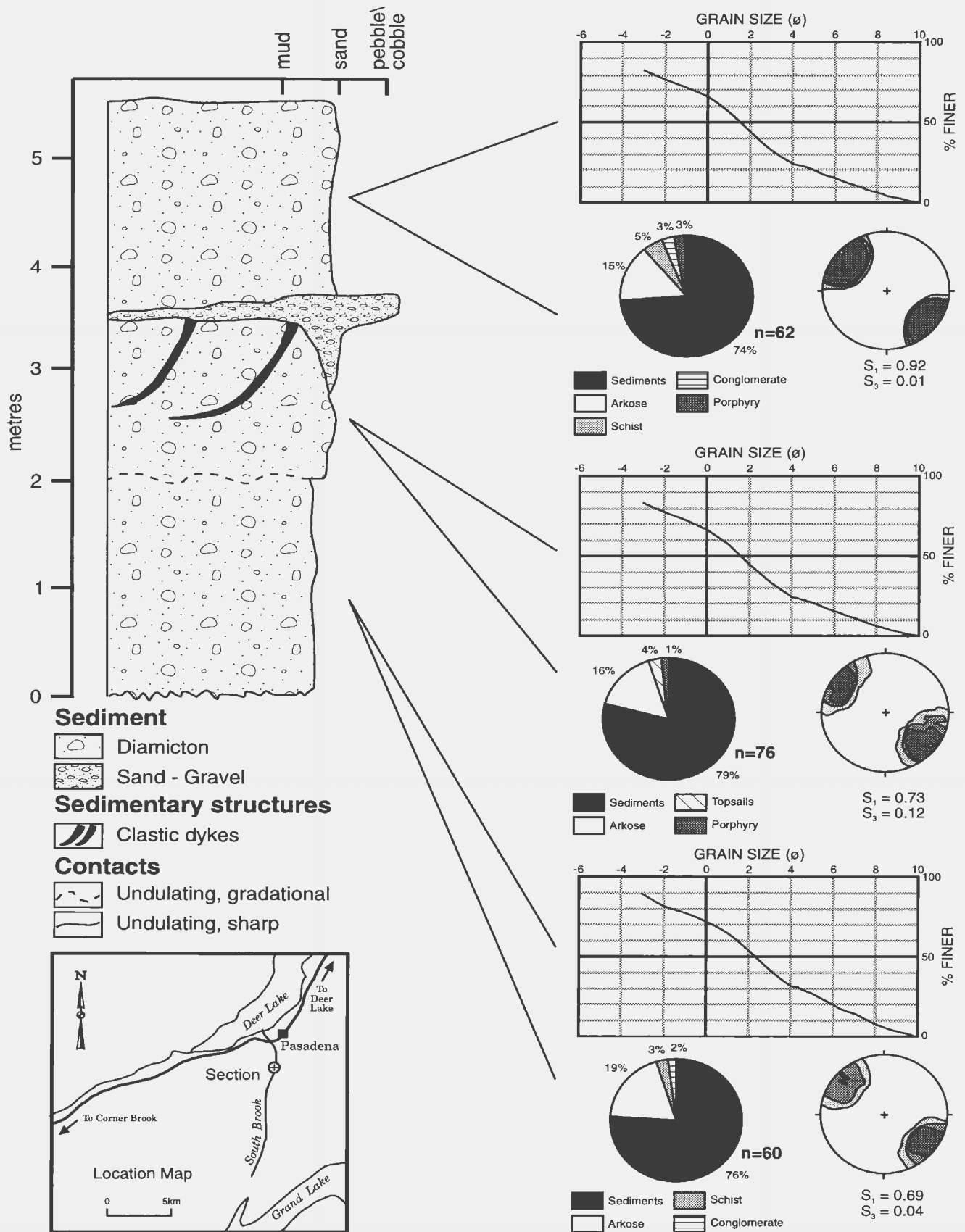
**Figure 3 - 8:** Stratigraphy of a diamicton exposure near Pasadena dump.

subrounded, mostly granule to cobble size, with rare boulders up to 50 cm diameter. Clasts are commonly striated. Two fabrics were completed in the unit, from about 6 m apart, at the same stratigraphic position within the middle of the unit. Both fabrics are strongly oriented and clustered (Table 3-1). Preferred clast trends are northwest and southeast. Clast rock types are mostly sandstone (50%), siltstone (26%) and arkose (16%), with minor granite (3%), quartz pebbles (3%), gabbro (1%), and quartz feldspar porphyry (1%).

The olive grey diamicton contains three irregular-shaped sheets of sand extending downward through the unit (Plate 3-2). The uppermost sheet is a thin (0.2 to 1.5 cm), contorted unit. It is composed mostly of moderately-sorted fine-sand. Thicker parts of the layer contain interbeds of fine- and very fine-sand oriented parallel to the sheet margins. The sheet is about 1.5 m long, and dips at about 5° to 50° towards the south, steeper at the upper end and approaching horizontal at depth. The middle sheet is about 150 cm long and subparallel to the upper sheet, separated by 5 to 20 cm of olive grey diamicton. This sheet is 1.0 to 3.5 cm thick, contorted, and composed of poorly-sorted medium- to coarse-sand with occasional granule to pebble clasts. Interbeds of moderately-sorted sand were noted. The lower sheet is the least extensive, being about 50 cm long, with similar internal structure to the upper sheet. All three sheets were traced into the exposure for greater than 20 cm.

The three sheets extend downward from a 10-15 cm thick, laterally discontinuous, north-south trending wedge of sandy gravel exposed along the contact between the olive grey diamicton and an overlying reddish brown diamicton. The sandy gravel has a poorly-sorted fine- to medium-sand matrix, subrounded to rounded, granule to pebble clasts of mixed rock types. The bed is generally structureless, although small, convexo-planar lenses of

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**Table 3-1:** Statistics of clast fabrics from the Pasadena dump site section.

| Unit | | $S_1$ | $S_3$ | Trend (°) | Plunge (°) |
|---|---|---|---|---|---|
| Lower | 1. | 0.79 | 0.05 | 303 | 14.2 |
| | 2. | 0.92 | 0.01 | 308 | 2.3 |
| Middle | 1. | 0.73 | 0.12 | 126 | 7.6 |
| | 2. | 0.72 | 0.13 | 316 | 2.3 |
| Upper | 1. | 0.75 | 0.09 | 084 | 4.2 |
| | 2. | 0.74 | 0.10 | 310 | 6.5 |
| | 3. | 0.69 | 0.04 | 129 | 1.9 |

**Plate 3-2:**
A clastic dyke within the middle diamicton unit at the Pasadena dump
exposure. The dyke contains sand-silt, and was formed by hydraulic
splitting in an unfrozen subglacial till.

well-sorted coarse-sand to open-work granule to pebble gravel were noted beneath some clasts. The northern extension of the sandy gravel penetrates the olive grey diamicton as a wedge-shaped feature, extending downward about 1 m (Plate 3-3). The wedge varies in inclination from 5° to 80°, with steeper angles at depth. Upper and lower contacts of the wedge are sharp.

The olive grey diamicton and the sandy gravel unit are overlain by a 2 m-thick compact, matrix-rich (60%) diamicton, along a generally sharp, undulating contact (Figure 3-8). The diamicton is dark reddish brown (5YR 4/2, moist) to light brown (7.5YR 6/4, dry). It has an extremely poorly-sorted (s.d. 4.05ø), silty sand matrix composed of 59% sand, 30% silt, and 11% clay. Clasts are subangular to subrounded, mostly granules to cobbles, with rare boulders up to 50 cm diameter. Clasts commonly are striated. Three fabrics were completed in the unit, spread laterally over about 10 m at the same stratigraphic position. Two of the fabrics are strongly oriented and clustered (Table 3-1). Preferred trend is 129° and 084° respectively. A third fabric shows a strongly oriented, girdle distribution, with a preferred clast orientation of 309°. Clast rock types are mostly sandstone (50%), siltstone (27%) and arkose (19%), with minor schist (3%) and conglomerate (1%).

### Interpretation

The lowest, dark brownish grey diamicton is interpreted as a primary subglacial till. This is supported by the striated clasts, and very strong and clustered clast fabrics. Preferred clast trend is southeast-northwest, parallel to regional striation patterns (see Chapter 5). Sandstone, arkosic sandstone, siltstone and conglomerate all occur within the North Brook Formation of the Deer Lake Group that underlie the Pasadena area, or from the Anguille

**Plate 3-3:**
A wedge of sand and gravel between the middle and upper till units at the Pasadena dump exposure. This sediment was deposited in a subglacial environment.

Group that crops out to the east. Quartz feldspar porphyry is found in the Topsails Intrusive Suite (unit Sq), which crops out west of Hinds Lake. Schist clasts are likely derived from the Mount Musgrave Group that crops out on the hills west of the South Brook valley. The unit is homogenous. No sorted lenses, boudins or other sedimentary structures were noted that would suggest either the presence of significant quantities of water during the sedimentation process, or that the till was resedimented.

The middle, olive grey diamicton is interpreted as a primary subglacial till. The gradational contact suggests depositional continuity with the underlying unit, and the presence of striated clasts and strongly oriented and clustered fabrics support a subglacial origin. Preferred clast trend is southeast-northwest, parallel to the northwestward regional striation pattern. Clast rock types suggest a northwestward ice flow direction. Sandstone, siltstone and arkose clasts are found in the North Brook Formation that underlies the dump site area. Granites are fine grained and pink, similar to rock types found in the Topsails Intrusive Suite (units Sg and Sm). This suite also contains quartz feldspar porphyry (unit Sq). All of these units crop out southwest of Hinds Lake. The gabbro clast is also likely from The Topsails, exposed in outcrop up-ice of the dump site in the Rainy Lake complex (Figure 1-5).

The sand sheets are interpreted as clastic dykes. They have been described in many areas (Larsen and Mangerud, 1992; Dreimanis and Rappol, 1997), including Nova Scotia (Mörner, 1973; Dredge and Grant, 1987). They include wedges injected downward from a basal till layer, either composed of till (e.g., Dreimanis, 1969, 1992; Åmark, 1986), or sorted sediment (e.g., Kruger, 1938; Åmark, 1986; Larsen and Mangerud, 1992; Dreimanis and Rappol, 1997). The clastic dykes at the Pasadena dumpsite penetrate till, and are therefore

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subglacially derived. They are composed of sorted and laminated sediments, with laminae parallel to dyke walls. The lamination and sorting shows deposition by water. The dykes extend downward from a unit of sandy gravel. This sediment must also have been subglacially deposited. The parallelism of laminae to dyke walls suggests incremental dyke development, as postulated by Larsen and Mangerud (1992). A wide crack that developed rapidly would likely produce horizontal lamination. The propagation of the cracks is therefore by hydraulic splitting generated by high hydraulic pressures. Such pressures are required to explain the near-horizontal angle of the dyke at depth that would otherwise have closed due to the weight of the overlying sediment.

These dykes are similar to glaciotectonic tension fractures produced by glacier drag as described from the Humber Valley near Toronto (Hicock and Dreimanis, 1985), and from the Northern Superior till, north of Lake Superior, Ontario (Hicock and Dreimanis, 1992). The thermal condition of the till into which the dykes were injected is difficult to determine. Dreimanis (1969; 1992) suggested that till wedges require a frozen substrate to facilitate cracking. Humlum (1978) argued that a frozen substrate would promote basal freezing and consequently glacial flow by internal deformation, rather than basal sliding required to promote glacial drag. At Pasadena dump, the presence of contorted segments within the dykes, and the irregular course of the dykes suggests the surrounding diamicton was unfrozen during dyke formation.

The upper reddish brown diamicton is interpreted as a primary subglacial till. It contains striated clasts, and well oriented, girdle to cluster, clast fabrics that generally have a preferred trend parallel to regional striation

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patterns. Clast rock types are of local provenance, derived from the underlying North Brook Formation.


Discussion

All three diamicton units have broadly similar characteristics. Grain size distributions for the lower, middle and upper tills are similar, and show 34%, 43% and 42% silt-clay, respectively. Clast fabrics are strong and clustered. The lowest diamicton possesses the strongest fabrics, with $S_1 > 0.75$ and $S_3 \leq$ 0.05. The middle and upper diamictons have similar fabrics, with $S_1 = 0.72$-$0.75$, and $S_3 = 0.09$-$0.13$. Clast dips are generally low within each diamicton unit. The preferred trend of clasts within each of the diamicton units is similar for 6 of 7 fabrics (~130° or 310°), similar to regional palaeo-ice flow directions determined from striations on bedrock. The regional trend shows ice moving west to northwest across the area from a source on The Topsails, crossing the South Brook valley. Clast provenance data are consistent with this interpretation, with exotic clasts (mostly granite or quartz-feldspar porphyry) found in outcrop on The Topsails.

All three diamictons are interpreted as basal tills. There is no evidence for an ice free period in the exposed stratigraphy, suggesting that glacial cover was continuous during deposition. The contact between the lower and middle tills is gradational. There were no non-glacial or oxidized sediments noted between the middle and upper tills. Sandy gravel exposed along the contact is formed subglacially, as indicated by the clastic dykes that propagate downward from it into the middle till. The upper till represents a different depositional phase, being in sharp contact with the middle diamicton and devoid of sedimentary structures indicative of glaciotectonism. Preferred clast

orientation and clast provenance show that the upper diamicton was deposited by ice from the same source as that which deposited the middle diamicton.

The clastic dykes found within the middle diamicton have not been reported from elsewhere in Newfoundland. Within the Humber River basin, similar sorted and laminated dykes are found north of Deer Lake (site 91163: Appendix A). At this site a lower reddish brown to light brown (5YR 5/3, moist to 7.5YR 6/4, dry), very poorly-sorted (s.d. 3.58ø), silty sand (49% sand, 36% silt, 15% clay) diamicton possessing a strong fabric ($S_1$=0.69; $S_3$=0.07) is overlain along an undulating, sharp and dipping contact by a reddish brown (2.5YR 4/4, moist) to light red (2.5YR 6/6, dry), very poorly-sorted (s.d. 3.91ø), silty sand (48% sand, 34% silt, 18% clay) diamicton with a strong fabric ($S_1$=0.74; $S_3$=0.07). The lower unit contains steeply dipping (~ 38°), thin (2-3 mm wide) dykes, containing reddish brown silt-clay, commonly with very thin (< 1 mm), medium-sand partings.

Evidence for glaciotectonism also comes from an exposure (site 91104: Appendix A) about 400 m upslope and 20 m higher than the Pasadena dump section. This section, termed Pasadena dump II, exposes about 2 m of diamicton, overlain by 1 to 2.5 m interbedded fine-sand, medium-sand and diamicton, overlain by 0.8 m diamicton (Figure 3-9). The upper and lower diamicton units are broadly similar, although the upper is slightly coarser (43% silt-clay) compared to the lower (32% silt-clay). Both are extremely poorly-sorted, structureless, brown to dark brown (10YR 5/3, moist to 7.5YR 4/4, moist) diamictons. Clast fabrics from each unit are strong and clustered. Clasts commonly are striated, and provenance is dominantly local, with exotic clasts being derived from The Topsails (quartz-feldspar porphyry from the
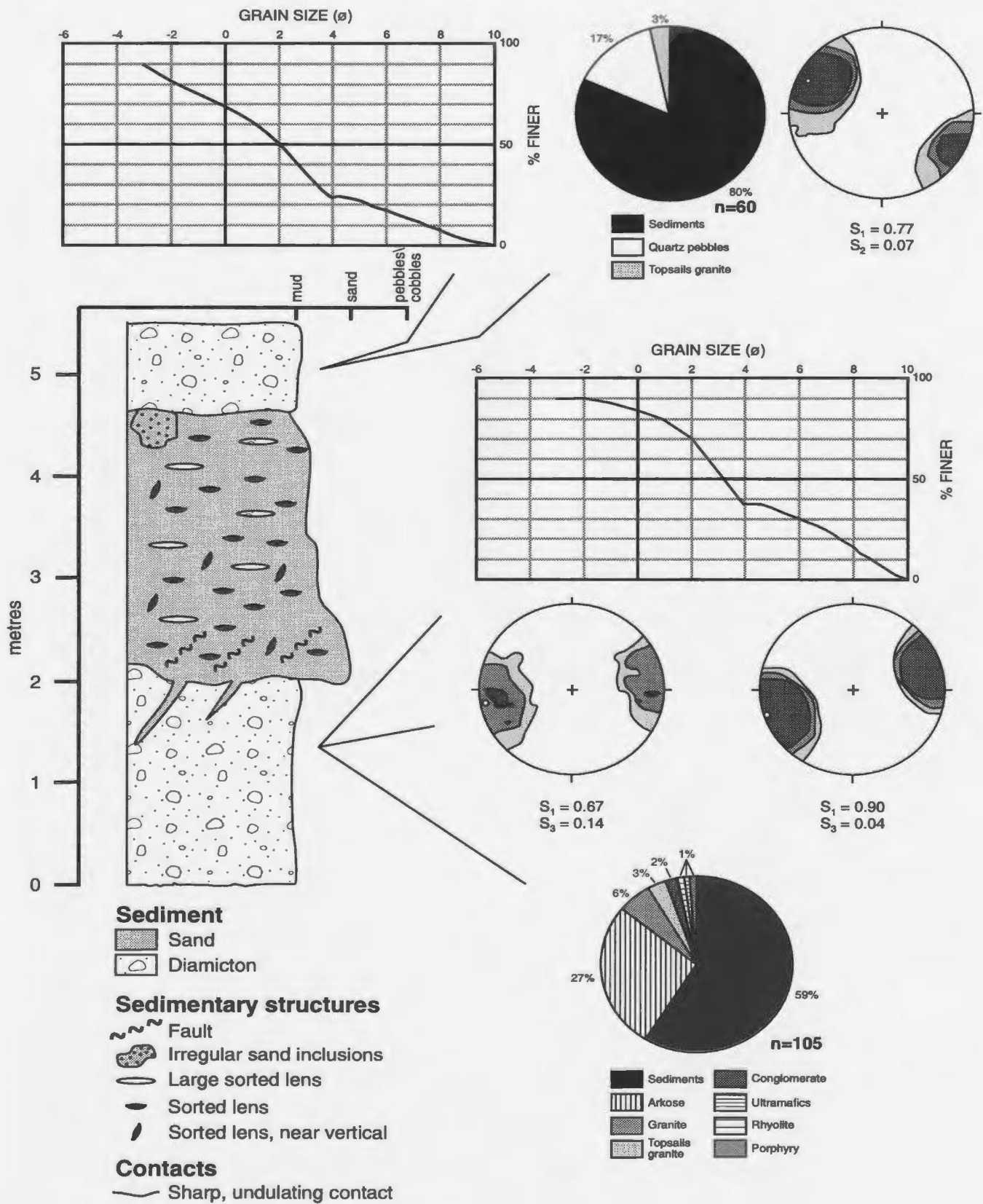
**Figure 3 - 9:** Stratigraphy of the Pasadena dump II exposure.

Topsails intrusive suite, and rhyolite from the Springdale Group). The upper diamicton contains fewer exotics than the lower diamicton. The two diamictons differ in the degree of compaction (lower more compact than upper), and the direction of preferred clast orientation (262° and 253° in the lower diamicton (similar to the Pasadena dump tills), and 297° in the upper diamicton).

Both diamictons are interpreted as primary subglacial tills, based on structure, striated clasts, and strong clast fabrics with preferred clast trend parallel to regional flow direction. The upper till is correlated with the upper till at the Pasadena dump site, based on similar stratigraphic position, clast characteristics and matrix colour. The lower till at Pasadena dump II and the lowest diamicton at Pasadena dump are also correlated with each other.

The unit separating the two diamictons units is a very compact, crudely horizontally stratified pebbly sand, with diamicton lenses. The unit includes interbeds of moderately-sorted medium- to very fine-sand. The diamicton forms a series of plano-convex lenses about 10 cm wide and 3 cm high. The lenses appear internally structureless, have a fine-sand matrix and granule to pebble sized clasts.

Numerous thin (0.1 cm), discontinuous, medium- to fine-sand strata or inclusions, up to about 30 cm long occur throughout the unit. In places, these inclusions truncate existing bedding. Twenty-five of these strata were excavated across the section, and their dip angle and orientation measured (Plate 3-4). They commonly are steeply dipping (mean 49°) towards 180°. They are also found in the lower till, although not in the upper one. In places, the middle sand unit contains clastic dykes, commonly deformed and faulted (Plate 3-5). The dykes consist of medium to coarse sand, and dip steeply (20 to

**Plate 3-4:**
Sand strata found within compact pro-glacial
lacustrine sands at the Pasadena dump II exposure.
These are interpreted as tension cracks produced by
glacial over-ridding. The sand is overlain by a
subglacial till.
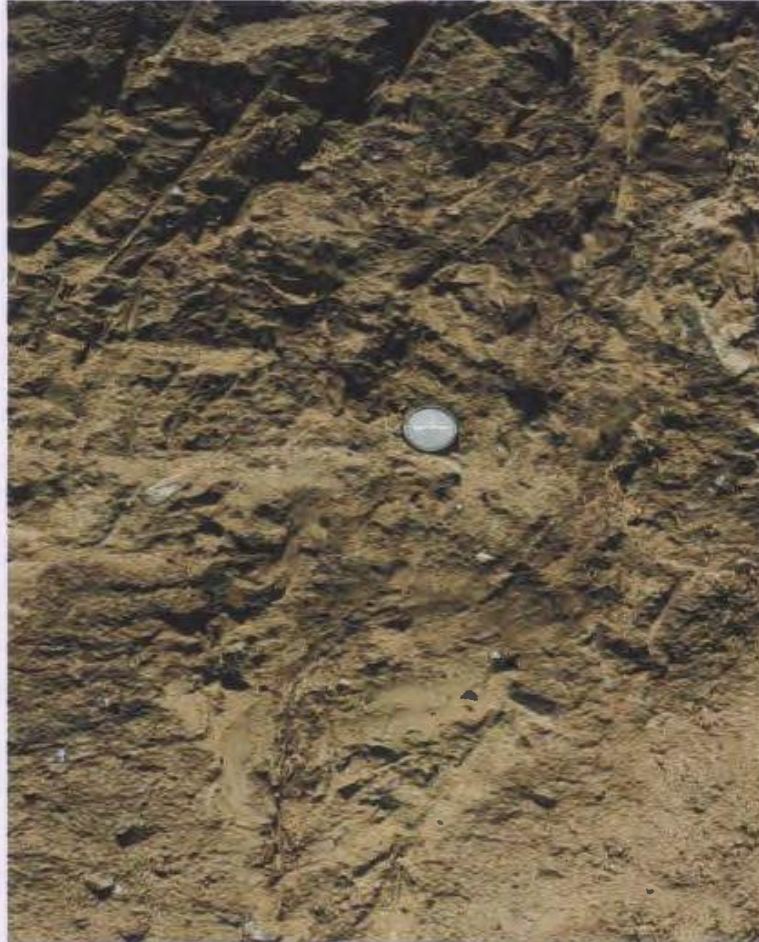
**Plate 3-5:**
Small, steeply dipping sub-parallel normal faults within a compact sand bed in the Pasadena dump II exposure. The faults were produced as a result of tension cracking from glacial over-riding of an ice marginal pond.

60°) westward. Larger dykes contain laminated silt and sand, with laminations parallel to the wedge margins. One of these extends into the lower diamicton unit.

A clast of unconsolidated sediment was found at the contact between the middle unit and the upper till. It was about 100 cm wide by 75 cm high, and was composed of loose, mica-rich, interbedded, moderately- to well-sorted, medium- and fine-sand. The bedding dips about 10° eastward, and is more distinct towards the top of the clast, whereas lower down it is more structureless (Plate 3-6).

This unit is interpreted as having been deposited in a small ice marginal or subglacial pond. The size of the pond may be estimated from the extent of the unit, which appears to pinch out to the south, and from the lack of similar exposures elsewhere. The pond is ice proximal, suggested by the lack of silt-clay, and the diamicton lenses (e.g., Lawson, 1982; Ashley et al., 1985; Eyles and Eyles, 1992). These are interpreted as having been deposited by debris flow. The geographic location of the deposit on a valley side wall suggests an ice marginal origin.

The pond has been over-ridden by ice. This is indicated by the clastic dykes and fine sand inclusions or plates contained within the pond sediments, interpreted as glaciotectonic features. Dreimanis (1992), Hicock and Dreimanis (1985, 1992), Broster *et al.* (1979), Broster (1991) and Derbyshire and Jones (1980) described similar features. They are interpreted as tension gashes or cracks produced in fine-grained sediments as a result of glacial over-riding. Where glaciers over-ride waterlain sediments, initial high pore water pressures are lowered as sediment is gradually dewatered. The sediment becomes denser, shear strength increases and cracking results from glacial

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**Plate 3-6:**
An unconsolidated clast along the contact between the compact sand
bed and the upper diamicton unit in the Pasadena dump II exposure.
This intraclast was frozen during emplacement, possibly from
subglacial fluvial sediment. The upper part of the intraclast has been
planned-off by glacial over-ridding.

drag (Hicock and Dreimanis, 1992). Whether the upper diamicton represents a readvance of regional significance, or reflects a local reactivation of the ice front cannot be determined from this section alone.

To be preserved, a loose, sand intraclast must have been frozen during emplacement, and remained frozen during glacial overriding and the development of the glaciotectonic features. The upper part of the sand intraclast was eroded during over-riding (Plate 3-6). The sorted and laminated clastic dykes suggest the surrounding sediment was unfrozen during their development. It is therefore possible that the sand intraclast was introduced to the pond as a frozen block derived from the subglacial drainage system. The sharp contacts with surrounding sediment, and dip angle of beds within the intraclast unrelated to bedding within the pond sediment support this conclusion. Glacial over-riding occurred subsequently, leading to the development of tension cracking and clastic dykes. Boulton (1970, 1979), Hooke (1970), Shaw (1982), Harris and Bothamley (1984), Menzies (1990a, b), and Hicock and Dreimanis (1992) described sand intraclasts within deformed or glaciotectonised sediment.

### 5. Pynn's Brook valley - evidence for glacial readvance (?)

This exposure was within a backhoe test pit (site 91239; NTS 12H04; UTM reference 461920E 5436600N) in the Pynn's Brook valley, north of Pasadena (Plate 3-7). The surface is generally flat (elevation 161 m asl), sloping gently towards Pynn's Brook to the east.

Description

The section exposed about 3 m of sediment with a lateral extent of

**Plate 3-7:**
General view of the Pynn's Brook valley exposure. This
section contains non-glacial sand and gravel overlain
by a subglacial till possibly produced by a local
readvance.

about 2 m (Figure 3-10). At the base was at least 1 m of light yellowish brown (10YR 6/4, moist) to pale brown (10YR 6/3, dry) silty sand. It is moderately-sorted (s.d. 1.4ø), and is composed of 70% sand, 28% silt and 2% clay, with a mean grain size of 3.9ø. The unit is normally graded. The unit contains rare pebble to cobble-sized clasts (<5%). It is crudely stratified and contains planar, sub-horizontal lenses of moderately-sorted medium- and coarse-sand, up to 15 cm long and 3 cm thick. Individual sand beds commonly are convoluted, showing simple folds in beds up to 20 cm in length. No current flow structures were noted.

This is overlain by a 1 cm thick, moderate to well sorted, structureless, very fine sand to silt unit, above a sharp, wavy contact (Plate 3-8). This, in turn, is overlain by a 20 cm-thick, cohesionless and structureless pebbly sand along a sharp, irregular contact. The unit has a fine to medium sand matrix, and subangular to subrounded granule to pebble clasts. This unit contains a steeply dipping (about 60°), 3-4 cm long lens extending from the underlying sand bed about 15 cm into the pebbly sand. The lens contains a structureless, moderately-sorted, fine- to medium-sand.

Overlying a gradational contact is 2 m of diamicton. The unit is generally homogenous apart from a 15 cm thick, structureless, sub-horizontal, laterally continuous, planar, fine- to medium-sand lens towards the base of the unit. The lens has sharp upper and lower contacts. The diamicton has a reddish brown (5YR 4/3, moist) to light brown (7.5YR 6/4, dry), very poorly-sorted (s.d. 4.58ø), sand-silt-clay matrix (28% sand, 37% silt and 35% clay), with a mean grain size of 4.48ø. Clasts are subangular to subrounded, commonly striated, and randomly distributed through the unit. The upper surfaces of clasts commonly are covered by a thin (< 1 mm) veneer of silt to fine sand,

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GRAIN SIZE (ø)

% FINER

mud sand pebbles\cobbles

metres

$S_1 = 0.67$
$S_3 = 0.13$

2% 2%
29%
67%
n=50

Sediments    Topsails granite
Metaseds    Gneiss

**Sediment**

Silty sand

Sand

Pebbly sand

Diamicton

**Sedimentary structures**

Folded strata

Large sorted lens

Sorted lens

Sorted lens, near vertical

**Contacts**

—— Sharp, planar

N

Deer Lake

To Deer Lake

Pynn's Brook

Glide Lake

Section

Brook

Glide

Location Map

Pasadena

0    5km

To Corner Brook

Grand Lake

**Figure 3 - 10:** Stratigraphy of an exposure in the Pynn's Brook valley.

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**Plate 3-8:**
Sand overlain by structureless very fine-sand to silt, pebbly sand and diamicton. The sorted units are interpreted as fluvial. The diamicton is evidence for a readvance of ice that covered the Pynn's Brook valley during deglaciation.

whereas lower surfaces are clean. Clast rock types include sandstone (56%), schist (28%), siltstone (10%), gneiss (2%), quartz pebble (2%) and granite (2%). Clast fabric is moderately strong and clustered ($S_1$=0.67, $S_3$=0.13), with a preferred clast orientation of 018° and a modal plunge of 17°. The diamicton is generally structureless, although small (1 mm thick), internally structureless, medium-sand lenses occur beneath clasts and do not extend beyond the width of the clast.

Interpretation

The lower sands are interpreted as a sub-aqueous deposit, as indicated by their texture and sorting, and the low proportions of coarse clasts. Current velocities, if any current was present, were very low. Waning flow or decreasing sediment supply explains the normally graded bed. Lack of current energy is suggested by the high (30%) silt-clay content in the matrix. The lenses suggest discrete current flow events, but whether these represent turbidity currents or channeled flows is not clear. The disturbance of the beds is interpreted to be the result of dewatering produced by loading. This is indicated by the overlying wavy contact with the pebbly sand, and the steeply dipping sand lens in the overlying pebbly sand bed. This feature is interpreted as a flame structure. Loading is provided by the overlying diamicton. Development of dewatering structures suggest rapid emplacement of the overlying diamicton onto a saturated lower unit, inducing the gravitational instability to induce upward movement of the underlying fines. The sands were deposited in a proglacial or subglacial environment. Sand beds have been described from both these environments (e.g., Rust and Romanelli, 1975;

Cheel and Rust, 1982; Ashley, 1988; Miall, 1992). The small lateral extent of the exposure makes further interpretation difficult.

The overlying diamicton is interpreted as a basal till. This is supported by the lack of sedimentary structures, striated clasts and moderate strength clustered fabric. Clast provenance is local. The site is underlain by metasediments of the Mount Musgrave Group, and sandstone, siltstone and quartz pebbles are likely derived from the adjacent Anguille Group. The gneiss and granite clasts are exotics. The granite is porphyritic and may have its source in The Topsails (unit Ssya?). Gneiss is also found on The Topsails, and in the Long Range Mountains. It could not be determined whether the glacier that deposited the diamicton had its source in the Long Range Mountain or The Topsails. Clast fabric is moderately strong and clustered, and falls within the basal till envelope on Figure 3-2. Preferred clast orientation is north-south, perpendicular to the trend of the valley in which the section was exposed.

An alternative interpretation is deposition as a sediment gravity flow. The diamicton is generally structureless, loads the underlying sediment (c.f., Leeder, 1982), and contains steeply dipping clasts (8 of 25 > 30°), similar to characteristics noted by Lawson (1979). However, clast fabric in sediment gravity flow deposits is commonly weak ($S_1$ < 0.6) and girdled (Dowdeswell $et$ $al.$, 1985; Dowdeswell and Sharp, 1986; Hart and Roberts, 1994). The diamicton exhibits a moderately strong, clustered fabric, is ungraded, shows no evidence for a traction carpet in the lower parts of the bed, and has a flat surface morphology. All of these factors are not typical of a sediment gravity flow deposit.

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The presence of a basal till overlying sand suggests a reactivation of the ice margin, if the sand was deposited in a proglacial environment. The source and extent of this reactivation is unclear. The Pynn's Brook exposure may be related to a poorly exposed section located farther to the east in the Pynn's Brook valley (site 92172; Appendix A), that shows a thin diamicton bed overlying interbedded sand and diamicton. Southward-oriented striae noted in the Glide Lake area have a similar trend to the clast fabric orientation at Pynn's Brook (see Chapter 5). The Pasadena dump II section exposes a similar stratigraphy. The surface diamicton at that section is locally derived, generally structureless, and has a similar clast fabric strength (although different preferred orientation) to the till at Pynn's Brook. These two tills are tentatively correlated with each other.

The anomalously high clay content in the diamicton (35%) is likely the result of over-riding of a fine-grained source by ice. The source of these fines could not be determined. Other diamictons in the area have clay contents of less than 10%. The clast component in the diamicton (mostly sandstone and schist) suggests the clay is not from a bedrock source. Similarly, the diamicton is located well above muds found in the Deer Lake basin to the west, and no fine grained sediments were located in the Pynn's Brook valley from which the clay may have been derived.

The Pynn's Brook exposure may represent depositional evidence for a local reactivation of the ice front during deglaciation. The presence of till overlying sand and gravel is unusual in Newfoundland, but the limited lateral extent of the exposure means that an alternative hypothesis of all sediment being deposited in a subglacial environment could not be dismissed. The suggestion that the exposure shows evidence for a readvance therefore

remains tentative. Excavation of more extensive exposures in the Pynn's Brook valley is required to test the validity of alternative hypotheses.


**Diamictons in the Humber River basin: Discussion**

The sections described from Rocky Brook, Hinds Lake dam, Pasadena dump, Pynn's Brook and Goose Arm represent the range of diamictons found across the Humber River basin.

The diamicton exposed at Rocky Brook is interpreted as a primary subglacial till deposited by lodgement. This exposure is anomalous. The high compaction and fracturing of the diamicton due to pressure release is not found elsewhere across the Humber River basin. Other characteristics of deposition by lodgement occur rarely in diamicton exposures. A section near Hinds Lake dam (site 92089: Appendix A) shows an intratill clast pavement, similar to the one noted at Rocky Brook. The pavement is composed of flat-lying clasts up to 15 cm diameter forming a well-defined 10 cm-thick layer (Plate 3-9), separating a lower dark greyish brown (10YR 4/2, moist), diamicton with a strong clast fabric ($S_1$=0.79; $S_3$=0.03) from an upper dark brown (7.5YR 4/2, moist) diamicton, with a moderate clast fabric ($S_1$=0.60, $S_3$=0.07), and containing numerous irregular-shaped, subhorizontal sand lenses.

Other small diamicton exposures that showed characteristics found in lodgement tills, including fissility, with strong fabrics with preferred orientation parallel to regional ice flow, and striae on clasts parallel to clast long axis were found at six sites (Table 3-2) (sites 91048, 91104, 91215, 92093, 92207, 92212, and 93133; Appendix A).

The diamictons exposed at the Hinds Brook dam site are interpreted as primary basal tills deposited by melt-out. Diamicton exposures showing

**Plate 3-9:**
An intra-till clast pavement within a diamicton unit from an exposure near Hinds Lake dam. This pavement was produced subglacially as a result of clast collisions. Such features are rare across the Humber River basin.

**Table 3-2**: Characteristics of diamictons interpreted as lodgement till found across the Humber River basin.

| Site | Compaction | Fabric | $S_1$ | $S_3$ | Parallel to ice flow | Fissile | Overlain by | Other structures | Striated clasts |
|------|-----------|--------|-------|-------|---------------------|---------|-------------|------------------|-----------------|
| 92093 | high | strong | 0.78 | 0.06 | yes | yes | sand - gravel | none | yes |
| 92207 | mod | mod | 0.64 | 0.09 | yes | yes | diamicton | none | no |
| 92212 | mod | strong | 0.84 | 0.04 | no | yes | surface | none | yes |
| 93133 | high | mod | 0.62 | 0.08 | yes | yes | surface | none | yes. // to flow |
| 91048 | high | mod | 0.64 | 0.08 | yes | yes | surface | none | yes |
| 91215 | high | mod | 0.68 | 0.10 | yes | no | sand - gravel | none | yes. // to flow |

similar characteristics (lenses of sorted sediment, possibly with strong fabrics, and clast orientation parallel to regional ice flow) are found at 39 sites across the study area (Sites 91062, 91064, 91193, 91222, 91231, 91242, 92018, 92024, 92033, 92035, 93036, 92039, 92089, 92096, 92111, 92112, 92154, 92178, 92196, 92202, 92205, 92207, 92209, 92213, 92214, 92215, 92216, 92217, 92224, 93011, 93019, 93020, 93174, 93093, 93097, 93103, 93105, 93122, and 93134; Appendix A).

The diamictons exposed near Goose Arm are interpreted as a basal till of local origin, overlain by a secondary till deposited by sediment gravity flow. Diamictons with characteristics consistent with subglacial deposition and short transport (e.g., dominated by local clasts, possibly with strong clast fabric with a preferred clast orientation parallel to regional ice flow) were found at 39 sites across the study area (Sites 91006, 91027, 91033, 91036, 91044, 91053, 91060, 91061, 91063, 91078, 91080, 91081, 91098, 91120, 91141, 91142, 91187, 91191, 91198, 91205, 92059, 92060, 92061, 92062, 92063, 92145, 92152, 92199, 92200, 92203, 92208, 92210, 92220, 92221, 93068, 93095, 93102, 93136, 93137, 93140; Appendix A).

Diamictons with similar properties to those found in the upper till at Goose Arm are commonly found along, or at the base of, steep slopes. Some had preferred clast trends and plunges parallel to local slopes. Examples are found in the lower Humber River (sites 91150 and 91184), Old Mans Pond (site 91208), South Brook (sites 91090 and 91097), Wild Cove (site 91222) and Grand Lake (site 93015) valleys, and along the foothills of Birchy Ridge (sites 93054 and 93104) and the Long Range Mountains (site 93044).

Other exposures showed thin (5-30 cm) diamicton beds interbedded with sand and gravel. The diamictons are interpreted as sediment gravity flow deposits. Examples of these are found in the South Brook (site 91087) and Wild Cove (site 91220) valleys, and near Cloudy Pond (site 92124).

The diamictons at the Pasadena dump and Pasadena dump II sites are interpreted as primary tills deposited in a subglacial depositional environment. The lowest till shows evidence of lodgement, the middle till contains glaciotectonic sedimentary structures, and the upper till is a primary basal till. Other exposures showing evidence for glaciotectonism are rare across the basin, and have been discussed previously. High proportions of silt and clay (commonly greater than 60%; Hicock and Dreimanis, 1992) are required to produce the necessary porewater pressures required to induce deformation. These high proportions of fines are rarely found in tills in the Humber River valley.

The diamicton exposed at Pynn's Brook is correlated with the upper Pasadena dump II till, and together these provide tentative evidence for a local readvance. Areas showing evidence of reactivation of an ice-margin are rare in the Humber River valley. Apart from those at Pynn's Brook and Pasadena dump, a diamicton near Birchy Lake in the upper Humber River valley (site 93088; Appendix A) shows 60 cm diamicton overlying a minimum of 15 cm sand-silt. The lower 5-10 cm of the diamicton contains rip-up intraclasts composed of sand-silt, derived from the underlying unit. This section is poorly exposed, but may represent evidence of local readvance.

Diamictons are generally either primary tills (ortho-till) or their derivatives (allo-till). Diamictons commonly have a silt sand matrix, and contain exotic clasts whose source in bedrock is found up-ice. Striated clasts are common.

Of the 249 diamicton exposures examined, over half (136) were small, with little vertical or lateral continuity from which genesis could be determined. There commonly was little between-site variability in grain-size

and clast provenance for closely spaced exposures. Clast provenance (i.e., erratics transported parallel to flow direction indicated by striae) or clast fabric (with a preferred orientation parallel to glacier flow) suggested glacial transport. Whether these diamictons were primary tills or their secondary derivatives (e.g., sediment gravity flow deposits) commonly could not be ascertained. The preservation of structures within diamictons is dependent on numerous factors, including local slope angle and aspect, sediment texture and water content, post-depositional weathering and modification by frost processes. It therefore is reasonable that diamictons showing features of primary glacial deposition should be juxtaposed with their secondary derivatives. It may therefore be assumed that diamictons, unless shown otherwise, were initially of glacial origin.

Single unit diamicton exposures were described from 136 locations throughout the study area. Of these, 32 exhibited well-oriented clast fabrics ($S_1$ > 0.6) (Sites 91014, 91050, 91176, 91177, 91225, 91227, 91233, 91236, 92007, 92020, 92021, 92056, 92058, 92097, 92163, 92171, 92191, 92193, 92197, 92206, 92218, 92222, 93028, 93035, 93045, 93067, 93077, 93080, 93087, 93101, 93127, 93128, and 93147; Appendix A). The sediments may indicate subglacial deposition. A further 23 exposures showed weak clast fabrics (Sites 91040, 91066, 91223, 91241, 92178, 92201, 92211, 92219, 93082, 93125, 93126, 93129, 93130, 93131, 93132, 93135, 93138, 93139, 93144, 93145, 93146, 93150, and 93151; Appendix A). The exposures may indicate secondary mobilization. Fabrics at the remaining 81 sites were not recorded.

# Chapter 4

# Deglacial and Postglacial Sediments and Stratigraphy

## Introduction

This chapter discusses sediments interpreted as deposited in proglacial and non-glacial environments. These are primarily subaqueous sediments deposited during deglaciation or in the early Holocene. Exposures of fine- and coarse-grained subaqueous deposits are found across the Humber River area, in existing or abandoned gravel pits, and along lake shores or in river cuts. Most are small, show little lateral continuity, and are scattered across the basin. This makes regional correlation difficult.

The Humber River basin contains 2 areas of continuous or near-continuous cover of subaqueous sediments, in the lower Humber River valley, and along the east shore of Grand Lake. In addition, valleys contain coarse-grained sand and gravel deposits that are commonly exposed in small borrow pits or roadside ditches. These exposures were discussed in Chapter 2.

The lower Humber River valley between the community of Deer Lake and the Humber River gorge has a thick cover of sand, silt and clay, reaching thicknesses of 100 m near Steady Brook. This area is generally at or below the marine limit of 50 m previously proposed for the area (Brookes, 1974). Exposures are poor, apart from at the head of Deer Lake, where sections at Rocky Brook and North Brook are described in detail (Figure 4-1). A small, fossil-bearing section in the Humber River gorge is also discussed. Adjacent to the modern coast, three exposures are described that provide the range of
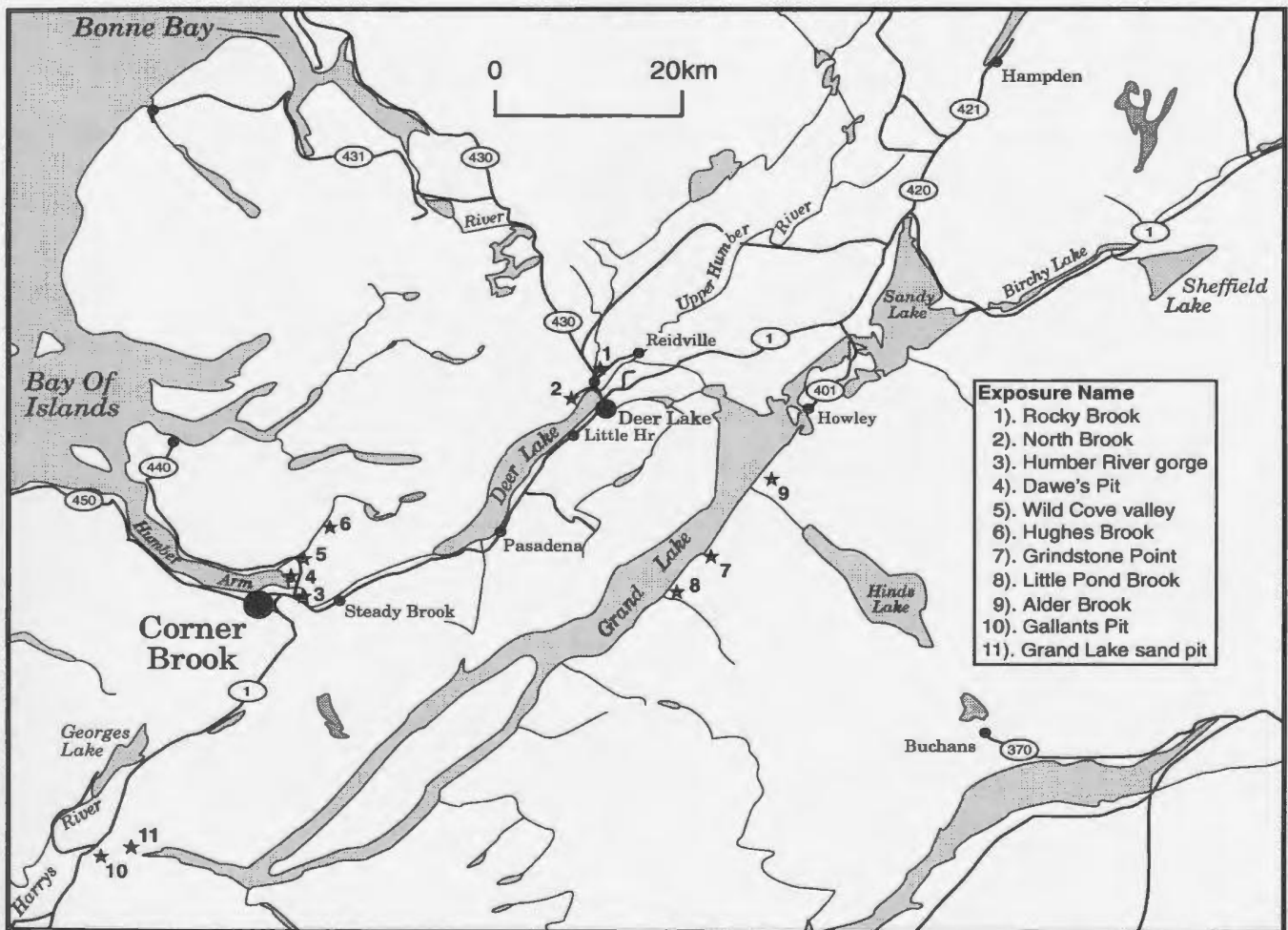
**Figure 4 - 1:** Location of exposures discussed in text.

depositional environments encountered. A section at Dawe's Pit is located near the mouth of the Humber River at the head of the Humber Arm. A series of small exposures along the south side of the Wild Cove valley, a parabolic valley 4 km north of the Humber River, shows sediment containing marine shells within fan-shaped features. In the Hughes Brook valley that enters the Humber Arm north of Wild Cove, a section in a gravel pit provides evidence for deltaic sedimentation.

A more-or-less continuous series of exposures are found for at least 20 km along the eastern shore of Grand Lake (Figure 4-1). They are well above the proposed marine limit. Most are obscured by slumping, although descriptions are presented from exposures near Grindstone Point, Little Pond Brook and Alder Brook.

The purpose of the following descriptions is to establish the depositional environments of sediments found. The interpretations may then be incorporated into discussions of the late-glacial history of the basin.


**Sections in the Deer Lake area**

### 1. Rocky Brook

This is a 19.5 m thick cut-bank river exposure (site 93034; Appendix A) in the side of a terrace (surface elevation 28 m asl), located 400 m downstream of the bridge on the Reidville road. A diamicton exposure located near the bridge was discussed in Chapter 3. The section is the site of active erosion by Rocky Brook (Plate 4-1), and has further been affected by bulldozing of material from the fields situated on the terrace surface.

**Plate 4-1:**
View of part of the Rocky Brook exposure. This section shows a tripartite stratigraphy of silt-clay at the base overlain by sand, and dipping beds of sand and gravel. The section is interpreted as showing prograding deltaic sediments. This delta was formed in a marine environment during postglacial marine inundation of the Deer Lake valley.

Description

The section is divided into 12 units (Figure 4-2). The bottom 2.0-2.5 m directly above the river is obscured.

Unit 1: laminated silt-clay rhythmites and clay

This basal unit extends 14 cm above the base of the exposed face. It shows rhythmically laminated silt, clayey silt and clay in a 3 couplet system. They are 0.3 to 0.5 cm thick, consisting of horizontally stratified grey silt grading upwards to reddish brown clayey silt. The silt layer is generally thicker than the clayey silt. They are commonly overlain by 0.8 to 1.2 cm clay, containing 2 to 5 silt laminae. These laminae are planar, horizontal, about 0.5 mm thick, with sharp upper and lower contacts. All laminae are laterally continuous for more than 2 m. A rhythmic sequence consisting of eight couplets was noted. Upper and lower contacts of individual rhythmites are sharp. Individual rhythmite beds showed no current structures.

The exception to the rhythmic bedding of the unit is a 1 mm-thick, structureless, roughly horizontal, silt lamina found 8 cm from the base that pinches and swells across the exposure.

Unit 2: Interbedded draped sand ripples and silt-clay

This unit is 11 cm thick, and is composed of flat-lying beds laterally continuous for greater than 2 m. The base of this unit is marked by the first occurrence of a ripple bed in the sequence. Ripple descriptions will be based on the terminology of Ashley (1975) in preference to those of Jopling and Walker (1968). This single bed contains asymmetric, erosional stoss (Ashley, 1975) ripples, with a wavelength ($\lambda$) of 15 cm, amplitude (H) of 1 cm, and

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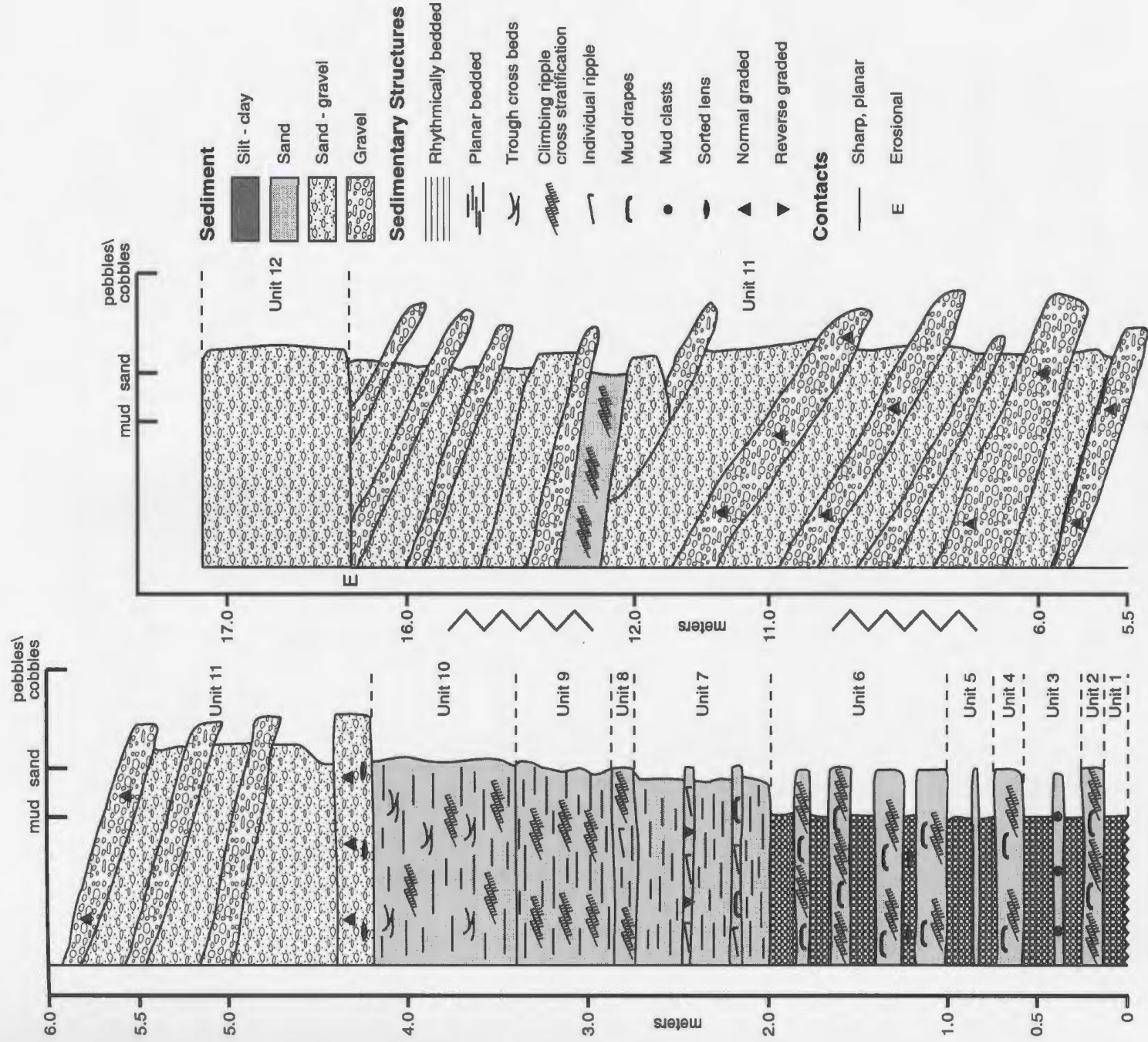
**Figure 4 - 2:** Stratigraphy of an exposure at Rocky Brook.

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ripple index (R.I.) of 15, composed of planar cross-stratified, very fine-sand. The ripples indicate flow towards 150°. The ripples are draped by 0.1 cm clay, over a sharp contact. Two other ripple beds are found within this unit, at 20 and 23 cm elevation above the base of the exposed section, the upper ripple bed marking the top of the unit. Both are similar to the lowest ripples in dimensions ($\lambda$=14 cm, H=1, R.I.=14; $\lambda$=13 cm, H=1.5, R.I.=9), and interpreted flow direction (150°). The lower ripples are draped by three silt-clayey silt-clay couplets, similar to those of Unit 1 described above. The higher ripples are draped by a 0.5 cm clay layer. Between the lowest and middle draped ripple beds are two normally graded beds of fine-sand to silt, 0.6 and 2.3 cm thick, separated by a sharp, horizontal contact. They are overlain by 1.5 cm normally graded fine- to very fine-sand, 0.2 cm clay, and 1.0 cm normally graded very fine-sand to silt. A 1.2 cm-thick, fine- to very fine-sand bed with 1 mm, discontinuous, planar, horizontal clay laminae separates the middle and upper draped ripple beds.

Unit 3: Interbedded silt-clay rhythmites and clay

This unit is 33 cm thick. The base of the unit is defined by a clay drape over the upper ripple bed in Unit 2. A 1 cm-thick, silt-clayey silt-clay couplet lies above a sharp contact. There is a gradational contact between silt and clayey silt, with the silt component is thicker than the clay. A sharp upper contact separates the clayey silt from an overlying 0.7 cm-thick clay stratum containing three 0.5 mm-thick silt layers each with sharp upper contacts. This is overlain by 1 cm-thick bed of well sorted, structureless fine sand, overlying a sharp contact. This is overlain by a rhythmically-bedded sequence of seven silt-clayey silt-clay couplets, with clayey silt thicker than silt in all cases,

overlain by a planar bedded, structureless fine sand-silt bed. This is overlain by two rhythmically beds composed of three and four silt-clayey silt-clay couplets separated by a 6 cm-thick, normally graded, fine to very fine sand bed that contains discontinuous clay rip-up intraclasts (Plate 4-2). The four couplet bed is overlain by structureless fine sand to silt, grading upwards into clay containing thin (<0.2 mm) planar silt laminae. The top of the unit is a 1.8 cm-thick rhythmite bed containing three silt-clay couplets, with silt approximately equal in thickness to clay.

Unit 4: Inter bedded draped sand ripples and sand-silt beds

This unit is 15 cm thick. The base is a 2.0 to 4.5 cm thick bed of rippled sand. They are asymmetric, erosional stoss ($\lambda$=15 cm, H=3, R.I.=5) planar cross-laminated, fine sand ripples, showing flow towards 150°. They are draped by 0.1 cm clay, 2.0 cm normally graded very fine-sand to silt, and 4.5 cm normally graded fine- to very fine-sand, all with sharp contacts. The draped strata are overlain by 4.5 cm fine- to very fine-sand, with a planar, horizontal upper contact, overlain by 1.5 cm silty clay containing three small (0.5 to 3 mm-thick) silt laminae with sharp upper and lower contacts. A second rippled sand bed occurs at 70 cm. These are asymmetric, erosional stoss ($\lambda$=12 cm, H=1.2, R.I.=10), planar cross-laminated, fine- to very fine-sand ripples, showing flow towards 150°. The ripples are draped by five 0.1 to 0.5 cm thick strata of alternating clay, and silt to very fine-sand, each with sharp contacts.

Unit 5: Rhythmically bedded silt-clay and interbedded sand

This unit is 24 cm thick. The base of the unit is a 2 cm-thick bed of rhythmically-stratified silt-clayey silt-clay couplets, similar to those described

**Plate 4-2:**
Rip-up intraclasts from unit 3 of the Rocky Brook exposure. These were formed by underflow currents in a subaqueous basin. Direction of flow on the photograph was left to right.

previously. This bed contains five couplets. Overlying a sharp, horizontal contact is 1.5 cm of planar, interbedded fine and very fine sand. This sequence is repeated in three overlying rhythmite and sand beds. Rhythmite beds are 2 to 3.8 cm thick and contain 5, 5 and 12 couplets respectively. The sand beds are 0.8 to 1.5 cm thick. The top of the unit is a 2 cm-thick rhythmite bed containing 4 silt-clay couplets. Unit 5 contains a total of 31 couplets.

Unit 6: Draped rippled sand and silt-clay rhythmites

This unit is 99 cm thick. At the base is a 12 cm bed of asymmetric, erosional stoss ripples ($\lambda$=13 cm, H=1.5 cm, R.I.=9), with fine-sand, planar, cross-laminae, indicating flow towards 150° (Plate 4-3). Individual ripples are draped by 0.5 cm to 5 cm silt-clay. The silt-clay is commonly rhythmically bedded, similar to that described in Unit 5 above. Four ripple sets are draped by silt-clay. A 10 cm-thick bed of planar bedded silt-clay rhythmites lies above the draped ripples, containing 20 couplets with silt approximately equal in thickness to clay. This bed also includes a biconvex lens (16 cm by 1.5 cm thick) of structureless fine sand. Overlying a sharp contact is 0.2 cm grey clay. The sequence of ripples draped by silt-clay is repeated four times through the unit, with the texture of the drape sediment coarsening upwards from clay to very fine sand. Similarly, the rhythmites coarsen upwards from silt-clay to very fine sand-silt. The rhythmites are found within seven beds, containing 6 to 36 couplets, similar to those described above. This unit contains a total of 129 couplets. Interbeds between the rhythmite beds or between ripple and rhythmite beds also coarsen upwards from clay near the base to fine sand at the top. These strata are up to 4 cm thick, although they are commonly much thinner (average 0.5 cm). Strata are ungraded to normally graded.
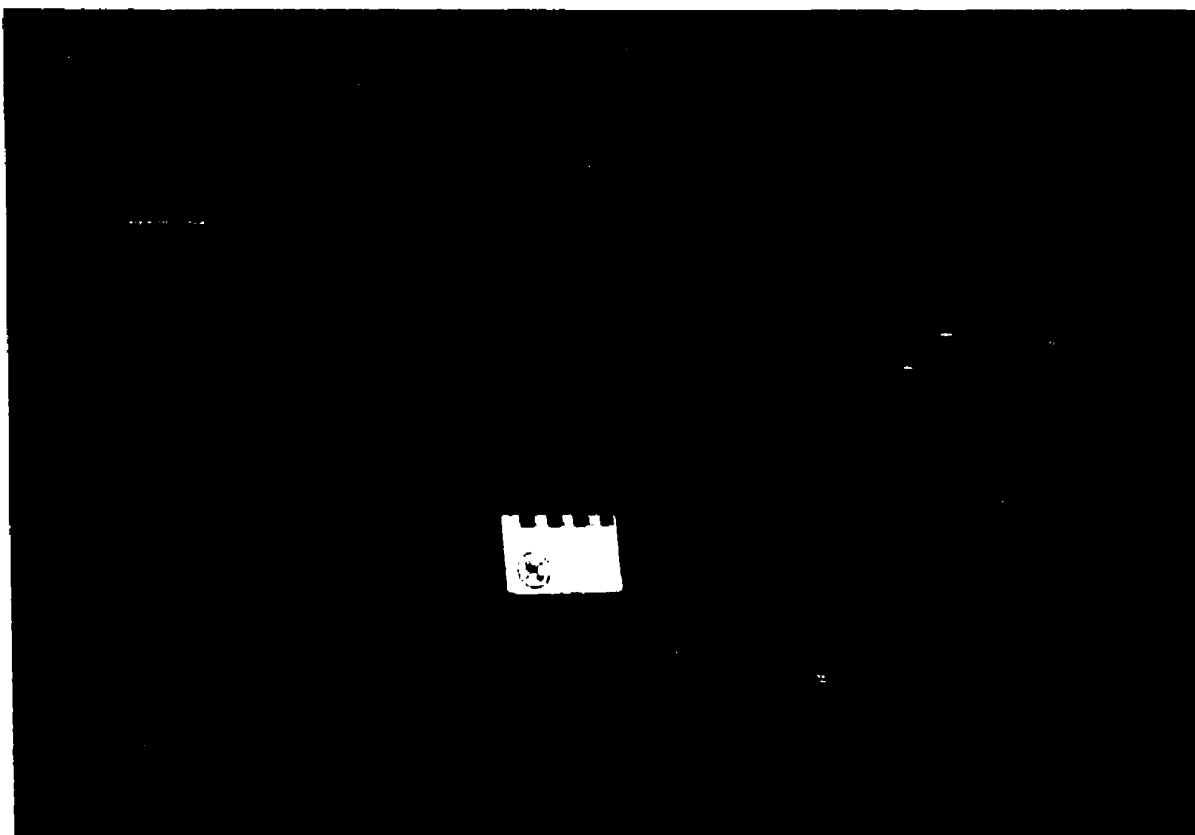
**Plate 4-3:**
Cross-stratified climbing ripples at the base of unit 6 in the Rocky Brook exposure. The ripples indicate flow towards 150° (right on photo). The ripples are underlain by rhythmically bedded silt-clay and interbedded sand (unit 5).

**Plate 4-3:**
Cross-stratified climbing ripples at the base of unit 6 in the Rocky Brook exposure. The ripples indicate flow towards 150° (right on photo). The ripples are underlain by rhythmically bedded silt-clay and interbedded sand (unit 5).

## Unit 8: Rippled sand and sand-silt graded beds

This unit is 11 cm thick, and contains 4 thin (0.5 to 1.3 cm) rippled sand strata. The ripples are all asymmetric ($\lambda$=4-11 cm, H=0.3-1.3 cm, R.I.=8-17), erosional stoss planar cross-laminated, fine-sand ripples indicating flow towards 180-190°. The rippled strata are separated by 1.2- to 3.5 cm-thick beds consisting of between five and seven normally graded, fine-sand to silt laminae, separated by sharp, horizontal contacts. In all cases, the sand thickness is approximately equal to the silt. Contacts between ripple beds and normally graded sand-silt are sharp, and undulating. This unit contains 17 graded beds.

## Unit 9: Planar bedded sand to silt

This unit is 56 cm thick. It consists of 91 beds and laminae of normally graded sand and silt. Each stratum contains ~ 1% coarse sand distributed randomly. In examples observed, the silt component was thicker than the sand. Towards the top of the unit, the sand-silt rhythmites are interbedded with planar horizontal, normally graded 0.2 to 0.4 cm-thick fine sand containing minor coarse-sand laminae, with sharp upper and lower contacts.

A single, 0.6 cm-thick interbed of rippled sand bed occurs at 303 cm elevation. It contains asymmetric ($\lambda$=9 cm, H=0.6 cm, R.I.=15), erosional stoss ripples composed of normally graded fine-sand. Ripple dimensions vary laterally. A pebble (1 cm diameter) is found within a coarse-sand - granule and fine-sand bed at 310 cm. The clast lies on a sharp, horizontal contact, but is draped by a thin (1 mm), silt bed.

Unit 10: Rippled sand

This unit is 81 cm thick. The base of the unit is a 17 cm-thick bed of asymmetric, sinuous out of phase, planar cross laminated, fine- to medium-sand, erosional stoss ripples. These are relatively large ripples ($\lambda$=25 cm, H=3 cm, R.I.=8), and are draped by 0.2 to 0.4 cm-thick beds of fine-sand. The ripples show flow towards 190°. The ripple sequence is truncated along a sharp, horizontal surface by a 3 cm-thick, planar, medium- to fine-sand bed, containing fine sand partings, overlain by a 28 cm-thick bed of trough cross-bedded and rippled sand. The ripples are erosional stoss, out of phase, asymmetric ($\lambda$=8 cm, H=1 cm, R.I.=8), moderately- to well-sorted, fine- to medium-sand, showing flow towards 190°. Planar tabular cross-beds occur within a loose, well-sorted fine-sand bed and indicate flow towards about 200° (Plate 4-4). The cross beds are overlain by well defined 9-15 cm-thick rippled sand, with sharp lower contacts. Ripple beds are separated by normally graded, sand to pebbly sand beds 3 - 15 cm thick. Individual beds within this unit dip about 9° towards 087°.


Unit 11: Interbedded gravel and sandy gravel

This unit is 1215 cm thick, and is composed mostly of loose gravel on steeply dipping surfaces. The base of the unit is a 17 cm-thick, normally graded, gravelly sand, with a fine- to medium-sand matrix. Coarse sand lenses occur beneath granule to cobble clasts of mixed rock types, up to 5 cm diameter. Many of the clasts are dip at 5-10° towards 065°. This bed grades upwards to 7 cm medium to fine interbedded sand.

The bottom 350 cm and the upper 400 cm of this unit are sand-dominated. The middle part of the unit is gravelly sand, sandy gravel, and

**Plate 4-4:**
Trough cross beds and climbing ripples within a cohesionless, well-sorted fine-sand bed (unit 10). The structures indicate flow towards 190° (left to right on photograph).

gravel beds. Gravelly sand beds are 15 to 43 cm-thick, normally graded and matrix supported. Sandy gravel beds are 26 to 38 cm-thick, commonly normally graded to ungraded, clast-supported with a medium- to coarse-sand matrix. They also contain interbeds of open-work granule gravel to pebble gravel. Much of the unit is dominated by 13 to 59 cm thick beds of granule-pebble to pebble-cobble gravel. These beds are clast-supported, commonly with an open-work structure, and contain less than 10% sand matrix. Planar interbeds of sandy gravel are common. Clasts are of mixed rock types. They are dominated by locally derived sandstone and siltstone, and but also include granite, gabbro and volcanic clasts. Clasts commonly dip parallel to the bedding.

Towards the base of the unit (416-672 cm above section base), beds dip about 24° (range 15° to 28°) towards 070° (range 060° to 080°). Above 672 cm from the section base, beds are more steeply dipping (mean 28.5°, range 20° to 36°) towards about 118° (range 105° to 130°).

Towards the top of the unit, the regular pattern of dipping beds is truncated by a trough-shaped bed with a lateral extent of about 90 cm. It contains normally graded, trough cross-stratified, gravelly sand and interbedded sand. This bed is truncated above a sharp, undulating contact by a well-sorted bed of cross bedded and rippled sand. These are out of phase, asymmetric ($\lambda$=10 cm, H=2 cm, R.I.=5), cross-laminated, fine-sand ripples. The ripples indicate flow towards about 150°. The sand bed is inclined about 20° towards 108°. The sand bed is overlain by interbedded gravelly sand and open-work gravel, with individual beds 8 to 20 cm thick, all dipping about 26° towards 120°.

Unit 12: Planar bedded sandy gravel

This unit is 80 cm thick, and is mostly within the zone of pedogenic modification. It truncates underlying beds over a sharp, horizontal contact, and consists of a sandy gravel, with a sand matrix, and gravel to cobble clasts of mixed rock types. Clasts are commonly subrounded, and either imbricate toward about 300° (i.e., dipping up the modern stream), or are flat-lying.

Interpretation

Unit 1: Interbedded silt-clay rhythmites and clay

This unit was deposited within standing water. The silt-clay couplets may either represent cyclical seasonal deposition (i.e., varves) or may have been deposited rapidly by underflow and overflow-interflow, with no temporal implication.

Varves have an annual rhythmicity. Silt is deposited in the summer through surge and underflow currents, and clay is deposited in the winter by suspension settling (Sauramo, 1923; Saarnisto et al., 1977; Ashley, 1988). The contact between the silt and overlying clay is therefore likely to be sharp (Sturm, 1979; Ashley, 1988), and the silt layers commonly contain clay beds and vice versa, as the result of depositional hiatuses. Biogenic structures (lebenspurren) and organics are also common within varves (Brunskill, 1969; Saarnisto, 1979; Ashley et al., 1985). Other causes of rhythmic sediments involve rapid deposition. These include slump-generated rhythmites deposited by surge currents triggered by episodic slumps and debris flow at the basin margin, stream discharge variations at the basin margins, and daily weather changes (Ashley et al., 1985). Sediment transported to a given site by surge current is likely to produce rhythmites with silt and clay layers of

proportionally similar thickness (Ashley, 1988). Sediments are similar in character to Bouma-model turbidity deposits (Bouma, 1962).

The silt-clay beds found in the Rocky Brook section are normally graded, with rare clay-silt interbeds, and no lebenspurren are found on any couplet. The couplets thus likely represent deposition from a combination of current flow and suspension settling. Descriptions of similar sediments have been well described from modern lacustrine (e.g., Gilbert, 1975, Gilbert and Shaw, 1981; Ashley, 1988), and marine (e.g., Miall, 1983; Mackiewicz *et al.*, 1984; Powell, 1990) environments have been applied to the interpretation of ancient fine-grained sediments (e.g., Ashley, 1975; Catto *et al.*, 1981; Catto, 1987; Liverman, 1991). Deposition by suspension settling is suggested by the lack of current flow structures, and the graded bedding. Within individual beds, the relative proportion of silt and clay is similar, suggesting sediment was transported to the site by at the same time, likely by turbidity currents (Ashley *et al.*, 1985). The overlying clay beds are interpreted to be deposited by suspension settling from overflow or interflow, except for the interbedded thin silts which likely result from underflows. Gravenor and Coyle (1985), and Shaw and Archer (1978) reported similar structures. The sharp lower contacts show depositional hiatuses and/or erosion.


Unit 2: Interbedded draped sand ripples and silt-clay

Erosional stoss ripples indicate unidirectional flow (in this case towards 150°), where ripple migration dominates over deposition (Jopling and Walker, 1968; Ashley, 1975). Draped laminations are formed from deposition by suspension settling as current flow wanes or ceases (Allen, 1984). This association of ripples and draped laminations is interpreted as the result of

density underflow deposits (c.f., Jopling and Walker, 1968; Ashley, 1972; Gustavson *et al.*, 1975; Shaw, 1975; Clemmensen and Houmark-Nielsen, 1981; Allen, 1993). Experiments have demonstrated that this sequence can develop rapidly (Ashley *et al.*, 1982). The overlying clay bed is ungraded, and may also aggrade rapidly as clay particles bond with free carbon ions to form sesquioxides (Chase, 1979). Planar beds are interpreted as having been deposited from underflow-interflows, as in Unit 1.

## Unit 3: Interbedded silt-clay rhythmites and clay

The silt-clayey silt-clay rhythmites were deposited in standing water by underflow either with or without overflow-interflow (similar to Unit 1). The discontinuous clay bed at the base of the unit and the clay intraclasts suggest erosion by the flow that deposited the sand bed. The intraclasts are interpreted as rip-up clasts, based on their shape and their random distribution within the bed. They were eroded and deposited by a turbidity current (Conybeare and Crook, 1968; Walker, 1992).

## Unit 4: Interbedded draped sand ripples and sand-silt

The ripples were likely thus deposited by turbid underflow current, in a manner similar to those in Unit 2. The overlying draped sequences were deposited by suspension settling during waning current flow or following flow cessation.

## Unit 5: Rhythmically bedded silt-clay and interbedded sand

This unit is similar to Unit 1 and Unit 3, and is also interpreted as having been deposited within standing water by suspension settling.

Individual rhythmites represent separate surge events. Interbedded sand laminae are deposited by underflow.

Unit 6: Draped rippled sand and silt-clay rhythmites

The thickness of ripple strata is greater in this unit compared to those below. However, they are interpreted in a manner similar to those in Unit 2 and Unit 4, being formed by turbidity currents. The larger ripple size is a function of increased current velocity. The ripples are commonly draped by silt-clay, deposited by suspension settling as current flow dropped.

Unit 7: Planar bedded sand and silt

This unit is interpreted in a manner similar to Unit 1, 3 and 5. The relative absence of clay and the relative increase in fine-sand within the couplets suggests this unit was deposited closer to the sediment source than the underlying units. The asymmetric, erosional stoss ripples indicate unidirectional flow (in this case toward 180°), where ripple migration dominates over deposition (Jopling and Walker, 1968; Ashley, 1975). The ripples were deposited by density underflow currents.

This unit contains small proportions of medium to coarse sand, especially within silt layers. The sand is randomly distributed, suggesting it may be unrelated to current flow. The origin of the sand could be an overflow from an injection of sediment above the thermocline, or as a high density turbidity current in a manner similar to that described by Lowe (1982). Alternatively, the sand could originate as windblown sand onto seasonal ice. Given the depositional environment within a recently deglaciated setting, and the presence of a near-continuous ice cover on modern Deer Lake during

the winter, the latter is considered most likely.

Unit 8: Rippled sand and sand-silt graded beds

These sediments are similar to those described in Units 2, 4 and 6 and are interpreted in a similar manner. The rippled beds and rhythmites are composed of coarser sediment than those found in the lower beds and this unit is therefore likely more proximal to the sediment supply than the lower ones.

Unit 9: Planar bedded sand to silt

The graded sand to silt beds are interpreted to have been deposited by suspension settling from underflow with or without overflow-interflow, in a manner similar to that described for Unit 7. The unit is clay-poor, suggesting either that inflowing sediment lacked a clay component, or that the sediment was deposited relatively close to the source and the clay component has been carried by suspension into more distal parts of the basin. The preferred interpretation is the latter, given the presence of clay-rich units within the section. Randomly distributed coarse sand is interpreted as rain-out of windblown sand from seasonal ice.

The pebble clast draped by silt is interpreted as a drop stone, deposited from floating ice in a manner similar to that described by Thomas and Connell (1985). Support for this interpretation is the coarse sand component found within the unit. The clast may have rolled onto seasonal ice and subsequently dropped through the water column. Alternatively, the clast may have been rafted on glacier ice. No other clasts or carapace structures were noted within the finer grained components of the section, and no sediments

interpreted as having been deposited in an ice-proximal environment were exposed within the section that would add support to the latter interpretation.

Unit 10: Rippled sand

The erosional stoss ripples show current flow. Grain size indicates that flow velocities are in the order of 20 to 80 cm sec$^{-1}$ (Harms *et al.*, 1982). The silt to fine sand drapes indicate deposition by suspension settling produced as current flow waned.

Planar sand beds are interpreted as upper-flow plane beds. The alternative interpretation of deposition under lower-flow conditions is considered unlikely because of the erosional contact, and the presence of fine sand partings, the result of grain sorting in the bedload (Kuenen and Migliorini, 1950; Moss, 1963; Kuenen, 1966a, 1966b). The grain size (medium sand) suggests flow velocities of 100 to 200 cm sec$^{-1}$ (Harms *et al.*, 1982).

The erosional stoss ripples, draped-lamination, and upper-flow plane beds show Unit 10 was deposited under a variable flow regime.

Unit 11: Interbedded gravel and sandy gravel

This unit is interpreted as foreset beds deposited within a delta produced by stream inflow into a basin. Fining upward sandy gravel and gravel beds are interpreted to have been produced during periods of sedimentation from either high discharge events or changes in the location of distributary channels on the delta surface (Ashley *et al.*, 1985). Individual beds dip at about 24-36°, the latter close to the angle of repose for gravel. These high angles indicate gravity-driven transport and deposition. The range of bed orientations from about 070° toward the base to 118° toward the top reflects

changing locations of delta front channels. Clast long-axis is commonly parallel to dip-direction of the depositional slope. This is produced by grain avalanching and has been observed and modeled in cross-bedded gravel (e.g., Wadell, 1936; Johansson, 1963; Allen, 1984; Ashley et al., 1985).

The trough-shaped bed containing trough cross-stratified sand is interpreted as a channel scour formed by a distributary channel on the delta surface. The asymmetric ripples overlying the channel are depositional stoss or stoss preserved (Ashley et al., 1982). They are slightly asymptotic climbing-ripples with an angle of climb of about 55°. They show unidirectional flow towards about 150°, under low-flow velocities ($< 40$ cm sec$^{-1}$) (Harms et al., 1982), where suspension sedimentation dominates over ripple migration rates. This interpretation is compatible with formation within a deltaic environment.


Unit 12: Planar bedded sandy gravel

This unit is poorly exposed and is mostly within the soil profile. The coarse texture, moderate-sorting, subrounded clasts commonly imbricate towards ~320° (i.e., parallel with the modern river) or flat-lying suggests this is a fluvial deposit.


Section summary

The section at Rocky Brook exposes a variety of sediments deposited within a sub-aqueous environment. The compact diamicton found 400 m upstream of the section was not exposed here. Rhythmically bedded silt-clay and sand-silt in the lower part of the unit show sedimentation within a basin in an environment distal from sediment supply. The Rocky Brook section

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contains over 300 silt-clay to sand-silt couplets. The couplets generally coarsen and thicken upwards, reflecting increasing sedimentation rates and proximity to sediment supply (c.f., the work of Gilbert (1975), Smith (1978), and Smith *et al.* (1982) in modern environments). The couplets show characteristics of rapid deposition rather than those of seasonally controlled varves. Thus they do not provide a reliable measure of the length of time taken to deposit the delta at Rocky Brook. Interbeds of rippled sand are from periodic surge currents. The upper part of the section shows deposition within a delta, proximal to stream input. This is a 'Gilbert-type' delta (Gilbert, 1890; Leeder, 1982; Miall, 1984; Ashley *et al.*, 1985; Edwards, 1986) characteristic of sediment-laden streams entering fresh or brackish water (Miall, 1984). The general upward coarsening of sediment suggests that this delta was prograding.

The ripples were produced by turbidity currents. The drapes and rhythmic bedding were deposited by suspension settling under slack water conditions. Some beds were structureless and poorly-sorted. Others show better sorting and normal-grading. Variable flow regimes are common in the mid-delta to lower delta areas (Ashley *et al.*, 1985).

The palaeo-geography of the Rocky Brook area shows the proposed delta formed at the head of a fjord, encompassing modern Deer Lake. The surface elevation shows water levels were at least 29 m above present. It is not an ice-proximal delta. This is suggested by the lack of diamicton interbeds from either sediment gravity flows or iceberg dumping, and the absence of load structures (c.f., Gustavson *et al.*, 1975; Eyles *et al.*, 1987; Ashley, 1988). Seasonal ice deposited rare dropstones. The delta was probably ice-distal, formed by water flowing from the north-northwest (i.e., similar to the flow direction of modern Rocky Brook), with headwaters in the Long Range

Mountains west of Adies Pond.

## 2. North Brook

This is a natural cut bank exposure 300 m upstream from the mouth of North Brook, where it enters Deer Lake (site 93157; Appendix A). The section has a surface elevation of about 20 m asl. North Brook flows south in a channel incised through a generally flat surface that gently slopes towards Deer Lake. The source of the brook is in a small basin in the eastern foothills of the Long Range Mountains west of Deer Lake. The North Brook section consists of about 635 cm of Quaternary sediment overlying bedrock, with a stratigraphy of 91 cm gravelly sand, overlain by 109 cm rippled and cross bedded sand, 315 cm rhythmically bedded silt-clay with sand interbeds, and 120 cm pebbly sand (Figure 4-3).

Description

Unit 1: Gravelly sand

This unit is 91 cm thick. It overlies grey to green siltstone and mudstone of the Rocky Brook Formation (Hyde, 1982), that extends about 6 m above the level of North Brook. The gravelly sand is generally structureless, dark brown (7.5YR 3/4, moist) to brown (7.5YR 5/2, dry), poorly-sorted (s.d. 1.4ø) with a mean grain size of -0.7ø. Silt and clay forms less than 2%, mostly found on the upper surfaces of clasts. Clasts are subrounded to subangular granules to boulders, and are mostly sandstone and mudstone. Clasts appear randomly distributed throughout the unit, with no obvious clast fabric. Local clast-supported zones containing open-work granule gravel are common beneath clasts.
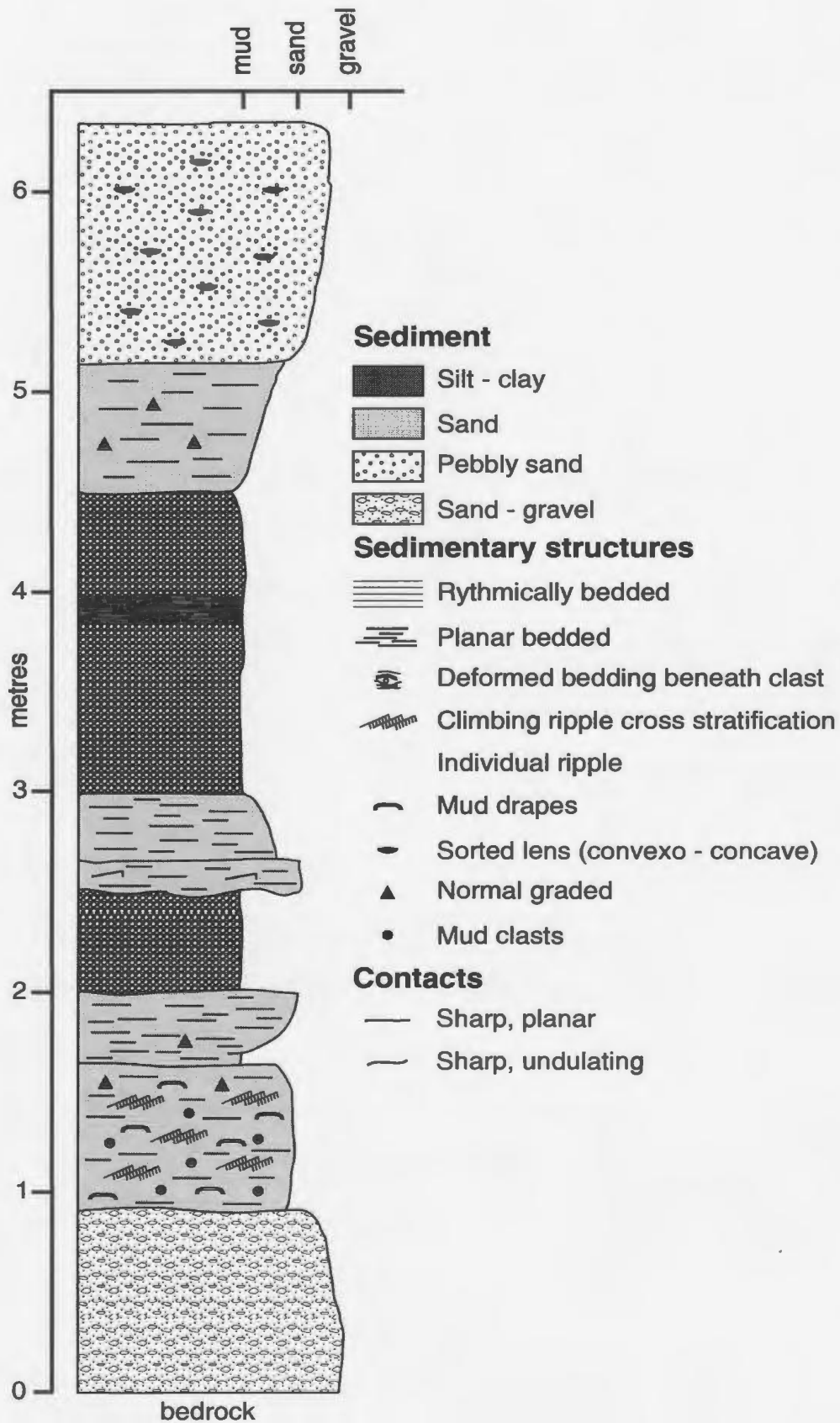
**Figure 4 - 3:** Stratigraphy of an exposure at North Brook.

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Unit 2: Rippled and cross bedded sand

This unit is 109 cm thick. The base of the unit is marked by a sharp, planar contact overlain by 54 cm of rippled and cross-bedded sand. The ripples are erosional stoss, climbing ripples (angle of climb ~5°). Ripples are out of phase, asymmetric ($\lambda$=13 cm, H=2 cm, R.I.=6.5), and formed in moderately to well-sorted fine sand, showing flow towards 150°. Coarse-sand to granule laminae, commonly 1-3 grains thick, are found along the bounding surfaces. Small (< 0.5 cm diameter), rounded to subrounded silt intraclasts are found randomly distributed through the ripple beds. Some ripples are draped by a thin (<1 mm), very fine-sand layer, although most show no draping.

Ripples draped by 0.1-0.3 cm moderately to well-sorted, normally graded, medium-sand laminae, thicker in the ripple troughs and thinner over the crests. This bed grades up into a 1 cm-thick bed containing four normally graded fine-sand to very fine-sand laminae, with sharp, planar contacts. The rhythmites are overlain along a sharp, planar contact by a 38 cm-thick bed of horizontally laminated fine-sand. Small (<1 cm), subrounded to rounded, randomly distributed, silty clay intraclasts occur in the lower 13 cm of this bed. This bed is overlain along a sharp, undulating contact by 2 cm bed of planar tabular cross-bedded, fine- to medium-sand indicating flow towards 140°.

The top of the unit consists of 16 cm planar-bedded sand. Individual strata are moderately to well-sorted, normally graded, 0.2 to 2.5 cm-thick with sharp, horizontal upper contacts. Rare clay intraclasts (<1 cm diameter) are found within the coarser sand beds, but not in the finer ones.

This unit generally fines upwards from medium-to fine-sand at the base to fine-sand to silt at the top. Individual beds are ungraded to normally graded, and show flow structures indicating flow towards 140°-150°.

Unit 3: Rhythmically bedded silt, clay and sand

This unit is 315 cm thick. It is dominated by a repetitive sequence of laminated sand-silt-silty clay-clay beds.

The lower 100 cm of the unit is a fining upward sequence of rhythmically bedded fine- to very fine-sand, and silt couplets. Individual couplets are defined by normally graded sand laminae, 0.1 to 1.0 cm thick, overlain by silty sand to silt across sharp planar contacts. This lower unit contains a total of 68 couplets. The rhythmic bedding is interrupted by 12 ungraded to normally graded, 0.2 to 3.7 cm thick, moderately- to well-sorted, fine- to medium-sand (mean 1.3ø) strata. These beds have sharp, planar to undulating contacts. Rare sand beds contain small (<1 cm diameter), randomly distributed, slightly elongate clay intraclasts with no preferred orientation.

The middle part of the exposure, between 301 and 451 cm above the base of the section, contains rhythmically bedded silt-silty clay-clay couplets (average 32% silt and 68% clay). Individual couplets comprise normally graded silt to silty clay (0.1 to 1.2 cm thick), overlain by clay (0.1 to 1.5 cm thick) across a sharp, planar contact. Clay is commonly thicker than silt. Couplet thickness decreases from about 1 cm at the base to 0.3 cm towards the top. This part of the exposure contains a total of 237 couplets.

Above the silt-silty clay rhythmites is 49 cm of laminated silty sand-silt and medium sand. The silty sand-silt laminae are about 1 cm thick, normally graded with silt thicker than silty sand. A total of 38 rhythmites were counted. The rhythmic bedding is interrupted by six 0.4 to 3.0 cm thick, ungraded to normally graded sand (mean ~1.3ø) beds overlying silty sand-silt rhythmites across sharp, planar contacts.

There are two exceptions to the sequence of rhythmic bedding and sand beds. The first is a 16 cm-thick bed of rippled and planar-tabular cross-bedded sand, exposed 253 cm above the base of the section. Ripples were typically out of phase, erosional stoss, asymmetric ($\lambda$=10 cm, H=1 cm, R.I.=10) indicating flow towards about 240°. The ripples are commonly draped by very fine-sand to silt. The second exception is deformation of silt-clay beds beneath a pebble located at 397 cm from the exposure base. The pebble deforms 2 couplets (~1 cm thick) and two couplets are draped over the pebble surface.

Unit 4: Pebbly sand

This unit is about 120 cm thick, of which 80 cm has been modified by pedogenesis. The unit is a loose, matrix-supported, pebble gravel. Matrix is dark reddish brown (5YR 3/3, moist) to light reddish brown (5YR 6/4, dry), medium- to coarse-sand (silt-clay less than 1%). Clasts are subrounded to rounded granules to pebbles (up to 6 cm diameter). Clast rock types are mixed and contain granite, porphyry, sandstone, and conglomerate. The unit is generally structureless, except for coarse sand lenses and rare open-work granule gravel lenses beneath clasts.

Interpretation

Unit 1: Gravelly sand.

This is a matrix-supported, polymodal, unstratified, ungraded sediment with an unordered clast fabric. It shows no horizontal bedding, clast imbrication or cross-bedding that may suggest a fluvial or glaciofluvial origin. Clasts are not striated and no percussion marks were noted. The unit is interpreted as a sediment gravity flow deposit (Middleton and Hampton, 1973;

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Lowe, 1982; Middleton, 1993), either a slurry flow or hyperconcentrated flow. Similar deposits occur in a range of environments, including alluvial (e.g., Miall, 1977, 1978; Rust, 1978; Rust and Koster, 1984), glacial (e.g., Eyles *et al.*, 1983b, 1988; Goldthwait and Matsch, 1988), glaciomarine (e.g., Powell and Molnia, 1989; Lønne, 1995) and glaciolacustrine (e.g., Rust, 1977; Eyles *et al.*, 1987; Ashley, 1988). Further interpretation is difficult due to poor lateral exposure of the unit.

## Unit 2: Rippled and cross-bedded sand

The ripples indicate unidirectional current flow, where migration rates exceeded deposition. Current flow was discontinuous, as suggested by draping of very fine sand to silt, deposited by suspension settling. Some draped beds are normally graded or show rhythmic bedding. This unit is interpreted as a density underflow deposit. Draped-laminations over fine-sand current ripples have been reported by many authors (e.g., Jopling and Walker, 1968; Ashley, 1972; Gustavson *et al.*, 1975; Shaw, 1975; Clemmensen and Houmark-Nielsen, 1981). The most common environment where this association occurs is mid-delta (Ashley *et al.*, 1985), under flow velocities less than about 60 cm sec$^{-1}$ (Harms *et al.*, 1982).

## Unit 3: Rhythmically bedded silt, clay and sand

This unit was largely deposited by suspension settling in standing water. The high clay content (~68%) suggests at least 2 months for settling to occur (e.g., Ashley *et al.*, 1985), although chemical flocculation (e.g., Chase, 1979) or biogenic pellitization (e.g., Smith and Syvitski, 1982) provide mechanisms to increase clay settling rates by up to two orders of magnitude.

Individual couplets are normally graded, and the similar relative proportions of clay and silt within individual couplets suggest sediment was introduced by turbid underflow currents (with or without overflow-interflow). The couplets show characteristics of rapid deposition, similar to those at Rocky Brook, rather than those of seasonally controlled varves. The rhythmites thin upwards from 1 cm to 0.3 cm, indicating either decreasing sediment input, increasing frequency of turbidity current events and/or increasing proximity to sediment input. Coarsening upwards suggests increasing proximity to sediment supply.

Indicators of current flow are rare, confined to several thin beds, where ripples indicate unidirectional flow towards about 240°. Contacts with underlying beds are sharp. These sand beds are interpreted as having been deposited by underflow currents. Sayles (1919), Caldenius (1932), Agterberg and Banerjee (1969), Shaw *et al.* (1978), and Shaw and Archer (1978) described similar deposits within rhythmically bedded silt and clay, and variously interpreted as turbidity currents generated by either cyclonic activity (Sayles, 1919), catastrophic drainage of glacial lakes (Caldenius, 1932) or failure of an adjacent delta front (Shaw *et al.*, 1978). Given the location of the exposure on a basin margin, adjacent to palaeo-deltas, the latter is the preferred interpretation. Failure at the basin margin is common in proglacial subaqueous environments (Ashley, 1988).

Some of the silt beds include small clay intraclasts. These are interpreted as rip-up clasts derived from underlying beds, deposited by turbid underflow currents, similar to features described by Shaw (1977) and Shaw *et al.* (1978) from lakes in British Columbia.

The pebble clast embedded within the silt-clay rhythmites is interpreted

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as a dropstone. The bending of stratum beneath and above the clast are formed by release of a clast from floating ice (Thomas and Connell, 1985).

Unit 4: Pebbly sand

This unit is poorly exposed. The general absence of silt and clay, and the crude stratification suggests deposition by current flow. The gently inclined surface slope towards modern Deer Lake suggests it is part of a graded fluvial system.

### Section Summary

The lowest sandy gravel unit may be interpreted as a hyperconcentrated gravity flow deposit, although whether from within a glaciofluvial, glaciomarine or glacial depositional environment is not clear. The lack of striated clasts does not support, or reject, a glacial hypothesis, although the overlying rippled sand beds makes a glacial origin unlikely. The sand, overlying silt and clay, and the topmost pebbly sand may be found in a marine or lacustrine environment that deepened and subsequently shallowed. This is supported by the gradual fining of sediment within Unit 3 from fine sand at the base to silt-clay in the middle part of the unit, which reflects gradual deepening of the water. Turbidity current activity is indicated by rippled beds and clay rip-ups. Bed inclination shows a source to the east or northeast, consistent with the orientation of ripples, and flow down the modern Humber River valley. Thickness of silt-clay couplets reaches a maximum in the middle of Unit 3, above which couplets thin and become increasingly coarse. This shows deposition within a shallowing water body. The unit is capped by a fluvial deposit.

General discussion

Apart from the delta described at Rocky Brook, deltas have also been identified at Nicholsville (surface elevation 48 m asl), near Little Harbour (44 m asl), and at near Junction Brook (45 m asl). Each expose steeply dipping interbedded sand and gravel, interpreted as foreset beds. Deltas are graded to fluvial systems upstream, and are likely not ice-proximal. Fine grained sediments are found at the base of the Rocky Brook and Nicholsville deltas, and on the flanks of the Junction Brook delta. These were deposited remote from the basin margins on the basin floor. The sediments exposed at North Brook, showing similar characteristics to those in the lower part of the Rocky Brook section, were deposited in similar environments. Similar fine-grained muds are found north along the modern Humber River to Harrimans Steady (20 m asl). Water level thus was at least 45 m modern elevation at the time of formation of the deltas. Figure 4-4 provides an interpretive sketch of the head of Deer Lake during the time of delta formation.

Coarsening-upwards sequences show increasing proximity to source. Rapid isostatic rebound of the coast in the early Holocene and the consequent fall in relative sea level (see Chapter 6 for further discussion) is the preferred explanation. The fall of sea level below the top of the delta resulted in fluvial sedimentation (topset beds), with flow directions similar to those of modern streams. Continued sea level fall led to grading of fluvial systems and incision of the delta at this site. The lack of deltaic deposits adjacent to the modern Humber River suggests reworking of deltas in this area, down to the muds.
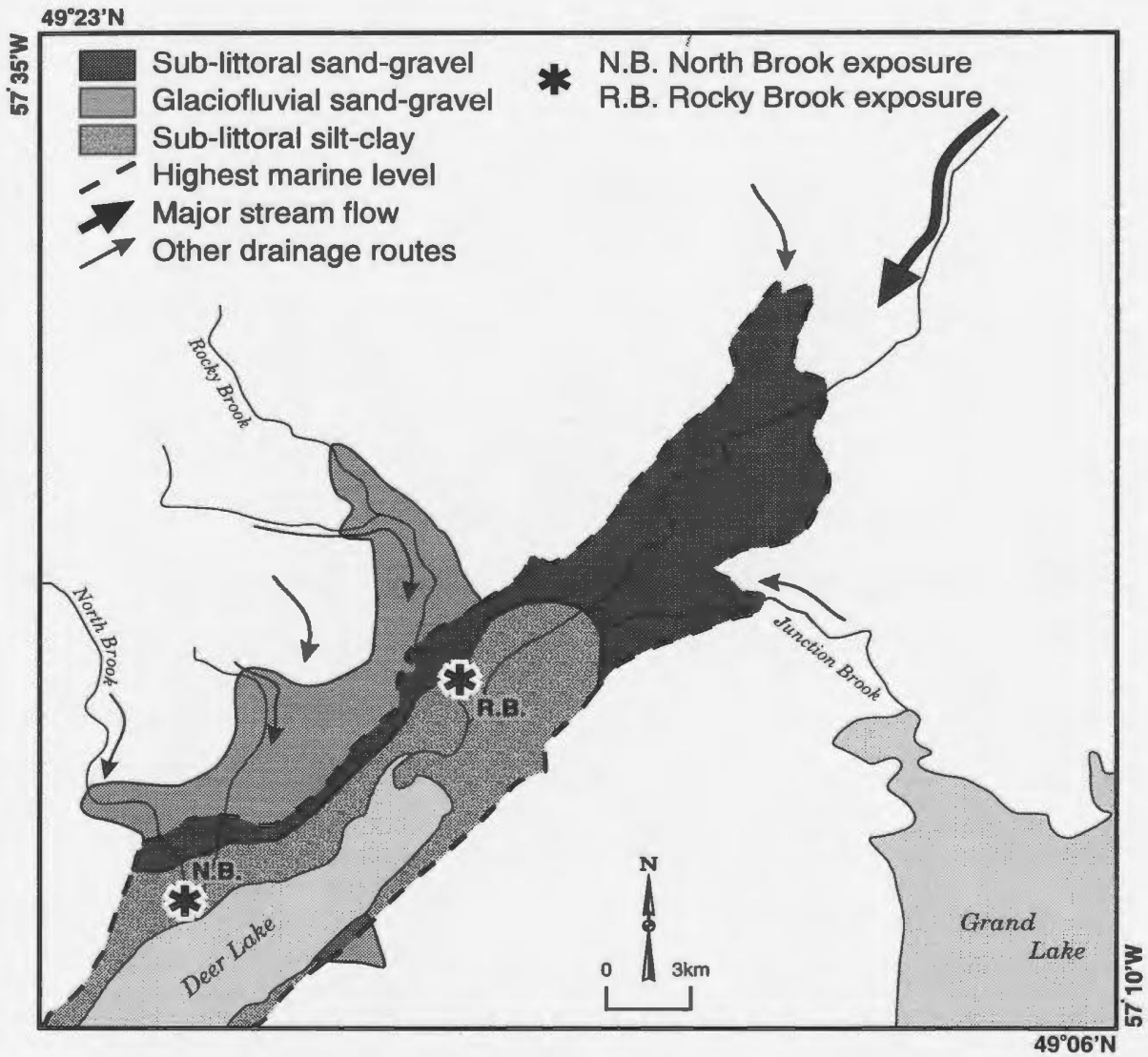
**Figure 4 - 4:** The palaeogeography of the northern part of the Deer Lake valley during deglaciation (circa 12.5 ka).

**Sections at the head of Humber Arm**

### 1. Humber River gorge

This is a small exposure excavated during highway reconstruction on the west side of the Humber River gorge in 1991 (site 91138; Appendix A). The site is within a north-south oriented fissure into limestone of the Reluctant Head Formation (Williams and Cawood, 1989), along a water-eroded west-east trending valley sidewall.

Description

Diamicton is smeared against the valley sidewall, and is up to 2 m thick. The matrix is a reddish brown (5YR 4/3, moist), matrix-supported (60% matrix), clayey silt. Soft-sediment deformation structures including regular folding, and disrupted and faulted (?) bedding are common, and matrix contains numerous marine shell fragments. These are mostly *Balanus hameri* (with plates up to 7 cm long), with a few whole *Hiatella arctica* shells. *Balanus hameri* shell fragments were submitted for radiocarbon dating. Clasts are angular carbonate fragments, granule to cobble size, with the largest clast 40 cm in diameter. Larger clast sizes are common, and are scattered throughout the unit.

Interpretation

The fine grained matrix containing marine macro-fossils is interpreted as having been deposited in the sea. *Balanus hameri* has ecological preferences of deep water (20 to 300 m), salinity in excess of 33‰, and mean annual sea surface temperatures of 3 - 15° C (Pilsbury, 1916; Nilsson-Cantell, 1978; Dyke *et al.*, 1996). The preferred salinity is similar to the modern values

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in the Humber Arm (Shaw *et al.*, 1995). The reddish brown colour is likely derived from the red Carboniferous sediments within the Deer Lake basin, upstream of this site. The clast component is entirely local and angular clasts suggest no fluvial transport. The sediment also contains no exotic clasts that would be expected if the deposit was fluvially derived. The clasts were therefore derived from the adjacent slopes by mass movement. The introduction of the clast component into the muds explains the soft sediment deformation structures seen in the sediment.

The *Balanus hameri* shell fragments were dated at 12,220 ± 90 years BP (TO-2885) (Table 6-1). This date indicates that the Humber River gorge was ice free before 12.2 ka.


### 2. Dawe's Pit

This is a gravel pit on the north side of the Humber River (Plate 4-5), just across the bridge connecting the north shore highway (Route 440) to Riverside Drive in Corner Brook (site 93037; Appendix A). The top of the pit is flat with a surface elevation of 30 m asl, and a surface area of about 0.4 km$^2$.

Much of the pit face is slumped. The areas where exposures are visible show a sand dominated north face (Figure 4-5); and a gravelly west face capped by silt-clay (Figure 4-6).


Description - North Face

The basal 3 m of the face is obscured by slumping. The first unit exposed is a minimum of 25 cm thick, consisting of well sorted, interbedded fine-medium and medium-coarse sand. The unit contains asymmetric ($\lambda$=17 cm, H=3 cm, R.I.=5.5), out of phase, erosional stoss, climbing ripples showing

**Plate 4-5:**
Oblique aerial view of Dawe's Pit, located on the north side of the Humber River near Corner Brook. The pit is cut into a flat-topped terrace composed of sediment deposited by the Humber River.
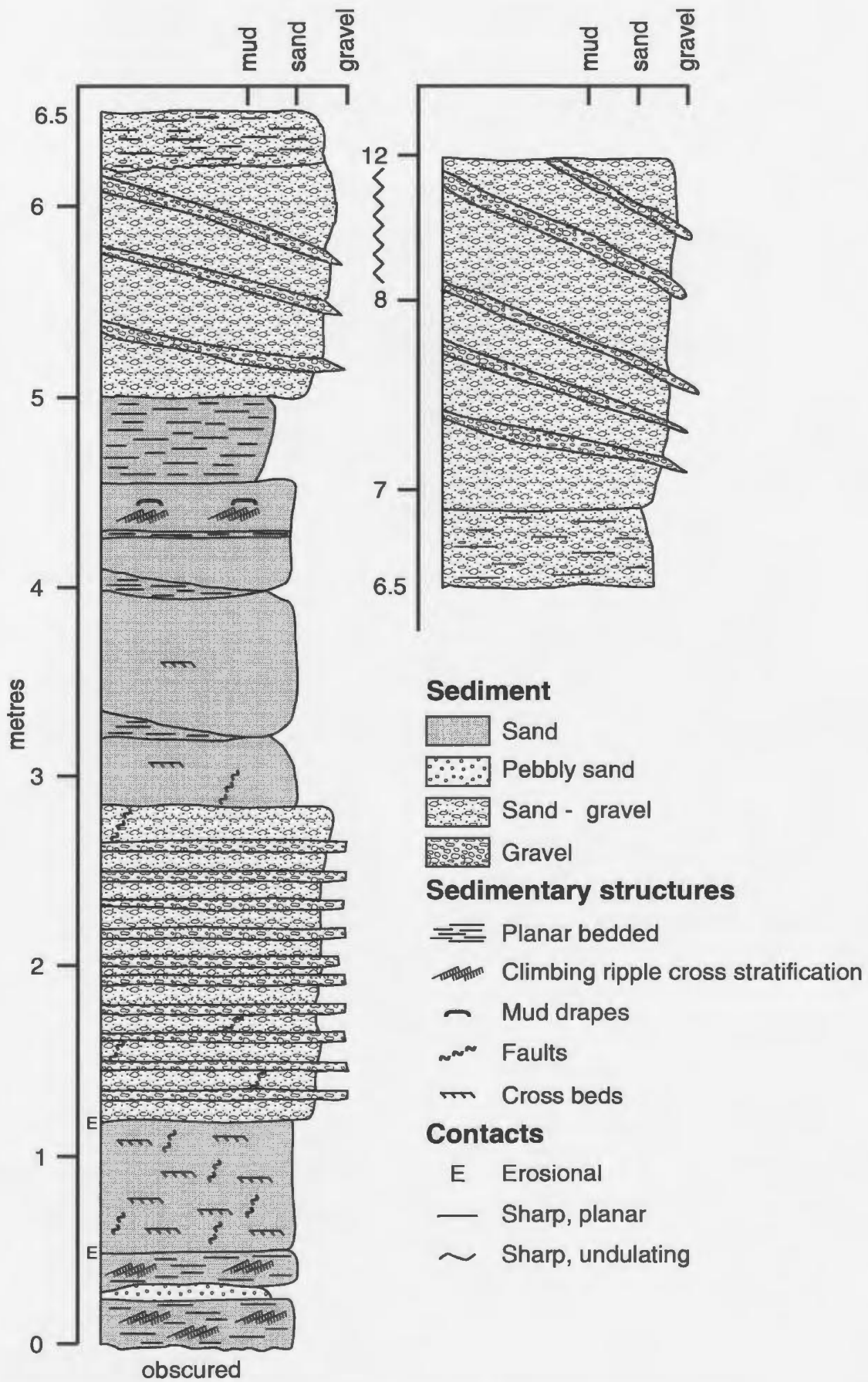
**Figure 4 - 5:** Stratigraphy of the northern exposure at Dawe's pit.
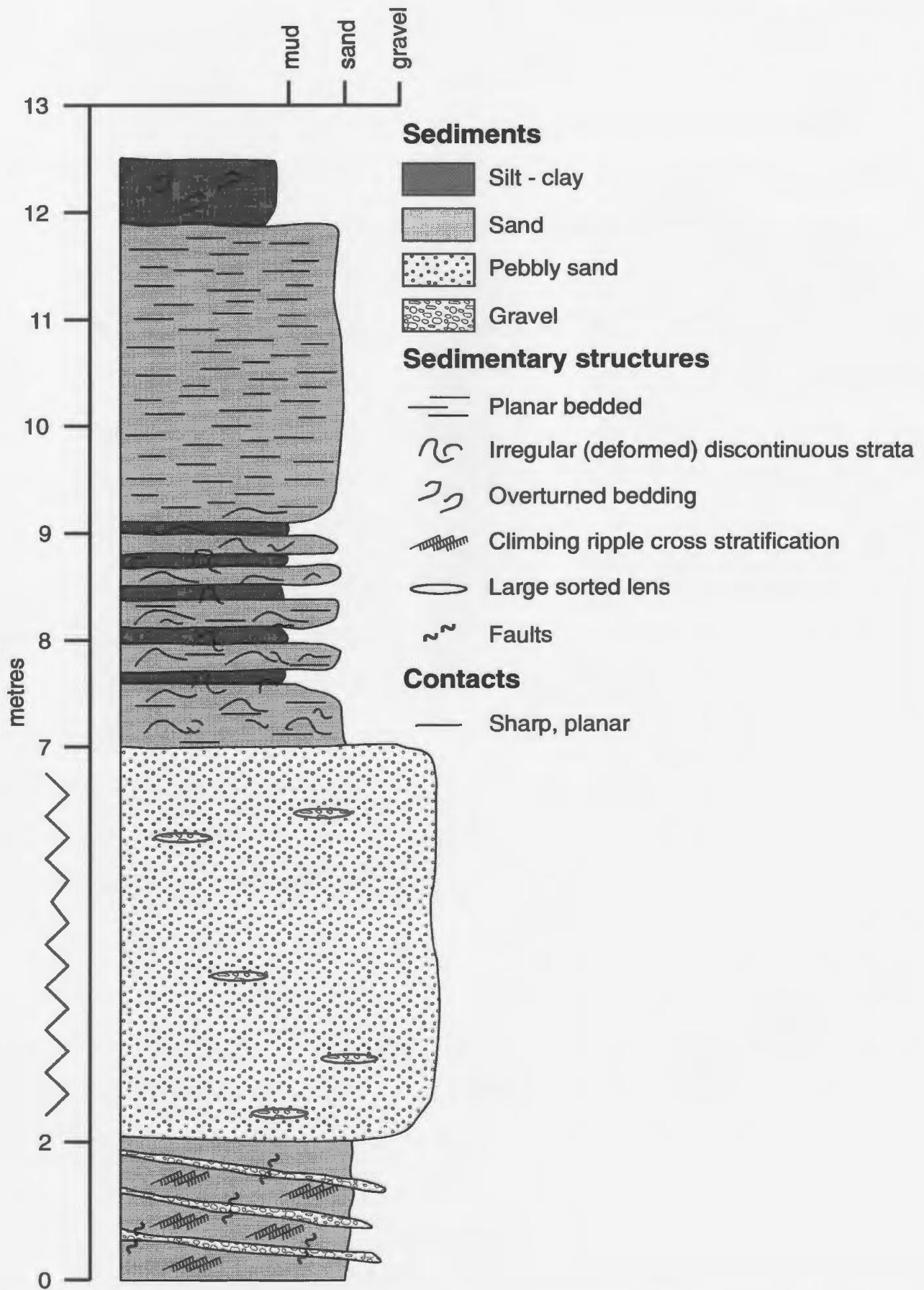
**Figure 4 - 6:** Stratigraphy of the western exposure at Dawe's pit.

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flow towards 330°, and trough cross-beds. The ripples are draped across a sharp, undulating contact by a 7 cm-thick layer of interbedded very fine-sand and silt, with rare pebble clasts. The clasts do not disturb underlying beds.

The drapes are overlain above a sharp, undulating contact by 20 cm fine- and very fine-sand. The sand contain out of phase, erosional stoss, trough cross-laminated, climbing-ripples. This rippled sand bed is truncated across a sharp, undulating contact by 68 cm of well- sorted, large-scale planar tabular cross-bedded, medium- to coarse-sand. Cross beds dip about 20° towards 340° at the base of the unit, and towards 300° at the top. Individual sets of cross beds are up to 28 cm thick. The unit contains rare pebble clasts that are aligned parallel to the cross beds.

The cross beds are truncated by a sharp, planar horizontal contact, overlain by 170 cm of clast-supported (80% clasts) sandy pebble gravel, with a coarse-sand matrix. The unit contains 10 laterally continuous beds of granule gravel to pebble gravel, each 1-3 cm thick. These beds have sharp, planar, horizontal upper and lower contacts, are ungraded, and contain subangular to subrounded clasts of mixed rock types.

A 142 cm-thick unit of well-sorted, mica-rich medium sand lies above a sharp, planar contact. The unit is generally structureless, although poorly defined planar-tabular cross-beds showing flow towards about 300° are present near the top of the unit. The unit contains two lenses, both oriented north-south. The lower lens is 35 cm above the base of the unit. It is 8 cm thick, has a sharp, planar lower contact and is composed of interbedded very fine-sand and silt. The lens dips 12° towards 280°. The upper lens is 130 cm above the base of the unit, has a lateral extent of about 8 m, and consists of normally graded very fine-sand and silt beds. Contacts between beds are sharp. The lens

is overlain by 50 cm of planar, interbedded, fine-sand.

A 28 cm-thick rippled sand bed lies above a sharp, planar horizontal contact. Ripples towards the base are out of phase, asymmetric ($\lambda$=12 cm, H=1.5 cm, R.I.=8), erosional stoss, planar laminated. In the central part of the unit are 4 cm erosional stoss, trough cross-laminated, medium- to fine-sand, climbing ripples. At the top, are asymmetric ($\lambda$=20 cm, H=2.5 cm, R.I.=8) trough cross-laminated ripples. Flow directions indicated by ripple asymmetry are 000° at the base of the bed, 340° in the middle, and 160° at the top of the bed. The drapes are overlain by 4 cm-thick bed of erosional stoss, climbing ripples and trough cross-laminations showing flow towards about 340°. All the ripples within this unit are draped by 0.3 to 1.0 cm-thick, very fine-sand - silt normally graded strata with similar characteristics to those described earlier.

This is overlain by 45 cm-thick unit of planar interbedded, fine- and fine - medium-sand, across a gradational, undulating contact, which in turn is overlain by 120 cm sandy gravel across a sharp, planar horizontal contact. This unit is clast supported (80% clasts) with a coarse-sand matrix. It contains 2-5 cm-thick interbeds of coarse sand-granule gravel, and sandy pebble gravel with clasts up to 5 cm diameter, that are commonly imbricate (dip at 10-14° towards 220-250°).

The sandy gravel bed is overlain across a sharp, planar horizontal contact by 20 cm interbedded sand and pebbly sand, with individual beds dipping at ~8° towards 240°; and subsequently across a sharp, planar contact by 50 cm of sandy pebble gravel.

The north face is capped by greater than 1 m, loose, interbedded pebble gravel and sandy gravel. Individual beds are up to 6 cm-thick, normally

graded and dip ~10° towards 050°, into the face.

Several of the beds in the lower 5 m of the north face are truncated by normal faults (Plate 4-6). Seven fault planes were noted, with angles of dip commonly 60-80° with 5 to 25 cm offsets. Faults are spaced 30-100 cm apart.

Description - West Face

Figure 4-6 shows a stratigraphic log. The lower part of the west face is correlated with the exposures of the north face. The lower slope is a unit of interbedded medium-sand, medium - coarse-sand, and coarse-sand to granule gravel, with sharp planar contacts. Individual beds dip at about 20° towards ~270° to ~360°, with no clear pattern distinguished. Beds are commonly truncated laterally by normal faults with up to 3 cm offsets. This unit was in sharp, planar contact with an overlying gravel.

The gravel unit is approximately 5 m-thick, crudely-stratified, and clast-supported (15% coarse-sand matrix). Clasts mostly are subrounded, granules to boulders (up to 50 cm diameter), dominated by micaceous schist, and less common basalt, rhyolite and sandstone clasts. Clasts generally plunge into the face ~20° towards 360° (Plate 4-7). Open-work granule gravel to pebble gravel lenses are common throughout the unit. A veneer (1 mm) of reddish brown silty clay covers the upper surfaces of clasts within the upper 50 cm of the unit.

The sandy gravel unit is overlain across a sharp contact by interbedded sand, silt and clay that occupy a trough-shaped depression that pinches out laterally to the east (Plate 4-8). The central part of the trough is 550 cm thick. At the base of the trough is 3 cm dark reddish brown (5YR 3/3, moist) to reddish brown (5YR 5/3, dry), structureless silty clay. It is overlain by 25 cm

**Plate 4-6:**
Synsedimentary normal faults within sand-gravel on
the north face of Dawe's Pit, looking northeast.

**Plate 4-7:**
Gravel bed showing clasts dipping northward on the
west face of Dawe's Pit. Clast imbrication indicates
southward current flow, opposite to the modern
Humber River. This was produced by eddy currents,
and the development of a longitudinal bar.

**Plate 4-8:**
Steeply-dipping silt-clay within the upper part of the
west face of Dawe's Pit. They were produced by loading
from a rapidly sedimented sand bed that overlies the
silt-clay.

planar-bedded, well-sorted, coarse- and medium-sand. Nine similar sequences of silty clay (or clayey silt) overlain by sand are present vertically through the unit. The silty clay (or clayey silt) beds are generally structureless, and 0.2 to 15 cm-thick, increasing in thickness upwards. Lower contacts are sharp and planar. Sand beds are thicker (7 to 43 cm), with sharp, irregular lower contacts. Both the sand and silt-clay beds dip steeply into the face (~40° towards 330°). This is overlain by about 260 cm interbedded fine- and very fine-sand, commonly with sharp irregular contacts between beds. The north face is capped by about 60 cm reddish brown, structureless, silty clay.

The general stratigraphy within the sand, silt and clay unit is commonly disrupted, particularly in the lower part. The eastern margins of the unit are steeply dipping (60-80°), with some beds deformed into recumbent folds. In other places the bedding has been totally disrupted. Soft sediment deformation features include regular folding, and chaotic and dislocated beds with associated diapiric structures. Folds are generally regular and symmetrical, with a wavelength of less than 4 cm and amplitude of less than 2 cm. Chaotic bedding and associated diapiric structures are common. Individual beds are contorted or disrupted. Diapirs are 4-8 cm high, and roughly symmetrical about the vertical axis.

Interpretation - West and North faces

The rippled sand, sandy gravel and interbedded silt that dominate the west face and are found at the base of the north face are interpreted as fluvial sand and gravels. The erosional stoss, climbing ripples were deposited by unidirectional current flow, in which ripple migration is greater than deposition. Ripples are generally small and fine-grained, suggesting

deposition by relatively low flows (~ 50 cm sec $^{-1}$) (Harms *et al.*, 1982). Flow directions are variable, ranging from 160° to 360°. Similar flow structures have been reported from sand flats on the South Saskatchewan River (Cant and Walker, 1976), and meandering streams (Jackson, 1976; Leeder, 1982), in which current velocities were low, but variable. Waning flow conditions are interpreted to have formed the thicker beds of cross-bedded sand overlying rippled sand beds (Harms *et al.*, 1982). Draped silt and silty clay beds overlying the ripples record periods of flow cessation. The dominantly sand unit shows general coarsening upwards. This sequence is either the result of increasing proximity to a sediment source or hydrologic changes producing greater runoff and sedimentation rates.

The clast-supported gravel unit on the west face is interpreted as a fluvial deposit. The matrix component is low (less than 10%) and composed of coarse-sand. The sediment was deposited by an energetic flow that kept sand in suspension. The imbricated clasts, dipping into the bank, show that flow was from the north. Crudely-bedded gravel with imbricate clasts are deposited in longitudinal bars (e.g., Smith, 1974; Hein and Walker, 1977; Miall, 1977, 1978). Clast imbrication is very rarely found in debris flow sediments (e.g., Rust and Koster, 1984). The unit is laterally discontinuous, suggesting channelized flow. The reddish brown silt-clay caps on the clasts in the upper 50 cm of the unit may result from post-depositional translocation of fines from overlying beds.

The silt-clay and interbedded sand unit at the top of the west face lies within a channel-shaped depression in the underlying fluvial gravels. The sediments contain no macrofossils and were not sampled for microfauna. Their position above fluvial gravel on an isostatically-rebounding coast

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suggests the muds are not marine. They therefore are interpreted to have been deposited in an abandoned channel by suspension settling. Similar fine-grained deposits associated with coarse-gravel have been described from gravely braided systems (Smith, 1974; Hein and Walker, 1977, 1982; Rust and Koster, 1984). The soft sediment deformation structures are interpreted as loading features. The small regular folds are interpreted as convolute laminations. Similar structures were described from fine grained turbidites (e.g., Kuenen, 1953; Bouma, 1962; Allen, 1984), or their fluvial-deltaic analogs (e.g., Picard and High, 1973; Allen, 1984). The chaotic bedding and associated diapiric features are interpreted as load casts. They are typical of fluvial and deltaic deposits (e.g., Potter and Pettijohn, 1963; Collinson and Thompson, 1982; Allen, 1984), and turbidites (e.g., Kuenen, 1953; Bouma, 1962; Allen, 1984). Such features are formed by rapid deposition of a relatively dense unit onto a saturated, finer substrate. The deformed silt-clay bed is overlain by up to 200 cm fine- and very fine-sand, showing poorly defined ripples. The grain size and the presence of current structures suggest the sand was deposited by a current flow of relatively low velocity that deposited the sand quickly over the sand-mud beds causing the unit to dewater and leading to the soft-sediment deformation structures observed. The structureless, undeformed silty clay bed overlying the sand shows that sedimentation by suspension settling continued following deposition of the sand bed.

Much of the section shows normal faults, indicating tensional stresses, with up to 25 cm offsets. Fault planes are sharp with small throws. Sediment thickness is consistent on both sides of faults. The upper part of the section is commonly not faulted. These factors show the faults are synsedimentary, probably produced by slumping.

Section interpretation

Dawe's Pit lies on the north side of the modern Humber River, within a small bedrock controlled embayment directly downstream of the Humber River gorge. Although sediments exposed within the pit exhibit considerable lateral and vertical variability, they are all interpreted to have been deposited within a fluvial environment. Fluvial sediments indicate current flow opposite to the general flow of the modern Humber River. This may be explained by current flow into a back channel in which Dawe's Pit is now situated (Figure 4-7). This interpretation is supported by the variable direction of current flow as indicated by the ripples, the local geomorphology in relation to river flow, and the abundant sediment supply provided by the Humber River. Current eddying explains ripples showing flow oblique or opposite to the modern Humber River. Draped ripples and planar-bedded gravel with similar characteristics to those found in Dawe's Pit are found within the Humber River gorge, and were exposed during highway construction in 1991 (site 91138, 91139; Appendix A).

The alternative explanation is that flow was from an adjacent valley. A small valley is found north of the pit area, but it is bedrock floored and has a small watershed situated on the bedrock-dominated highlands overlooking the Humber River valley. The lack of an obvious sediment supply suggests this is an unlikely source for the sediment in Dawe's Pit.

The section thus is interpreted as fluvial sediment, deposited by current flow into a bedrock controlled back channel on the north side of the modern Humber River. Flow strength was generally low, and stopped during certain periods, perhaps during winter freeze up. The section generally coarsens
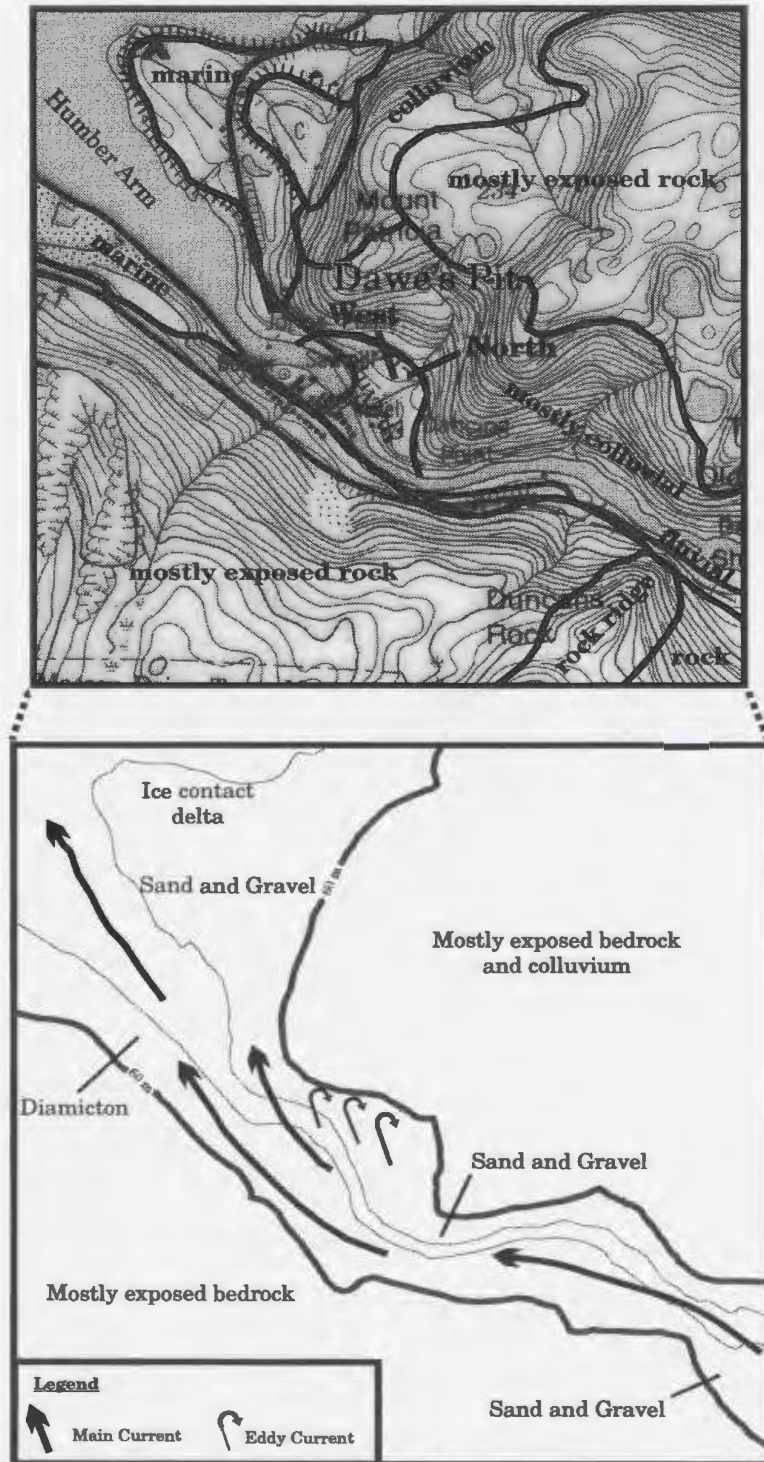
**Figure 4-7:** Palaeogeography of the Dawe's Pit area. The 60 m contour line represents the marine limit for the area. The dashed line is the modern coastline and course of the Humber River. Sediments found within Dawe's Pit are interpreted to have been deposited by fluvial activity through current eddying into a bedrock controlled embayment.

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upwards, reflecting increasing proximity to a sediment source, possibly caused by a fall in relative sea level. The alternative explanation is increased discharge and sedimentation rates produced by changing climate, but this could not be corroborated (c.f., Macpherson, 1981). The gravel-rich bed is interpreted as a longitudinal bar formed across the mouth of the embayment, possibly as river depths decreased during relative sea level lowering. A channel on the north side of this bar isolated from the main channel became an area of standing water. Sedimentation in this pond was by suspension settling. Introduction of sand into the pond (during a flood?) produced the loading structures observed. Sediment was eroded and a terrace formed during sea level fall and the continual grading of the Humber River to reduced base levels. The removal of the lateral support produced the collapse features noted throughout much of the sand unit.

Grant (in Blake, 1987, p. 6) previously described the exposure at Dawe's Pit as a "kettled glacier-marginal kame delta", in discussion of a radiocarbon date of 12,700 ± 300 BP (GSC-4272) from *Macoma balthica* shells at 15 m above present sea level found in muds adjacent to the site. Such a delta would have formed in a glacio-marine environment, similar to features and sediments described by Cheel and Rust (1982). The interpretation of the depositional environment for the sediments exposed at Dawe's Pit does not support this interpretation. Fluvial deposition is indicated by the presence of low velocity current ripples, and the moderately sorted, imbricate gravel that show no evidence (e.g., striations) of glacial transport. Dawe's Pit does not contain the oversized, angular boulders, debris flow deposits, and rapid lateral and vertical changes in grain size that may be expected from an ice-proximal environment. Although the Humber River discharge was probably

dominated by glacial meltwater, ice was not proximal to this site during deposition of the sediments found in Dawe's Pit.

### 3. Wild Cove valley

The Wild Cove valley is an east-west oriented, flat-bottomed valley, the mouth of which is about 5 km north of the mouth of the Humber River. Wild Cove is separated from the Humber River valley near Steady Brook by a col at an elevation of 90 m asl. Up to 16 m of marine clay cover the valley floor (Ricketts, 1987). A small delta is found at the head of Wild Cove with a surface elevation of 50 m asl (site 91219; Appendix A). The north side of the valley shows active scree slopes. In contrast, the south side of the valley shows fan-shaped features (Plate 4-9), extending 1.8 km from the southwestern end of the valley to near the delta. Sediments within the fans are poorly exposed. Two sections are described. One is a small borrow pit that contains marine macrofossils. The other is a backhoe pit.

Borrow pit description

A small borrow pit at the southwestern end of the valley (site 91025; Appendix A) exposes 2 m of sediment, over a lateral extent of about 4 m, at the base of a steep slope. A section log is shown in Figure 4-8. Top of the pit is about 33 m asl.

At the base is at least 20 cm of sandy gravel. The gravel unit is matrix-supported, with a moderately-sorted medium- to coarse-sand matrix. Clasts are subangular to subrounded, granules to cobbles of mixed rock types. Some clasts are striated. The unit contains sub-horizontal lenses of open-work pebble gravel, dipping northward into the valley.

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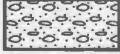
**Plate 4-9:**
View of the Wild Cove valley showing fans (right side). The valley floor is underlain by clay-silt. The fans were produced in an ice-proximal glaciomarine environment during marine incursion of the Wild Cove valley.
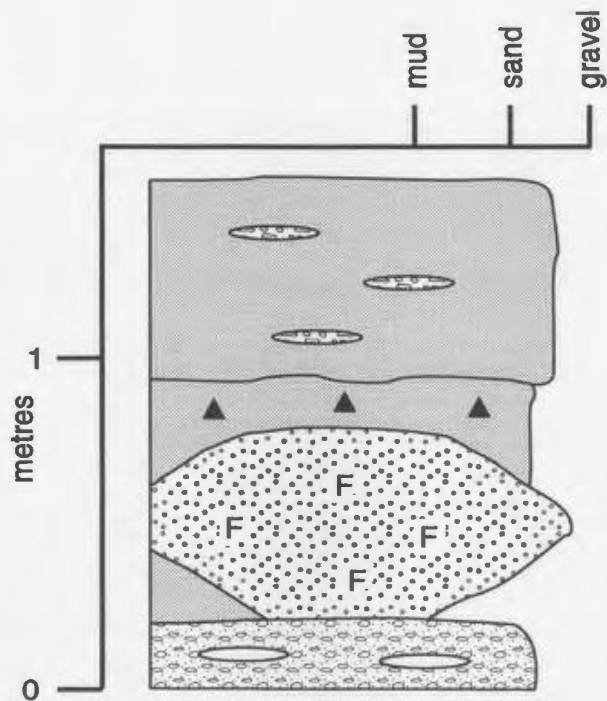
**Sediment**

| | |
|---|---|
| | Sand |
| | Pebbly sand |
| | Sand - gravel |
| | Gravel |

**Sedimentary structures**

⬭  Large sorted lens

F  Fossils

▲  Normal graded

**Contacts**

─── Sharp, planar

∿ Sharp, undulating

**Figure 4 - 8:** Stratigraphy of an exposure in the Wild Cove valley.

This unit is overlain across a sharp undulating contact by a 30-60 cm-thick bed of pebbly sand, composed of moderately-sorted fine-sand, that pinches out east and west. Medium- and coarse-sand fractions are largely absent. Pebbles are subangular to angular, and of mixed rock types. The matrix contains marine shells, mostly *Mya truncata*, but also *Mya arenaria* and *Macoma calcarea*. Specimens are commonly whole valves, although not in growth position. The fossiliferous pebbly sand bed is draped by a 10-30 cm-thick moderately-sorted, normally graded, coarse- to medium-sand (80%) and granule gravel (20%) bed.

This unit is overlain across a sharp, undulating contact by about 60 cm pebbly sand. It is composed of about 60%, structureless, moderately-sorted fine-sand. Medium- and coarse-sand is poorly represented. Subangular to subrounded pebbles of mixed rock type account for 40% of the unit. The bed contains convexo-concave and convexo-planar lenses, 40 cm to greater than 80 cm lateral extent, and 10-20 cm thick. They contain generally structureless medium- to coarse-sand and pebbles. The lenses pinch out east and west, and are continuous into the exposure, dipping 15° upslope. The lateral extent of this unit is unknown.

Backhoe pit description

A backhoe pit was excavated in the fan about 1100 m east of the borrow pit along a narrow gravel road about 20 m above the valley floor (site 91220; Appendix A). It exposed a vertical section of 3.8 m containing interbedded diamicton, sand and silt-clay (Figure 4-9). The pit was 3 m wide, and had a surface elevation of about 41 m asl.

The bottom unit is a greater than 150 cm-thick bed of loose, brown
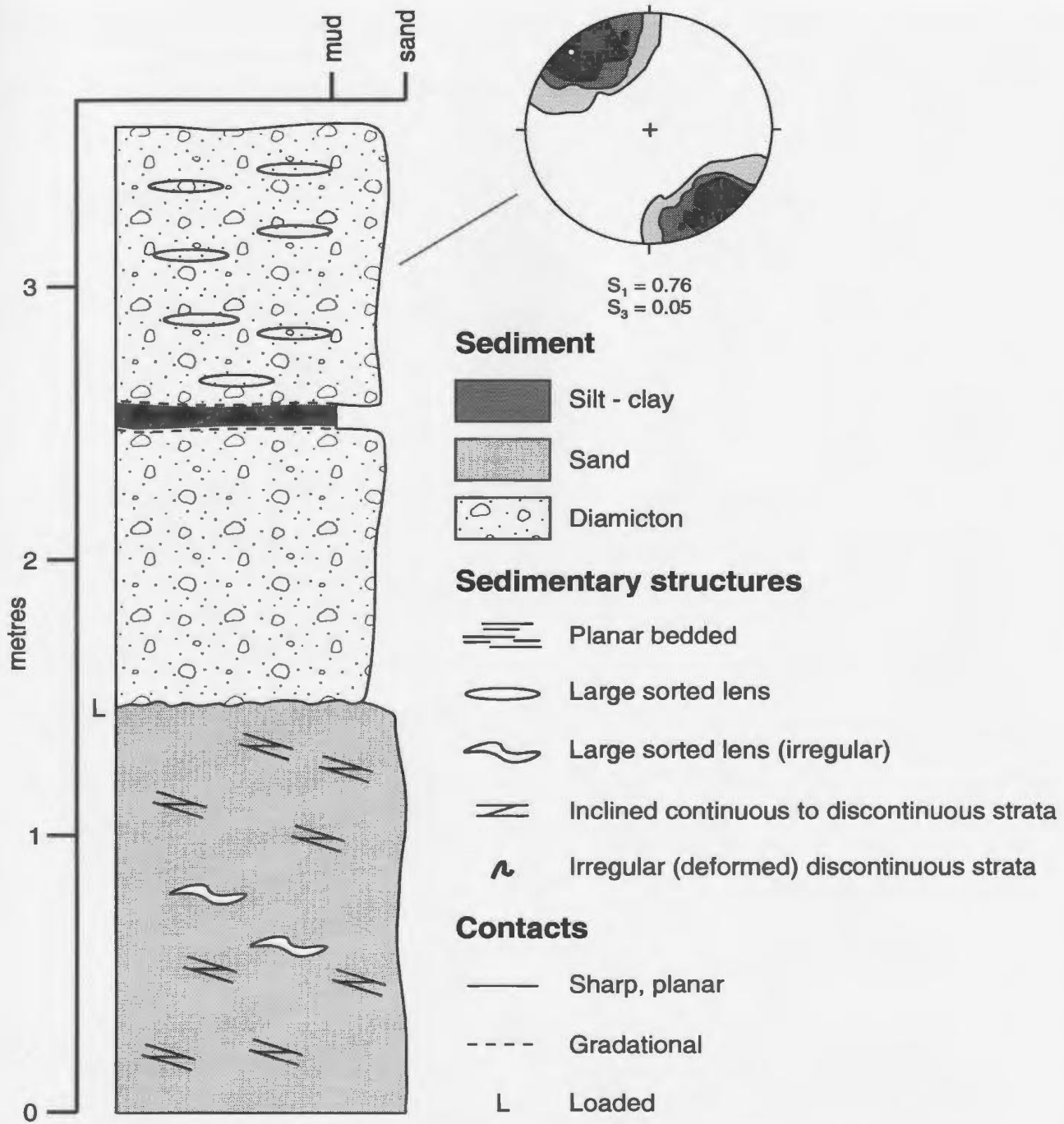
**Figure 4 - 9:** Stratigraphy of a backhoe pit exposure in the Wild Cove valley.

(10YR 4/3, moist), poorly-sorted (s.d 1.9ø), fine-sand (mean 2.8ø). The unit is generally structureless, apart from planar, very fine-sand laminae, and a single sub-horizontal, irregular-shaped lens, 5 cm wide by 1 cm high, pinching out east and west, containing structureless very fine-sand. The lens dips about 6° downslope. The unit is overlain by 100 cm diamicton across a sharp, wavy contact. The diamicton is dark yellowish brown (10YR 4/4, moist), matrix-supported, and structureless with an extremely poorly-sorted (s.d. 4.2ø), silty sand matrix (mean 0.8ø). Clasts are subangular to subrounded, granules to boulders up to 70 cm diameter, of mixed rock types. Larger clasts are concentrated towards the top of the unit. Clasts have a strong, slightly clustered fabric ($S_1$=0.76, $S_3$=0.05) with a preferred clast orientation towards 325° (i.e., downslope).

The diamicton is overlain by 10 cm of brown (7.5YR 5/4, moist), laminated, very poorly-sorted (s.d. 2.8ø), silt (mean 5.6ø) across a sharp, wavy contact, that grades upwards into 5 cm of laminated fine-sand. Laminae are up to 0.5 cm thick, and ungraded, and contain 10% to 20% (increasing upwards) randomly distributed coarse-sand and granule gravel. Individual lamina in both the silt and sand units are commonly contorted (mostly regular folds) and, rarely, disrupted.

The sand bed is overlain by 100 cm of diamicton across a wavy (loaded?), gradational contact. It is matrix-supported (mostly fine-sand), with less than 10% silt-clay. Sub-horizontal lenses of structureless sandy gravel with a medium- to coarse-sand matrix, and subangular to subrounded granule to cobble clasts, are common throughout the unit. Clasts are preferentially oriented downslope. The diamicton extends to the top of the backhoe pit.

Interpretation

Sediments exposed in the backhoe pit are interpreted as having been deposited in an ice-proximal subaqueous fan environment. The basal sand bed is waterlain, deposited on an inclined surface, likely by sediment gravity flow (grain flow?). The overlying diamicton bed is interpreted as a hyperconcentrated sediment gravity flow deposit. This is supported by the deposition on an inclined surface, poor sorting, and the preferred concentration of larger clasts towards the top of the bed (c.f., Lowe, 1982; Lønne, 1995; Benn, 1996). The clast fabric is strong compared to many sediment gravity flow deposits (c.f., Lawson, 1979; Dowdeswell and Sharp, 1986), but the preferred clast orientation downslope is most likely due to flow controlled by slope, rather than being related to the westward glacial flow (see Chapter 5). The diamicton is both underlain and overlain by fine-grained sediments interpreted to have been deposited in a subaqueous environment.

The uppermost diamicton is also interpreted as a sediment gravity flow deposit. The sediment gravity flow that deposited the diamicton was likely thus subaqueous. Diamictons located on inclined surfaces, and interbedded with sand, silt and/or gravel, are interpreted as sediment gravity flow deposits, possibly formed in an ice-contact environment (Powell, 1981, 1983; Lawson, 1988; Lønne, 1995). The deformation of sand and silt beds is interpreted as having been produced as a result of loading by the diamicton bed that overlies it.

The sediments described above and the gentle dip to inclined beds suggests deposition as an ice-contact subaqueous fan. The glacier terminated in the sea, rather than on land. This would preserve diamicton beds that otherwise would likely have been reworked by surface streams. Apart from

the section at the western end of the fan, the sediments examined along the southern wall of the Wild Cove valley do not contain marine macro-fossils. This may be the result of the high sedimentation rates likely in ice-proximal subaqueous environments (e.g., Powell, 1991; Syvitski *et al.*, 1996), and the consequent unsuitable habitats.

Sediment genesis in the borrow pit section is difficult to determine due to the poor exposure. The basal sand and gravel unit contains striated clasts, suggesting a glacial source. The inclined granule-gravel lenses indicate concentrated flow down slope. The fossiliferous sand unit is marine. Macro-fossil species are pelecypods of a pioneer assemblage (Dyke *et al.*, 1996), that prefers shallow arctic waters. A single *Mya truncata* shell was radiocarbon dated at 12,450 ± 90 years BP (TO-2884), and provides a minimum date for deglaciation of this site (Table 6-1). Pebbly sand beds are interpreted as sediment deposited in a channelised subaqueous fan environment (c.f., Hein and Walker, 1982; Walker, 1978, 1984). This interpretation is supported by the close association with marine deposits, and the gravelly sand lenses found within the unit.

The angle of inclined beds towards the valley, the lack of features (e.g., faults) showing collapse, and the flat bottomed valley underlain by up to 16 m silt-clay, suggests that the sediment source was the highlands to the south, rather than ice marginal sedimentation from a glacier occupying the Wild Cove valley.

### 4. Hughes Brook Pit

Hughes Brook has its source in Hughes Lake, located 6 km west of Deer Lake. The brook flows west through Long Pond and Balls Pond before turning

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south and flowing through a broad valley until it enters Humber Arm east of Irishtown (Figure 1-2). The upper reaches are bedrock dominated; the middle reaches contain sand and gravel; and the lower reaches are incised through a narrow rock gorge about 400 m long characterized by numerous pot holes, downstream of which are marine muds at the outlet. Much of the lower reaches lie below the previously suggested marine limit of 49 m asl (Brookes, 1974). The valley contains several abandoned sand and gravel pits, but most are slumped or sloped with no good exposure. One active pit exists, operated by North Star Cement of Corner Brook, hereafter called the Hughes Brook pit.

The Hughes Brook pit is located on the east side of the valley about 5 km upstream from Humber Arm (site 91173; Appendix A). The surface of the pit is 61 ± 2 m asl (altimeter estimate). The pit is at the mouth of a small, narrow valley that extends 7 km eastward. Descriptions were made from two fresh faces, on the south and west sides of the pit.


Description - South Face

This part of the pit shows a 5.5 m thick exposure of sand and pebbly to gravelly sand extending from the pit floor to modern surface. An unknown quantity of material has been removed, but likely less than 3 m in thickness based on comparison to the adjacent, unmodified slopes. Beds are commonly laterally continuous for at least 2 m, except where otherwise noted (Figure 4-10).

The base of the exposure shows more than 20 cm gravelly sand interbedded with coarse sand-granule gravel. The gravelly sand is loose, poorly-sorted (< 2% silt-clay), with subangular to subrounded, granule to cobble clasts (up to 8 cm diameter), composed of mixed rock types. Coarse
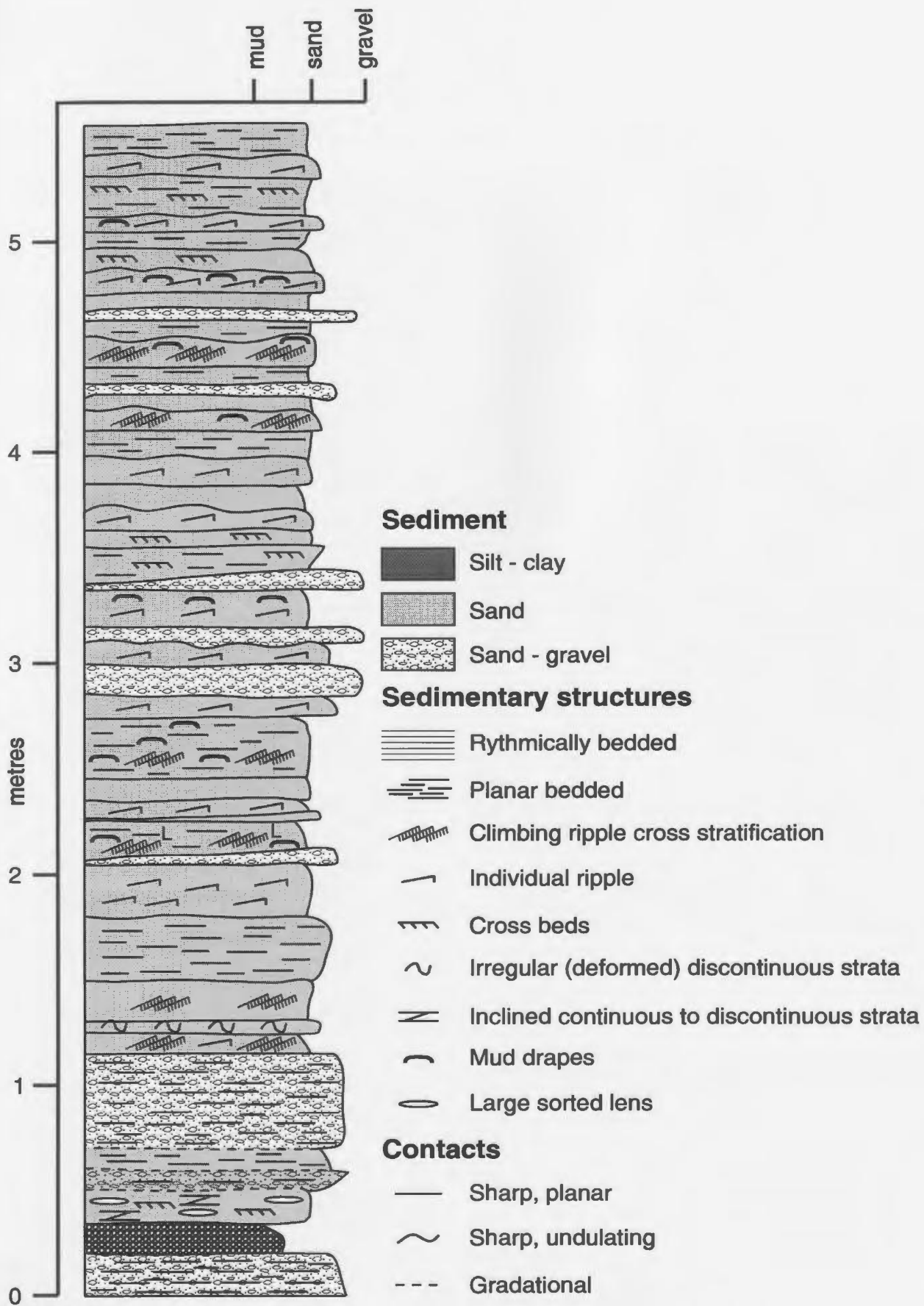
**Figure 4 - 10:** Stratigraphy of the southern exposure in the Hughes Brook pit.

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sand-granule gravel interbeds are 1 to 1.5 cm thick, with sharp, planar upper and lower contacts. Granule gravel interbeds are commonly open-work.

This is overlain by 15 cm of planar-stratified, sand and silt-silty clay. At the base of the unit is a 2 cm-thick bed of normally graded clayey silt, with the silt component thicker than clay, overlain by rhythmically-bedded fine to very fine sand. Individual couplets are normally graded, 0.1 to 1.8 cm-thick. Couplets have gradational internal contacts (i.e., fine- to very fine-sand), and sharp between-couplet (i.e., very fine- to fine-sand) contacts. Thirteen couplets were counted within this bed.

This unit is overlain by 16 cm of interbedded fine-sand, and medium-to fine-sand. Individual beds are 0.2 to 1.0 cm thick, normally-graded, and dip at ~20° towards 160°. Planar-tabular cross-beds are common and show flow towards 210°. The unit also contains a small (3.5 cm wide and 1 cm high) channel containing normally graded coarse-sand. The channel lies on an inclined surface that dips at ~20° towards 220°.

The cross-bedded sand are overlain by 9 cm of interbedded coarse-sand and granule gravel across a planar, gradational contact, 10 cm of interbedded fine-sand and medium - fine-sand, and 44 cm of gravelly sand and interbedded coarse-sand and granule gravel, each with gradational planar lower contacts.

These beds are overlain by a 10 cm-thick bed of draped rippled sand. They are mostly erosional stoss, asymmetric, trough cross-bedded, climbing ripples (λ=13 cm, H=1.8 cm, R.I.=7) showing flow towards 080° (Plate 4-10). Some depositional stoss ripples of similar size were also found. Angle of climb is low (~6°). The ripples are draped by 0.1 to 0.3 cm thick very fine-sand to silt laminae. In places, the draped laminae are contorted or, rarely, discontinuous (Plate 4-11).

**Plate 4-10:**
Climbing ripple cross-stratification with a low angle of climb found within sand beds on the south side of the Hughes Brook pit. The ripples show flow towards 080°, and were deposited in a prodeltaic marine environment.

**Plate 4-11:**
Draped ripples within sand beds on the south side of the Hughes Brook pit.
The drapes are very fine sand to silt, and indicate periods of suspension
settling. Sediment composing the Hughes Brook section was deposited in the
sea during marine incursion of the valley.

The remaining 420 cm of the south face is a repetitive sequence of rippled and cross-bedded sand, planar-bedded fine- to coarse-sand, and gravelly sand, occasionally containing interbedded coarse-sand and granule gravel.

Ripples commonly are composed of moderately to well-sorted fine- to medium-sand, showing little vertical variation in texture. Where measurable, ripples are generally small ($\lambda$ = 5.5 to 16.5 cm), with low to moderate ripple indices (7 to 11), erosional stoss to depositional stoss climbing ripples. Angle of climb varies between 2° and 16°. The ripples are oriented between 020° and 270°, being more variable towards the base of the section (065° to 250°), and consistently towards 240° to 270° in the upper part. Upper parts of ripples are commonly eroded.

Rippled beds are commonly draped by silt to very fine sand. Drapes are 0.1 to 2.0 cm thick, rarely thicker over ripple-troughs, and are either ungraded silt to very fine-sand laminae, or normally graded, rhythmically bedded silt and fine-sand. Rippled beds commonly truncate underlying sediment. Draped laminae commonly show soft sediment deformation structures, including flame structures, chaotic and discontinuous strata. The flame structures are commonly less than 1 cm high, and angled down flow (Plate 4-12). Discontinuous beds, where found, are commonly on the downflow side of ripple peaks.

Pebbly sand beds are moderately-sorted, with a fine- to medium-sand matrix, and granule to pebble clasts randomly distributed throughout the unit. They are generally normally graded to ungraded, 1 cm to 13 cm thick, and generally confined to the upper 300 cm of the section. Basal contacts are sharp, planar and horizontal. Gravelly sand beds are thicker (up to 44 cm),

**Plate 4-12:**
Flame structures (indicated by arrow) on ripple surface from sand beds on the south side of the Hughes Brook pit. These are sediment deformation structures produced by rapid deposition of the overlying sand bed.

coarser than the pebbly sand beds, and commonly contain interbeds of normally to ungraded, well-sorted coarse-sand and open-work granule gravel.

Planar-laminated fine- to coarse-sand have with sharp, flat contacts between laminae. Individual sand strata are 0.1 to 0.5 cm thick, and coarser laminae are 0.2 to 1.0 cm thick. Units of laminated sand commonly coarsen upwards.

Individual beds are inclined. The degree and direction of inclination varies between 16° towards 160° at the base of the section, to 8° towards 230° in the middle, and 8-14° towards 225° at the top. Although most beds are planar and can be traced laterally for greater than 1 m, some beds are truncated along sharp contacts by troughs.

### West Face

The west face is a 600 cm-thick exposure, the bottom 150 cm of which is obscured. The remainder consists of interbedded pebbly sands, pebbly gravel and sand (Figure 4-11).

The lowest exposed unit is at least 45 cm of gravelly sand, composed of moderately-sorted fine- to medium-sand (60% matrix) with less than 5% silt-clay. Clasts are subrounded and up to 1.5 cm diameter. The unit contains 0.5 to 1.0 cm-thick laterally continuous (> 2 m) interbeds of normally graded, granule gravel to coarse-sand with sharp, planar lower contacts. Granule gravel beds are commonly open-work. Individual beds within this unit are inclined at ~24° towards 340°.

This is overlain by 18 cm of moderately-sorted, normally graded, coarse-sand to granule gravel, containing 80% sand, across a sharp, planar contact. A sharp, undulating contact separates this bed from 3-15 cm of
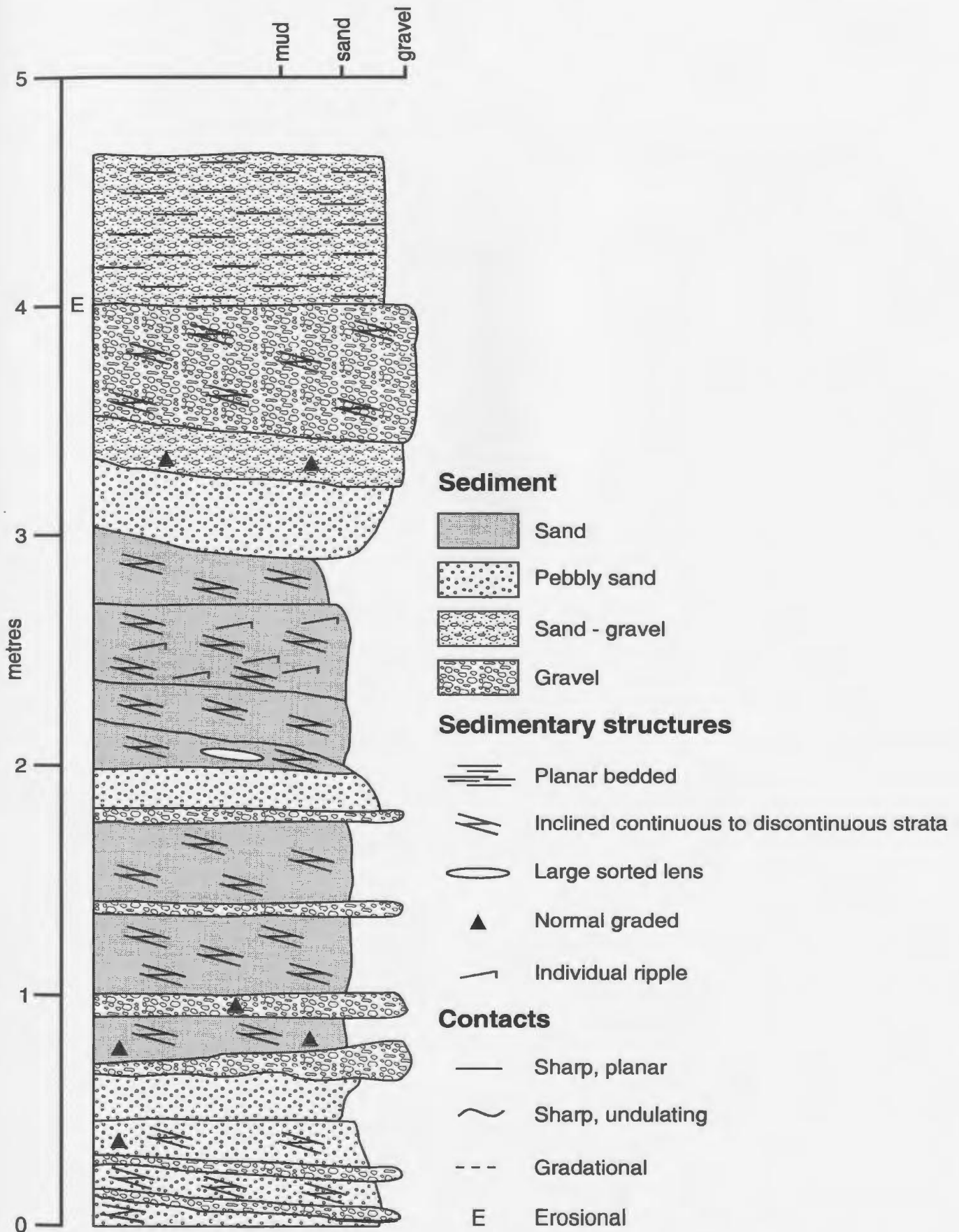
**Figure 4 - 11:** Stratigraphy of the western exposure in the Hughes Brook pit.

normally graded, open-work granule gravel to pebble gravel bed that occupies a northward- thickening trough. This bed is overlain across a sharp, planar contact by 97 cm planar-laminated sand, containing 1 cm to 10 cm-thick (mostly 1-3 cm) interbeds of pebbly sand. Individual beds are inclined at 25° towards 340°.

Above this is a 77 cm-thick sand unit, composed of 0.2 to 1.0 cm-thick interbedded fine-, medium- and coarse-sand. Individual beds are ungraded, with sharp, planar lower contacts. Bed inclination varies from 25° towards 310° at the base of the unit, to 18° towards 325° in the middle, to 26° towards 315° at the top. One 30 cm-thick sand bed showed poorly-defined ripples, with no clear asymmetry. Individual beds are commonly continuous laterally for greater than 2 m, although a lens truncates some beds. The lens is convexo-planar, with sharp lower contacts, 11 cm wide and 1.5 cm high, and contains a core of granule gravel flanked by moderately-sorted coarse-sand.

The sand are overlain across a sharp, planar contact by 30 cm structureless pebbly sand, with ~90% matrix and rare clasts up to 3 cm diameter. This bed is overlain across a sharp, planar contact by 18 cm clast supported, normally graded sandy gravel, with ~10% matrix and granule to pebble clasts up to 3 cm diameter. The uppermost inclined bed is a 60 cm-thick bed of open-work, normally graded, interbedded pebble gravel to granule gravel. Lower contacts are sharp, planar. The unit contains subrounded clasts, of mixed rock types up to 5 cm diameter. Clasts are commonly oriented parallel to bedding. Beds are inclined at 25° towards 240°.

The inclined beds are truncated along a sharp, planar horizontal contact by 65 cm sandy gravel. This uppermost unit lies entirely within the soil profile. It is structureless with a sand matrix, and subrounded, mixed rock

type, granule to boulder clasts up to 13 cm diameter of mixed rock types. Clast long axis is commonly oriented towards 250-260° (i.e., perpendicular to the axis of Hughes Brook), with generally flat dips. The surface has been grubbed-off during pit development. From the presence of roots in the soil profile, it is estimated that 10-20 cm of soil has been removed from this site.

Interpretation

South Face

The sand dominated units that compose the entire south face are interpreted as mid-delta foresets deposited by a combination of current flow and sediment gravity flow.

Climbing-ripple cross laminae (Ashley *et al.*, 1982) are common throughout the section. Ripple texture and angle of climb indicates fluctuating rates of ripple migration relative to ripple aggradation rates. Climbing-ripples have been described from fluvial and delta environments (e.g., Sorby, 1859; Jopling and Walker, 1968; Picard and High, 1973; Banerjee and McDonald, 1975; Gustavson *et al.*, 1975; Rust and Romanelli, 1975; Allen, 1984; Ashley *et al.*, 1985). Draped laminations (Gustavson *et al.*, 1975) are produced during waning flows. Ashley *et al.* (1982) demonstrated experimentally the production of drapes from suspension settling over inactive ripples. This mechanism was postulated by Allen (1963), McKee (1965), Gustavson *et al.* (1975) and Hunter (1977), although challenged by Jopling and Walker (1968) and Banerjee (1977) who preferred formation during periods of low flow (less than 10 cm sec$^{-1}$). The presence of climbing ripples, commonly capped by draped laminae, and deposited on inclined beds is typical a mid-delta depositional environment where sediment and current are supplied by

underflows. Most drapes were supplied by overflow-interflow, because they produce beds of constant thickness over the ripples. Some however, show thinning over ripple crests and thickening over ripple-troughs. These drapes were likely deposited by underflow (e.g., Ashley *et al.*, 1985).

Normally graded to ungraded, pebble sand beds, deposited on slopes inclined about 8° - 16° also indicate a delta depositional environment. These pebbly sand beds are interpreted as sediment gravity flows, from either grain flow or high density turbidity currents (c.f., Kuenen, 1950, 1966a, 1966b; Kuenen and Migliorini, 1950; Middleton, 1967; Lowe, 1976, 1982; Collinson and Thompson, 1982; Leeder, 1982; Allen, 1984; Ashley *et al.*, 1985). Sediment was deposited rapidly, supported by the presence of soft sediment deformation structures (Collinson and Thompson, 1982; Allen, 1984).

### West face

The interbedded sand and gravel that characterizes the west face are interpreted as upper delta foresets of a typical 'Gilbert-style' delta (e.g., Gilbert, 1890; Ashley *et al.*, 1985; Nemec and Steel, 1988; Colella and Prior, 1990; Corner *et al.*, 1990; Prior and Bornhold, 1990; Lønne, 1995; Postma, 1995). Individual beds are inclined at between 18° and 26°, and were deposited mostly by grainflow and avalanching down the delta front. Clast long axes oriented parallel to bedding support this interpretation. The sharp contact between beds shows episodic accretion of sediment. Although most beds are planar, some are truncated by channels that are interpreted as ephemeral distributary channels on the delta. Channel migration explains the presence of sandy interbeds in the delta foresets. Progradation of the delta into the valley, and changes in sediment entry points also are shown by changes in the direction

of bed inclination, from ~315° in the central part of the face, to 240° near the top.

The uppermost sandy gravel unit is interpreted as a fluvial sediment, and thus forms delta topsets. It truncates the underlying inclined beds along an erosional contact. The unit contains no noted current flow indicators. Given the location of the delta extending into the Hughes Brook valley, it is likely the sandy gravel unit was deposited by current flow down Hughes Brook.

Discussion

The sediments exposed in Hughes Brook pit were deposited in a delta produced by a stream entering the Hughes Brook valley on the east side. Only the western and southern parts of the delta currently are exposed, showing steeply dipping, gravelly upper foresets and sandy mid-foresets, respectively.

The surface morphology of the delta, grading upstream into fluvial sediment, shows this was not an ice contact delta. Sediment deposited in standing water adjacent to a glacier commonly consist of coarse-grained outwash deposited close to ice at the mouths of ice tunnels (Rust and Romanelli, 1975; Ashley et al., 1985). Sedimentation rates are commonly high in such environments and syndepositional collapse features, as the result of the melting-out of buried ice blocks, are common. Similarly, ice-proximal lacustrine or marine sediment commonly exhibits abrupt lateral and vertical changes in texture, as the result of constant shifting in the point sources of sediment input. Diamicton, deposited from debris flows, is also common (e.g., Lawson, 1982). Finer grained sediments commonly contain dropstones deposited from floating ice (e.g., Thomas and Connell, 1985). None of these

features are found in the Hughes Brook delta, suggesting it was distal to the ice front. However, sediment and water discharge to the delta was likely controlled by melting ice on the highlands. The modern stream occupies a small, narrow valley with discharge buffered by three lakes within the drainage basin. Following emergence of the delta during post-glacial isostatic rebound, the stream was unable to incise through the delta and was instead deflected northward.

The delta was formed by fluvial discharge into a lake or the ocean. Formation in a lake would require the presence downstream of an ice dam in order to impound standing water. Eventual draining of a proglacial lake in this area should have produced drainage channels. The existence of the delta only 5 km upstream of the modern coast suggests that formation adjacent to a higher post-glacial sea is more likely.

The existence of a marine delta in the Hughes Brook valley with a surface elevation of 61 ± 2 m asl requires a revision of the post-glacial sea level history for the area. Brookes (1974) suggested a marine limit at the head of the Humber Arm of approximately 49 m asl, based on the presence of a delta at Humbermouth extending on both sides of the modern Humber River. Other supporting evidence for a higher marine limit is fragmentary. A possible delta (site 91029; Appendix A) exists near the community of Hughes Brook at 58 m asl, and a terrace (site 91008; Appendix A) at ~61 m asl was identified at Humbermouth, on the opposite side of the Humber River from Dawe's Pit.


Deposition at the head of the Humber Arm: Discussion

Inflow of water and sediment into the head of the Humber Arm during

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deglaciation was from three major valleys, Humber River, Wild Cove, and Hughes Brook. Each shows evidence of fluvial, marine, or ice-proximal sedimentation.

Primary basal till is found at the head of the Humber Arm (site 94003; Appendix A), with a reddish brown matrix and red sandstone clasts both derived from the Carboniferous rocks of the Deer Lake basin. Clast fabric is strong ($S_1$=0.78, $S_3$=0.06), with a preferred clast orientation showing flow from the adjacent Humber River gorge. A diamicton exposure on the north shore of Wild Cove (site 91014; Appendix A) shows a dark greyish brown, primary basal till with a strong clast fabric ($S_1$=0.64, $S_3$=0.16) and a preferred clast orientation indicating flow from the Wild Cove valley. The two sites indicate that ice entered the Humber Arm via the Wild Cove and Humber River valleys. Only small exposures of till were present in the Hughes Brook valley.

During deglaciation, melting ice in the gorge produced a large ice contact delta at Humbermouth (Brookes, 1974), shown by a flat-topped, steep-sided feature composed of sand and gravel, with a surface elevation of 50 m asl. Sedimentary evidence for this is fragmentary, following aggregate extraction on the south side of the Humber Arm, and the development of a cemetery on the north side. The internal structure of a feature in the Hughes Brook valley, with surface elevation of about 60 m asl, was identified as a delta formed by fluvial input from a tributary valley. Similarly, a delta was identified at the head of Wild Cove (50 m asl), also on the basis of internal structure (site 91221; Appendix A).

The elevation of delta surfaces suggests the marine limit was about 60 m asl. A postglacial sea flooded the lower reaches of Hughes Brook valley, and the Wild Cove valley, as shown by the delta, subaqueous fans, and the thick

silt-clay covering the valley floor. Marine shells found near Steady Brook record marine inundation through the Humber River gorge. Radiocarbon dating of marine shells in the Humber River gorge and Wild Cove provides a minimum date for marine inundation and thus deglaciation at 12.2 - 12.5 ka.

The re-establishment of subsequent fluvial sedimentation in the lower reaches of the Humber River valley is shown by sediments in Dawe's Pit, the Humber River gorge, and in the Hughes Brook valley. There has been minimal fluvial sedimentation in the Wild Cove valley following deglaciation, and the emergence of the valley floor from below sea level.

**Sections exposed along the shores of Grand Lake**

Introduction

Grand Lake is the largest lake in insular Newfoundland, with a surface elevation of ~82 m asl. The shoreline shows a distinct contrast between the west and east shore. The west shoreline is bedrock dominated, with scattered outcrops of sand and gravel mostly found at the mouths of small tributaries. In contrast, the east shore is dominated by Quaternary sediment, with rare bedrock outcrops.

On the east shore Quaternary sediment occupies a narrow belt, between 500 and 1300 m wide, increasing in width northwards. Coastal bluffs (Plate 4-13) are commonly separated from the lake by a gently sloping, cobble to boulder beach up to 50 m wide. Prevailing winds are parallel to the lake orientation, whereas the effects of those oriented across the lake are relatively minimal due to protection from the surrounding highlands. Thus little

**Plate 4-13:**
Lakeshore exposure of a fan-delta on the east shore of Grand Lake. This delta, and others found along Grand Lake, were deposited in a proglacial lake during deglaciation of the Grand Lake valley.

evidence of wave impact on the bluffs was found and sediments are thus poorly exposed, being largely obscured by slope failure.

A total of 32 lakeshore exposures was examined between Harrys Brook and Howley. Exposures had little vertical or lateral continuity. Descriptions are presented from three of the best exposed sections, representing the range of sediment types found. This is followed by a general discussion of sediment genesis, incorporating data from other exposures.

### 1. Grindstone Point section

Description

The section is located about 1200 m north along the shore from Grindstone Point (site 93009; Appendix A). The section is about 22 m high, poorly exposed, with 4 m of Carboniferous red sandstone of the Little Brook Formation at the base (Figure 4-12). The overlying 12 m is obscured, and only the upper 6 m of the section is well exposed. The lowest exposed unit is at least 1 m of moderately-sorted (s.d. 0.8ø), planar-bedded fine-, medium- and coarse-sand (1% granules, 98% sand and 1% silt; mean 2ø). Beds are 1 to 5 cm thick, normally graded to ungraded, and laterally continuous for greater than 2 m. Contacts between beds are commonly sharp. The unit contains rare subrounded cobble clasts, that disturb the bedding (Plate 4-14). Sand beds characteristically are compressed beneath the clasts. Clasts compose less than 10% of the unit and range from granule to cobble size, and are randomly distributed throughout.

The sand unit is overlain across a sharp, planar contact by 4.5 cm of laminated clayey silt and coarse-sand. Clayey silt laminae are about 0.5 cm thick, normally graded to ungraded, with sharp lower contacts. The coarse-

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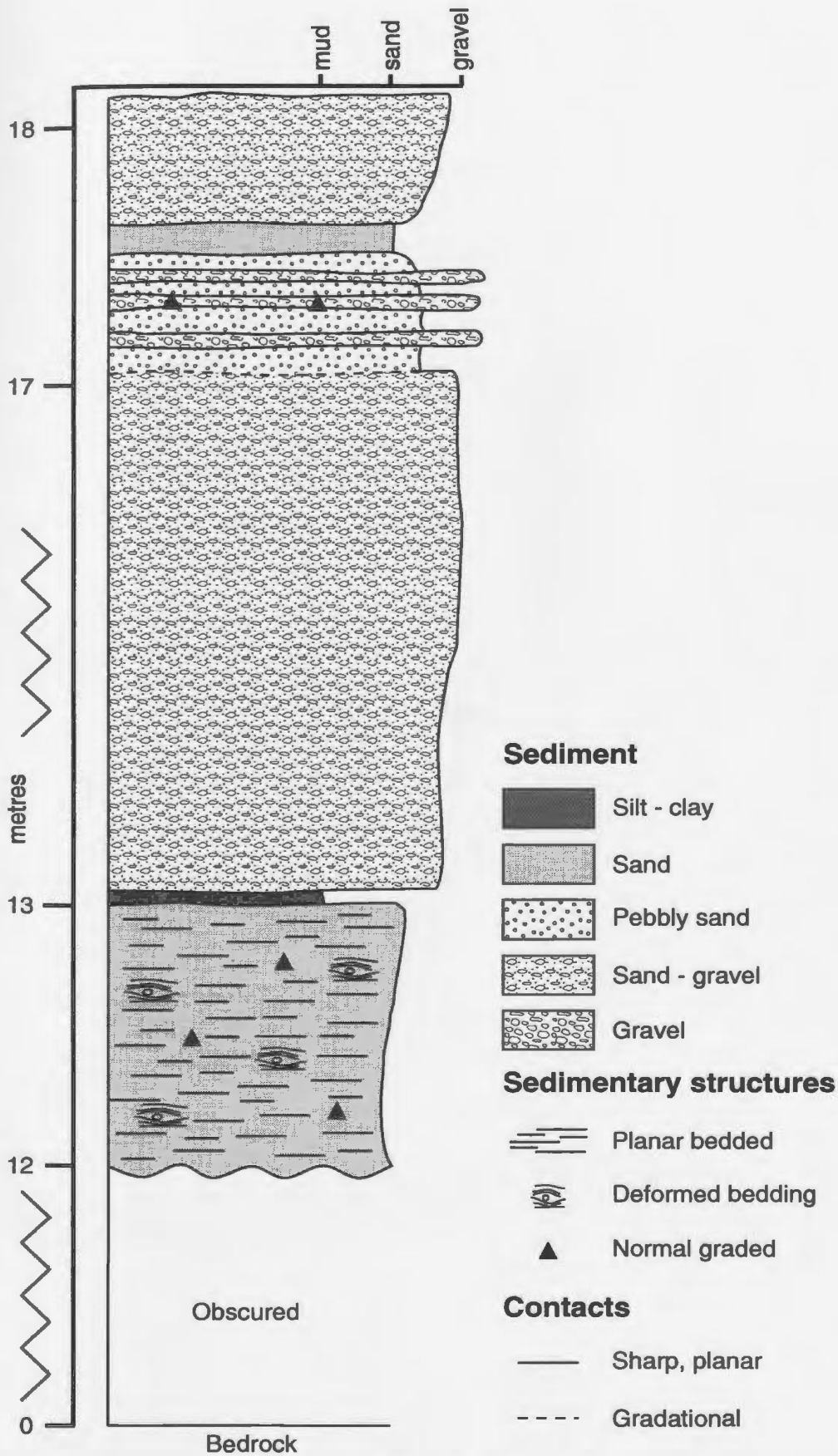
**Figure 4 - 12:** Stratigraphy of an exposure at Grindstone Point, Grand Lake.

**Plate 4-14:**
Sand-silt rhythmites within the Little Pond Brook
section on Grand Lake. This indicates standing water in
the Grand Lake valley, at least up to 16 m above present
lake levels.

sand beds are 1 cm thick, well-sorted, normally graded, with sharp lower contacts. There are three clayey silt laminae separated by three sand beds. A single channel sample for this unit showed a very poorly-sorted sediment composed of 60% sand, 37% silt and 3% clay, with a mean grain size of 3.6ø.

The sand-silt bed is overlain across a sharp, planar, horizontal contact by a 4 m-thick unit of sandy gravel. The unit is crudely stratified, and matrix supported. The matrix is medium- to coarse-sand, supporting subrounded, granule to boulder clasts up to 30 cm diameter, with numerous cobbles. Rhyolite (36%), basalt (24%), granite (17%), tuff (14%), and minor porphyry (7%), and gneiss (2%) comprise the rock types. Clasts long axes are commonly oriented downslope (at ~ 20° towards 290°).

A 45 cm-thick unit of interbedded granule gravel and pebbly sand overlies a gradational, planar contact. Five granule gravel beds were noted, each with greater than 2 m lateral extent. They were 1-2 cm thick, moderately- to well-sorted, normally graded (2 beds) to ungraded (3 beds), with undulating, gradational lower contacts. Pebbly sand beds are 5-12 cm-thick, have a poorly-sorted, fine- to medium-sand matrix and contain granule to pebble clasts up to 1.5 cm diameter. Four pebbly sand beds were found, all of which were internally structureless.

A 12 cm-thick bed of structureless, well-sorted coarse-sand overlies a sharp, planar contact, which is overlain by a 50 cm-thick bed of pedogenically modified sandy gravel, that forms the top of the section.


Interpretation

Sediments exposed in the Grindstone Point section are interpreted to have been deposited in standing water, by a combination of sediment gravity

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flow and suspension settling.

The basal planar-laminated sand, and overlying laminated clayey silt and coarse-sand are interpreted as having been deposited by sediment gravity flow, likely grain flow (c.f., Lowe, 1976, 1982). The thin, commonly ungraded beds with sharp lower contacts, suggest deposition from separate pulses of sedimentation. Periods of no flow are indicated by the normally graded beds of clayey silt, deposited by suspension settling. Sedimentation was thus initially by grain flow and subsequently by suspension settling. There are no flow structures suggesting current flow, and the bed geometry and lateral continuity of individual strata are compatible with deposition by turbidity current (Bouma, 1962; Ashley, 1988). Cobble-sized clasts that produce the downfolding of sand beds and which deform underlying sand-silts are interpreted as dropstones. Thomas and Connell (1985) described similar features, indicating that ice was in contact with at least part of the basin.

The crudely-stratified sandy gravel bed is also interpreted as having been deposited in standing water. Clasts lying conformable to bedding are interpreted as clasts moved by grain avalanching down bedding plane surfaces (Wadell, 1936; Johansson, 1963; Allen, 1984; Ashley *et al.*, 1985). The sediment source was from the adjacent hills. Clast assemblages from Grindstone Point show mostly rhyolite, basalt derived from the Springdale Group (Ssf and Ssm), porphyry and some granite from the Topsails Intrusive Suite (Sq and Sm), and coarse grained pink granite from the Hinds Brook granite (Whalen and Currie, 1988), all of which are found on the hills above Grindstone Point.

The sediments exposed at the Grindstone Point section were all deposited in standing water. The laminated sand-clayey silt, lack of current flow structures indicating fluvial transport, and the presence of dropstones all

support this conclusion.

## 2. Little Pond Brook section

### Description

This is the southernmost section examined and is located about 2100 m south of the mouth of Little Pond Brook (site 93013; Appendix A). It is 16 m thick, but only small areas are well exposed (Figure 4-12). The lower 4.5 m of the section is obscured, above which is a small area with 100 cm lateral and 142 vertical extent. It is generally composed of interbedded sand, gravelly sand, and diamicton. The central 8 m of the section is obscured, although small exposures show gravelly sand and interbedded fine-, medium- and coarse-sand beds. The upper 2 m is composed of rhythmically bedded sand-silt couplets, overlain by sandy gravel and gravelly sand.

The base of the lower 4.5 m is a planar stratified sand with a minimum thickness of 30 cm. Individual strata are moderately-sorted, fine-, medium- and coarse-sand, 0.5 to 1.0 cm thick, ungraded and contain rare pebble clasts. Lower contacts are sharp and commonly undulating.

A 15 cm-thick bed of structureless, medium- to coarse-sand, with rare granule to pebble clasts up to 1.5 cm diameter overlies a sharp, undulating contact. This unit is overlain across a sharp, undulating contact by a 10 cm-thick bed of reverse graded, pebbly sand, with a medium- to coarse-sand matrix (85% matrix), and granule to pebble clasts up to 2 cm diameter.

A 7 cm-thick, structureless, fine- to medium-sand bed overlies the pebbly sand bed above a sharp, undulating contact, and this in turn is overlain by a diamicton. The lower contact is sharp and undulating, and the diamicton bed is up to 25 cm thick, pinching out to the north over 100 cm. The diamicton
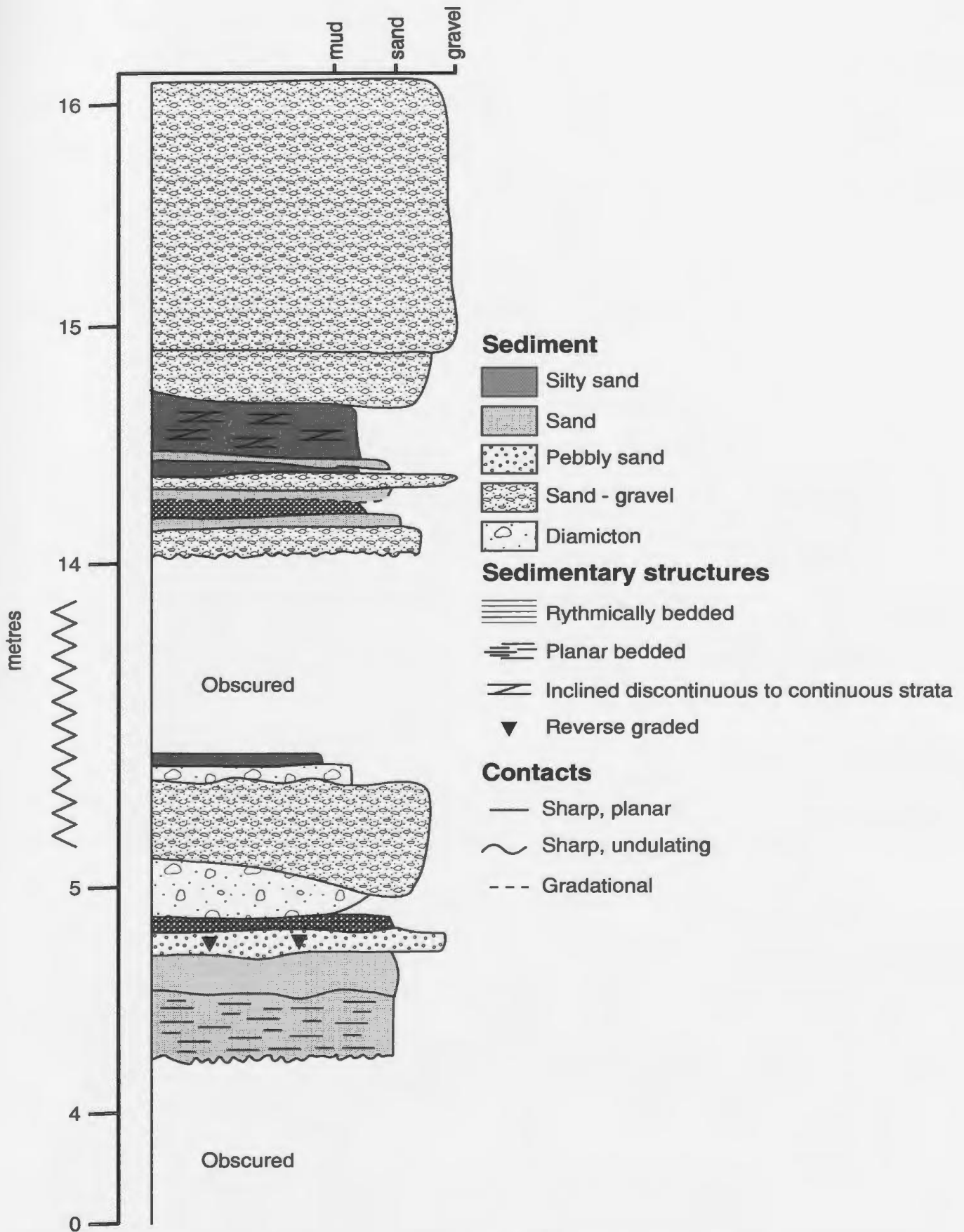
**Figure 4 - 13:** Stratigraphy of an exposure at Little Brook Pond, Grand Lake.

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is structureless, with a fine-sand to silt matrix, subangular to subrounded, granule to cobble clasts up to 20 cm diameter. A 40 cm-thick bed of structureless gravelly sand, with a medium- to coarse-sand matrix, and subangular to subrounded, granule to cobble clasts up to 20 cm diameter overlies a sharp, undulating contact. This unit is overlain by 5 cm diamicton across a sharp, undulating contact. The diamicton has similar characteristics to that underlying the gravelly sand. This is overlain by 5 cm structureless, poorly-sorted, dark reddish brown (5YR 3/4, moist) to pinkish grey (7.5YR 7/2, dry), silt (8% sand, 90% silt, 2% clay), with a mean grain size of 5.6ø (sample 934014; Appendix A).

The upper 200 cm, including the soil profile is well exposed (Figure 4-12). A stratigraphic log shows a basal unit of at least 10 cm of structureless gravelly sand, with a medium- to coarse-sand matrix, and granule to cobble clasts. It is overlain by a 3 cm-thick bed of well-sorted, structureless coarse-sand, and 6 cm rhythmically bedded very fine-sand to silt, both across sharp, planar contacts. The rhythmites consist of planar and horizontal, 0.1 to 0.5 cm-thick, normally graded laminae. There were twelve rhythmites. Contacts between laminae are sharp, and planar. Grain size analysis from a small area covering several silt-sand laminae shows a sediment composed of 24% sand, 76% silt and 0% clay, with a mean grain size of 4.9ø (sample 934015; Appendix A). Individual beds are inclined at about 10° towards 320°.

The silt-sand unit grades upwards into 5 cm of structureless medium sand. This is overlain across a sharp contact by 5 cm of clast-supported sandy gravel, with a coarse-sand matrix, and granule to pebble clasts. Open-work granule gravel lenses occur throughout the unit. The beds (Plate 4-15) are overlain by a sequence of very fine-sand - silt rhythmites (5 cm), structureless .

**Plate 4-15:**
Deformed bedding beneath drop-stone in the Grindstone Point section.
This is evidence for a proglacial lake in the Grand Lake valley formed
during deglaciation.

medium- to coarse-sand (7 cm), and sand-silt rhythmites (25 cm). These beds dip ~10° towards 320°. They are overlain by 20 cm structureless, matrix-supported, sandy gravel with a medium- to coarse-sand matrix, and granule to pebble clasts up to 5 cm diameter.

The section is capped by a 120 cm-thick bed of structureless gravelly sand, with a medium-sand matrix and granule to cobble clasts up to 20 cm diameter. Much of this unit is within the soil profile.

Interpretation

The sediments exposed within the Little Pond Brook section are interpreted to have been deposited within standing water. The sediments have characteristics similar to those exposed at Grindstone Point, and are interpreted in a similar manner.

Planar-laminated sand at the bottom of the exposure are interpreted as sediment gravity flow deposits, likely from grain flow (c.f., Lowe, 1976, 1982). The thin, commonly ungraded beds with sharp lower contacts, suggest separate pulses of sedimentation. Reverse graded beds are formed by grain avalanching on slip faces (Bagnold, 1954; Allen, 1984), and are typical of grain flows (Lowe, 1976; Walker, 1984). Rhythmically bedded sand-silt are interpreted to have been deposited by suspension settling from overflow-interflow. There are no structures to indicate current flow within the exposure. Matrix-supported sandy gravel beds found in the upper part of the section suggest deposition by sediment gravity flow rather than current flow.

The Little Pond Brook section contains diamicton beds. These beds are thin, structureless and pinch out laterally above sharp contacts. They are commonly overlain by sand or sandy gravels. Their characteristics and

stratigraphic relationships indicate that these diamicton beds are derived from debris flows within a subaqueous depositional environment. Diamictons interbedded with sand and gravel, with bedding dipping towards modern Grand Lake suggests deposition within an ice-proximal, deltaic (?) environment (e.g., Middleton and Hampton, 1976; Lawson, 1982; Ashley *et al.*, 1985; Nemec and Steel, 1988; Colella and Prior, 1990; Lønne, 1995).

### 3. Alder Brook section

Description

Several sand and gravel pits exist along the road leading to the hydroelectric station at Hinds Lake. Most of these have been graded and no exposures remain. A section located 800 m south of Alder Brook bridge (site 93018; Appendix A) has a surface elevation of 125 m asl. The pit has a 15 m face, most of which is obscured by slumping. The upper 3.6 m was cleared for examination (Figure 4-14). Most of the exposure is composed of a monotonous sequence of planar-laminated sand, capped by 80 cm of planar-bedded pebbly sand, and sand and gravel.

The lower 2.8 m of the exposure is mostly planar-laminated to planar-bedded sand. Beds are all laterally continuous over 2 m, and are inclined at 10° to 14° towards ~275° (i.e., downslope). Textural analysis shows a moderately-sorted (s.d. 0.8ø) sediment, composed of 99.8% sand and 0.2% silt-clay, with a mean of 2.3ø (sample 934020; Appendix A). There are 161 strata within the exposure, most separated by sharp, undulating contacts. Individual beds are ungraded to normally graded medium - fine-sand, medium - coarse-sand and coarse-sand. Coarse-sand strata are thin (0.2 to 0.5 cm) and confined to the lower 20 cm of the exposure. Medium- to coarse-sand strata range in
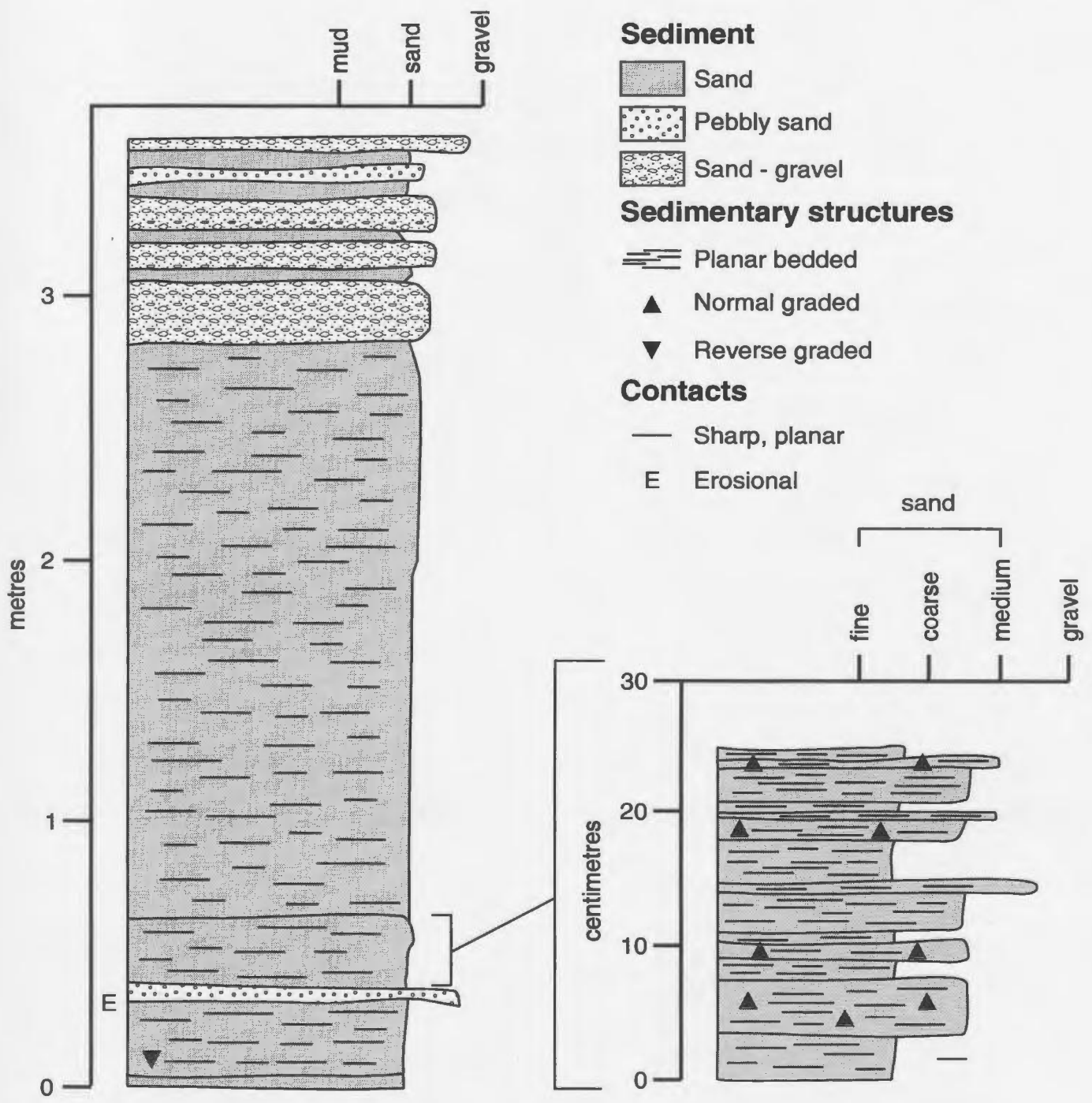
**Figure 4 - 14:** Stratigraphy of an exposure at Alder Brook, Grand Lake.

thickness from 0.2 to 4.0 cm, are mostly ungraded or normally graded, although rare reverse-graded strata were noted low in the exposure. The medium- to coarse-sand strata are interstratified with 0.2 to 5.5 cm thick, ungraded, medium- to fine-sand layers. The only interruption to the rhythmic stratification is a 5 cm-thick bed of ungraded pebbly sand containing subrounded pebble to granule clasts up to 4 cm diameter found near the base of the exposure. It overlies a medium- to fine-sand lamina across a sharp (erosional?) contact.

The upper 80 cm of the exposure is planar-bedded sand, pebbly sand and gravelly sand. Coarser beds are normally graded, and contain subangular to subrounded, granule to cobble clasts up to 12 cm diameter. Clasts are commonly flat lying, with long axes conformable to bedding. Coarse-sand accumulations are commonly found on the upslope side of clasts. Clast rock types include granite, rhyolite, basalt, gabbro, sandstone and shale.

Interpretation

The Alder Brook section contains the least variety of sediment types of the three sections described, being largely composed of a repetitive sequence of inclined beds of planar-laminated sand. These sands are interpreted to represent grain flows into a body of standing water. Laminae are thin, commonly ungraded with sharp lower contacts suggesting they were deposited incrementally. Reverse graded beds are formed by grain flow avalanching on slip faces (Bagnold, 1954; Allen, 1984). The uniformity of grain size and bed geometry suggest that rates of sediment input were consistent during deposition of this sediment. Dropstones and diamicton beds deposited by debris flow found at the Grindstone Point and Little Pond Brook exposures

indicated ice-proximal conditions. The structures were not found here, and may indicate that ice was distal to this part of the basin during deposition of these sediments. Individual beds dip towards modern Grand Lake, although angles of dip are low (10 to 14°). The grain-size, lateral continuity of beds, and the low angle bedding indicates deposition in a subaqueous fan.

The sequence generally coarsens upwards, suggesting either increased sediment input or increasing proximity to sediment source. The source of the sandy gravel was likely from the overlying hillside. Clasts in the upper part of the Alder Brook section are derived from the Topsails Intrusive Suite (Sp, Sm and Sq), the Springdale Group (Ssf and Ssm), the Hungry Mountain Complex and Ordovician granites (Oib and Oic), all of which are found on the hills above the section.

### Discussion

Sediments exposed within the Grindstone Point, Little Pond Brook and Alder Brook sections are all interpreted as being deposited in a subaqueous environment, during a period of higher water level in the Grand Lake basin. Sediments at Little Pond Brook and Alder Brook are interpreted to have been deposited in a fan or delta environment. There is evidence for ice-distal and ice-proximal sedimentation in these exposures.

Although the Grindstone Point, Little Pond Brook and Alder Brook exposures are the best along the shoreline, 29 other sections were examined (Figure 4-15). Many of the characteristics described from these three sections are found in sediments from the other exposures.
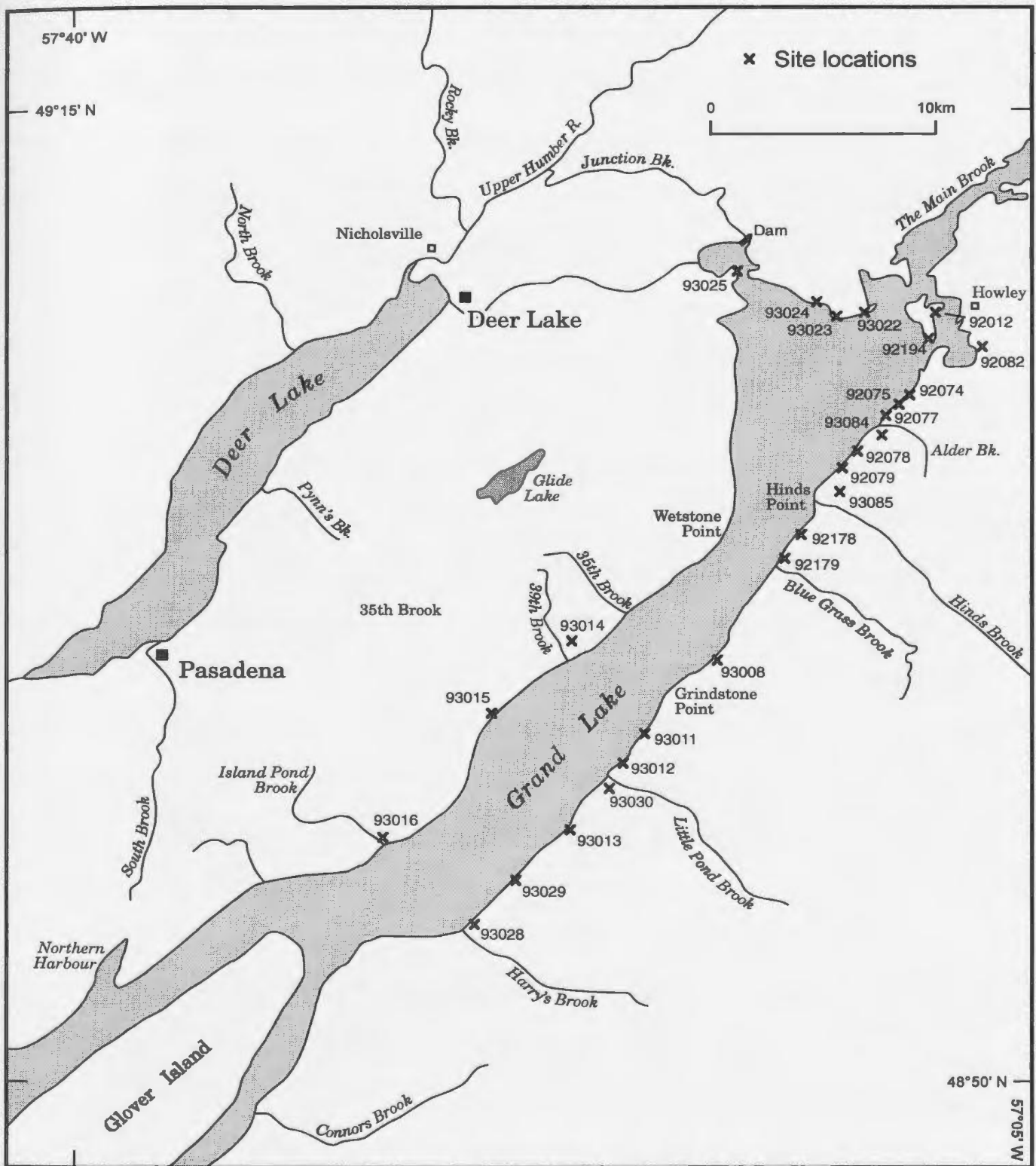
**Figure 4 - 15:** Location of sections described around the shores of Grand Lake.

Silt and clay

Rhythmically bedded silt and sand with or without clay is found at five locations, apart from the Little Pond Brook section:

On the west side of Grand Lake, just north of Thirty-fifth Brook (site 93015; Appendix A) (Figure 4-15), 3 m of interbedded fine sand, silt and clay is found below 93 m asl. The sediment is dark reddish brown (5YR 3/3, moist) to reddish grey (5YR 5/2, dry), with one channel sample showing a sediment composed of 35% sand, 40% silt and 25% clay, with a mean of 5.4ø. Beds are highly contorted, and overlain across a sharp, undulating contact by gravelly sand. This relationship suggests rapid deposition of the gravelly sand onto a saturated substrate producing soft sediment deformation structures.

On the north shore of Grand Lake, 1.3 km east of Blow Hard Point (Figure 4-15), a 7 cm-thick bed of contorted silt and clay is found at an elevation of 89 m asl (site 92022; Appendix A). Soft sediment deformation features include isoclinal folds and flame structures, and were induced by deposition of an overlying cross-bedded sand unit.

On the east side of Grand Lake, 2.2 km north of Hinds Brook (Figure 4-15), a 6 m exposure of mostly rippled sand was found on the west side of a well defined, northwest-trending, sand-dominated ridge. The section contains a unit of at least 20 cm-thick of planar-laminated silt and clay, with interbeds of sand extending up to 91 m asl (site 92078; Appendix A). The unit shows 16 normally graded silt-clay laminae. Sharp, planar contacts separate individual laminae. Silt beds within this unit are commonly overlain unconformably by 0.5 to 3.0 cm-thick, well-sorted, ungraded, fine-sand strata with sharp lower contacts. The unit is overlain by a bed containing draped ripples. The silt and clay rhythmites are interpreted as having been deposited by suspension

settling in standing water, with the fine-sand interbeds representing grain flows or high density turbidity currents.

About 500 m north of the Hinds Brook dam gate on the east side of the road (Figure 4-15), an 8 m-high section shows poorly exposed fine sand and silt (site 93085; Appendix A). The sediments are exposed in a unit containing laminated, fine- and very fine-sand, and silt. A single channel sample showed a grain size distribution of 12% sand, 86% silt and 2% clay, with a mean of 5.4ø. Laminae are highly contorted and deformed by subrounded, pebble to boulder clasts up to 60 cm diameter. The laminae were deposited by suspension settling in a body of standing water. The clasts were deposited following the laminae, likely by sediment gravity flow. This is suggested by the absence of medium- to coarse-sand in the matrix and the distortion of beds beneath clasts. The deformed unit is overlain by planar-laminated medium-, fine- and very fine-sands.

About 1.4 km north of Blue Grass Brook (Figure 4-15), a 20 m exposure of mostly interbedded sandy gravel and gravelly sand, contains a 90 cm-thick bed of planar-laminated silt and clayey silt (30 cm) grading up into fine-sand and silt (60 cm) (site 92178; Appendix A). The bed extends up to 99 m asl. Individual silt-clay lamina are normally graded and separated by sharp, planar contacts. Silt is thicker than clay, and commonly contains 2 to 4 mm-thick, planar, well-sorted, ungraded fine-sand strata. The unit is interpreted as having been deposited mostly by suspension settling, with periodic rapid sedimentation of sand from traction current.

Gravel and sand

Loose gravel and sand beds are found in 24 of 29 sections examined.

Sand-gravel units commonly compose the bulk of the sections. They commonly are loose, crudely horizontally-stratified, normally to ungraded beds of sandy gravel, gravelly sand, open-work granule to pebble gravel, and sand. Lenses of sorted sediment are common throughout. Sand strata are commonly thin (< 10 cm), well sorted, ungraded, with sharp upper and lower contacts. All beds are laterally continuous across the sections for at least 2 m. Interbedded sand and sand-gravel commonly are inclined, dipping between 8° and 26°, with dip angles consistently increasing with stratigraphic elevation. The direction of dip is always towards Grand Lake (Figure 4-15), suggesting the sediment was derived from the adjacent hills.

Pebble samples were taken from 22 exposures on the east side of Grand Lake. They indicate that clasts are mostly of rock types found on The Topsails, generally with sources directly upslope of the sections. Carboniferous sandstone and siltstone are relatively rare, despite the fact they underlie most of the sections along Grand Lake. Carboniferous clasts are generally confined to exposures on the north and west shore (e.g., sites 93014, 93023, 93025; Figure 4-15), or are associated with deposits at the mouths of the larger streams south of Hinds Brook (e.g., sites 93013, 93016; Figure 4-15).

Diamicton

Diamicton beds are found in six sections (sites 92178, 93008, 93011, 93015, 93028, 93029; Figure 4-15), all on the east side of Grand Lake. Table 4-1 lists the characteristics of these diamictons. Where diamictons are found interbedded with fine grained sediments or sand-gravel, have weak, girdle clast fabrics, and irregular-shaped sand lenses, they are interpreted as debris flow deposits, similar to those at Little Pond Brook. This interpretation applies to diamictons

**Table 4-1:** Characteristics of diamictons exposed along the east shore of Grand Lake.

| Site | Thick (cm) | Colour | Sand (%) | Silt (%) | Clay (%) | Sorting (ø) | $S_1$ | $S_3$ | Trend (°) | Structures | Overlain by | Underlain by |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92178 | 50+ | 7.5YR 4/2 | 71 | 27 | 2 | 3.5 | | | | None | Silt-clay rhythmites | ? |
| 93008 | 30 | 5YR 3/3 | 73 | 15 | 12 | 2.4 | | | | None | Sandy gravel | Sandy gravel |
| 93011 | 120+ | 5YR 3/3 | 76 | 21 | 3 | 3.1 | 0.56 | 0.13 | 047 | Irregular planar lenses | Sandy gravel | ? |
| 93011 | 110 | 7.5YR 4/2 | 86 | 11 | 3 | 4.0 | 0.51 | 0.21 | 025 | Irregular planar lenses | Surface | Sandy gravel |
| 93015 | 100 | 7.5YR 3/4 | 64 | 26 | 10 | 4.6 | | | | None | Surface | Gravelly sand |
| 93028 | 600 | 10YR 3/4 | 70 | 23 | 7 | 4.0 | 0.61 | 0.12 | 302 | Irregular planar lenses | Surface | ? |
| 93029 | 400 | 5YR 3/4 | 75 | 21 | 4 | 3.4 | | | | None | Sandy gravel | ? |

exposed at sites 93011 and 93015. There are no clast fabric data from sites 92178, 93008 and 93029, and thus no interpretation is presented. The close association of diamicton beds with fine-grained sediments or other waterlain deposits suggests they were deposited in a subaqueous environment.

The diamicton exposed at the base of section 93028 is interpreted as a debris flow deposit. Clast fabric is moderate, slightly girdled ($S_1=0.61$, $S_3=0.12$), with a preferred clast orientation towards 302°. Ice flow in this direction would have crossed gabbro and diorite of the Rainy Lake Complex (unit Sor1 of Whalen and Currie, 1988; Figure 1-5). The diamicton contains none of these rock types. Instead, clast rock types suggest derivation from the northeast. The presence of large proportions of rhyolite and porphyry indicates a source in the Springdale Group (Ssf) and Topsails Intrusive Suite (Sqa), respectively. Based on the fabric strength, the clast provenance unrelated to preferred clast orientation, and geographic location of the unit at the base of a steep hill, the diamicton at site 93028 is interpreted as having been deposited by debris flow.


Cross bedded and rippled sand

Cross-bedded and rippled sand are found in six sections (sites 92012, 92078, 92082, 92194, 93022, 93024) (Figure 4-15). Most of these are on the north shore of Grand Lake. Current flow indicators towards the Junction Brook area (sites 93022, 93024, 92194), towards Howley (site 92012), or towards Sandy Lake (site 92082). On the east side of Grand Lake, 2.8 km north of Hinds Brook, a 2 m section shows fine- to medium-sand, asymmetric erosional stoss climbing ripples ($\lambda$=12 cm, H=1.5 cm, R.I.=8) indicating northward current flow. The ripples are commonly draped by 0.5 to 1.0 mm reddish brown silty clay. The

draped ripples showing deposition from suspension settling during waning flow conditions, and is consistent with deposition within a standing water body. Draped ripples are also found at site 92194, on the north shore.

The small number of palaeo-current flow measurements taken from a small number of poor exposures allows no meaningful interpretation of palaeo-flow directions.

### Grand Lake sections: Discussion

The sediments and features along the east side of Grand Lake are the result of deltaic or fan-delta deposition. Sand and gravel beds dipping into the lake, rhythmically-bedded sand, silt and clay, draped ripples, and geomorphology all support this interpretation. An alternative hypothesis is deposition as paraglacial alluvial fans, similar to those described by Ryder (1971a, 1971b), and Church and Ryder (1972). Rhythmically bedded sediments, dropstones and diamicton lenses are not typical of alluvial fans. Alluvial fans should grade toward their source areas, and therefore the elevation of the tops of alluvial fans within a valley should vary. Along Grand Lake, the elevations of the surfaces are generally consistent.

Flat-topped features at the mouths of larger streams, such as Harrys Brook, Little Pond Brook, Hinds Brook, and brooks north of Grindstone Point with surface elevations of 118 to 157 m asl, are interpreted as deltas (see Chapter 2). The features show higher water levels in Grand Lake. The development of flat-topped surfaces in these deltas presumably reflects more stable streams, rather than the more episodic discharge onto the fan-shaped deltas north of Hinds Brook.

Rhythmically bedded sand, silt and clay, and draped ripples are

evidence for standing water conditions at a higher elevation than the surface of modern Grand Lake. These deposits are found up to an elevation of 99 m asl, 12 m above the modern lake surface. Individually, each of these deposits could be explained as being developed in ice marginal lake. The distribution of sites containing silt and clay, on the west, east and north sides of the lake, all have similar elevations. Deposition within a single body of standing water is thus more likely.

The elevation of sediments and features indicating standing water shows water surfaces up to 150-160 m asl. This is substantially above the marine limit of 60 m defined for the Humber Arm in this thesis, and elevations derived from other coastal areas of western Newfoundland (e.g., Liverman, 1994; Grant, 1980; Brookes et al., 1985). The deltaic deposition was therefore associated with a lacustrine environment. The orientation of inclined beds, the distribution of sediment and clast provenance show that the major source of sediment and water discharge was from The Topsails, to the east of the basin. The area north of Hinds Brook is characterized by fan-deltas. This area has only small tributary valleys with steep profiles entering the modern lake. In these cases, it is probable that the source of water and sediment was wasting ice on the adjacent hilltops, that entered the valley as poorly confined flows. South of Hinds Brook, several larger streams enter Grand Lake. Meltwater and sediment discharge in these areas was along well-defined channels. At the mouths of these streams flat-topped deltas are found, with surface elevations, from north to south, including 118 m and 157 m asl (Hinds Brook), 144 m asl (Harry's Brook, brook north of Grindstone Point), 140 m asl (Little Pond Brook), 135 m asl (south Grand Pond Point), 130 m asl (Connors Brook), and 128 m asl (Lewaseechjeech Brook). The progressive

decrease elevation from north to south is likely related to post-glacial isostatic rebound (see Chapter 6). The flat-topped features were established during a period of relative stability in lake development.


**Sediments exposed at the southwestern end of Grand Lake**

Several small sections were briefly examined at the southwestern end of Grand Lake. These sections are outside the Humber River basin, but were examined because of their relevance to discussions of the Quaternary history of the basin.

Gallants Pit

A large, abandoned gravel pit is located opposite the junction between the Trans Canada Highway and the road to Gallants (site 91137; Appendix A). The pit is located on the south side of a channel extending from modern Grand Lake towards the Harrys River valley. Surface elevation of the pit is about 145 m asl.

The sediments are more than 15 m thick, poorly exposed, but where evident consist of weakly-stratified gravel, sandy gravel and sand beds. The gravel and sandy gravel beds are 20-30 cm thick, normally graded or ungraded, commonly clast-supported, and contain sub-rounded, commonly granite and felsic volcanic granules to boulders, up to 1.5 m diameter. Clasts show no obvious imbrication. Gravel beds are open-work, normally graded and planar bedded. Beds have sharp, sub-horizontal upper and lower contacts. Sand beds are 10 to 30 cm thick, laterally discontinuous, planar-bedded, well-sorted medium- to coarse-grained. Some trough cross-bedded sand showed flow directions between 230° and 110°.

The sediments found within the Gallants pit were deposited by current

flow. Beds are commonly well-sorted gravel to sand, indicating variable current flow velocities, including high energy flows. Trough cross-bedding indicates variable flow directions. The combination of roughly horizontally stratified gravels, horizontally-stratified sand and planar cross-stratified sand suggests deposition in an ice-proximal braided stream environment as described by Rust (1975, 1978) and Miall (1978). No collapse structures, faulting, diamicton beds, or high angle cross-beds were noted that would suggest that the deposits formed in an ice-contact environment.

### Grand Lake road sand pit

An abandoned pit is within the Grand Lake Brook valley, and is located about 1.1 km from Grand Lake on the north side of a gravel road leading to the Trans Canada Highway (site 91136; Appendix A). The pit exposes about 15 m of sediment with a surface elevation of about 120 m asl.

Sediment exposed within the pit is mostly moderately-sorted medium-sand. Clasts are rare, and where found are pebble to cobble size. Sands are rippled, mostly erosional stoss. Of ripples noted, wavelength was 15 to 25 cm, and ripple height 4 to 7 cm, producing a ripple index of 4 to 6. Planar-tabular cross-beds and trough cross-beds are common across the pit. Palaeo-flow indicators showed westward flow (~ 230° to 270°), i.e., away from Grand Lake.

The sediment in the Grand Lake sand pit was deposited by unidirectional current flow, as shown by the rippled and cross-bedded sand. Erosional stoss ripples indicate migration rates greater than deposition, and grain size and ripple dimensions suggest low current flow velocity (less than 50 cm sec$^{-1}$) (Harms *et al.*, 1982).

The pit is within a channel, and the lack of clasts in an area elsewhere

dominated by sand and gravel (c.f., Gallants pit) suggests deposition within a lake. Alternative depositional environments are subglacial or proglacial. Deposition within a subglacial tunnel would likely include coarse material and diamicton, either incorporated by falling from the tunnel roof, or as debris flows from the channel sides (e.g., Cheel and Rust, 1982; Eyles and Eyles, 1992). A proglacial depositional environment is characterized by highly variable water and sediment discharge, commonly producing a gravel-dominated braided stream system (e.g., Miall, 1992). Non-marine, sand-dominated systems are rare in Newfoundland. Sommerville (1997) describes similar sediments in the Terra Nova River area, eastern Newfoundland and also interprets them as having been deposited in a proglacial lacustrine environment.

**Fine-grained sediment in the Humber River basin: discussion**

Other exposures of fine grained, rhythmically bedded sediments in the Deer Lake - Grand Lake basin were described by other workers. Normally graded, rhythmically stratified, sand to silt laminae occur at the base of the Gillard's Lake section at 140 m asl, overlain by 30 m of interbedded silt, sand and diamicton (Liverman and St. Croix, 1989b). The sediments were interpreted as glaciolacustrine, deposited in a pro-delta setting and overlain by debris-flow diamictons, originating from an ice margin abutting standing water.

Lundqvist (1965) described a section at an elevation of 104 m asl in a canal cut across the Indian Brook-Birchy Lake drainage divide. Liverman and St. Croix (1989b) re-examined the section and found 1 m of rhythmically laminated sand, silt and clay, overlain by sand and gravels. This sequence

indicates that a brief period of glaciolacustrine rhythmite sedimentation was followed by progradation of deltaic sediments. Clast-supported, horizontally bedded gravel exposed at the surface is probably fluvial, and was deposited following lake drainage.

Fine-grained sediments along the eastern and northern shores of Grand Lake were described in the discussion of sediments exposed in sections along Grand Lake above.

Elsewhere throughout the Humber River basin below approximately 25 m asl, diamicton and glaciofluvial sediment is overlain by reddish-brown, rhythmically bedded silt and clay. These extend from Harrimans Steady near Reidville to the modern coast, the exception being the Humber River gorge, where only small pockets of rhythmites are found. Silt-clay thickness exceeds 60 m at Deer Lake airport (Environment Canada, 1980), and over 100 m near Steady Brook (Golder Associates, 1983), but more commonly is 10 m or less (Appendix B). The sedimentology of these fine-grained sediments has been described from exposures at Rocky Brook and North Brook.

Fine-grained deposits found below published estimates of marine limit may be marine and those above lacustrine or glaciolacustrine. To test this hypothesis, other indicators of depositional environment, including macro- or micro-fauna, and geochemistry are considered.


Macro-fauna

Marine shells found within fine-grained sediments above modern sea level are restricted to areas around the modern coastline (Figure 4-16; Table 4-2). The table is restricted to reported data, and in some cases may not include the range of species found at a particular site. Radiocarbon dates on shells

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from these locations range between 10.6 and 13.1 ka.

Dyke *et al.*, 1996 have reviewed the distribution of collected marine shells in Canada, and in comparison to modern distributions have characterised fossil assemblages as they relate to water temperature and, to a lesser degree, salinity. The restricted Arctic assemblage contains few species (*Hiatella arctica, Mya truncata, Portlandia arctica*). No known modern assemblage contains only these species, and thus it may characterize ice-proximal marine environments. The diverse Arctic assemblage contains a range of gastropods (e.g., *Natica clausa*), pelecypods (e.g., *Mya truncata, Macoma calcarea, Hiatella arctica, Nuculana penula*) and Cirrepeds (e.g., *Balanus balanus*). These species are found in environments with 7-12 months sea ice cover, and shallow water (less than 100 m) with summer temperatures up to 5°C. This assemblage reflects the arrival of species shortly after deglaciation The arctic assemblage with boreal species characterizes a zone of slightly warmer water temperatures, allowing survival of more stenothermal species (e.g., *Chlamys islandicus, Macoma balthica, Mytilus edulis, Balanus hameri*). Other assemblages (the boreal assemblage with Arctic species, boreal assemblage, and Virginian assemblage) reflect increasingly temperate conditions. Marine fossils may thus provide an indicator of palaeo-environmental conditions at the time of their death.

Marine pelecypods, gastropods and cirrepeds found in the Humber River basin are cold water species (Lubinsky, 1980; Dyke et al., 1996). Arctic and diverse Arctic assemblages are found in Goose Arm and Wild Cove. They are typical of recently deglaciated marine environments. The remainder of the area is generally characterised by an Arctic assemblage with boreal species. The
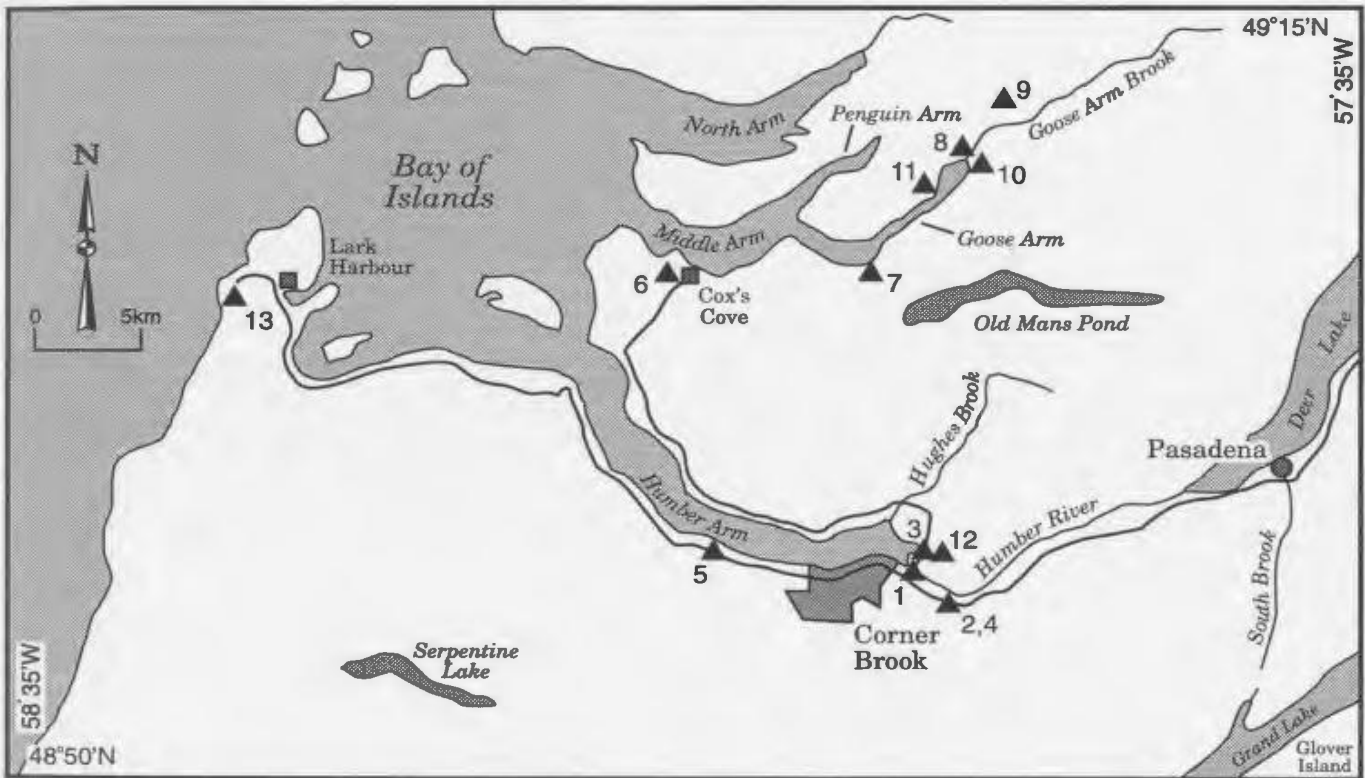
**Figure 4 - 16:** Location of marine shells found in the Humber River basin area. Numbers refer to locations described in Table 4-2.

**Table 4-2**: Marine macro-fauna species found in the coastal areas of the Humber River basin, and their modern

habitats, using the terminology of Dyke *et al.* (1996).

| # | Location | NTS | Latitude (°N) | Longitude (°W) | Elev. (m asl) | Reference | Species | Fossil assemblage |
|---|----------|-----|---------------|----------------|---------------|-----------|---------|-------------------|
| 1 | Dancing Point | 12A13 | 48°57' | 57°53' | 15 | GSC Paper 87-7 | *Macoma balthica* | Arctic-dominated with boreal (?) |
| 2 | Humber River gorge | 12A13 | 48°56.9' | 57°50.8' | 13 | This thesis | *Balanus hameri* *Hiatella arctica* | Arctic-dominated with boreal |
| 3 | Wild Cove | 12A13 | 48°58.3' | 57°52.7' | 18 | Batterson *et al.*, 1993 | *Mya truncata* *Hiatella arctica* *Mya arenaria* *Macoma calcarea* | Diverse Arctic |
| 4 | Humber River gorge | 12A13 | 48°56.9' | 57°50.8 | 13 | Batterson *et al.*, 1993 | *Balanus hameri* *Hiatella arctica* | Arctic-dominated with boreal |
| 5 | Curling | 12A13 | 48°57.5' | 57°59.3' | 10 | This thesis | *Mya truncata* *Hiatella arctica* *Chlamys islandicus* | Arctic-dominated with boreal |
| 7 | Goose Arm | 12H04 | 49°07.4' | 57°56' | 6 | GSC Paper 89-7 | *Mya truncata* | Arctic (?) |
| 8 | Goose Arm | 12H04 | 49°11.0' | 57°51.8' | 28.5 | This thesis | *Hiatella arctica* *Chlamys islandicus* *Macoma balthica* *Mya arenaria* | Arctic-dominated with boreal |
| 9 | Goose Arm | 12H04 | 49°12.7' | 57°49.7' | 50 | Batterson *et al.*, 1993 | *Mya truncata* | Arctic (?) |
| 10 | Goose Arm | 12H04 | 49°10.9' | 57°51.5' | 7 | This thesis | *Nuculana penula* *Mya truncata* *Balanus crenatus* *Natica clausa* | Diverse Arctic |
| 11 | Goose Arm | 12H04 | 49°10.1' | 57°53.1' | 26.5 | This thesis | *Mya truncata* | Arctic (?) |
| 12 | Wild Cove | 12A13 | 48°58.3' | 57°53.3' | 7 | This thesis | *Macoma calcarea* *Hiatella arctica* *Balanus crenatus* *Nuculana* sp. *Chlamys islandicus* *Natica clausa* | Arctic-dominated with boreal |

| # | Location | NTS | Latitude (°N) | Longitude (°W) | Elev. (m asl) | Reference | Species | Fossil assemblage |
|---|----------|-----|---------------|----------------|---------------|-----------|---------|-------------------|
| 13 | Little Port | 12G01 | 49°06.7' | 58°24.8' | 37 | Brookes, 1974 | *Mytilus edulis* | Arctic-dominated with boreal |

areas may have experienced increased seasonal warming, but not sufficient to prevent arctic species from dominating (Dyke et al., 1996). Marine shells in the inner part of the Humber Arm, including the Humber River gorge are part of this assemblage. *Macoma balthica* shells identified at Dancing Point also fall into the Arctic assemblage with boreal species. Grant (in Blake, 1987) interprets the sediment in which the shells are found to be part of an ice-proximal delta (see discussion of Dawe's Pit). *Macoma balthica* are dominantly a boreal species, although they are commonly found in arctic assemblages (Dyke *et al.*, 1996). They are not associated with modern, ice-proximal, glaciomarine environments (Rodrigues, 1992), and are not found within the Arctic or diverse arctic assemblages. The presence of marine shells with boreal affinities at the head of Humber Arm indicates the infusion of warmer water into the area following deglaciation.

The presence of marine shells in fine-grained sediments adjacent to the modern coast, and within the Humber River gorge shows these areas were inundated by the sea shortly after deglaciation. Fine-grained sediment examined in sections at Pasadena, Reidville, and Steady Brook, and in numerous small roadside exposures between Corner Brook and Deer Lake, did not contain macro-fossils.

### Micro-fauna

Fourteen silt-clay samples from coastal exposures, the Deer Lake valley, and the shores of Grand Lake were examined for foraminifera. Samples were wet sieved through a 4ø sieve, and the coarser than 4ø fraction dry sieved through a nest of 1ø, 2ø and 3ø sieves. The retained fraction was examined using a binocular microscope.

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Samples from fine-grained sediments adjacent to the modern coast commonly contained foraminifera of *Elphidium excavatum* and rare specimens of *Cassidulina reniforme*. The two species tolerate a wide range of temperature and salinity conditions, and are commonly the first species to appear following deglaciation (Knudsen, 1971; Scott *et al.*, 1984; Vilks *et al.*, 1989). They thus represent a glaciomarine environment, with temperature and salinity about 0°C and 25-30‰, respectively. This assemblage has been identified from marine muds in the Humber Arm (Shaw *et al.*, 1995), and elsewhere in eastern Canada (e.g., Vilks *et al.*, 1989; Maclean *et al.*, 1992; Rodriques *et al.*, 1993).

Samples of fine-grained sediment collected from along the shores of Deer Lake and Grand Lake showed no well-preserved foraminifera. Near Reidville (site 91010; Appendix A), and at Eastern Brook, near Pasadena (site 91192; Appendix A) samples contained agglutinated grains (C. Periera, Department of Mines and Energy, personal communication, 1996). These are silt-sized masses agglutinated by extraneous material (Moore, 1964), in this case chitin-like endoskeletons. Species identification is hampered by the agglutinates, and no surface pattern was noted to aid classification. Scott *et al.* (1980) and Murray (1991) state that agglutinated foraminifera dominate brackish water and estuarine environments in Atlantic Canada.

Fine-grained sediment samples examined from elsewhere in the basin were devoid of micro-fauna. The lack of microfauna (or microflora, such as diatoms) does not imply the area was not inundated by the sea. Low to zero concentrations of microfauna were reported in other areas of eastern Canada, including the Gulf of St. Lawrence (Rodriques *et al.*, 1993), in the Hudson Strait (Vilks *et al.*, 1989), and at the base of a core from the Humber Arm

(Shaw *et al.*, 1995). Rodriques *et al.* (1993) attributed these low values to high meltwater discharge. It is also likely that turbidity within the water column hampered the influx of microfauna (or microflora), and in areas undergoing isostatic rebound, such as the lower Humber River valley, the length of time available for migration was short. The Humber River gorge provides a narrow entrance to the Deer Lake basin through which modern discharge rates are high (mean annual discharge about 120 $m^3/s$) (Department of Environment and Lands, 1992). This would also prove a severe impediment to the in-migration of marine microfauna. Palaeontological evidence in muds inland of the Humber River gorge is scarce, and does not conclusively demonstrate a marine or lacustrine depositional environment.

### Geochemistry

Geochemistry, particularly boron chemistry, is used as a palaeo-environmental indicator of conditions during deposition of silt-clay. Sea water contains about 4.6 p.p.m. boron (mostly as hydroxides), compared to 0.1 p.p.m. for freshwater environments (Goodarzi and Swaine, 1994). Boron may be incorporated rapidly into clay minerals (particularly illite), initially by surface absorption and more slowly by replacement of alumina in tetrahedral sites of the mica structure. The concentration of boron within fine grained sediments is proportional to the salinity of the solution in which it was deposited, and boron thus may be used as an indicator of palaeosalinity (Lerman, 1966; Shimp *et al.*, 1969; Couch, 1971; Catto *et al.*, 1981; Mosser, 1983; Goodarzi and Swaine, 1994). Harder (1970) suggested that boron content is dependent on a number of factors including the boron content of water in the zone of sedimentation, distance traveled by particles during sedimentation, water temperature and

grain size. Shimp *et al.* (1969) and Levinson and Ludwick (1966) considered that boron content increases with decreasing grain size. Catto *et al.* (1981) suggested that boron values greater than 105 p.p.m. are likely representative of marine environments, whereas those below 30 p.p.m. are freshwater. Similar ranges were reported by Goodarzi and Swaine (1994) in coals.

Boron analysis was completed on silt-clay samples from sediments independently identified to represent raised marine and freshwater environments (Table 4-3). Methods of analysis were described in Chapter 1. The marine samples were from coastal locations in the Humber Arm and near Springdale, and commonly the sediments sampled contained marine mollusca. Freshwater sediments were from raised pro-glacial or ice-marginal lakes in the Tulks River valley in central Newfoundland, the Birchy Lake valley at a site previously described by Lundqvist (1965), and from the South Brook valley near Pasadena. In each case, sediments were from well above marine limit for the local area. Samples from within the Humber Valley were all from elevations below 50 m asl.

Data show that freshwater muds had values from 36 to 73 p.p.m. boron (mean 56 p.p.m.). The boron content of muds from areas of known marine or glaciomarine sedimentation in the Cook's Brook and Wild Cove areas ranged in value from 57 to 70 p.p.m. (mean 63 p.p.m.), indicative of brackish water conditions. Samples from the Indian Brook valley, east of Birchy Lake, record a wide range of boron values from 28 to 131 p.p.m. (mean 54 p.p.m.). Scott *et al.* (1991) suggested samples from this area were deposited in a brackish water environment based on their vanadium content. Samples from below marine limit in the Humber River valley ranged from 50 to 78 p.p.m. (mean 64 p.p.m.). The data may also be interpreted to indicate brackish water conditions.

**Table 4-3:** Boron geochemistry of fine-grained sediments in the lower Humber River valley, compared with other areas in west-central Newfoundland. Samples originally collected by Sparkes, Liverman and Kirby (all Newfoundland Geological Survey) were analysed for boron and data released below.

| Geographic Location | Source | Environment | Value (p.p.m.) |
|---|---|---|---|
| Tulks Valley | Sparkes, unpublished data | freshwater | 45 |
| Birchy Lake | Liverman, unpublished data | freshwater | 49 |
| Birchy Lake | Liverman, unpublished data | freshwater | 36 |
| South Brook | Kirby, unpublished data | freshwater | 63 |
| South Brook | Kirby, unpublished data | freshwater | 68 |
| South Brook | Kirby, unpublished data | freshwater | 73 |
| South Brook | Kirby, unpublished data | freshwater | 57 |
| | | | |
| Indian Brook 1 - base | Liverman, unpublished data | glaciomarine | 31 |
| Indian Brook 1 | Liverman, unpublished data | glaciomarine | 104 |
| Indian Brook 1 | Liverman, unpublished data | glaciomarine | 28 |
| Indian Brook 1 | Liverman, unpublished data | glaciomarine | 29 |
| Indian Brook 1 - top | Liverman, unpublished data | glaciomarine | 32 |
| Indian Brook 2 - middle | Liverman, unpublished data | glaciomarine | 63 |
| Indian Brook 2 - all | Liverman, unpublished data | glaciomarine | 131 |
| Indian Brook 2 - top | Liverman, unpublished data | glaciomarine | 34 |
| Indian Brook 3 | Liverman, unpublished data | glaciomarine | 30 |
| | | | |
| Cook's Brook | This thesis | marine | 57 |
| Cook's Brook | This thesis | marine | 64 |
| Cook's Brook | This thesis | marine | 70 |
| Wild Cove | This thesis | marine | 58 |
| | | | |
| Near Steady Brook | This thesis | unknown | 54 |
| North Brook | This thesis | unknown | 72 |
| North Brook | This thesis | unknown | 57 |
| North Brook | This thesis | unknown | 59 |
| North Brook | This thesis | unknown | 57 |
| North Brook | This thesis | unknown | 68 |
| North Brook | This thesis | unknown | 78 |
| North Brook | This thesis | unknown | 64 |
| Rocky Brook | Liverman, unpublished data | unknown | 69 |
| Rocky Brook | Liverman, unpublished data | unknown | 50 |
| Rocky Brook | Liverman, unpublished data | unknown | 76 |
| Rocky Brook | Liverman, unpublished data | unknown | 67 |
| Rocky Brook | Liverman, unpublished data | unknown | 73 |
| Reidville | This thesis | unknown | 50 |
| Reidville | This thesis | unknown | 60 |

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There is considerable overlap in the range of values between different sedimentary environments, and conclusions concerning the palaeo-salinity of muds within the Humber River valley must be considered speculative. Samples of fine grained sediment from the area are clay-rich (mean 43.4%, n=10), and clay mineralogy is dominated by illite (Vanderveer, 1977), both suitable for boron absorption. However, the fine-grained sediments in the lower Humber River valley were deposited in an area of rapid isostatic adjustment that was a major conduit for glacial meltwater, and they may thus contain a large component of non-clay minerals in the clay-sized fraction. There may also have been insufficient time for the absorption of boron to occur, or that the large input of turbid freshwater may have served to dilute sea water and produce local differences in geochemistry (Scott *et al.*, 1991). Samples containing marine macro-fossils were deposited in fjord environments, rather than open coastal waters. They may also represent brackish water conditions.

The boron content of fine grained sediments from within the Humber River valley suggests brackish water conditions (c.f., Catto *et al.*, 1982; Goodarzi and Swaine, 1994). Values are above those of sediments deposited in known freshwater environments from the Tulks valley and Birchy Lake valley, although not above those from South Brook. Boron values from marine or glaciomarine sediments found in the Indian Brook valley contain low concentrations that may be explained by turbid freshwater input.

Conclusion

The problem of differentiating sediments deposited in a marine from freshwater environment is not unique to the Humber River basin. Similar

problems have been encountered in environments where fine-grained sediments found below published marine limits are devoid of macro- or micro-fauna, e.g., Alaska (D. Barclay, University of Buffalo, personal communication, 1996), Cape Cod, Massachusetts (Winkler, 1994), and Puget Sound, Washington State (R. Thorson, University of Connecticut, personal communication, 1997).

The depositional environment of fine-grained sediments in the lower Humber River valley remains speculative. The sediments contained no macrofossils, no microflora, and only rare foraminifera, and had no distinct geochemical signature. A sedimentological examination showed the sediments were deposited in standing water. Isotopic examination has been used to differentiate freshwater from marine environments in Israel (Reinhardt, 1996), but analyses were of the molluscs, foraminifera and ostracods, rather than the sediment in which they were found. Analyses of strontium isotopes within sediment deposited in a brackish marine environment may be hampered by a $^{87}Sr/^{86}Sr$ ratio that may be similar to that in sea water, because there may not be enough dissolved Sr in the glacial meltwater to overcome the high concentration of Sr in sea water (E. Reinhardt, Dalhousie University, personal communication, 1996).

**Stratigraphic relationships in the Humber River basin**

Exposures of Quaternary sediment scattered across the Humber River basin, described in this and the preceding chapter, contain sediments deposited in a range of environments, including subglacial, proglacial, glaciolacustrine, glaciomarine and fluvial. Correlation between sections is equivocal, because of the wide spatial distribution, the consequent inability to

demonstrate facies changes, and the poorly defined temporal relationships. Sediments from the same depositional environment are time transgressive. Stratigraphic relationships are therefore proposed based on similar depositional environments, with stratigraphic succession providing a relative dating control.

Stratigraphic relationships are presented as a series of five transect lines oriented roughly parallel with, and perpendicular to, the basin axis (Figure 4-17a). Descriptions of individual sections found along these up-valley and across-valley profiles, are used to construct an idealized chrono-stratigraphic column for the area (Figure 4-17b). It represents the sediment types and depositional environments found across the basin, rather than inferring regional correlation of individual sections. A composite section is presented in Figure 4-17b a chronological representation and does not exist at any individual site.

Transect A-B extends along the axis of the Humber River valley from Corner Brook to north of Cormack. It includes exposures described at Humbermouth, Hughes Brook, the lower Humber River valley, and from the head of Deer Lake, as well as general descriptions from the Deer Lake basin and the Cormack area. The lowest Quaternary stratigraphic unit in the Humber River valley is a diamicton. Diamicton is found in each of the areas described, but only exposed as the surface sediment in the upper Humber River valley, away from the modern Humber River. The character of diamicton varies considerably along the valley. The colour and grain size of the matrices have been strongly influenced by local bedrock. For example, areas underlain by Carboniferous bedrock show rapid variation in matrix colour, reflecting changes from green to red to buff bedrock. The changes

**Figure 4 - 17:** Stratigraphic relationships across the Humber River basin.
(A) Location of profile lines
(B) Idealized chrono-stratigraphic column.

# B



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Site columns (left to right):
Humbermouth · Hughes Brook · Lower Humber River · Deer Lake Basin · Head of Deer Lake · Upper Humber River · Grand Lake Shoreline · Howley Lowlands · North Sandy Lake · West Deer Lake · Deer Lake Basin · Glide Lake Basin · Grand Lake Highlands · Grand Lake Shoreline · Hinds Lake · NW Birchy Lake · Birchy Lake Valley · Sheffield Lake

Groups: A · B · C · D · E · F · G · H

mud — sand — sand-gravel

| Sediment Type | Description |
| --- | --- |
| Colluvium | Generally coarse grained deposit composed of angular clasts derived from overlying slopes, and deposited by gravity-related processes, including free-fall, debris-flow and avalanching. |
| Fluvial | Poorly to well sorted sand and gravel. Planar bedded, cross bedded, rippled and faulted in places. May contain fine grained sediment. Beds generally discontinuous. Found within terraces, as well as valley floors. |
| Nearshore Marine | Poorly to well sorted sand and gravel. Commonly deposited on inclined planar beds by grain avalanching as basin marginal deltas. May contain rippled sand beds, commonly draped by fine grained sediment. Rarely contains diamicton interbeds. Commonly grades up into fluvial (topset) sediment. Maximum elevation 60 m asl. |
| Basinal Marine | Moderately to well sorted, rhythmically bedded to structureless silt-clay. May contain minor amounts of sand. Deposited by combination of underflow and overflow-interflow. Dropstones are rare. May grade up into sublitoral deltaic sediment. Elevation range 0 to 25 m asl. |
| Glacio-lacustrine | Poorly to moderately sorted sand and gravel. Commonly deposited on inclined planar beds by grain avalanching. May contain laterally discontinuous diamicton interbeds derived from debris flow sedimentation. May contain discontinuous beds of rhythmically bedded to massive fine grained sediment, commonly disrupted by dropstones. Elevation range 90 to 170 m asl. |
| Ice Contact gravels | Poorly to moderately sorted sand and gravel. Commonly chaotically bedded. High angle cross beds, faults common. Commonly contains large boulders. Generally confined to palaeo-channels for meltwater discharge. May contain discontinuous diamicton beds deposited by sediment gravity flow. |
| Diamicton | Very poorly sorted to unsorted sediment. May be compact. Commonly deposited subglacially by melt-out, lodgement or deformation processes. Locally resedimented during post-glacial, especially on slopes. Clast rock types and matrix-colour mainly controlled by underlying bedrock geology. |

Holocene — 0 ka

Deglaciation — c. 10.0 ka

c. 12.5 ka

Glaciation

commonly occur within 100 m down-ice of bedrock colour changes (Kirby, 1988). Diamictons interpreted as primary tills are commonly found adjacent to diamictons with characteristics suggesting remobilisation. This suggests a similar initial genesis as subglacial deposits for most of the diamictons. Where more than one diamicton was exposed (e.g., Pasadena dump), they commonly displayed similar textural, clast fabric and clast provenance characteristics. Preferred clast orientations are generally parallel to the last ice flow direction derived from striation data, and clasts within diamictons have their source in bedrock up-ice of the sections in which they were found.

Diamicton exposures representing deposition during more than one glacial advance have not been recognised. Apart from the diamicton exposed at Rocky Brook, all diamictons are interpreted to have been deposited during the Late Wisconsinan. The basal diamicton at Rocky Brook was described as a pre-Late Wisconsinan till (Vanderveer and Sparkes, 1982). Although some characteristics of this sediment (e.g., compaction) are different than those of other diamictons in the Humber River valley, clast provenance, texture and fabric data are similar to adjacent diamictons. No datable material was found below the single exposure of this diamicton. The suggestion by Vanderveer and Sparkes (1982) that this diamicton represented the oldest till in the upper Humber River valley could not be confirmed by an examination of drill core data. Without dating and stratigraphic corroboration from elsewhere in the basin, this till cannot be unequivocally assigned a pre-Wisconsinan age.

Ice-contact sand and gravel is found within deltas in the Humbermouth area, originally described by Brookes (1974). Exposures are fragmentary as a result of removal for aggregate and community development. Ice-contact sediment is also found at the mouth of Deer Lake, within the delta that

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impounds the lake.

Rhythmically bedded silt and clay dominate the lower part of the Humber River valley below about 30 m asl, except for the Humbermouth - Humber River gorge area where current velocity precluded deposition. The sediments have been described from the Rocky Brook and North Brook sections, and are also exposed in sections at Coal Brook, Reidville, Pasadena, Humber village, Goose Arm, and Wild Cove. In drill core from Steady Brook, sediment thickness was over 100 m. Silt-clay deposits are found as far north as Harrimans Steady on the Humber River (elevation 30 m asl). They were deposited in standing water by a combination of underflow currents and suspension settling. Micropalaeontological evidence shows foraminifera in sediments adjacent to the modern coast (at Wild Cove and Goose Arm), and agglutinated silt grains in fine grained sediments inland. Boron geochemistry, used as a potential means of distinguishing deposition within fresh or saline water was inconclusive. The similarity in physical characteristics, the continuity in sediment outcrop and the similarity in elevation suggests that all rhythmically bedded silt-clay sediments in the Humber River valley below about 30 m asl, were deposited in a marine environment. Differences in couplet thickness and grain size are a function of proximity to sediment source, and local sediment and water input. During periods of higher relative sea level, it is likely that sea water inland of the narrow Humber River gorge would have a large freshwater component due to wasting ice in the Humber River watershed. Modern discharge is about 3.8 billion cubic metres of water annually (Department of Environment and Lands, 1992), which would have been increased by glacier meltwater contributions during deglaciation, assuming a similar drainage basin area.

Mid-delta and upper-delta foresets lie above silt-clay rhythmites at Rocky Brook. The sediments were deposited in a prograding deltaic environment. A similar stratigraphy is found at Hughes Brook. Delta foresets in the Humber River valley are found at Nicholsville, Little Harbour, Pynn's Brook, Pasadena, Little Rapids and Corner Brook, with surfaces all at similar elevations. Deltas at similar elevations in an area experiencing isostatic adjustment suggests that all deltas are roughly the same age. Deltas are absent from the upper Humber River valley area above Cormack.

Fluvial topset gravels cap deltas at Rocky Brook, North Brook and Hughes Brook. Topset gravel deposits are also found overlying all other deltas in the Humber River valley. Deglacial fluvial sediments were deposited in post-glacial drainage systems, that have reworked previously deposited sediment. Fluvial systems were re-established in the lower parts of the Humber River valley as sea level fell due to isostatic rebound. Fluvial sediments are therefore found in river terraces, up to elevations of about 30 m asl. Such deposits are found at Dawe's Pit, in the Humber River gorge, and on the Humber River flood plain. Contrasts in grain size reflect changes in local flow conditions, with increased current flow through the Humber River gorge depositing gravel-dominated sediment, in contrast to the sandy (commonly cross-bedded) sediments found along the lower reaches of the Humber River.

Colluvium is restricted to the base of steep slopes, and is common within the Humber River gorge, and along North Arm, Penguin Arm and Goose Arm. The lack of vegetation on talus slopes indicates modern activity.

Transect C-D extends along the axis of the Grand Lake valley to the Sandy Lake lowland (Figure 4-16a, b). Diamicton interpreted as subglacial till is found in some locations at the base of exposures, along the shores of Grand

Lake, and is the surface sediment along the north shore of Sandy Lake. Where strong fabrics are found, they either indicate flow northward out of the Sandy Lake basin or westward across Grand Lake. Clast types indicate ice flow and dispersal from The Topsails. The east and north shores of Grand Lake are dominated by sand and gravel. These sediments are interpreted as glacio-lacustrine deltas or fan-deltas, formed in a proglacial lake with an ice dam located at the northern end of the Grand Lake basin, with water and sediment derived from melting ice on The Topsails. Proximity of glacier ice is indicated in some exposures by the presence of diamicton beds or dropstones in fine-grained sediment. Glaciolacustrine sediments extend to the surface, and were not reworked, thus suggesting the lake drained rapidly. Deltas at the mouths of modern permanent streams were however incised following lake drainage. Sections along the north shore show lacustrine sediments at the base of some exposures, but they mostly contain glaciofluvial gravels. Current flow structures commonly indicate flow towards Junction Brook. Near Howley, sandy gravel exposed in hummocky terrain is interpreted to represent areas of ice stagnation. The presence of large boulders (commonly greater than 1 m diameter) near the surface of some hummocks, suggests subglacial deposition.

Transect E-F reveals a stratigraphy reflecting an association with elevation across the basin. The lowest Quaternary stratigraphic unit is diamicton. Physical characteristics of these diamictons reflect underlying bedrock geology. For example, thicker diamictons commonly are found in areas underlain by softer, easily eroded rock types.

Diamicton is exposed at the surface on the highlands west of Deer Lake. Diamictons are common between Deer Lake and Grand Lake, and on The Topsails east of Grand Lake. In the Pynn's Brook area, sediment interpreted as

subglacial till is found overlying sand and gravel. This sequence is interpreted as indicating local readvance of ice down the Pynn's Brook valley into Deer Lake. This stratigraphy is unique across the Humber River basin. In the Hinds Brook valley diamictons are commonly overlain by glaciofluvial sand and gravel derived from meltwater draining through the valley towards Grand Lake.

The intervening Deer Lake and Grand Lake valleys contain thick sediments deposited in standing water. The higher Grand Lake basin contains glaciolacustrine sand and gravel, commonly indicating ice-proximal conditions. The Deer Lake basin contains fine grained sediment deposited in a post-glacial sea that inundated the Deer Lake basin to beyond Reidville. The Grand Lake and Deer Lake valleys are connected by the Junction Brook valley, through which Grand Lake drained.

Transect G-H (Figure 4-17a) is across the Birchy Lake valley from the northwest to the Sheffield Lake area. Diamicton is the lowest Quaternary stratigraphic unit. It is generally thin (less than 3 m), with characteristics largely determined by the underlying bedrock geology, and was commonly formed in a subglacial depositional environment. It forms the surface sediment on the highlands either side of the Birchy Lake valley. Diamicton is overlain by glaciofluvial sand and gravel in some exposures in the Sheffield Lake area, and more commonly, in the Birchy Lake valley. Some of the gravel was deposited in an ice-contact depositional environment (Grant, 1989b). Glaciofluvial sediments grade upwards into deltaic sediments, indicating the presence of standing water in the Birchy Lake valley. Evidence for standing water was noted in the Gillard's Lake valley (Liverman and St. Croix, 1989b), on the watershed with the Indian Brook valley (Lundqvist, 1965), and in the Voyins Brook valley south of Mount Sykes. Much of the Birchy Lake valley,

particularly the steeper central and southern portions is flanked by colluvium derived from the easily weathered slopes. Some slopes are still active, although many are not. Many of the small peninsulas marking the southern shore of Birchy Lake are debris-flow fans, partially drowned following dam construction at Junction Brook.

## Periglacial features

Periglacial features do not occur as mappable units, but are significant for reconstruction of the post-glacial history. Structures interpreted as indicative of former permafrost are found within the South Brook valley. In a borrow pit adjacent to the Pasadena incinerator (site 91105; Appendix A) a distinct wedge structure was formed within a poorly-sorted sand and gravel unit, about 1 m below the present surface, at about 109 m asl. The wedge was 20 cm wide, 150 cm deep, and contained vertically aligned clasts on its margins surrounding a structureless sand and gravel fill. The wedge structure truncated primary bedding planes that dip eastward into the South Brook valley.

A second occurrence is two structures exposed in a small gravel pit (site 89006; Appendix A) at 135 m asl. The pit exposes deltaic sediments in the form of interbedded, moderately-sorted sand and gravel foresets dipping 10 to 20° into the South Brook valley. Each structure consists of a narrow wedge, 30 to 40 cm wide at the top, and 50 to 60 cm deep. The wedges are filled with poorly-sorted sand and gravel. Clast sizes in the gravel are mostly granules, but with some pebbles in the upper part of the structure. The wedge truncates bedding. Where beds meet the wedge in its upper part, they are gently deformed to dip parallel to the wedge sides. The structure is overlain by poorly-sorted pebble to cobble gravel.

<u>Interpretation</u>

The wedge structures in the South Brook valley are interpreted as epigenetic ice wedge casts. Epigenetic features are those that form subsequent to deposition of surrounding sediment, as opposed to syngenetic features whose development accompanies the accumulation of sediment (French, 1976; Washburn, 1980). Syngenetic ice wedges are found on alluvial plains in northern Siberia, and are commonly large features, up to 3 to 4 metres wide and 5 to 10 metres deep, generated during extended periods of permafrost conditions. Epigenetic features are commonly smaller, and may form during relatively brief periods of permafrost conditions. An epigenetic origin for the South Brook wedges is suggested by the truncation in bedding in confining sediment, the coarse sediment that has been interpreted to have formed over a brief time period, and the palynological record from the southern end of the South Brook valley (Thane Anderson, personal communication, 1996) that suggests a brief period of tundra conditions before the development of forest vegetation.

The development of ice wedges in coarse-grained sediment requires that drainage be impeded. This may be achieved by a higher water table or by the presence of a frozen layer. The delta surfaces on which the ice wedge casts are found are not directly dated, but were developed in a proglacial lake formed during deglaciation.

<u>Discussion</u>

The identification of ice wedge casts has palaeoclimatic implications. Ice wedges generally require a mean annual air temperature of -6°C to -8°C (Péwé, 1966), although Washburn (1980) suggests that they can form at slightly higher

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temperatures caused by micro-climatic effects. Mackay (1990, 1992), working in the Mackenzie Delta, shows that although ice wedges develop at the temperatures indicated by Péwé (1966), they may develop at higher temperatures, up to -1°C in some areas.

Fossil ice-wedge casts have been described from several other areas adjacent to the study area. Liverman and St. Croix (1989b) described ice wedge casts from the Indian River valley. They are found at about 65 m asl, within cross-bedded and cross-laminated sand and gravel, interpreted as part of a delta sequence. Brookes (1971) described structures from St. David's on St. George's Bay, and from York Harbour in the Bay of Islands (Figure 1-2). In both areas, the ice wedges were found within bedded gravel, and the wedge casts were filled with chaotic sand and gravel. They formed sometime after deglaciation at about 12.6 ka (Brookes, 1974). Corney (1993) described ice wedge casts in beach ridges close to modern sea level in the Fox Island River area. Forbes *et al.* (1993) produce a well-constrained sea level curve for St. George's / Port au Port Bays, that date these features as younger than 12 ka.

Liverman *et al.* (in prep) examined evidence for fossil ice wedge casts across Newfoundland, and suggested that most, especially those below marine limit, may have formed during the Younger Dryas cooling event, between 11 ka and 10.4 ka. The features found in the South Brook valley are poorly dated. It is possible that they were formed during the Younger Dryas, but it is equally possible they formed shortly after deglaciation of the area.

# Chapter 5

# Ice Flow History

**Introduction**

Determination of patterns of ice flow history is a critical component of any reconstruction of the Quaternary history in glaciated areas. Previous reconstructions of the ice flow history in the Humber River basin by Rogerson (1979), Vanderveer and Sparkes (1982), and Batterson and Taylor (1990) are contradictory. The objective of this chapter is to examine the evidence used to construct these hypotheses and produce one that best explains the palaeo-ice flow data, including striations and other erosional features, clast fabrics, and clast dispersal patterns, and distribution of glacial landforms. Glacial landforms and clast fabrics from diamictons have been considered previously (in Chapter 2 and 3, respectively), but will be discussed in the summary of this chapter.

**Ice flow indicators**

Striations and other erosional features

Erosional forms on bedrock surfaces cover a wide range of dimensions from large scale (e.g., fjords) to micro forms (e.g., striations). The larger features indicate regional ice flow trends and are commonly formed over successive glacial periods. The orientation of these features is generally controlled by bedrock structure (e.g., faults). Small-scale wear marks on

bedrock outcrops indicate local flow at that site.

The most common small-scale features within the study area are striations. They were produced subglacially by abrasion of material held within the base of the ice on the underlying bedrock surface. Striations are shallow (< 1-2 mm), parallel scratches commonly centimetres long. Longer and deeper parallel indentations are termed grooves.

Striations are commonly of three types: those that increase in depth and width to a point from which width and depth decrease to end as it began; those that increase in depth and width from the up-ice end to the deepest point when it suddenly ends; and those which start abruptly and gradually taper off (Chamberlin, 1888; Iverson, 1991). Striation morphology is determined by the relative hardness of the tool and bedrock surface, the angle of the clast tip, and the overlying load (Sugden and John, 1976; Drewry, 1986). Most striations indicate a trend of ice flow movement, from which no direction can be determined. Ice flow direction is commonly inferred from bedrock surface morphology (e.g., miniature stoss-and-lee features) or from rat-tail features. They are formed when a resistant part of the bedrock surface (e.g., a quartz crystal) protects softer rock directly down-ice producing a tapering ramp of bedrock (Plate 5-1). Some rock surfaces are unlikely to preserve small erosional features such as striations. In particular, coarse-grained rocks commonly do not host fine striations, and erosional indicators are restricted to bedrock stossing and grooves. Many of the rock types within the study area are coarse-grained (coarse sandstone, gneiss, schist, and most of the granites) on which striations are poorly preserved. Finer grained rocks, such as limestone, commonly have well-striated surfaces when first exposed, but weather quickly, removing the finer striations. In the study area, outcrops

**Plate 5-1:**
Rat-tail from quartz crystal in shale bedrock, near Corner Brook.
This feature indicates a northwestward ice flow direction at this
site.

exposed along roads constructed for logging that have been abandoned for more than 10 years have few or no preserved striations. New logging roads commonly have numerous striated outcrops. The development of a vegetation mat over bedrock outcrops and the effects of acidic precipitation on soluble bedrock surfaces, such as limestone, result in striation erosion.

Striations reflect ice flow at a given site. Subglacial topography locally may be important in determining ice flow direction, particularly during periods of glacial build-up and decline. Areas with considerable relief may show divergence of flow around topographic highs (e.g., Lawson, 1996). Ice flow initially may be topographically-controlled, but as ice thickens flow is less influenced by subglacial topography and more by ice sheet topography (Denton and Hughes, 1981; Eyles, 1983). Individual rock outcrops therefore may show more than one set of striations, that reflect changes in the location of glacial dispersal centres, rather than separate glacial advances, especially if there is no evidence for intervening ice free periods (e.g., weathered surfaces). Determinations of regional ice flow directions should be from numerous striation measurements (e.g., Virkkala, 1960; Embleton and King, 1968; Flint, 1971; Kleman, 1990; Kleman and Borgström, 1996).

Other non-glacial processes produce features morphologically similar to glacial striations. They include mudflows (Sharpe, 1938; Scott, 1988), avalanches (Dyson, 1937), river, sea or lake ice (Washburn, 1947; Clayton *et al.*, 1965), and movement along faults (Engelder, 1974; Hancock and Barka, 1987; Power and Tullis, 1989). In the Falkland Islands, 'striations' are produced by penguins sliding down coastal rock surfaces (Splettstoesser, 1985). In the study area, most striation sites occur away from steep slopes, above the limits of present or palaeo-lakes, or removed from faults, making a glacial origin most

likely. Individual sites may have been influenced by debris flows. Analysis of the regional pattern of striations allows potential influences from debris flow activity to be recognised and discounted.

Bedrock outcrops were systematically examined for ice flow indicators. Numerous striations were commonly found on a single outcrop, showing a wide divergence of orientations. Similar patterns are found at the margins of modern glaciers where ice flow direction is evident (Iverson, 1991). Striations commonly showed minor (<5-10°) divergence, and mean directions were determined from 10 to 20 observations. Individual striations at variance with the general trend were ignored. Ice flow direction was determined from rat-tail features, and stoss-and-lee forms on the bedrock surface. More than one set of striations commonly were found on a single bedrock outcrop. The relative age of striations was determined from cross-cutting relationships, and lee-side preservation (Lundqvist, 1990) (Figure 5-1). A regional pattern was recognised where a similar age relationship could be determined over a number of outcrops within an area.

Across the study area, 250 striated bedrock outcrops were examined, 43 of which recorded more than one ice flow direction (Batterson and Vatcher, 1992b; Batterson, 1994d, e, f). The data were supplemented by ice-flow records from published sources (e.g., Neale and Nash, 1963; Brookes, 1974; Alley, 1975; Alley and Slatt, 1975; Vanderveer, 1981, 1987; Grant, 1989b, 1991; Liverman *et al.*, 1990, 1991; Taylor and Vatcher, 1993; Taylor, 1994), as compiled in the Newfoundland striation database (Taylor *et al.*, 1994). More than 800 observations have been recorded in the study area.

All the striations examined appeared fresh, and where more than one
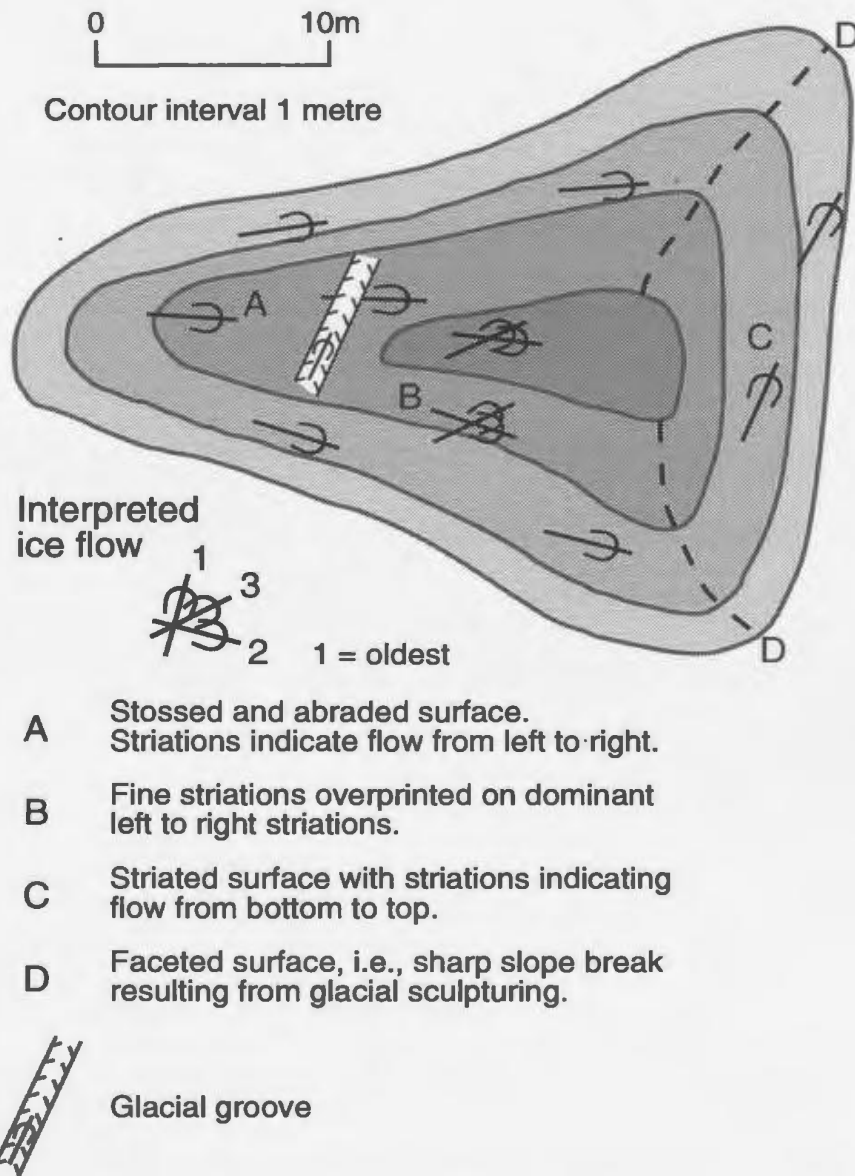
**Figure 5 - 1:** Schematic diagram showing striation types and their relationship to ice flow direction.

set of striations was found on an outcrop there were no visible contrasts in the degree of weathering. It is therefore likely that all the striations were formed during the Late Wisconsinan.

### Clast fabrics

Clast fabric data has been discussed in Chapter 3. It is suggested that diamictons with $S_1$ values > 0.6, and which contained other characteristics of glacigenic origin (e.g., striated clasts), likely were primary tills. Clast long axes in these depositional environments are commonly parallel or transverse to ice flow as determined from independent sources.

Of the 173 clast fabrics completed in the Humber River basin, 119 had $S_1$ values greater than 0.6. Clast fabric trends from strongly oriented clast fabrics are commonly similar to striation directions on adjacent bedrock surfaces. This is well demonstrated in the area around Corner Brook (Figure 5-2). The striation record shows two regional flows, an early southward flow from a source in the Long Range Mountains (?), and a later event towards the Humber Arm from a source in The Topsails. Clast fabric data show similar patterns. Most preferred clast orientations in strong fabrics (i.e., $S_1$ > 0.6) show flow towards Humber Arm. However, several sites show southward palaeo-flow. A site near Summerside (site 91036; Appendix A) shows two diamicton units, the lower of which has a preferred clast orientation towards 206° ($S_1$=0.78), and the upper has a preferred clast orientation towards 295° ($S_1$=0.78). A similar relationship between striations and preferred clast orientation in tills is found in other areas.

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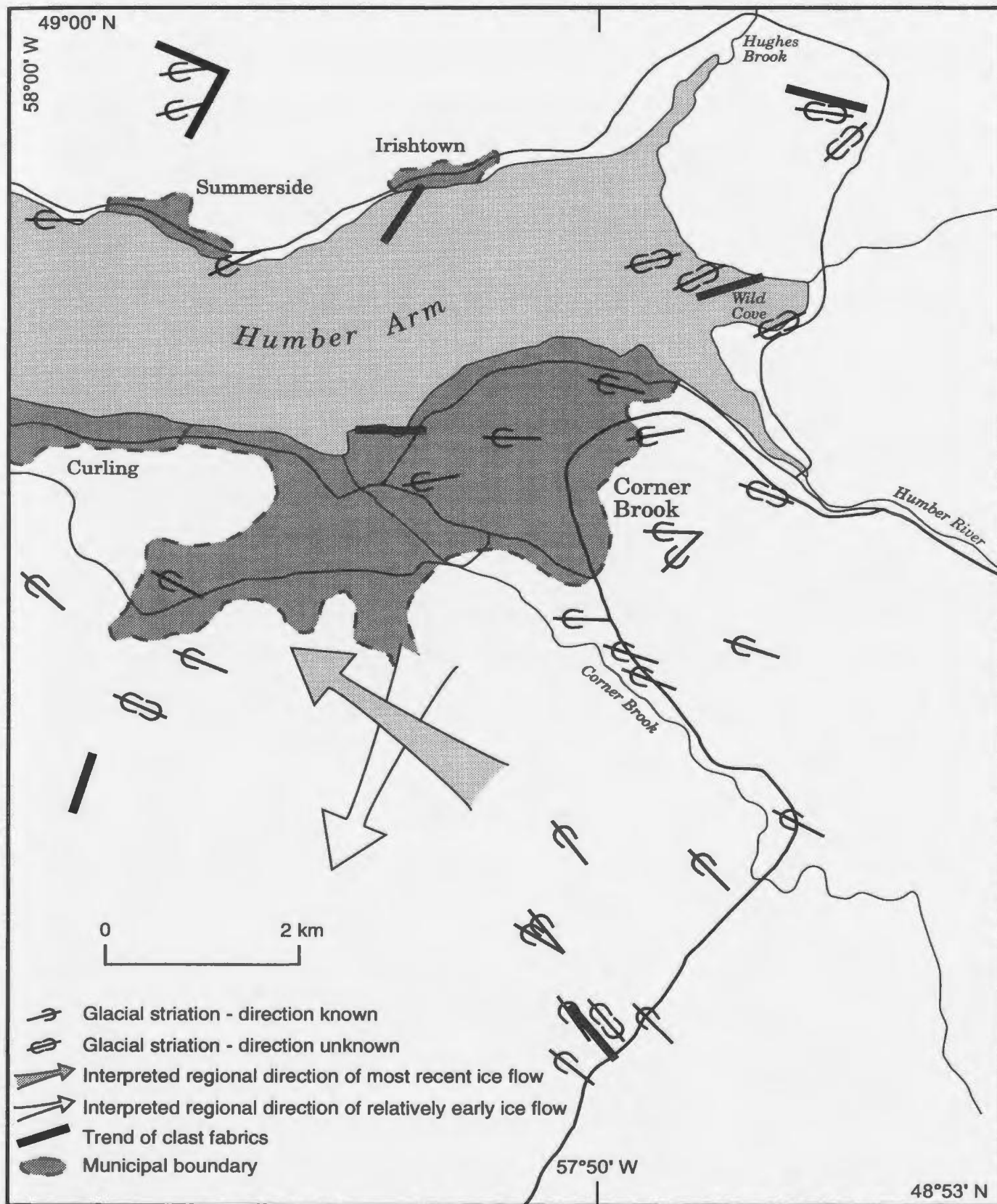
**Figure 5 - 2:** Comparison of striation and preferred clast fabric orientation data for the Corner Brook area.

## Clast Dispersal

The ice-flow pattern from striations indicates the general direction of glacial flow, but not concerning the specific location of ice dispersal centres. Rock types, identified from glacial diamictons, that possess a distinctive character and a defined bedrock source can help determine both direction and distance of glacial transport.

Clast samples were collected from 351 diamicton sites across the Humber River basin. Samples consisted of at least 50 pebbles and/or cobbles, and included all those clasts distinct from the underlying bedrock geology, determined from bedrock geology maps. Exotic clasts commonly represented far less than 1% of the clast component, but were sampled because of their potential significance to dispersal patterns. It is therefore accepted that exotics may be over-represented in clast percentages. Clasts were cleaned and the presence of striations or other surface features were noted. Clast rock type was identified, commonly by comparison to a reference collection of bedrock samples collected during the field program. A total of 19,723 clasts were identified and assigned into 31 different categories (Appendix C). Groupings were into rock type (e.g., limestone, sandstone, gneiss, rhyolite), or, where possible, specific rock groups or formations (e.g., Sp granite, Hungry Mountain Complex, Hinds Brook granite). An outline of the bedrock geology of the study area is provided in Chapter 1, including a discussion of distinctive rock types and their characteristics (Table 1-1). The dispersal patterns of distinctive rock types is described below.

### Carboniferous rocks

The central part of the Humber River basin is underlain by

Carboniferous sandstone and siltstone. The Humber Falls, Rocky Brook, and North Brook formations of the Deer Lake Group are dominantly red (Hyde 1979, 1984). They underlie the upper Humber River basin and the area around the northern end of Glover Island. The Little Brook Formation and the Howley Formation in the Grand Lake - Sandy Lake basins are red and grey sediments, whereas the Anguille Group that underlies Birchy Ridge is grey. Red sediments in western Newfoundland are restricted to the Deer Lake basin. Carboniferous rocks also contain fluvial conglomerates, found within the North Brook Formation that outcrops on the western, northern and southern margins, and the Humber Falls Formation found in the central part of the basin. The North Brook conglomerate contains arkosic sandstone clasts, and felsic volcanic clasts dominate the Humber Falls Formation conglomerate.

Sandstone-siltstone clasts are dispersed across much of the Humber River basin (Figure 5-3). They are found along the shores of Grand Lake, between Grand Lake and Deer Lake, on the highlands north and south of Old Mans Pond, on Birchy Ridge and in the upper Humber River valley. Red sandstone clasts were also noted near the summit of North Arm Mountain, at 640 m asl. They generally are not found on the Long Range Mountains west of Adies Pond, except at one site in the foothills. Similarly, they are rare on The Topsails, with only three sites recording sandstone clasts. A site near Hinds Lake showed two arkosic sandstone clasts. Apart from within Carboniferous sediments, arkose is reported within the Springdale Group (Whalen and Currie, 1988), which outcrops in the vicinity and is therefore a potential source of these clasts. A second site in the Hinds Brook valley recorded a single brown sandstone clast for which there is no obvious source, and a third

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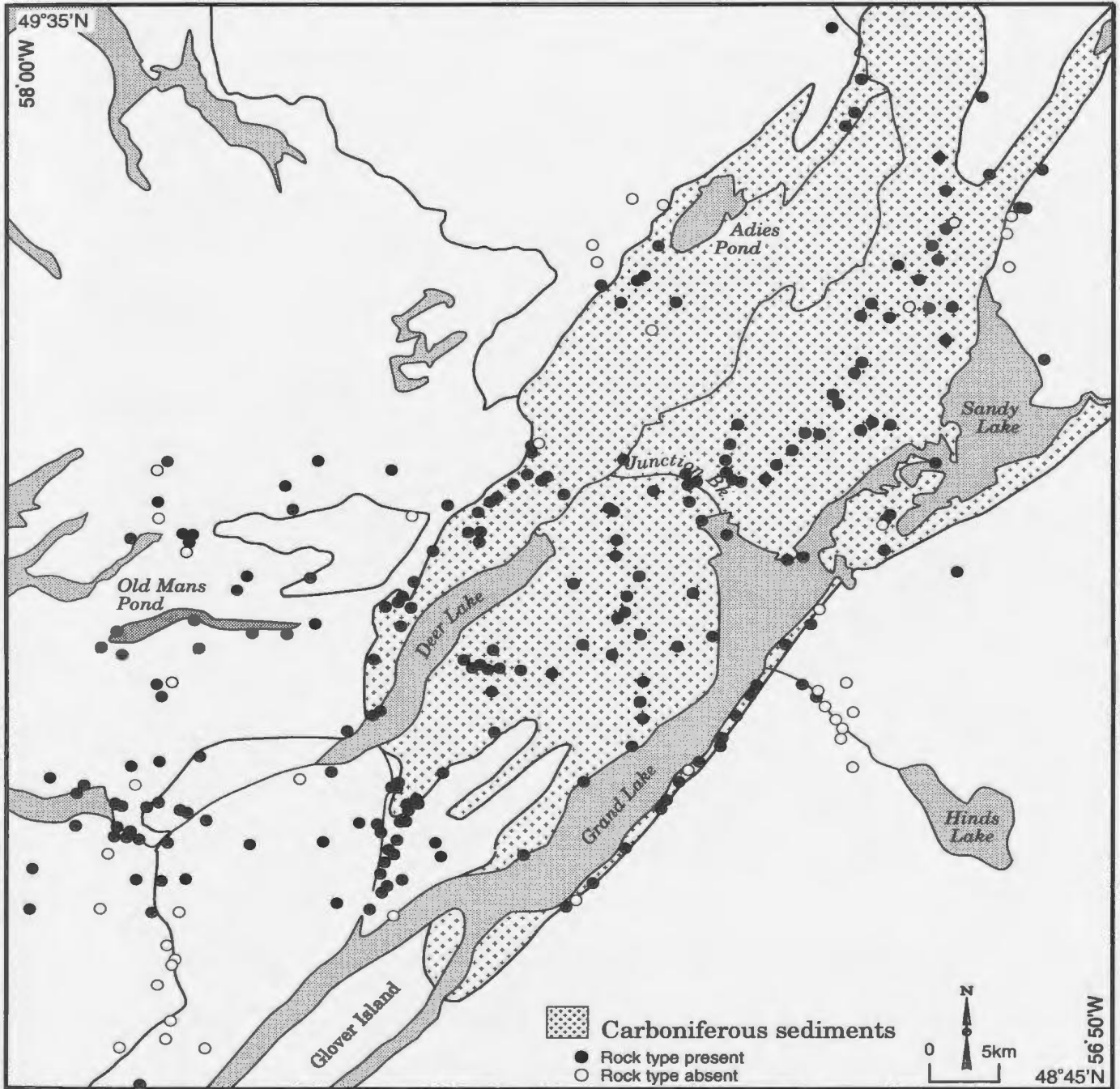
**Figure 5-3:** Dispersal of Carboniferous clasts across the Humber River basin.

site near Goose Pond recorded four red sandstone clasts. This latter site is about 2 km east and 100 m higher than the nearest sandstone outcrop, in an area with only a few striations showing ice flow towards the northeast, from the Grand Lake basin towards Sheffield Lake. A flow in that direction would not have crossed Carboniferous bedrock. Other clasts found at the site are generally consistent with northeast transport, including Oib (granite-granodiorite), OHma (gabbro) clasts, and Oic (granite) clasts, the latter of which only crop out to the southwest. However, the sample also includes Sp (granite) clasts which are found on the highlands 2.5 km to the east, and which are inconsistent with northeast transport. The transport history for clasts at this site remains unresolved.

Topsails Intrusive Suite

The Topsails Intrusive Suite is confined to the east side of Grand Lake (Whalen and Currie, 1988). Clasts from distinctive bedrock units within it such as Sp granite (Figures 5-4) and Sq porphyry (Figure 5-5) show similar dispersal patterns. Clasts from these areas are found dispersed on the highland between the Grand Lake and Deer Lake valleys, and over the limestone bedrock west and southwest of Deer Lake. In the north, Sp and Sq clasts are recorded on Birchy Ridge and in the Sandy Lake lowlands to the east. Other granitic rock types from The Topsails, but with less distinctive characteristics, such as Sm granites (white to red, fine- to medium-grained, equigranular granites), and Sg granite (white to pink, medium-to coarse-grained, biotite-amphibole granite) showed similar patterns to dispersal of the Sp and Sq units. Clasts from bedrock unit Ssy (mostly quartz syenite) rarely were found, possibly because of the small areas of surface exposure.
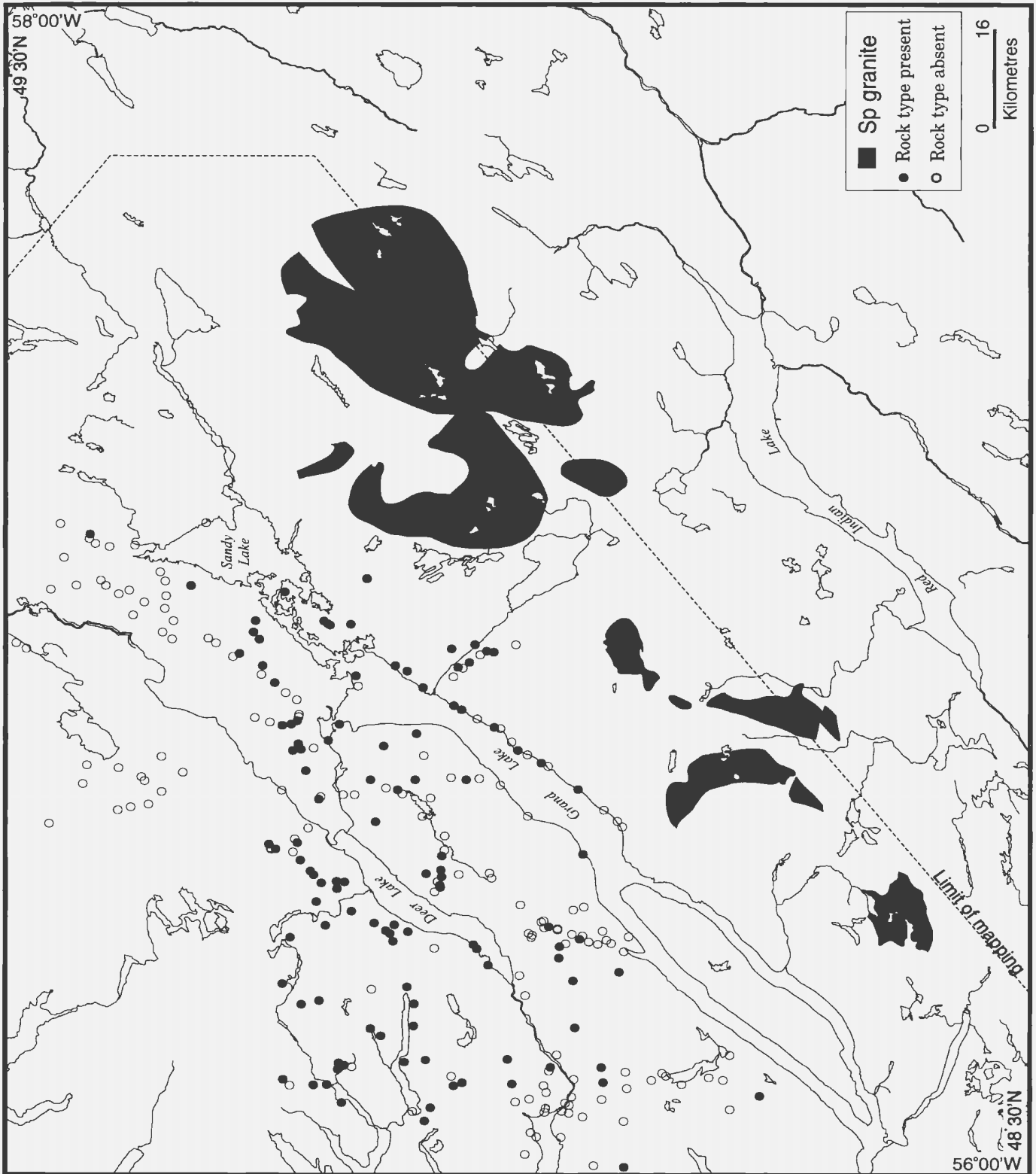
**Figure 5-4:** Dispersal of Sp (Topsails) granite clasts across the Humber River basin. Shaded areas indicate known outcrops of Sp granite. See Figure 1-5 for base map details. Closed circles indicate Sp granite clasts present at a site, and open circles indicate site showed no Sp granite clasts present.
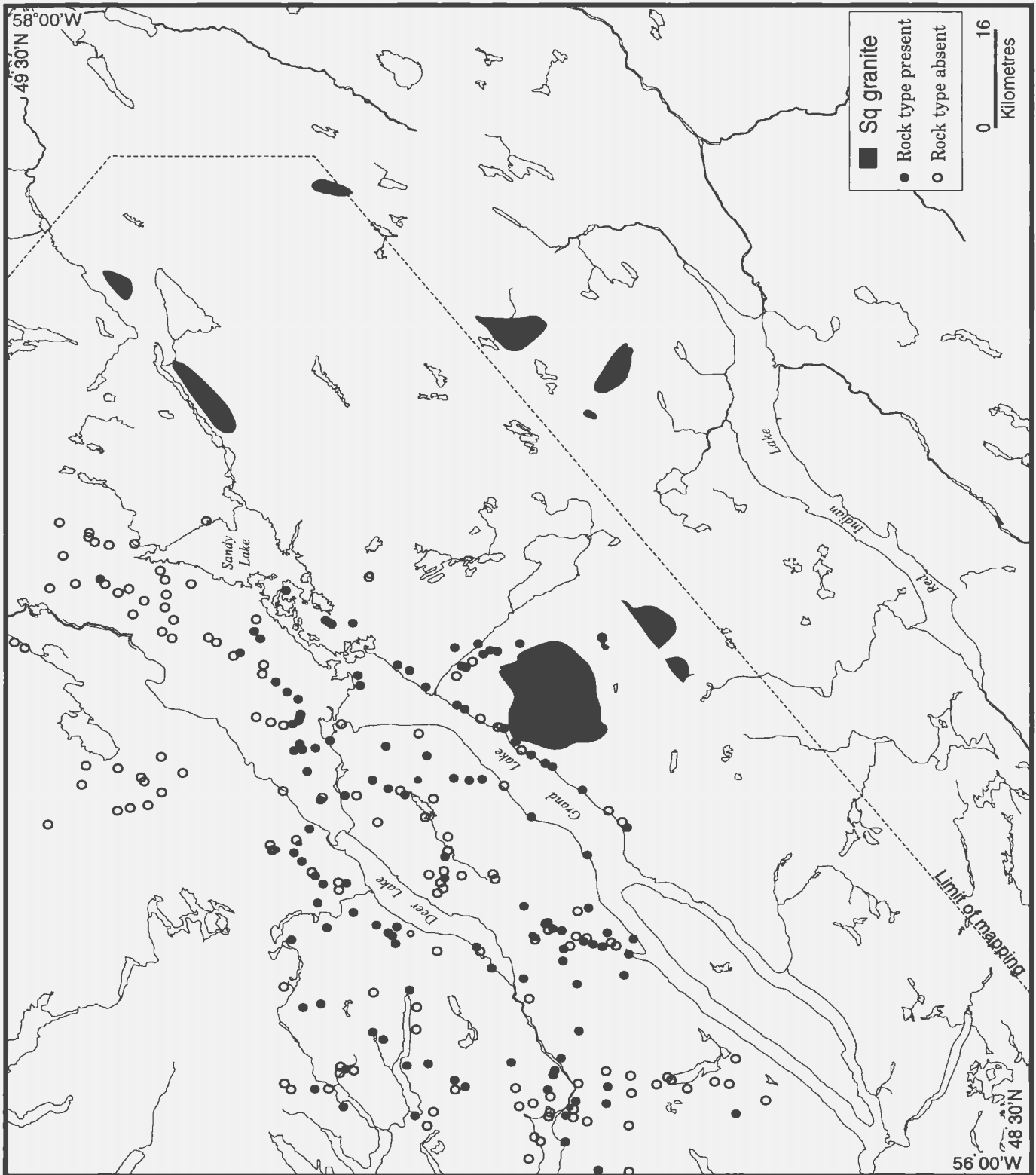
**Figure 5-5:** Dispersal of Sq (Topsails) porphyry clasts across the Humber River basin. Shaded areas indicate known areas of Sq porphyry. See Figure 1-5 for base map details. Closed circles indicate Sq clasts present at a site, and open circles indicate site showed no Sq clasts present.

No Sp or Sq clasts were found in the Upper Humber River basin west of Birchy Ridge or over the Long Range Mountains west of Adies Pond. Examination of boulder piles created during land clearing in the Cormack area (Plate 5-2) showed that clasts derived from The Topsails were present as far north as the Middle East Branch valley. Only Grenville gneiss and Carboniferous sandstone clasts were found north of this area.

### Gabbro

Gabbro bedrock is found on The Topsails within the Rainy Lake Complex (SOrl), Hungry Mountain Complex (OHma), unit Om, or the Buchans Group (Ob) (Whalen and Currie, 1988). Gabbro also crops out within the Gull Lake intrusive suite west of White Bay (Saunders and Smyth, 1990).

Gabbro clasts are dispersed across the central and southern parts of the Humber River basin (Figure 5-6). They are found south of Birchy Ridge, in the Old Mans Pond area, and south of Corner Brook. They were not found on Birchy Ridge, within the Upper Humber River valley, or around Sandy Lake.

### Red flow banded rhyolite

Red flow-banded rhyolite crops out in the Springdale Group on the central and northern parts of The Topsails (Whalen and Currie, 1988), and within the Sops Arm Group, west of White Bay (Smyth and Schillereff, 1982).

Red flow-banded rhyolite clasts are found across much of the area (Figure 5-7), including Birchy Ridge and in the Sandy Lake basin to the east, but are absent from the Upper Humber River basin.

**Plate 5-2:**
Topsail granite erratic in cleared field in the Cormack area. This boulder was transported at least 40 km from its bedrock source in The Topsails. Boulders such as this are common in the area west of Grand Lake and the distribution of these boulders are important in the development of the ice flow history of the Humber River basin.
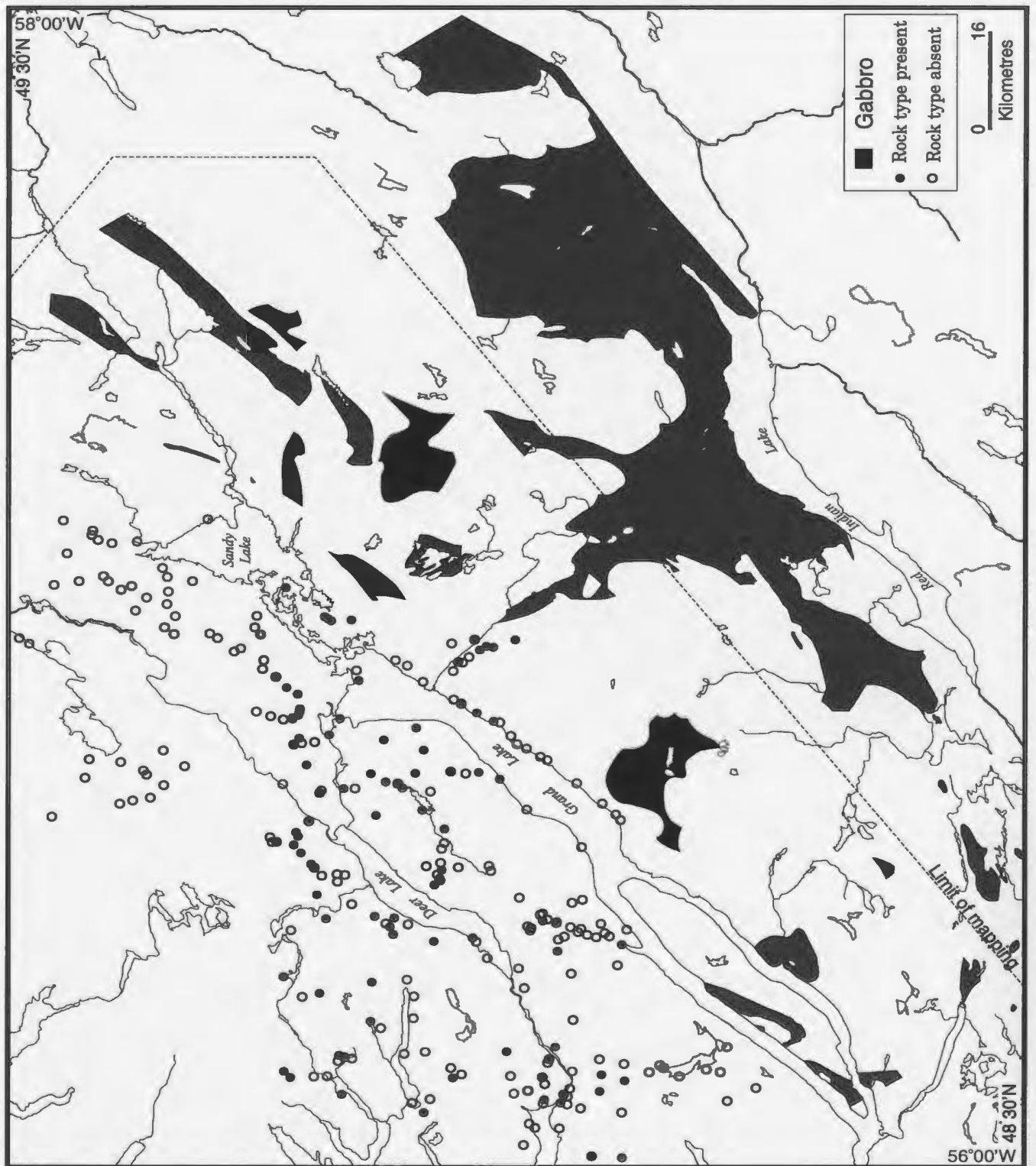
**Figure 5-6:** Dispersal of gabbro clasts across the Humber River basin. Shaded areas indicate known outcrops of gabbro on The Topsails. See Figure 1-5 for base map details. Closed circles indicate gabbro clasts present at a site, and open circles indicate site showed no gabbro clasts present.
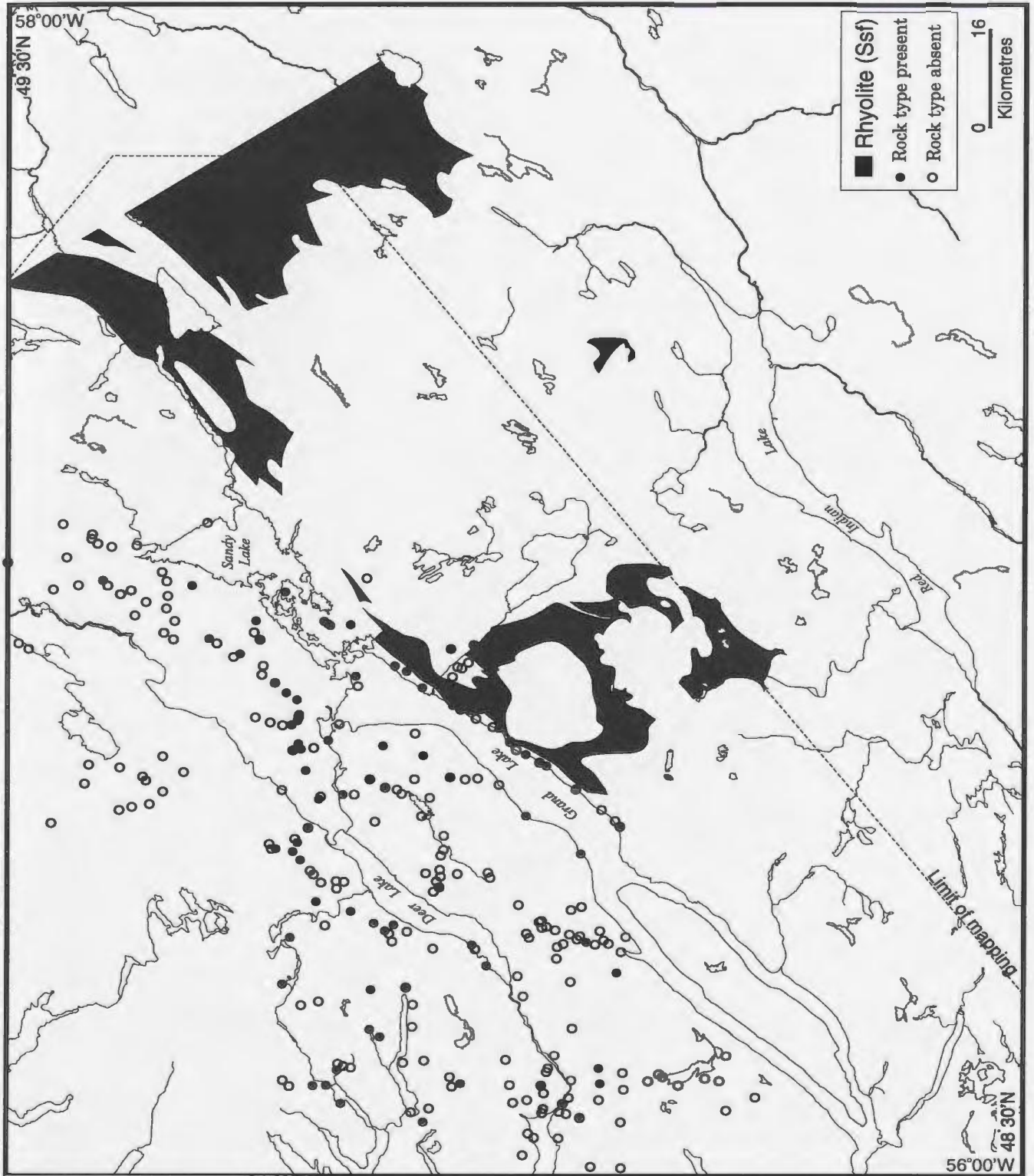
**Figure 5-7:** Dispersal of Springdale Group rhyolite clasts (Ssf) across the Humber River basin. Shaded areas indicate known outcrops of Ssf rhyolite. See Figure 1-5 for base map details. Closed circles indicate Ssf rhyolite clasts present at a site, and open circles indicate site showed no clasts present.

Limestone

Limestone bedrock underlies a large part of western Newfoundland, from St. George's Bay extending north along the Great Northern Peninsula (Williams and Cawood, 1989; Colman-Sadd et al., 1990). Within the Humber River basin, limestone underlies the western part, as far east as Deer Lake. Limestone is found within numerous bedrock units in the study area, including the St. George and Port au Port Groups, Reluctant Head Formation, and Old Mans Pond Group. It also comprises small parts of the Humber Falls and Rocky Brook formations in the Deer Lake basin. Limestone from each of these areas is visually similar, and therefore specific source areas for limestone clasts could not be determined. No other limestone outcrops occur within the study area.

Limestone clasts are generally found west of their source area (Figure 5-8), and therefore suggests transport by the regional westward ice flow from The Topsails. The exception is two limestone clasts found within a very compact till in Rocky Brook (see Chapter 3), about 4.5 km northeast of the nearest source. This till also contains clasts identified as Topsails intrusive suite (Sm, Sq), Springdale Group (Ssf) and Ordovician granite (Oid) all of which are derived from the east to southeast. Other clasts from within the Rocky Brook till were also derived from The Topsails. The limestone may therefore be from the Humber Falls or Rocky Brook formations. The till at Rocky Brook also contains numerous sandstone and siltstone clasts from these formations. The data show the Rocky Brook till was deposited by westward flowing ice from a source in The Topsails.
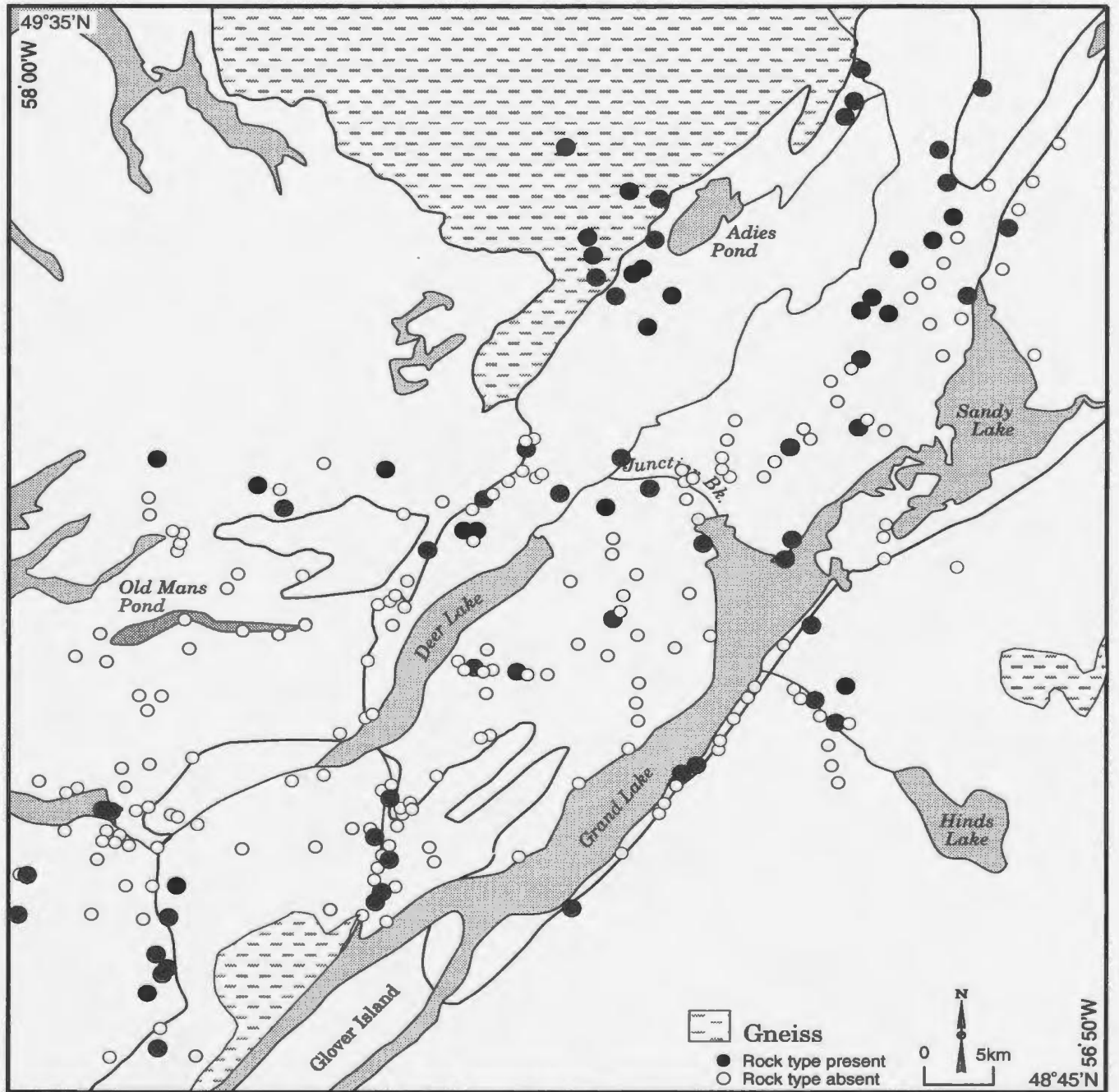
**Figure 5-9:** Dispersal of gneiss clasts across the Humber River basin.

### Gneiss

The largest source of gneiss within the Humber River basin is the Grenville basement that underlies the Long Range Mountains, northwest of the upper Humber River valley; and along the southern end of Grand Lake. It is a Precambrian, high grade, medium grained pink to grey, quartzo-feldspathic gneiss (Owen and Erdmer, 1986; Williams and Cawood, 1989). However, there are several other sources of gneiss in the area. The Hungry Mountain Complex, northeast of Hinds Lake is host to a medium grained, white to pink biotite-muscovite gneiss (Whalen and Currie, 1988). Granitoid gneiss and psammitic paragneiss are found in the Caribou Lake complex along the western shore of Grand Lake south of Northern Harbour (Cawood and van Gool, 1992, 1993), and hybrid gneisses are associated with Ordovician granites (Unit Oid) north of Sandy Lake. Similarly, foliated granite clasts may be confused with gneisses. Foliated granites have been reported from the Hughes Lake complex north of Deer Lake (Williams and Cawood, 1989), and the Glover Group (unit Og) (Whalen and Currie, 1988).

Clasts identified as gneiss are scattered in samples from across the study area (Figure 5-9). Concentrations of gneiss clasts occur in the upper Humber River valley, south and west of Adies Pond, on Birchy Ridge, and south of Deer Lake. Other gneiss clasts are found between Deer Lake and Grand Lake, and between Deer Lake and the coast, north of Old Mans Pond. The distribution of clasts in the upper Humber River valley, their association with Carboniferous sandstone-siltstone clasts, and the lack of clasts from The Topsails suggests southwestward transport down the valley. The large number of gneiss clasts on Birchy Ridge also may be explained by southwestward ice-flow down the valley, from a source at the north end of
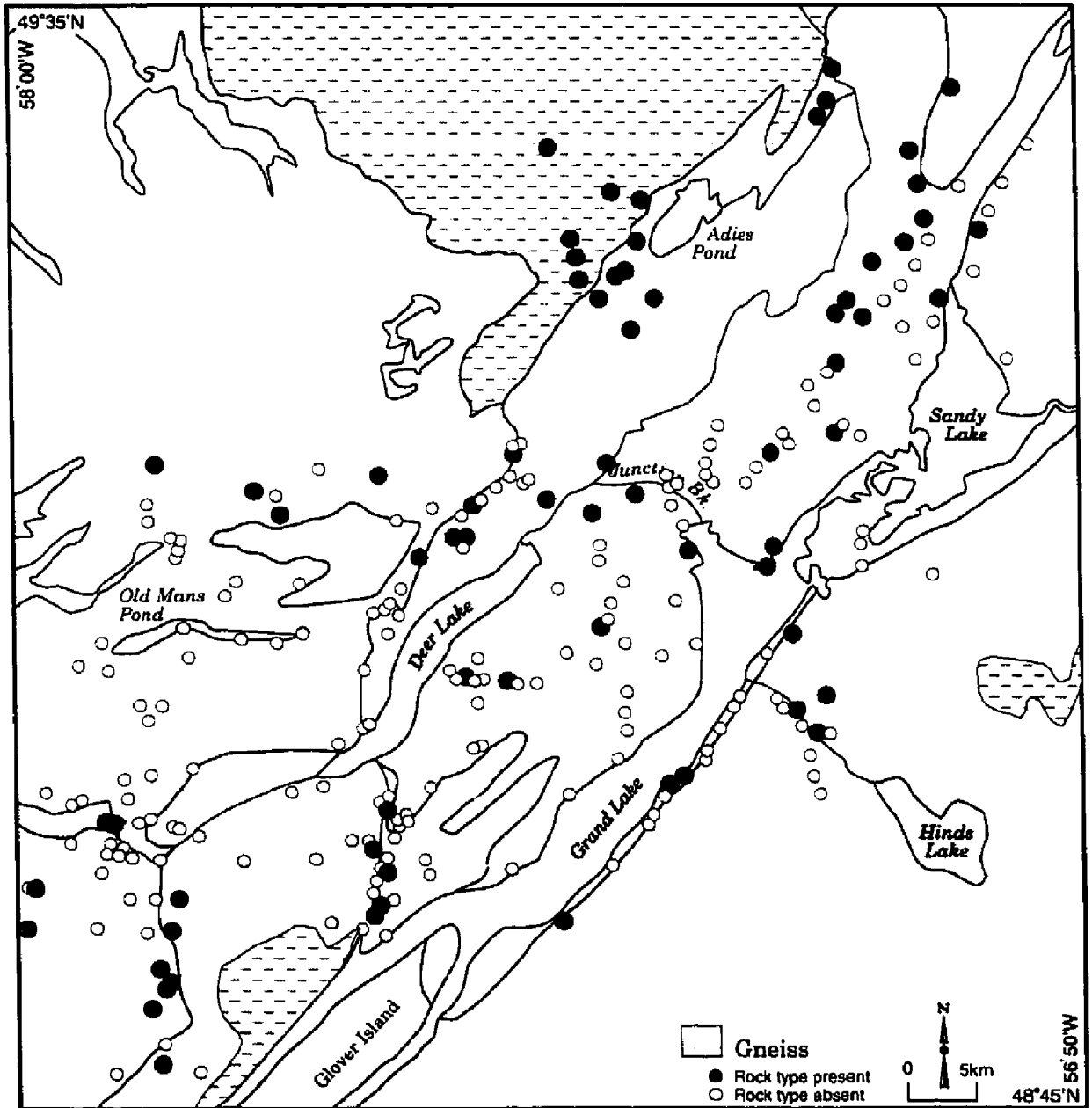
**Figure 5-9:** Dispersal of gneiss clasts across the Humber River basin.

the valley. The concentration of sites with gneiss clasts south of Deer Lake, mostly over the Caribou Lake complex, suggests a local source. Other sites across the study area contain gneiss clasts that may have been derived from a number of sources, although those found around Grand Lake are consistent with dispersal from the source in the Hungry Mountain Complex, north of Hinds Lake.

**Palaeo-ice flow in the Humber River Basin**

For the purposes of discussion of the ice flow history, the Humber River Basin is subdivided into six regions on the basis of physiography and ice flow patterns found within each. These are: 1. south of Corner Brook along the western edge of the Long Range Mountains; 2. within the Deer Lake valley; 3. between Deer Lake and Grand Lake; 4. the northern part of the upper Humber River valley; 5. the area over Birchy Ridge; and 6. the Sandy Lake/Birchy Lake valleys. The regions are described separately and subsequently integrated into a discussion of the palaeo-ice flow history of the basin. It should not be assumed that the earliest ice flow event in one area is temporally related to an early flow in another area. Ice flow trends are derived primarily from striations, unless otherwise noted.

### 1. Corner Brook and south

An early south to south-southwest flow is recorded in the area south of Corner Brook, along the western edge of the Long Range Mountains (Figure 5-10). Evidence is generally confined to the Georges Lake valley, although similar trends are recorded as far north as the North Star quarry in Corner

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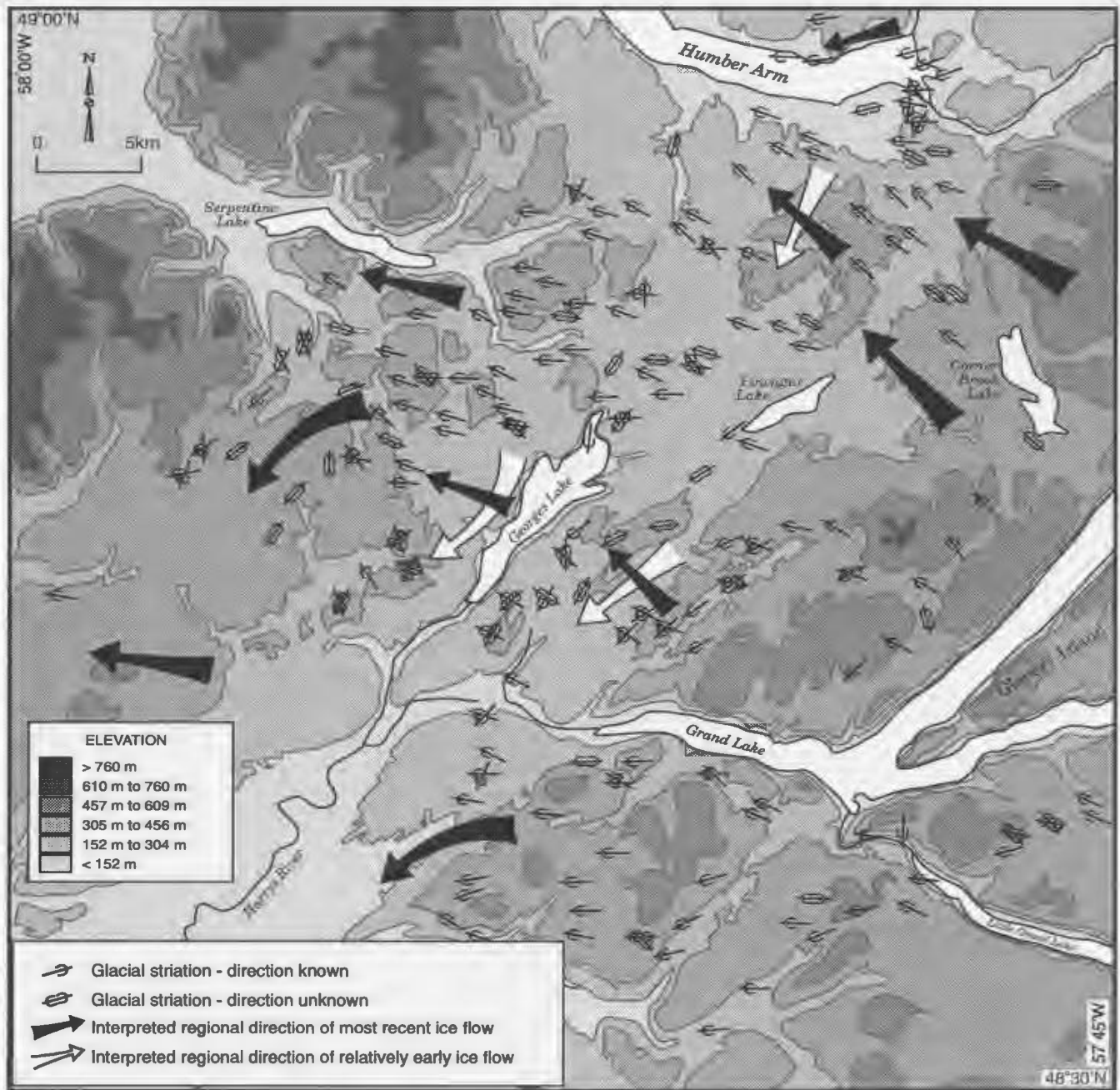
**Figure 5 - 10:** Ice flow patterns in the Corner Brook area and south.

Brook (elevation 280 m asl), and between Cooks Brook and Serpentine Lake (elevation 240 m asl). South to south-southwest-oriented striations have been recorded as far east as the north end of Corner Brook Lake. The source of this early ice flow is unclear. Strong clast fabrics with a preferred clast orientation trending north-south are found on the north shore of the Humber Arm near Irishtown, and south of Corner Brook. Further support for southward flow is the presence of red micaceous sandstone clasts seen near Pinchgut Lake. Carbonate clasts of local origin are also found (Department of Mines and Energy, unpublished data). Red Carboniferous clasts indicate that ice flowed across the Deer Lake basin to reach this area. An alternative source for these clasts in the North Brook Formation exposed at the northern end of Glover Island is not supported by striation and clast provenance data. Ice flow across this source would also have crossed basalt, diabase, tuff of the Glover Group, possibly gabbro of the Rainy Lake Complex, and granites from the Topsails Intrusive Suite (Whalen and Currie, 1988). None of these rock types are found associated with the red sandstone clasts at Pinchgut Lake. Similarly, no striations indicate a flow across Glover Island towards Pinchgut Lake.

The early southward flow was followed by a coastward ice flow from the interior. At the southwest end of Grand Lake, ice flow was westward to southwestward into the Harrys River valley and thence southwestward to St. George's Bay. Farther north, ice moved northwest to westward across the Georges Lake valley, shown by striations that crosscut the earlier southward directed striations. Flow was directed either through the Serpentine Lake valley, or deflected southward along the eastern margins of the Lewis Hills, and out to the coast through the Fox Island River valley. No evidence (e.g., striations, clast provenance) was found to suggest that Topsails-centred ice

crossed the Lewis Hills, and there is also no indication that ice flowed east from the Lewis Hills. These highlands are underlain by ultrabasic rocks. Soil supports only sparse vegetation. Lack of vegetation coupled with altitude and a coastal aspect combines to produce an intensely frost weathered environment in which periglacial features (e.g., felsenmeer, gelifluction lobes) are common (Batterson and Liverman, 1995). The presence of erratics and unweathered striated bedrock surfaces found on the Lewis Hills shows the area supported, or was crossed by, glacier ice. Timing of glacier cover is speculative. Surfaces with similar characteristics in Gros Morne National Park that were considered to have remained ice free during the Wisconsinan (Grant, 1987) are now considered to have been ice covered during this period on the basis of cosmogenic isotopic analysis (Gosse and Grant, 1993).

## 2. Deer Lake valley

An early southwestward ice flow is recorded along the shores of Deer Lake, and within the Humber River gorge, near Corner Brook (Figure 5-11). No evidence for this flow is found on the higher ground west or east of the valley, suggesting this was a local, topographically controlled flow.

This early flow was followed by westward to northwestward flow from a source in the interior. Ice crossed Grand Lake and flowed towards Humber Arm at Corner Brook. North of the Steady Brook valley ice-flow was westward (270 ± 10°). This reflects the draw-down of ice into the Humber Arm basin. The coastal highlands (North Arm Mountain, Mount Gregory and Table Mountain area) (Figure 1-2) and the major fjords between Humber Arm and Bonne Bay (Old Mans Pond, Goose Arm, Penguin Arm, North Arm) were a major influence on ice movement. Ice flow west of Deer Lake was
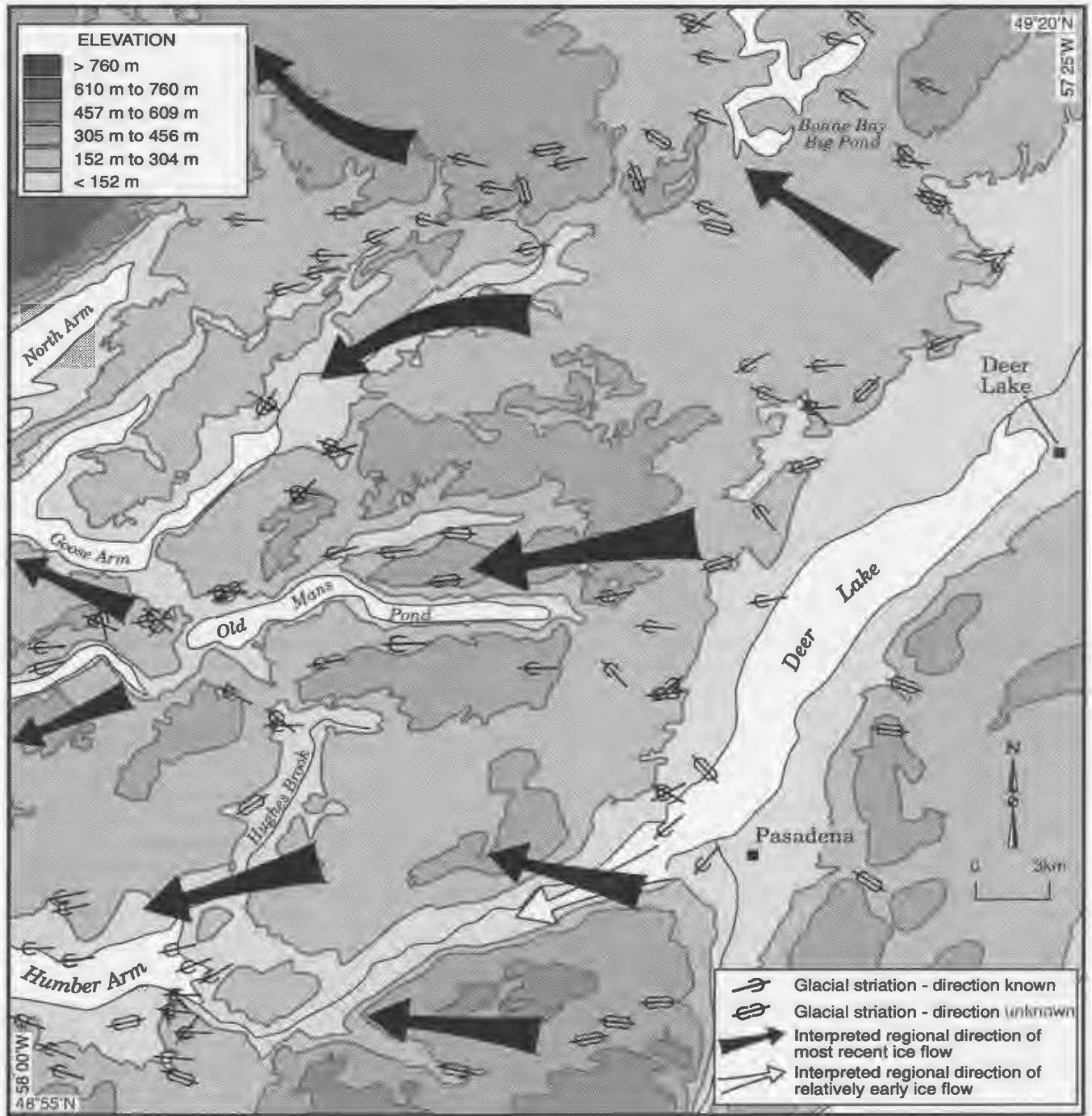
**Figure 5 - 11:** Ice flow patterns in the Deer Lake valley.

either westward along Old Mans Pond and into Goose Arm, or was drawn southwestward into Humber Arm. Northwest of Deer Lake, ice flow was either northwestward towards Bonne Bay or Trout River Pond, or was drawn southwestward into North Arm. There is little published evidence to indicate ice flowing inland off the coastal highlands or that they were over-topped by ice flowing from the interior (Taylor *et al.*, 1994).

Regional ice flow from the interior is supported by clast dispersal patterns, particularly for those rock types found on The Topsails. Preferred clast orientation for tills in the Corner Brook area is towards the Humber Arm, with some indication of flow through the Humber River gorge. Preferred orientations trending westward are parallel to the regional ice flow patterns that show flow from The Topsails. The exceptions are clast fabrics with a preferred orientation perpendicular to ice flow events described by the striation record. At the mouth of the Pynn's Brook valley, four clast fabrics taken from glacial diamictons showed preferred orientations perpendicular to striations showing flow down the valley. One of these is from a till overlying sand-gravel that was interpreted to represent local readvance (see Chapter 3).

### 3. Deer Lake - Grand Lake

The highlands between Glide Brook and Grand Lake record striations showing an early east-northeastward ice flow (Figure 5-12). This flow had its source in The Topsails as shown by the clast provenance of diamictons. Conversely, strong fabrics in diamictons in this area also have a preferred clast orientation trending west to northwest.

The early northeast flow from The Topsails was followed by a later south-southwestward flow down the Glide Brook valley towards Deer Lake,
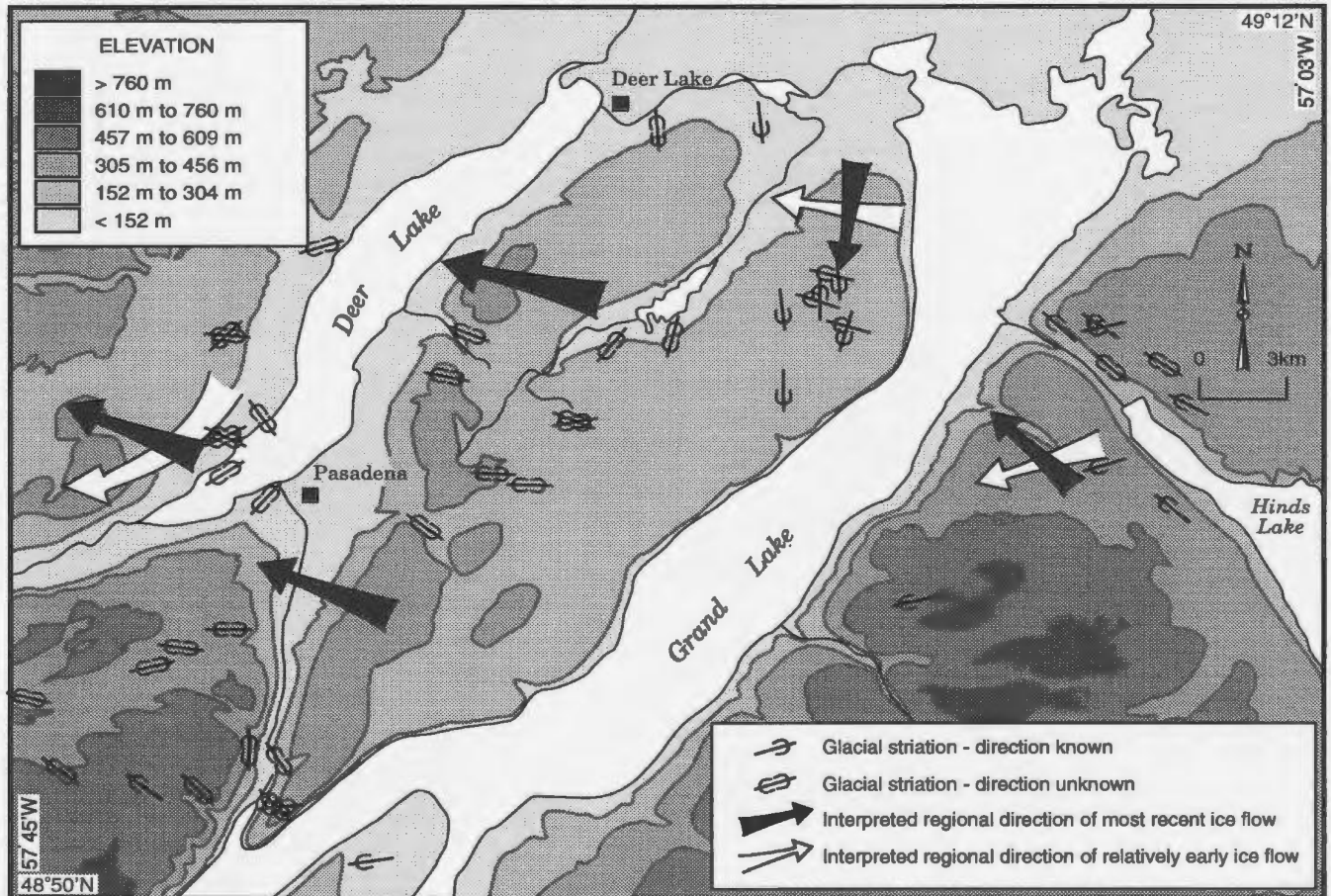
**Figure 5 - 12:** Ice flow patterns between Deer Lake and Grand Lake.

and a southward flow east of Glide Brook towards Grand Lake, as interpreted from striations. The source of this ice is uncertain. If it was from the Humber River valley, this should be reflected in the clast provenance of surface clasts. There were no Carboniferous sandstone clasts found in the area. Tills have a preferred clast orientation and clast provenance showing flow from The Topsails, suggesting that the southward ice flow did not rework sediment in the area.

### 4. Upper Humber River valley

The northern part of the upper Humber River valley has a complicated ice flow history (Figure 5-13). An early eastward to east-northeastward ice flow is interpreted from striations in the upper Humber River-Taylor Brook area, flowing towards White Bay. This flow was likely from the Long Range Mountains.

The earlier eastward to east-northeastward ice flow event produced striations. They were crosscut by striations from a southeast to southward ice flow event that entered the upper Humber River valley, and subsequently flowed southwestward along the valley axis. Ice flowing into the upper Humber River basin was recorded east to the Taylor Brook valley. Ice flow was northeastward towards White Bay on the highlands west of White Bay. Ice flow was generally southward on the uplands northwest of Adies Pond, although striations are oriented eastward along the margins of the Carboniferous basement southwest of Adies Pond. Palaeo-ice flow was northwestward or westward towards the coast in the area south of the Middle East Branch valley near Cormack. This is demonstrated by the clast provenance data showing rock types from The Topsails to the south of the
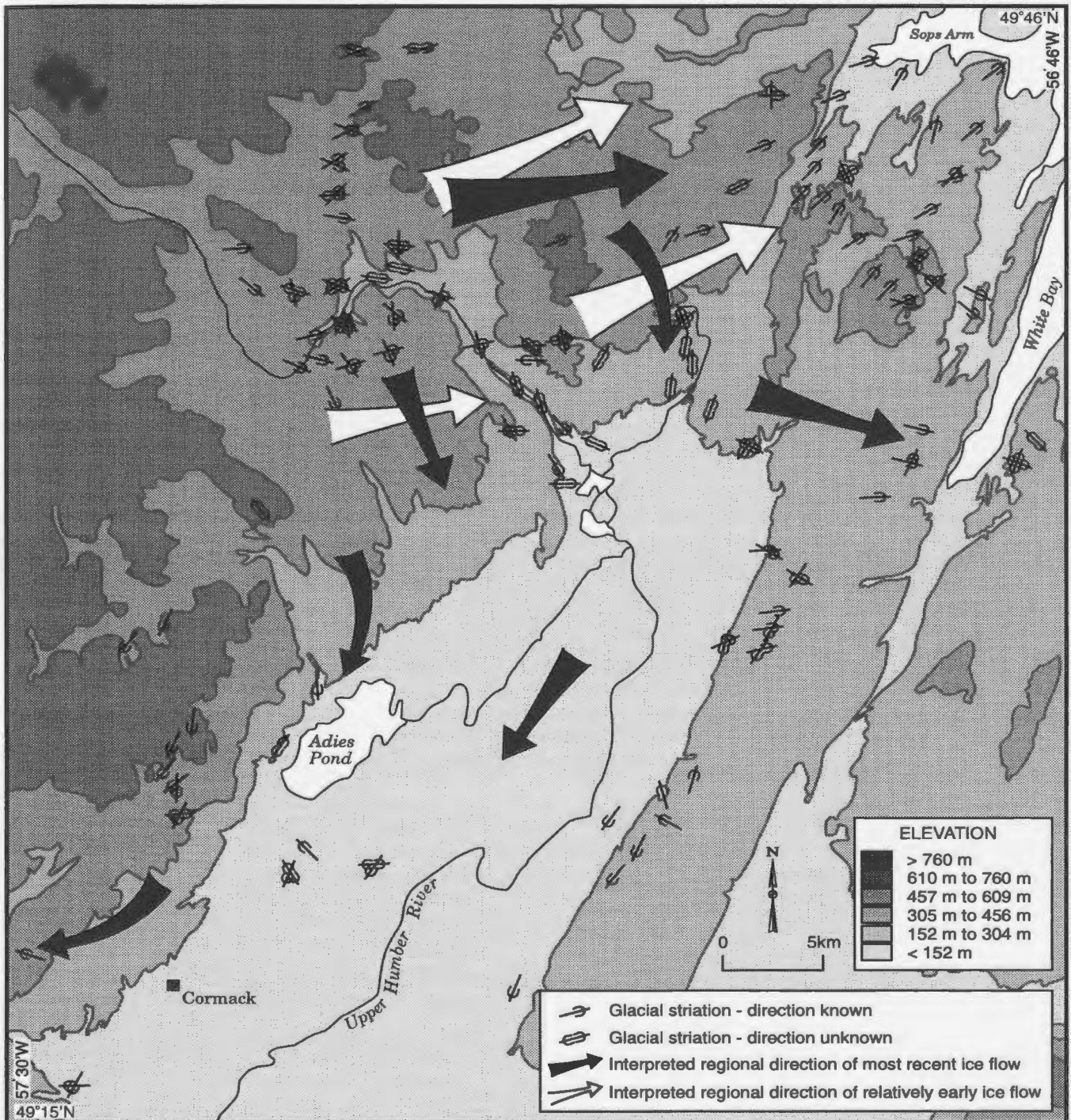
**Figure 5 - 13:** Ice flow patterns in the upper Humber River valley.

valley, but not to the north.

The pattern of striations in the upper Humber River valley shows that rock types in the area of the Gull Lake intrusive suite were covered by ice flowing eastward towards White Bay, rather than southward down the Humber River valley. A source in the Gull Lake intrusive suite had been the preferred source for gabbro clasts found in diamictons near Deer Lake (Vanderveer and Sparkes, 1982), used to demonstrate southwestward ice flow down the Upper Humber River valley. Southward-flowing ice did not cross areas underlain by the Moose Lake granite and the Devil's Room granite that cropout west of White Bay (Saunders and Smyth, 1990). These rocks have similar grain size, colour and mineral composition to some granites on The Topsails. Dispersal of gabbro and granite clasts in the upper Humber River and areas to the south were therefore derived from a source in The Topsails.

### 5. Birchy Ridge

Birchy Ridge is a northeast-southwest trending ridge (200 - 280 m asl) between the Sandy Lake basin to the east and upper Humber River valley to the west (Figure 5-14). Bedrock is mostly grey mudstone and arkosic sandstone of the Anguille Group (Hyde, 1984). This area provides evidence of ice flow with northward, eastward and southward ice flow indicators. Much of the data were collected from bedrock exposed during construction of the Trans-Canada highway and during mineral exploration for uranium during the late 1970's - early 1980's. The bedrock outcrops are now either partially weathered or overgrown by vegetation.

The northwestern part of the ridge shows an early eastward flow that may be a southern extension of the eastward flow recorded in the upper
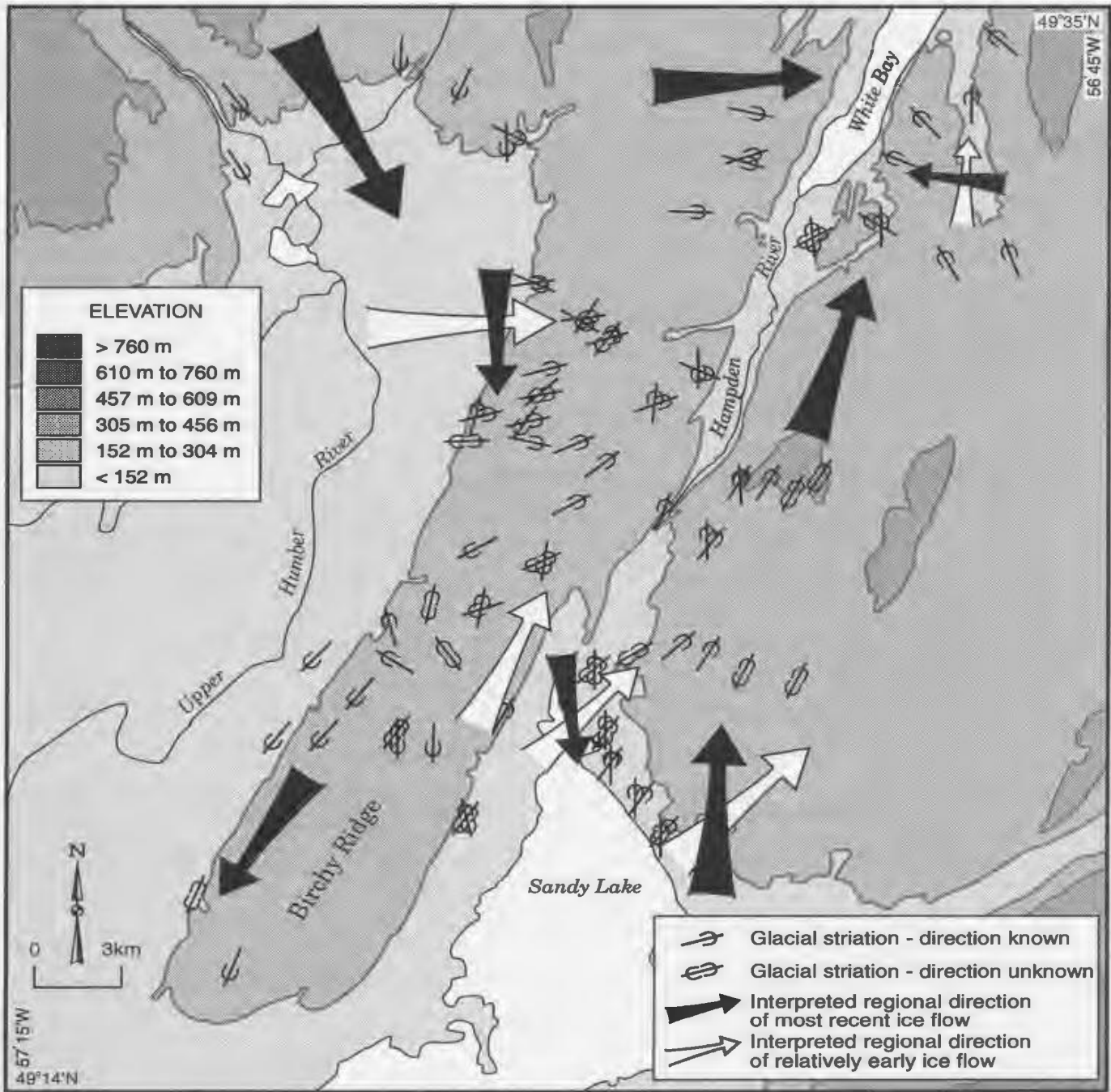
**Figure 5 - 14:** Ice flow patterns in the Birchy Ridge area.

Humber River. In the northeast of the ridge, an early southward flow is found, whereas closer to White Bay an early northward flow is recorded.

Striations show a late south-southwestward ice flow along the southern part of the ridge. However, in the north several sites show northward-directed striations. Other sites in this area record recent south-southwestward and northeastward flow. Evidence of complex ice flow is not restricted to Birchy Ridge. At the north end of Sandy Lake, adjacent to the eastern margin of Birchy Ridge southward oriented striations crosscut earlier north-northeastward striations. Grant (1989b) recorded a similar southward oriented striations in a quarry on the east side of Birchy Ridge. At sites less than 1 km east along the highway, striations indicate ice flow dominantly was northward. The presence of striations indicating southward ice flow suggests that a late flow of ice from a source to the north (Long Range Mountains?). The extent of this flow was undetermined.

Clast provenance of diamictons shows that ice from The Topsails did not overtop Birchy Ridge, although granite (Sp) and porphyry (Sq) clasts from The Topsails are found at the northern and southern ends of the ridge. Drill core and test pit data from the Wigwam Brook uranium exploration area on the western flanks of the ridge show dominantly sandstone clasts from the underlying Humber Falls Formation. Non-local clasts included gabbro, granite, and rhyolite, all of which may have been derived from diamictons on Birchy Ridge. Clast fabrics from test pits adjacent to the drill core locations (Vanderveer, unpublished data) show weak, girdle fabrics, possibly indicating that sediments were deposited by sediment gravity flow. Clasts identified in drill core as mudstone from the Rocky Brook Formation or granite from the Gales Brook area (Appendix B) were derived from the north-northeast.

## 6. Birchy Lake - Sandy Lake

Along the north shore of Sandy Lake an early northeastward flow is recorded at several sites (Figure 5-15). A similar ice flow direction is also recorded at scattered sites near Sheffield Lake and south of Upper Indian Pond. This ice flow was towards Green Bay and Halls Bay.

To the north of The Topsails, ice flow was either northward through the Sandy Lake basin or across the Birchy Lake valley towards White Bay. This ice flow cross-cut the earlier northeastward ice flow event recorded in the valleys. The exception is evidence for southward-flowing ice found at the northern end of Sandy Lake, close to Birchy Ridge. Less than 1 km east, ice flow indicators record northward flowing ice. This suggests a complex interaction of southward flowing ice from the Long Range Mountains and northward flowing ice from The Topsails. The temporal relationship between the two flow events is not apparent, but clearly could not have occurred contemporaneously. Towards Sheffield Lake, the most recent ice flow is northeastward towards Green Bay and Halls Bay.

**Summary of Ice Flow Events**

The pattern of glacial striations and clast dispersal suggests a sequence of early flow from a source in the Long Range Mountains that covered the northern and western margins of the basin, followed by a regional radial flow from a dispersal centre on The Topsails that covered most of the basin apart from the upper Humber River valley and north. Deglaciation produced local, small ice caps on coastal and interior hilltops.

All of the Humber River basin has been glaciated. Coastal highlands
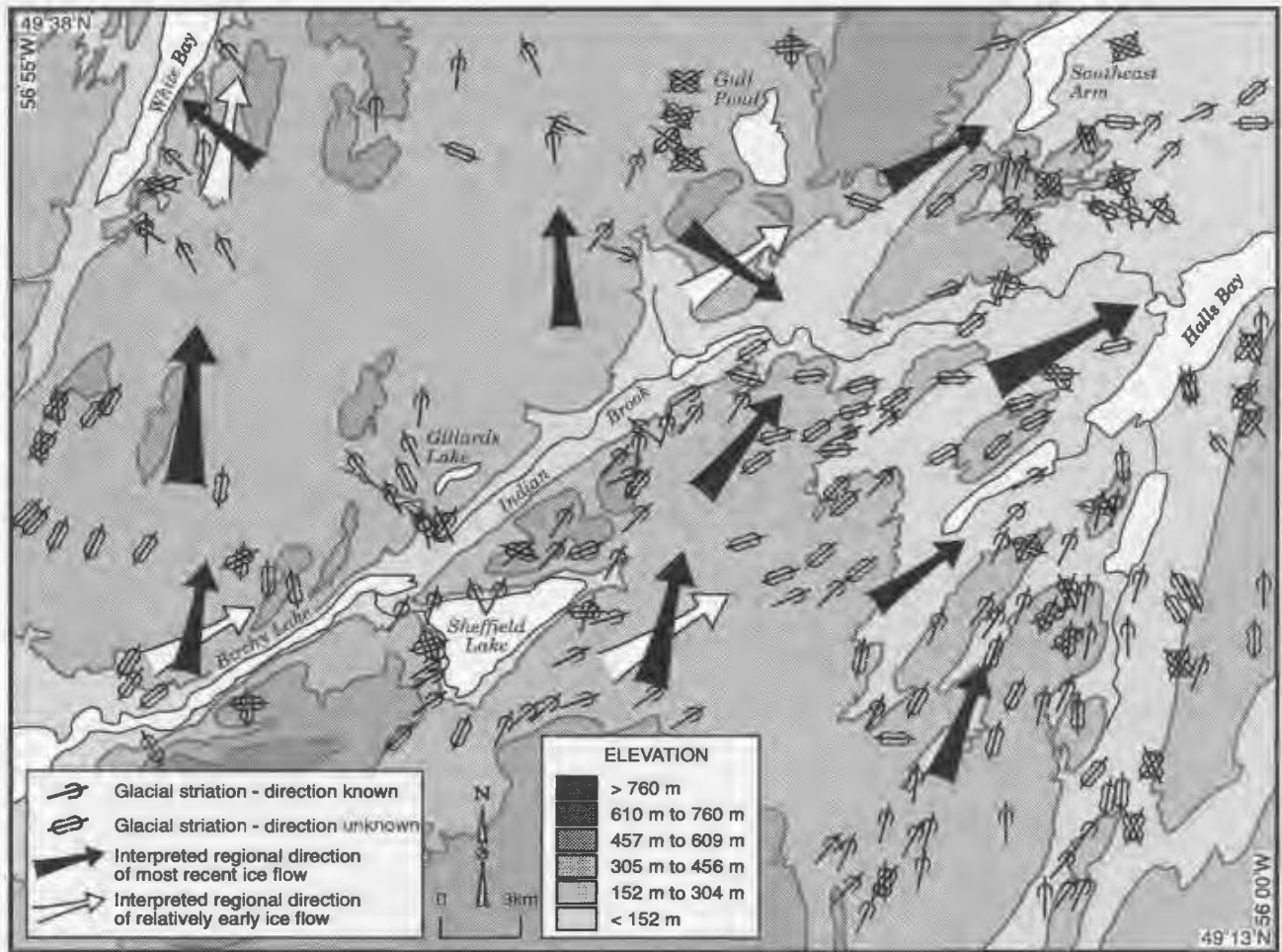
**Figure 5 - 15:** Ice flow patterns in the Birchy Lake to Sandy Lake area.

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such as the Lewis Hills, Blow Me Down mountain, and North Arm Mountain were thought to have been free of ice during the Late Wisconsinan (Grant, 1989a, 1991) or throughout the Quaternary (Coleman, 1926). However, fresh striations and erratics from the Lewis Hills, Blow Me Down Mountains and North Arm Mountain indicate these areas were ice covered. Striations to 293° were reported from near Blow Me Down (elevation 640 m asl) by Batterson (in Taylor *et al.*, 1994). Peridotite clasts derived from a source to the southeast were also found at the site. Taylor *et al.* (1994) also reported striations oriented 290-295° in the Frenchman's Cove area (elevation less than 50 m asl). A clast identified as a granite from the Topsails Intrusive Suite (probably Sp) was collected on the southern part of the Blow Me Down massif (D. Taylor, Department of Mines and Energy, personal communication, 1995). Several sites on the Lewis Hills show striations, with trends of 240° and 310° from the west and east parts, respectively. The striations had no preserved directional indicators and no clasts were found indicating dispersal from The Topsails. Clasts identified as red Carboniferous sandstone and siltstone clasts were found on North Arm Mountain. This indicates glacial transport across the Deer Lake basin and overtopping of North Arm Mountain.

### Glacial flow from the Long Range Mountains

Ice from the Long Range Mountains covered the western and northern parts of the Humber River basin (Figure 5-16). Evidence (mostly striations) for an early southward flow is found within the Deer Lake valley, and in the Corner Brook area and south. Clast fabrics from diamicton exposed along the shores of the Humber Arm, and clast provenance data from near Pinchgut Lake provide further evidence for this flow. An early palaeo-ice flow, roughly

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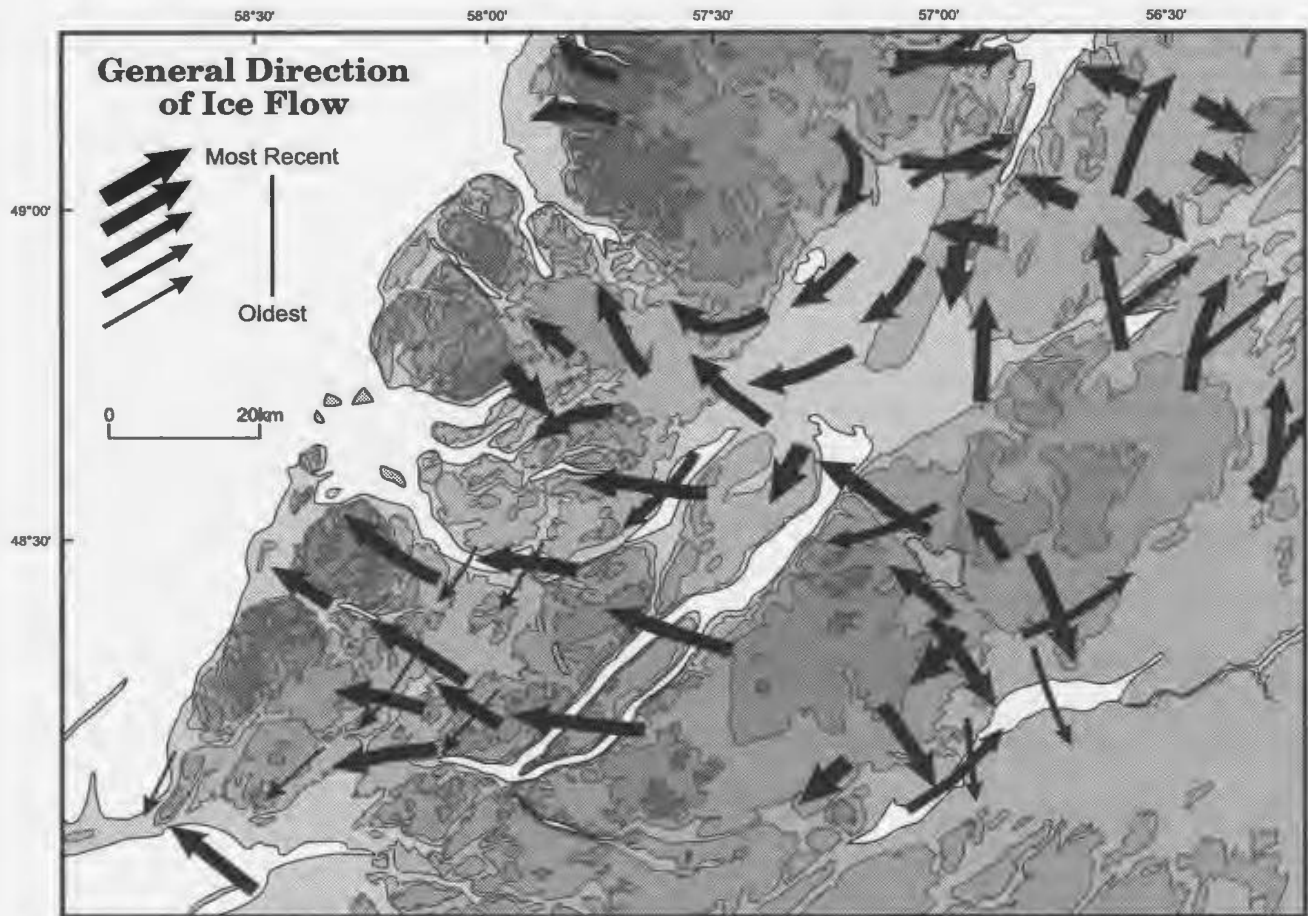
**Figure 5-16:** Summary of ice flow history across the Humber River basin. Arrows represent the mean of multiple determinations.

parallel to the west coast, has been described elsewhere. Mihychuk (1986) described southward flow along the coastal plain in the Bellburns area of the Northern Peninsula, interpreted as resulting from Laurentide ice. Grant (1994a) noted similarly oriented striations in the same area, and attributed them to piedmont glaciers from the Long Range Mountains. Early southward oriented striations also have been noted on the Port au Port Peninsula (MacClintock and Twenhofel, 1940; Taylor, 1994), formed possibly by ice from the Lewis Hills (Brookes, 1974). Taylor *et al.* (1994) also showed a southward (160°) flow on the coast near Cape Ray in the extreme southwest of Newfoundland, that may have resulted from an ice flow down the Laurentian Channel (Grant, 1987). Evidence for an early southward ice flow along the west coast of Newfoundland is thus fragmentary. All striations are unweathered and, where found, are the youngest.

The ice that eroded the southward striations within the Humber River basin had its source to the north of the basin, probably within the Long Range Mountains (Figure 5-17). The alternative explanation is that they were produced by Laurentide ice. This hypothesis would require ice to cross the highlands between North Arm and Bonne Bay, or to flow into Bonne Bay and subsequently flow southward. There are no recorded striations to support either proposition. There is also no direct evidence (e.g., erratics) of Laurentide ice impinging on the coast south of the tip of the Northern Peninsula. The frequency of coast-parallel striations is, however, difficult to explain. Although Laurentide ice may not have occupied the Humber River basin, it may have occupied the Esquiman Channel offshore (Figure 1-9). This ice would have deflected island-based ice southward. The hypothesis remains untested, and requires drilling offshore to identify diamictons with a Labrador clast
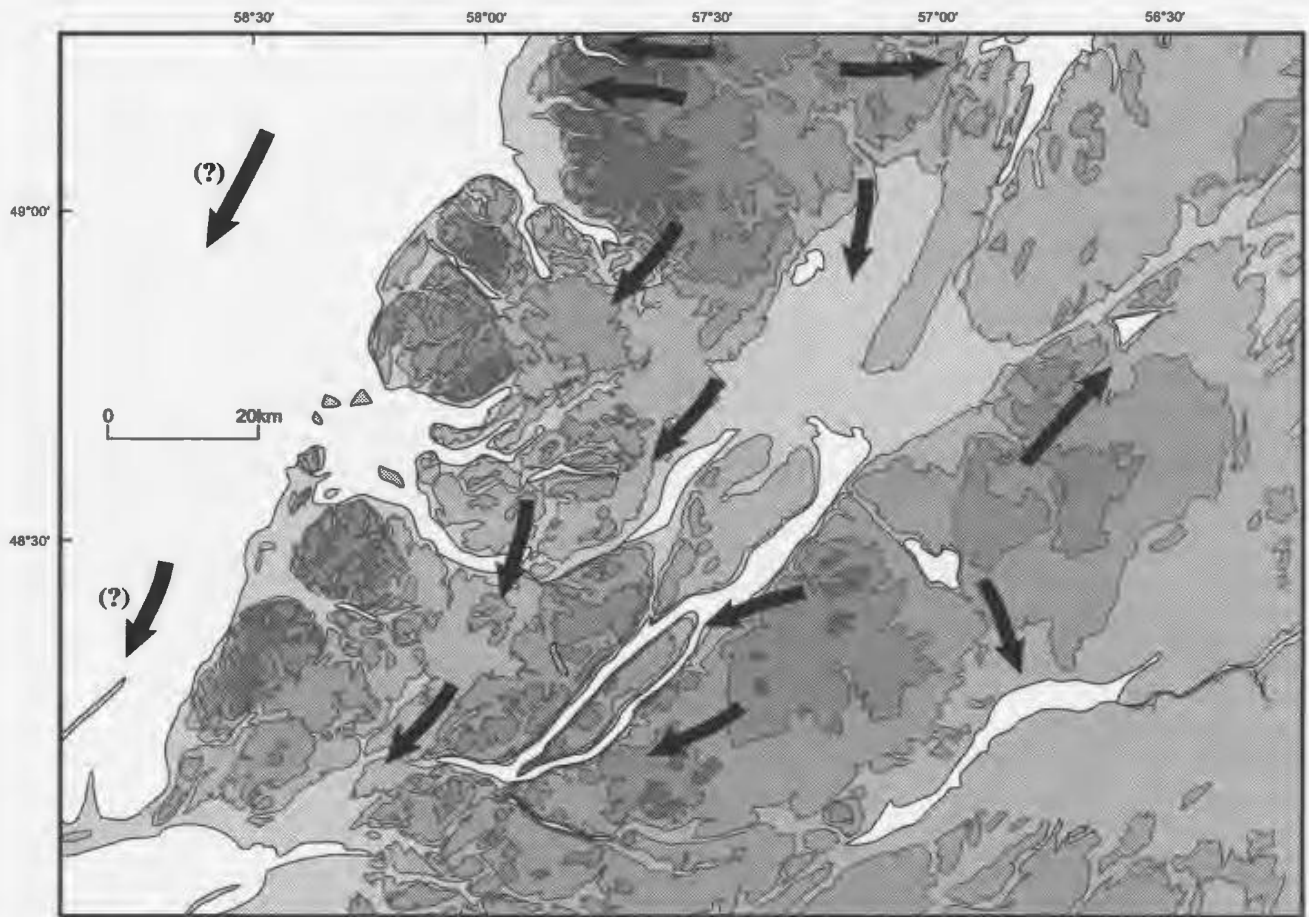
**Figure 5 - 17:** Early ice flow history of the Humber River basin. Most of the basin is covered by ice from the Long Range Mountain ice centre with limited influence of The Topsails ice centre. Ice may have occupied the Gulf of St. Lawrence at the time.

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provenance.

The northern part of the Humber River valley was covered by ice from the Long Range Mountains (Figure 5-17). Striations record an early ice flow from the mountains towards White Bay, crossed by striations produced by a later flow moving southeast to southwestward into the Humber River valley. In the area roughly defined by the highlands underlain by the Gull Lake intrusive suite, the only ice flow recorded is a northeastward flow into White Bay (Vanderveer and Taylor 1987; Taylor and Vatcher, 1993).

Ice from the Long Range Mountains ice centre entered the upper Humber River valley and flowed southward toward the Deer Lake valley. This is shown by southwestward oriented striations in the upper Humber River valley and along the shores of Deer Lake. The textural distribution of diamictons across the Humber River basin also demonstrates this flow. In the Upper Humber River basin diamictons are relatively coarse, although the area is underlain by friable Carboniferous siltstone and sandstone. Similarly, diamicton matrix colour is commonly dark brown (10YR 3/3) rather than reddish brown that is characteristic of Quaternary sediments in many areas underlain by Carboniferous bedrock. Ice moving southwestward down the Humber River from a source in the Long Range Mountains would disperse gneiss clasts over the Carboniferous bedrock, and produce a coarser, brown till. Gneiss clasts dominate the clast assemblage in diamictons found in the upper Humber River valley.

Ice from the Long Range Mountains remained in the upper Humber River valley during the Late Wisconsinan, as indicated by the landform, clast fabric, striations and clast provenance data.

## Glacial flow from The Topsails

Most of the Humber River basin was covered by ice from a dispersal centre on The Topsails (Figure 5-18). Ice flow was generally radial. In the southwest of the basin, ice flow from The Topsails was either southwest towards St. George's Bay, or northwest towards Serpentine Lake or the Humber Arm. Numerous striations indicate ice was deflected southward around the eastern margin of the Lewis Hills.

The west to northwestward flow from The Topsails produced striations that crosscut earlier ones from southward flow down the Georges Lake valley. Similarly, evidence for an early flow down Deer Lake and the lower Humber River valley is cross cut by a later flow oriented across the valley. Striations and clast dispersal data demonstrate this flow had its source in The Topsails, and extended out to the coast through the major fjords. The coastal highlands deflected ice flow, although striations and non-local clasts show that they were crossed by glaciers.

West of Deer Lake, diamictons are reddish brown (5YR 4/3) although they are underlain by grey limestone. Reddish brown diamictons have been reported as far west as Bonne Bay (Brookes, 1974), although the only local source for red sediments is the Deer Lake basin. Similarly, ice flow from The Topsails explains the relative coarseness of diamictons on the highlands east of Glide Lake, and the common occurrence of granite clasts. The area is underlain by Carboniferous rocks, but lies along a glacial flow path on The Topsails indicated by striations. The position of the Glide Lake highlands (elevation 320 m) as the first uplands west of Grand Lake would likely intercept material carried englacially (c.f., Batterson, 1989; Liverman, 1992).

Ice flowed northward out of the Sandy Lake basin, towards White Bay.
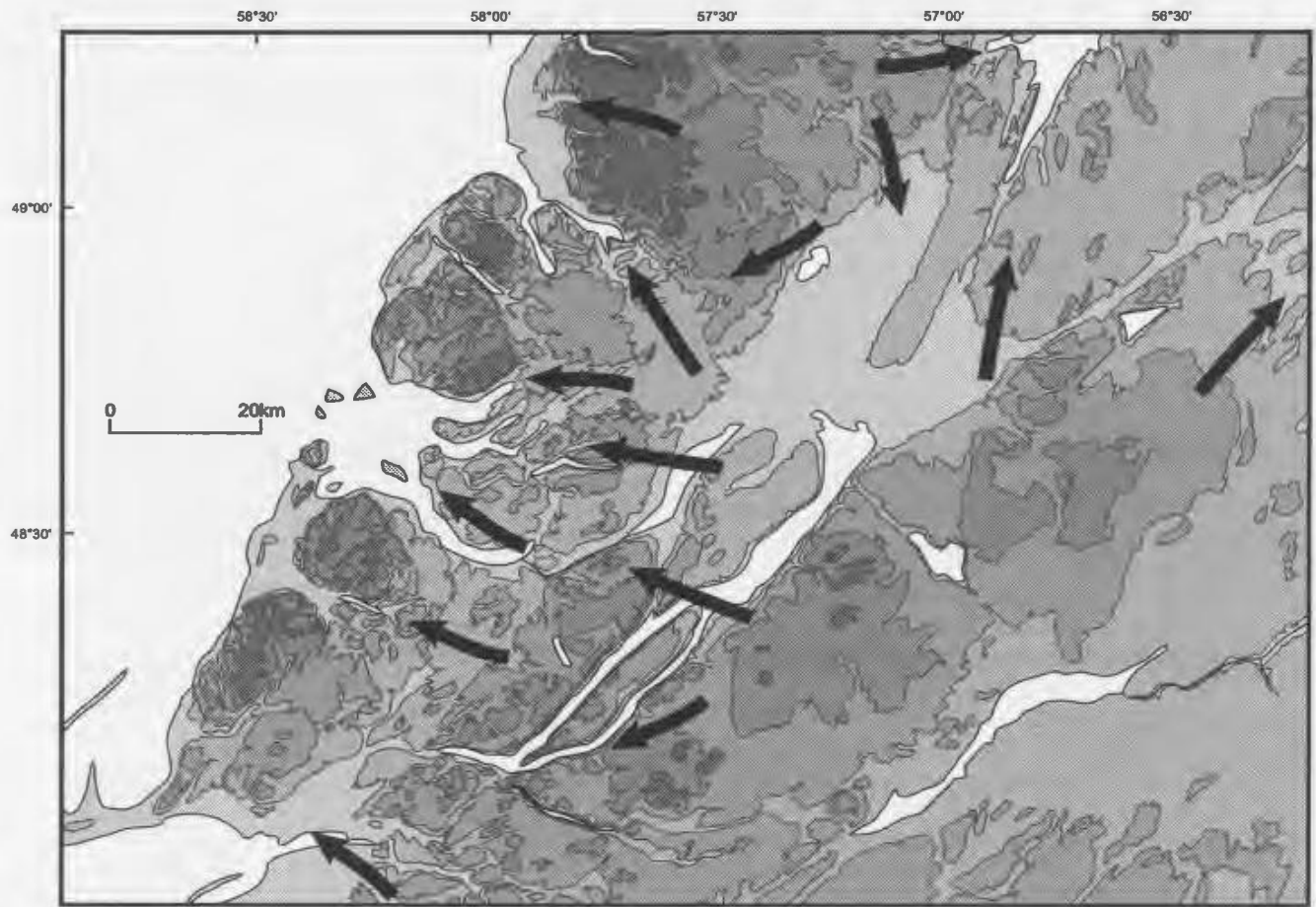
**Figure 5 - 18:** Glacial maximum ice flow patterns across the Humber River basin. Most of the basin is covered by ice from The Topsails ice centre with limited influence from the Long Range Mountains ice centre.

This is shown by clast dispersal data, particularly those from bedrock types restricted to The Topsails (e.g., Sp, Sm, Sq and Oib). This corresponds to observations of striations and landforms by MacClintock and Twenhofel (1940) and Grant (1989a). Clast provenance and striation evidence suggests ice from The Topsails flowed northward onto the central and southern parts of Birchy Ridge. There is no evidence to suggest this ice flow crossed Birchy Ridge into the upper Humber River basin. Farther east, in the Birchy Lake valley, ice flow was northeastward towards the coast.

Insufficient data are available to determine the exact location of The Topsails dispersal centre, although it almost certainly was not static during the Late Wisconsinan. Evidence for migrating ice centres has been described from other parts of Newfoundland and Labrador (e.g., Klassen and Thompson, 1993; Catto *et al.*, 1995). On The Topsails, an early westward ice flow is recorded by striations in the Hinds Brook valley, and as far east as the high plateau area northeast of Hinds Lake. Only one ice flow direction is recorded by striations in other areas of The Topsails. Northwestward ice flow was recorded over the central parts of The Topsails as far east as the Hinds Lake to Buchans Lake area (Klassen, 1994). This ice flow extended down the Hinds Brook valley, and also formed the till ridges in the Goose Pond area, but did not cover the high plateau of The Topsails, which only has evidence for northeastward flowing ice. In the southwest of The Topsails, ice flow generally was westward. Vanderveer and Sparkes (1982) reported southwestward flow in the Star Lake area. There is only one striation site recorded in the central part of The Topsails between Hinds Lake and Rainy Lake. Interpolation from adjacent areas would suggest northwestward to westward ice flow in this area. Based on these limited data, it is likely a major

ice dispersal centre was located on The Topsails, with an ice divide extending along the southwestern margin of the plateau overlooking the Red Indian Lake valley.

Late Wisconsinan ice flow within the upper Humber River valley and on adjacent highlands to the west was into and down the basin towards Deer Lake, as shown by striations and clast provenance data. No clasts from The Topsails were found in the valley. The southwestward ice flow is dominant as far south as Cormack. Southwest of this point, the increasing proportion of clasts from The Topsails suggests influence of northwestward flowing ice. Striations found west of Adies Pond are oriented increasingly westward the farther south they are traced, eventually becoming confluent with The Topsails-centred ice flowing northwestward towards Bonne Bay (Figure 5-18).

### Late-stage ice caps

Striations and clast fabric data support the presence of several late-stage ice caps, produced during retreat of ice. They were located on Birchy Ridge, the highlands east of Glide Lake, and highlands adjacent to the modern coast (Figure 5-19).

Striation evidence suggests ice flowed southward over Birchy Ridge, although the presence of clasts from The Topsails shows that at least part of the ridge, especially north of the old Trans Canada Highway, was covered by northward flowing ice from The Topsails ice centre. The ice flow history over Birchy Ridge is further complicated by southward striations found on the east side of Birchy Ridge at the head of Sandy Lake (Taylor and Vatcher, 1993). These suggest that southward flowing ice from the Long Range Mountain ice centre crossed Birchy Ridge and flowed into the northern part of the Sandy
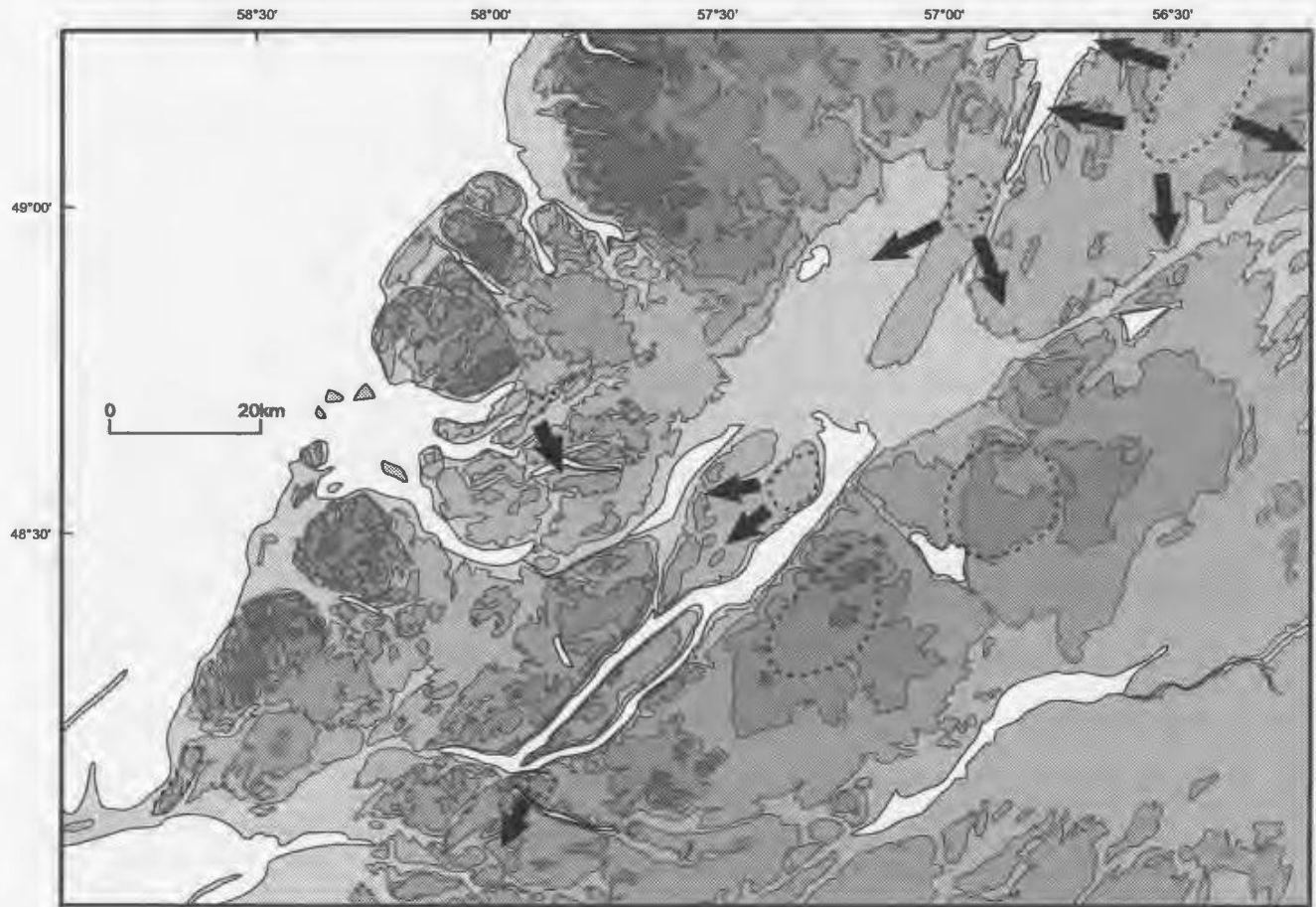
**Figure 5 - 19:** Remnant ice centres (dashed lines) in the Humber River basin. Individual centres are not necessarily contemporaneous.

Lake basin. This ice flow did not extend as far west as the area underlain by the Gull Lake intrusive suite. Grant (1989b) also recorded a southward flow along the west side of Sandy Lake. Cross-cutting striations show that this southward flow followed an earlier regional northward flow from The Topsails, and suggest it was a late-stage event that occurred at a time when ice from The Topsails had retreated from the basin.

Late-stage southward ice flow also is recorded on the highlands east of Glide Lake (Batterson and McGrath, 1993). No evidence was found to link this event with southward-flowing ice in Sandy Lake. Ice from this area flowed down the Pynn's Brook valley, as shown by till overlying sands discussed in Chapter 3.

Several sites were found that showed striations at variance with the regional ice flow patterns. Near Goose Arm striations record a late southeastward flow that post-dated a regional southwestward flow into Goose Arm. A late southward ice flow was recorded at the mouth of Little Grand Lake, following the regional westward ice flow. A late south-southwestward flow was recorded at Bonne Bay Little Pond, where the regional flow was northwestward. In the headwaters of the Humber River, striations show a late westward ice flow towards the coastal mountains, where the regional flow was east to southeastward. In each case, the striations recording the late ice flow direction could not be traced over a distance larger than 1 km. These are all interpreted to represent late-stage movements from remnant ice centres that developed on highland areas during the waning stages of the main ice caps. Each of the sites is downslope of a highland area.

# Chapter 6

# Sea Level History of the Humber River Basin

## Introduction

The available evidence clearly indicates that relative sea level was higher during deglaciation than present, and that there was a protracted episode of standing water in the Deer Lake basin at elevations below 50 m asl, resulting in the deposition of deltas along the margins and rhythmically bedded sediments in the basin. The presence of *Balanus hameri* shell fragments in the Humber River gorge, however, confirms that the lower Humber River valley was inundated by the sea. The marine limit in the Bay of Islands is defined by raised deltas (Flint, 1940; Brookes, 1974), and dated at circa 12,600 yrs BP. The delta at Humbermouth (49 m asl) (Plate 6-1) was an ice-contact feature (Brookes, 1974) that extended on both sides of the valley. Sediments exposed within the delta were interpreted as showing that "the snout of a valley glacier in the Humber Valley stood near the fiord head when a proglacial delta was being built into the sea at 160 feet (49 m)" (Brookes, 1974, p. 18). It was dissected by meltwater flowing through the Humber River gorge following retreat of ice from the lower Humber River area. The deltas at Nicholsville, Junction Brook and elsewhere in the Deer Lake area must therefore have formed after those in the Humber Arm district. The date of 12,220 ± 90 yrs BP (TO-2885) from *Balanus hameri* fossils in the Humber River gorge suggests that marine invasion of the Deer Lake basin took place shortly after construction of deltas on the coast.

**Plate 6-1:**
Raised marine delta at Humbermouth, with a surface elevation of 50 m asl. This feature is not dated, although marine shells from the Wild Cove valley (right background) date at 12.5 ka, and shells from Dancing Point (just off photograph to right) that date at 12.7 ka provide a minimum age for the delta.

The samples analysed for micro-palaeontology were taken from pro-delta or bottomset beds on the east side of the Deer Lake basin. These environments would be strongly influenced by inflowing meltwater, and likely had low salinities and a high suspended sediment content. This may explain the low faunal contents in sediments from the Deer Lake basin itself.

Seabrook (1962) in a survey of fish species in Deer Lake reported the presence of tom cod (*Microgadus tomcod*). Freshwater occurrences of tom cod are rare, and the Deer Lake fish are considered to be permanently landlocked populations (Scott and Crossman, 1973). Strong current flow through the Humber River gorge would preclude recent migration of cod into Deer Lake. Marine invasion and subsequent isolation of the Deer Lake basin early in the Holocene is a more likely explanation of their presence.

There is no published relative sea level curve for the Humber River basin area. Regional sea level studies have been undertaken in the St. George's Bay - Port au Port Bay area (Brookes *et al.*, 1985; Forbes *et al.*, 1993), and around Springdale (MacClintock and Twenhofel, 1940; Jenness, 1960; Tucker, 1974a). The areas form the southwest and northeast margins of the basin.

The pattern of relative sea level change in areas adjacent to continental ice sheets is controlled by passage of an ice marginal forebulge, produced by crustal displacement (Clark *et al.*, 1978; Quinlan and Beaumont, 1981). Clark *et al.* (1978) suggested Newfoundland was transitional between zones of continual emergence and continual submergence. Quinlan and Beaumont (1981) identified four zones of relative sea level change in Newfoundland, controlled by location relative to the migrating forebulge. Curves varied between continual emergence (Type A) and continual submergence (Type D).

A curve showing initial emergence and subsequent submergence is characteristic of a Type B curve (Quinlan and Beaumont, 1981, 1982).

One of the best documented and well-constrained sea level curves in Newfoundland is from the St. George's Bay - Port au Port Bay area. Early work by Brookes (1977a) suggested initial emergence from a marine limit of 27-45 m asl, followed by a transition from emergence to submergence at about 11.5 ka, with a -15 m low stand at about 10 ka and relative sea level returning to near present at about 5.5 ka (Figure 6-1). Brookes *et al.* (1985) refined this curve based on radiocarbon dates from marine shells, and analysis of foraminifera and pollen, and showed the emergence-submergence transition was about 9.5 ± 0.3 ka, with a low stand of 11-14 m below present at about 5.8 ka, followed by gradual emergence to present (Figure 6-1). Forbes *et al.* (1993) provided a further iteration. Using the elevation of submerged deltas and terraces, and additional radiocarbon dates, they demonstrated that the emergence-submergence transition occurred about 11.7 ka, with a lowstand at 25 m below present at 9.5 ka (Figure 6-1).

The Springdale area has a less well constrained relative sea level history than St. George's Bay. Marine limit was about 75 m above present, based on the elevation of deltas at Springdale and around Hall's Bay (MacClintock and Twenhofel, 1940; Jenness, 1960) and dated at 12-11 ka (Grant, 1974; Tucker, 1974a). The dating of the marine limit has been challenged by Scott *et al.* (1991). The implications are that at least the lower reaches of the Indian Brook valley were ice free at 12.5 ka, and that the marine limit deltas could predate 12.5 ka. There are no data on possible low stands on this part of
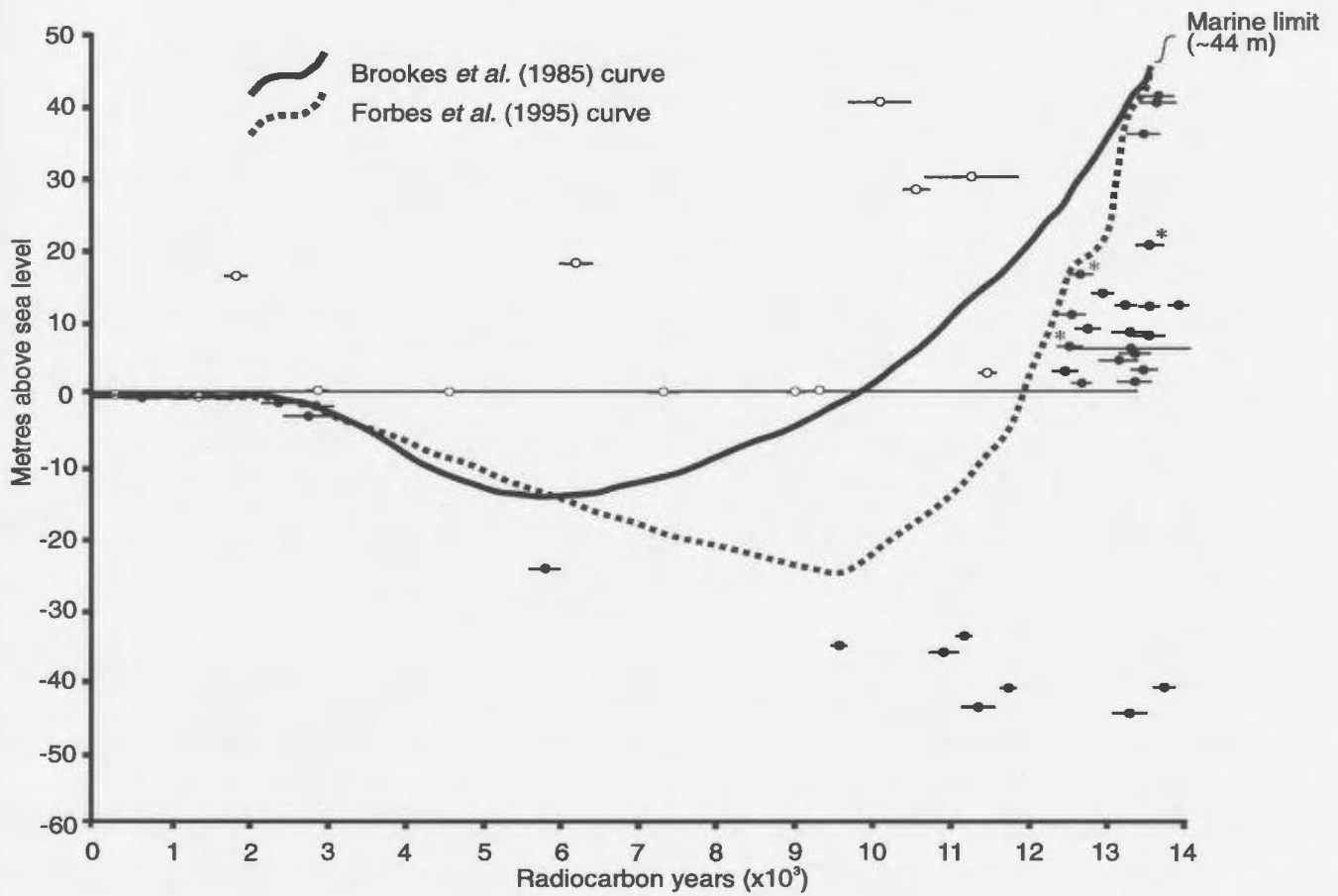
**Figure 6-1:** Relative sea level curves for St. George's Bay. Data from Brookes *et al.* (1985) and Forbes *et al.* (1995), except for points indicated by asterisk (*). These were generated by this thesis.

the coast, although Liverman (1994) speculated the area should have a Type B curve based on the distribution of radiocarbon dates.

Bonne Bay at the northwestern extension of the study area was deglaciated before 12.4 ka, based on dates from Neddy Harbour (12,400 ± 140 yrs BP, GSC-4553; Table 6-1), although inner parts of the bay may not have been ice free until some time later, possibly as late as 10.5 ka (Brookes, 1974). Marine limit in Bonne Bay was about 70 m above present (Brookes, 1974).

The preceding data suggest that the margins of the Humber River basin were deglaciated at roughly the same time, and that marine limit was higher in the northeast part of the basin compared to the southwest. Originally horizontal surfaces through the Humber River basin should now be inclined upward toward the northeast, as a result of differential isostatic uplift.

### Relative Sea Level Curve for the Humber Arm - Bay of Islands

A tentative relative sea level curve was constructed for the Bay of Islands area, based on $^{14}C$ dates of marine shells (Figure 6-2; Table 6-1), and published data on lowstand features. The elevation of marine limit is based on the top of the Hughes Brook delta at 60 m asl. Shaw and Forbes (1995) identified a sea level lowstand of 6 m below present at Corner Brook. Although this lowstand is not directly dated, interpolation between those dates derived for St. George's Bay (Forbes et al., 1993; Shaw and Forbes, 1995) and Bonne Bay (Brookes and Stevens, 1985; Grant, 1972) suggests the lowstand was at about 7.9 ka. Only one terrestrial date is recorded in the Bay of Islands area, that of 9,050 ± 130 BP (GSC-4281) on gyttja at 52 m asl from York Harbour (McNeely and McCuaig, 1991).

**Table 6-1:** Radiocarbon dates referred to in text and used to construct presented relative sea level curves. The assigned numbers (first column) correspond to sample points in Figure 6-2. Dates from the University of Toronto (designated TO) are adjusted using a 410 year correction.

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|----------|--------------|---|----------|-----------|------------|-----------|--------|----------|

## Humber Arm and Basin

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|----------|--------------|---|----------|-----------|------------|-----------|--------|----------|
| 1 | South Brook | 13100 | 220 | GSC-5302 | 48°54.9' | 57°37.7' | 135 | Batterson et al., 1995 | Bulk organics |
| 2 | Goose Arm | 13070 | 90 | TO-3624 | 49°12.7' | 57°49.7' | 50 | Batterson et al., 1993 | Shells (*Mya truncata*) |
| 3 | Dancing Point | 12700 | 300 | GSC-4272 | 48°57' | 57°53' | 15 | GSC Paper 87-7 | Shells (*Macoma balthica*) |
| 4 | Cox's Cove | 12600 | 170 | GSC-868 | 49°07' | 58°05' | 38 | Brookes, 1974 | Shells (*Hiatella arctica*) |
| 5 | Wild Cove | 12450 | 90 | TO-2884 | 48°58.3' | 57°52.7' | 18 | Batterson et al., 1993 | Shells (*Mya truncata*) |
| 6 | Humber River gorge | 12300 | 110 | GSC-5300 | 48°56.9' | 57°50.8' | 13 | This thesis | Shells (*Balanus hameri*) |
| 6 | Humber River gorge | 12220 | 90 | TO-2885 | 48°56.9' | 57°50.8 | 13 | Batterson et al., 1993 | Shells (*Balanus hameri*) |
| 7 | Goose Arm | 12120 | 90 | TO-3623 | 49°11.0' | 57°51.8' | 29 | This thesis | Shells (*Mya truncata*) |
| 8 | Goose Arm | 12100 | 130 | GSC-5538 | 49°10.9' | 57°51.5' | 7 | This thesis | Shells (*Nuculana pernula*) |
| 9 | Curling | 12090 | 90 | TO-4358 | 48°57.5' | 57°59.3' | 10 | This thesis | Shells (*Mya truncata*) |
| 10 | Little Port | 12000 | 320 | GSC-1462 | 49°06.7' | 58°24.8' | 37 | Brookes, 1974 | Shells (*Mytilus edulis*) |
| 11 | Goose Arm | 11900 | 120 | GSC-5516 | 49°10.1' | 57°53.1' | 27 | This thesis | Shells (*Mya truncata*) |
| 12 | Goose Arm | 10600 | 100 | GSC-4400 | 49°07.4' | 57°56' | 6 | GSC Paper 89-7, p. 17 | Shells (*Mya truncata*) |
| 1 | South Brook | 9540 | 90 | TO-5707 | 48°54.9' | 57°37.7' | 135 | This thesis | Salix twig |
| 13 | York Harbour | 9050 | 130 | GSC-4281 | 49°02.8' | 58°22.4 | 52 | GSC Paper 89-7, p. 17 | Gyttja |

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|---|---|---|---|---|---|---|---|---|

## Bonne Bay area

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|---|---|---|---|---|---|---|---|---|
| 14 | Muddy Brook | 12100 | 160 | GSC-4158 | 49°29.5' | 57°55.6' | 20 | GSC Paper 87-7, p. 5 | Shell (*Macoma calcarea*) |
| 15 | Glenbumie | 11200 | 150 | GSC-4279 | 49°26.1' | 57°53.9' | 15 | GSC Paper 87-7 | Shells (*Cyrtodaria siliqua*) |
| 16 | Lomond | 11200 | 130 | GSC-4790 | 49°27.3' | 57°45.1' | 2 | GSC Paper 89-7, p. 17 | Shells (*Macoma calcarea*) |
| 16 | Lomond | 10500 | 300 | GSC-1575 | 49°27.3' | 57°45.3' | 4 | Brookes 1974 | Shells (*Macoma calcarea*) |
| 17 | Bonne Bay | 1730 | 140 | GSC-1266 | 49°28.1' | 57°57.4' | 260 | GSC Paper 71-7, p. 260 | Peat |

## St. George's Bay area

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|---|---|---|---|---|---|---|---|---|
| 18 | Fiods Cove | 26600 | 550 | GSC-4563 | 48°30.9' | 58°57.4' | 5-10 | GSC Paper 89-7, p. 18 | Shells (*Mya, Astatre, Nuculana*) |
| 19 | Port au Port Bay | 13710 | 115 | Beta 30002 | 48°43' | 58°43' | -41 | Forbes and Shaw 1989 | Shells (*Portlandia arctica*) |
| 20 | Abraham's Cove | 13700 | 230 | GSC-1074 | 48°31.5' | 58°55' | 45 | GSC Paper 71-7, p. 263 | Shells (*Hiatella arctica*) |
| 21 | Romaines Brook | 13680 | 100 | TO-6137 | 48°34.1' | 58°40.3' | 37 | This thesis | Shells (*Mya truncata*) |
| 20 | Abraham's Cove | 13600 | 110 | GSC-2015 | 48°32' | 58°54' | 40 | GSC Paper 75-7, p. 6 | Shells (*Hiatella arctica*) |
| 20 | Abraham's Cove | 13600 | 180 | GSC-968 | 48°31.5' | 58°55' | 7.5 | GSC Paper 71-7, p. 262 | Shells (*Hiatella arctica*) |
| 22 | Port au Port | 13400 | 290 | GSC-1187 | 48°33.8' | 58°42.6' | 2 | GSC Paper 71-7, p. 261 | Shells (*Balanus* sp.) |
| 23 | Romaines | 13345 | 230 | S-3074 | 48°33' | 58°41' | 6-8 | Grant 1991 | Whale bone |
| 24 | Stephenville | 13300 | 810 | GSC-2063 | 48°32' | 58°37' | 5-6 | Brookes 1977a | Shells |
| 25 | Rocky Point | 13200 | 220 | GSC-937 | 48°39.1' | 58°57.4' | 3.7 | GSC Paper 70-2, p. 51 | Shells (*Mya arenaria*) |

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev. (m) | Source | Material |
|---|---|---|---|---|---|---|---|---|---|
| 23 | Romaines | 13100 | 180 | GSC-4095 | 48°33.2' | 58°41' | 3 | GSC Paper 87-7, p. 6 | Shells (*Mya truncata*) |
| 26 | Campbells Cove | 13300 | 120 | GSC-4346 | 48°31.5' | 58°51.2' | 11 | GSC Paper 87-7 | Shells (*Hiatella arctica*) |
| 27 | Piccadilly | 13000 | 110 | GSC-4584 | 48°34.2' | 58°54.6' | 14 | GSC Paper 89-7, p. 18 | Shells (*Mya truncata*) |
| 23 | Romaines | 12800 | 130 | GSC-5030 | 48°33.2' | 58°41.0' | 2-4 | GSC Paper 95-G, p. 13 | Shells (*Hiatella arctica* ) |
| 23 | Romaines | 12800 | 130 | GSC-4858 | 48°33.2' | 58°41.0' | 6-8 | GSC Paper 89-7, p. 18 | Shells (*Hiatella arctica* ) |
| 23 | Romaines | 12700 | 110 | GSC-4017 | 48°33.3' | 58°41.1' | 1 | GSC Paper 87-7, p. 6 | Plant debris |
| 24 | Kippens | 12610 | 100 | TO-6138 | 48°32.7' | 58°37.8' | 8 | This thesis | Shells (*Hiatella arctica, Macoma Calcarea*) |
| 24 | Kippens | 12600 | 120 | GSC-5942 | 48°32.6' | 58°38.0' | 21 | This thesis | Shells (*Mya truncata*) |
| 24 | Stephenville | 12600 | 140 | GSC-2295 | 48°32.6' | 58°36.7' | 10 | Brookes 1977b | Shells |
| 19 | Port au Port Bay | 11740 | 100 | Beta 30004 | 48°43' | 58°43' | −41 | Forbes and Shaw 1989 | Shells (*Astarte undata*) |
| 23 | Romaines | 11500 | 100 | GSC-4291 | 48°33.3' | 58°41.1' | 1 | GSC Paper 87-7 | Peat |
| 28 | Port au Port Bay | 11300 | 100 | Beta 30005 | 48°38' | 58°43' | −34 | Forbes and Shaw 1989 | Shells (*Astarte undata*) |
| 28 | Port au Port Bay | 11165 | 95 | Beta 30003 | 48°38' | 58°43' | −34 | Forbes and Shaw 1989 | Shells |
| 28 | Port au Port Bay | 9570 | 150 | GSC-4724 | 48°38' | 58°43' | −34 | Forbes and Shaw 1989 | Shell (*Spisula polynyma*) |
| 19 | Port au Port Bay | 5800 | 210 | GSC-1203 | 48°43' | 58°50' | 24 | GSC Paper 71-7, p. 262 | Shells (*Hiatella arctica*) |
| 29 | St. George's Bay | 3695 | 95 | Beta 30001 | 48°31' | 58°40' | −42 | Forbes and Shaw 1989 | Polychaete worm tubes |
| 30 | Victor's Brook | 2840 | 80 | GSC-4243 | 48°37.8' | 58°58.5' | 3.2 | GSC Paper 87-7 | Wood |

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev (m) | Source | Material |
|---|----------|--------------|---|----------|-----------|------------|----------|--------|----------|
| 31 | Hynes Brook | 2770 | 300 | UQ-646 | 48°36' | 58°57' | 2.8 | Brookes et al., 1985 | Peat |
| 31 | Hynes Brook | 2365 | 175 | GX-9527 | 48°36' | 58°57' | 1.8 | Brookes et al., 1985 | Peat |

## Hall's Bay area

| # | Location | Date (Corr.) | ± | Lab. No. | Lat. (°N) | Long. (°W) | Elev (m) | Source | Material |
|---|----------|--------------|---|----------|-----------|------------|----------|--------|----------|
| 32 | Hall's Bay | 12470 | 380 | TO-2305 | 49°30' | 56°11' | 29 | Scott et al., 1991 | Shell (Mya truncata) |
| 33 | Deer Cove Pond | 12400 | 110 | GSC-4700 | 50°0.6' | 56°03.3 | 72 | GSC Paper 89-7, p. 13 | Shell (Hiatella arctica) |
| 34 | South Brook | 12000 | 220 | GSC-1733 | 49°25.5' | 56°06.5' | 20 | GSC Paper 83-7, p. 6 | Shell (Balanus sp.) |
| 35 | Southwest Arm | 11880 | 190 | GSC-87 | 49°35' | 56°12' | 12 | GSC Paper 63-21 | Shell |
| 36 | Kings Point | 11800 | 200 | GSC-3957 | 49°31.2' | 56°11.8' | 102 | GSC Paper 86-7, p. 4 | Gyttja |
| 37 | Hall's Bay | 11340 | 150 | TO-2306 | 49°30' | 56°10' | 24 | Scott et al., 1991 | Organic detritus |
| 38 | Jacksons Arm | 11200 | 100 | GSC-4247 | 49°51.7' | 56°49.0' | 22-28 | GSC Paper 87-7, p. 8 | Shell (Mya truncata) |
| 39 | Ming's Bight | 10400 | 160 | GSC-3966 | 49°57.0' | 56°05.3' | 122 | Dyer, 1986 | Gyttja |
| 40 | Sops Arm | 10200 | 100 | GSC-4023 | 49°43.5' | 56°55.7' | 27 | GSC Paper 87-7, p. 8 | Shell (Mya truncata) |
| 41 | Hall's Bay | 7890 | 80 | TO-2304 | 49°30' | 56°11' | 27 | Scott et al., 1991 | Shell (Mya arenaria) |
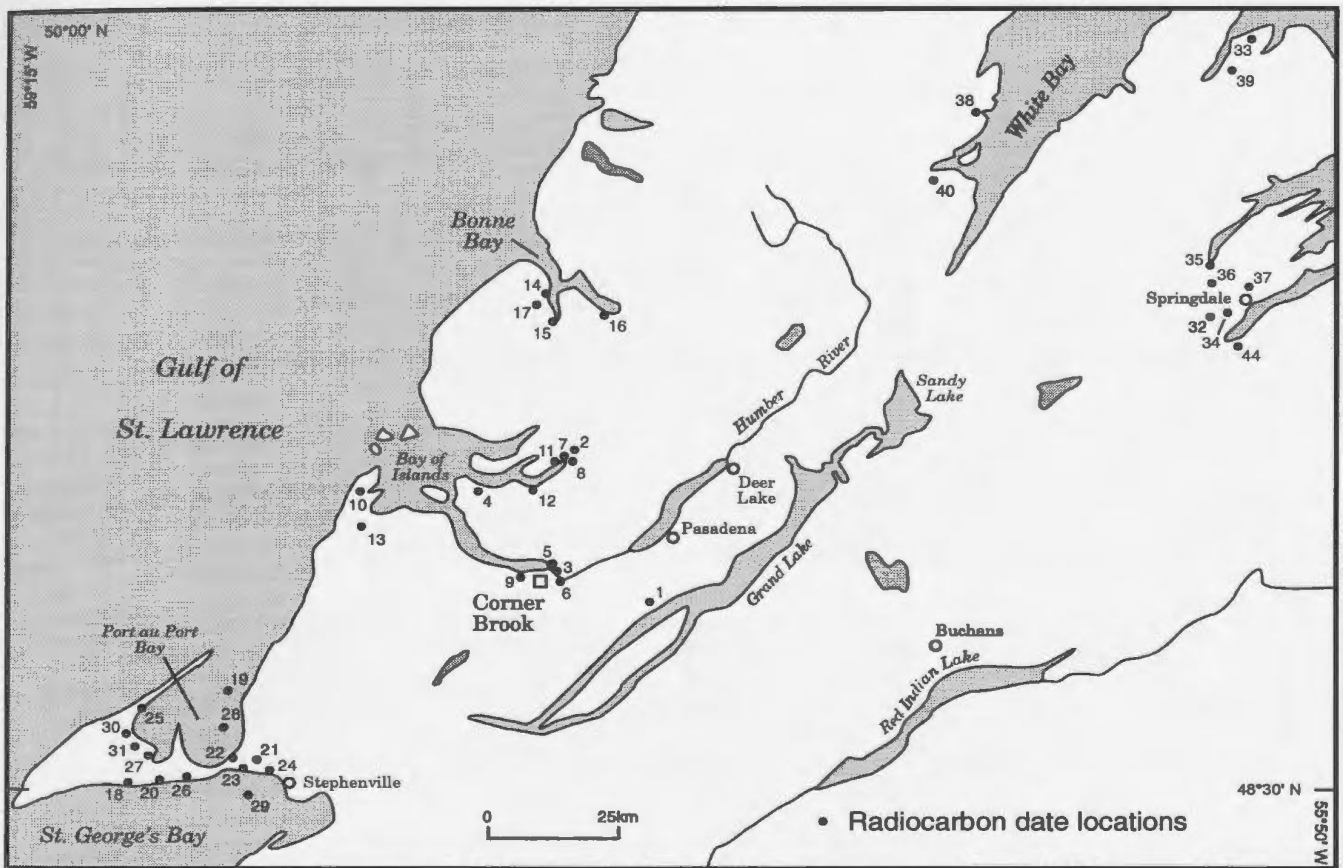
**Figure 6 - 2:** Location of sites from which radiocarbon dates were derived.

Figure 6-3 shows three relative sea level curves produced from this data. Dashed line 1 is a smooth, steep curve that incorporates all dates from the area. Extrapolation suggests that a marine limit of 60 m asl should date at about 12.2 ka. However, a marine shell sample from Goose Arm Brook at 50 m asl was $^{14}$C dated at 13,070 ± 90 yrs BP (TO-3624).

Dashed line 2 shows a perturbation in the curve around the Little Port date. The older part of the curve is more in accordance with the Goose Arm Brook date, and shows the marine limit at about 13.2 ka. Forbes *et al.* (1993) recognised a similar distortion in their curve for St. George's Bay. The perturbation there occurs at about 12.6 ka at 14-16 m asl. Terraces have been recorded around St. George's Bay at this elevation (e.g., Brookes, 1974). The features were produced during a stillstand of unknown cause. The distortion in the Bay of Islands curve occurs at 11.5 - 12.0 ka at about 37 m asl. No associated terraces or deltas have been recorded in the Bay of Islands at this elevation (c.f., Brookes, 1974; Flint, 1940). The date from Little Port of 12,000 ± 320 BP (GSC-1462) appears to be anomalous when compared to other dates in the area. The date was interpreted by Brookes (1974) as dating the 47 m asl marine limit for the area. This is similar to the 49 m asl delta at Cox's Cove dated at 12,600 ± 170 BP (GSC-868). Brookes (1974) questions the reliability of the Little Port date (although with the large error bars the dates are statistically similar), and suggests the difference in dates may be attributed to ice lingering in constricted valleys on the outer coast. Such an age difference should also be shown in an elevational difference of delta surfaces, due to the influence of isostatic rebound, but this is not the case. The Little Port date is therefore considered potentially spurious.
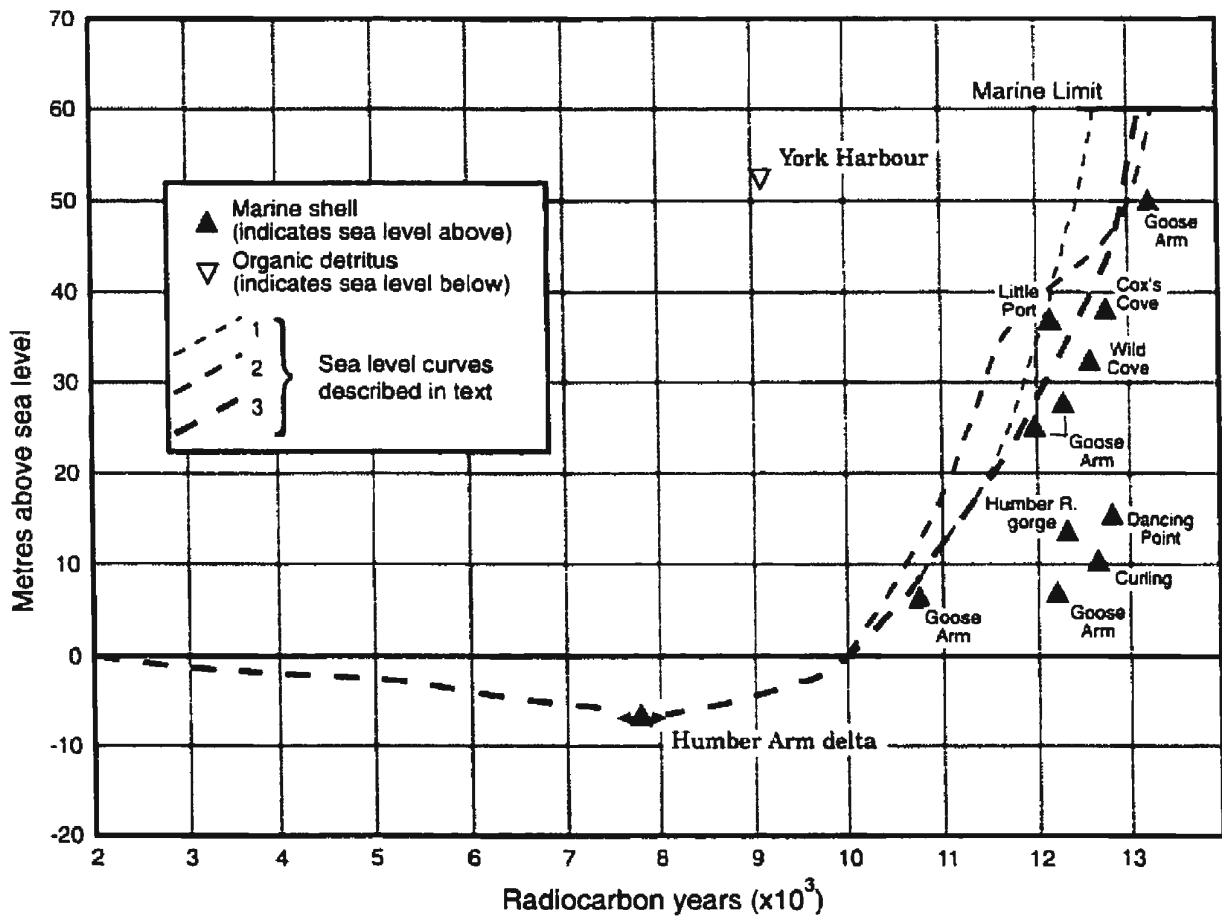
**Figure 6 - 3:** Relative sea level curve for the Humber Arm area.

Dashed curve 3 incorporates all dates apart from Little Port. The upper part of the curve is based on the Goose Arm Brook date, and places the marine limit at about 13.2 ka. The central part of the curve is based on dates in the Goose Arm area and the delta at Cox's Cove. The lower part is constrained by the date from the central part of Goose Arm. In the absence of conflicting data, a smooth relative sea level curve is considered a reasonable first approximation of events in the Bay of Islands.

## Discussion

The Bay of Islands relative sea level curve is a Type B curve using the terminology of Quinlan and Beaumont (1981, 1982), showing initial emergence and subsequent submergence of the coastline. The details of the curve are consistent with the model of relative sea level change for Newfoundland developed by Liverman (1994), using the ^{14}C date compilation of Batterson et al. (1992). Liverman's model uses the distribution of ^{14}C dated marine molluscs to predict the date at which sea level fell below present, which is then tested against existing relative sea level curves. The model predicts that a sea level fall below that of present should have occurred about 10.5 ka for the Bay of Islands. The relative sea level curve presented above suggests this transition occurred about 500 years later.

The relative sea level curve for the Bay of Islands area is in qualitative agreement with that predicted by the maximum ice model of Quinlan and Beaumont (1981, 1982). Their minimum ice model suggested the Bay of Islands should be a Type C curve where no sea level features above present are found. Grant (1989a) used this model to support the concept of limited ice over Newfoundland during the Late Wisconsinan. The timing of the

transition from emergence to submergence, and the elevation and date of the marine limit are quantitatively different from Quinlan and Beaumont's model. Liverman (1994) described similar incompatibilities for Newfoundland as a whole, which is characterised largely by Type B relative sea level curves. This is in contrast to the narrow belt of Type B curves described by Quinlan and Beaumont (1981, 1982), and suggests an underestimate of the area affected, and speed of migration of the collapsing forebulge (Liverman, 1994).

The data show a disparity between model predictions and field data, that are likely the result of the geological inputs to initial model. Following the work of Quinlan and Beaumont (1981, 1982), different geophysical inputs have been applied to models considering relative sea level changes in areas marginal to continental ice sheets (e.g., Lambeck *et al.*, 1990, 1996; Mitrovica and Peltier, 1995; Davis and Mitrovica, 1996). Although beyond the scope of this thesis, it is perhaps an appropriate time to apply newer ice and Earth inputs in models of relative sea level change in Newfoundland, to be tested against an increasing body of field data.

# Chapter 7

# Quaternary History of the Humber River Basin

## Introduction

The preceding chapters have described the surficial geology, sediment and stratigraphy, and ice flow history of the Humber River basin. This chapter will integrate data in a discussion of the glacial and post-glacial history of the area.

## Phase 1: Glaciation

The entire Humber River basin was glaciated. Striated bedrock surfaces and exotic clast rock types were found on the highest hills within, and along the margins of the basin (Plate 7-1). Diamictons are fresh, and striated bedrock surfaces unweathered. The Rocky Brook till, suggested by Vanderveer and Sparkes (1982) to be pre-Wisconsinan, remains undated. Dateable material was not found beneath glacial sediments. $^{14}C$ dating of marine shells stratigraphically above the diamictons shows that glaciation predated about 13 ka. It is thus most reasonable to assume that tills were deposited during the Late Wisconsinan in the absence of evidence to the contrary. Exposures with multiple till units are interpreted to have been deposited during a single glacial episode. Definitive Pre-Late Wisconsinan deposits were not recognised within the study area.

The Humber River basin was covered by ice advancing from two major dispersal centres, the Long Range Mountains and The Topsails. Initial

**Plate 7-1:**
View of North Arm Mountain. This area is underlain by ultramafic ophiolitic bedrock that has a brown weathered surface. The siltstone erratics from the Deer Lake basin found here show that this area was overtopped by ice.

advance was from the Long Range Mountain ice cap southward into the upper Humber River valley, flowing into the Deer Lake basin. The southwestern extent of this flow is uncertain. Striation and clast provenance data from the Corner Brook area, near Georges Lake and near Stephenville, indicate an early southward flow, but it is uncertain if these features are correlative.

There is no evidence to show this early flow covered the Grand Lake valley, although the lack of striated bedrock surfaces and the lack of distinctive rock types to trace dispersal, does not preclude the possibility. The extent of Topsails-centred ice during this early phase remains unresolved.

Striation and clast dispersal patterns are dominated by radial ice flow from an ice centre on The Topsails extending along the southwestern margin of the plateau overlooking the Red Indian Lake valley. In the Hinds Lake area ice flow was northwestward, whereas flow on the high plateau to the east was northeastward. This constrains the position of the northeast part of the dispersal centre. Topsails-centred ice crossed the Glide Lake highlands and Deer Lake, flowing towards the coast. It covered the lower part of the upper Humber River valley south of Cormack. In the north of the Humber River basin, ice crossed Sandy Lake and Birchy Lake and flowed towards the coast into White Bay or Hall's Bay, while in the southwest ice flow was towards St. George's Bay or through Serpentine Lake.

The occurrence of erratics demonstrates that ice crossed the coastal highlands from the interior. The elevation of coastal highlands range from 814 m asl for the Lewis Hills, 650 m asl for Blow-me-Down Mountain, to 706 m asl for North Arm Mountain. If the erratics are assumed to have been deposited during the Late Wisconsinan, this represents a minimum ice

thickness over The Topsails of 260 m (the elevation difference between the two areas). The surface slope of most glaciers is small, between 1:100 and 1:1000 (Drewry, 1986), suggesting an ice thickness of 350 to 1200 m.

The striation pattern shows that ice was deflected by coastal highlands. Ice flow was northwestward near the community of Deer Lake, but was drawn southwestward towards the coastal fjords of North Arm, Goose Arm and Penguin Arm. Similarly, westward ice flow across the Georges Lake valley was deflected southward by the Lewis Hills.


## Phase 2: Deglaciation

Deglaciation of the Bay of Islands commenced about 13 ka, based on the radiocarbon date of 13.1 ka from Goose Arm Brook. The inner part of Humber Arm was ice free by 12.5 to 12.7 ka based on dates from Wild Cove and Dancing Point. This is similar timing to deglaciation of the southwest and northeast margins of the Humber River basin (Brookes, 1974; Macpherson and Anderson, 1985; Scott *et al.*, 1991).

The distribution of eskers, meltwater channels and hummocky moraine suggests some directions and areas of ice wastage. The distribution of hummocky moraine in the central and eastern parts of the basin indicates that ice retreated across the highlands west of the Humber River valley, and stagnated at locations;within the upper Humber River valley, on the Glide Lake highlands, in the lowlands around Howley, and on The Topsails. Meltwater channels are also present at these locations (see Figure 2-1).

The lack of meltwater channels over the highlands west of Deer Lake, and in the southern part of the Grenville inlier is evidence that ice retreated rapidly from these areas, and did not waste *in situ*. In contrast, the numerous

meltwater channels on The Topsails plateau show this location to be a site of ice disintegration. Meltwater channels drained radially outward into the Hinds Brook and Kelvin Brook valleys, and into the Sandy Lake-Grand Lake basins from the 340 m asl plateau between Goose Pond and Hinds Lake (Figure 2-1). The presence of meltwater channels across the slope between this plateau surface and the higher level at about 520 m asl to the east of Goose Pond, suggests ice remained on the lower plateau as the slopes to the upper plateau became ice free.

The radial pattern of meltwater channels also imply that remnant ice was located on the southern end of Birchy Ridge, on the highlands between the Glide Lake and Deer Lake valleys, overlooking the South Brook valley, and on The Topsails southwest of Hinds Brook. These remnant ice centres remained active, at least for a short period, as indicated by striation patterns. In the Glide Lake - Pynn's Brook area, till found overlying glaciofluvial sand-gravel is interpreted as representing evidence for a local readvance down the Pynn's Brook valley.

## Phase 3: Glacial Lake Development

Features and sediments related to deposition in standing water are found on the shores of Grand Lake and in adjacent valleys, such as South Brook (Figure 7-1). They were formed within either a marine or lacustrine depositional environment. The surface elevations of deltas are at least 70 m above known marine features adjacent to the modern coast. Features deposited in a marine environment found at modern elevations of 145 m asl are found in southern Labrador (Grant, 1992), approximately 300 km north of Grand Lake. Sediments around Grand Lake contained no marine macro- or
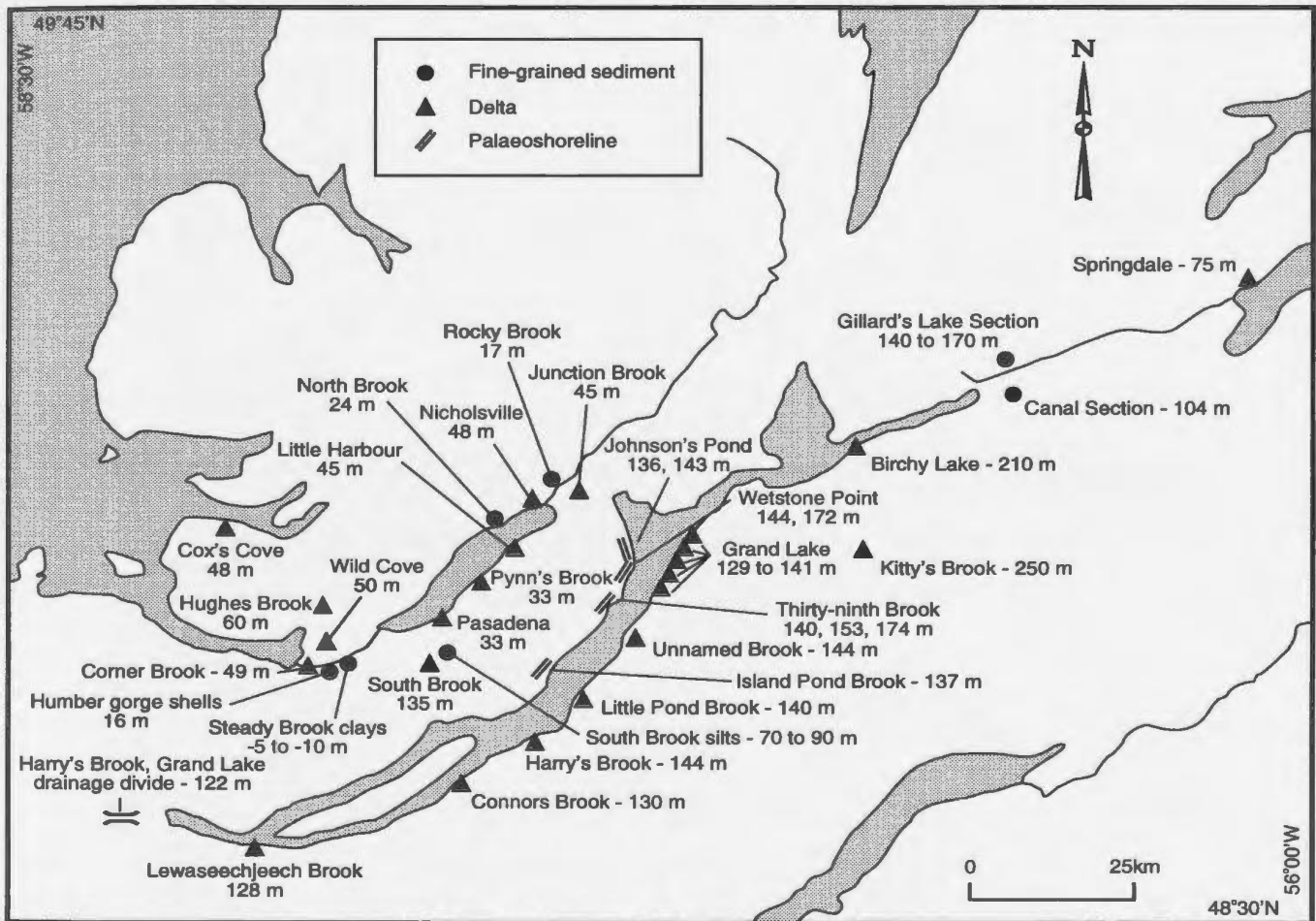
**Figure 7 - 1:** Location map showing features related to higher water levels in the Humber River basin.

micro-fossils. The sedimentology and elevation of the deposits indicate deposition in a glaciolacustrine environment.

Deposition was either in a single glacial lake, or in a series of smaller ice-marginal lakes. A single lake would require that all shoreline features be at similar elevations, or must show a progressive change related to isostatic deformation; it must be able to include all shoreline features, without unreasonably complex or numerous ice dams; and any postulated spillway must be at the lowest elevation on the lake margin, in an area free of ice dams.

The formation of pro-glacial lakes during regional stagnation of ice masses in undulating terrain has been documented in many places, including the Ural Mountains (Arkhipov et al., 1995); the Scottish Highlands (Sissons, 1979; Sissons and Cornish, 1983; Lowe and Cairns, 1991); the Interior Plateau of British Columbia (Fulton, 1969, 1975; Huntley and Broster, 1994, 1997); Alberta and northeastern British Columbia (St. Onge, 1972; Mathews, 1980); and in the Mackenzie River valley of the Northwest Territories (Smith, 1992, 1994). In contrast to the strongly developed strandlines of lake basins in some lowland areas, such as the Great Lakes basin (Karrow and Calkin, 1985; Colman et al., 1994; Lewis et al., 1994), and southern Lake Agassiz (Fisher and Smith, 1994; Teller and Clayton, 1983; Teller et al., 1983), lacustrine features in areas of variable topography tend to be discontinuous and scattered. Identification of individual lake stages and recognition of their spatial and temporal relationships is based on the presence and elevations of spillways, strandlines, deltas, and sediments. A lake developed over a broad area is delineated by assemblages of features at similar elevations or a consistent trend of elevations where affected by isostatic rebound. In contrast, sediments

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and landforms associated with small, isolated transitory lakes formed at the margins of a downwasting ice mass and not hydrostatically linked will be found over a range of elevations, with each lake producing a local series of unrelated features.

The spatial and consistent elevation distribution of features related to higher water levels in the Grand Lake basin (Figure 7-2) suggest formation in a single glacial lake, that occupied most of the basin with a shoreline at approximately 120 m asl in the south to 140 m asl in the north. The name 'glacial Lake Howley' was proposed for this body of water (Batterson *et al.*, 1993).

Three reconstructions are presented for the extent and duration of glacial Lake Howley: a maximum; minimum; and intermediate view.

### Maximum reconstruction

This is the reconstruction of Batterson *et al.* (1993) (Figure 7-3), who proposed a lake more than 125 km long, and up to 25 km wide, with a surface area of about 1850 km$^2$. Impoundment of a lake with a shoreline at approximately 140 m asl in the Grand Lake basin requires damming of two low points on the basin margin, the lower Humber River valley (likely in the Humber River gorge) ($\pm$ 0 m asl) and the Birchy Lake valley ($\pm$ 110 m asl). The origin of the Humber gorge ice dam was speculated by Batterson *et al.* (1993) to be dead ice isolated during retreat of The Topsails ice. The lake was proposed as covering the entire Humber River valley, including the modern day Grand Lake, Sandy Lake, Deer Lake and Birchy Lake valleys, with an outlet at the western end of Grand Lake (Batterson *et al.*, 1993). This was a tentative hypothesis based on the data known as of 1993, and involved extrapolating
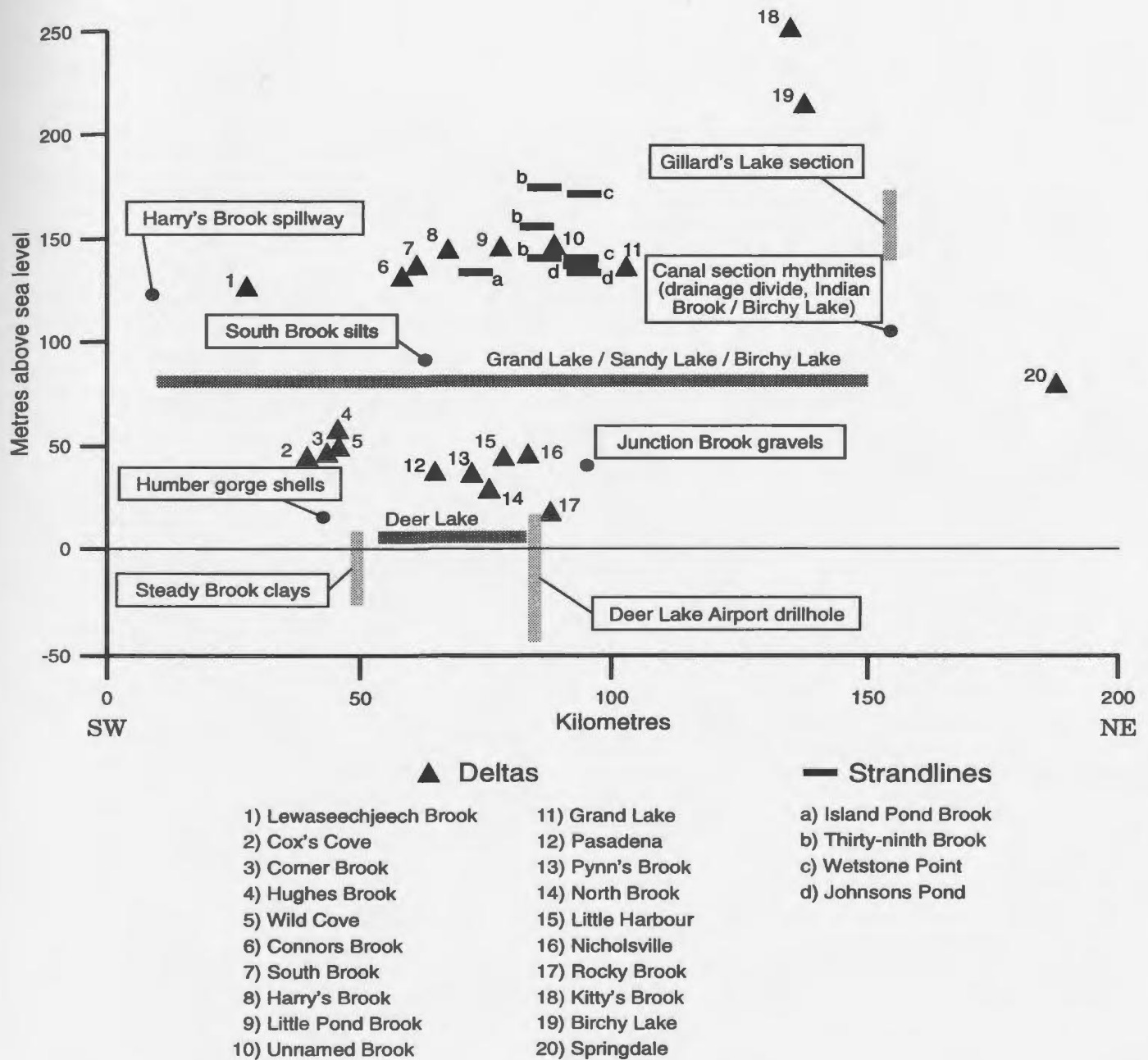
**Figure 7 - 2:** Spatial and elevational distribution of features related to higher water levels in the Humber River basin.
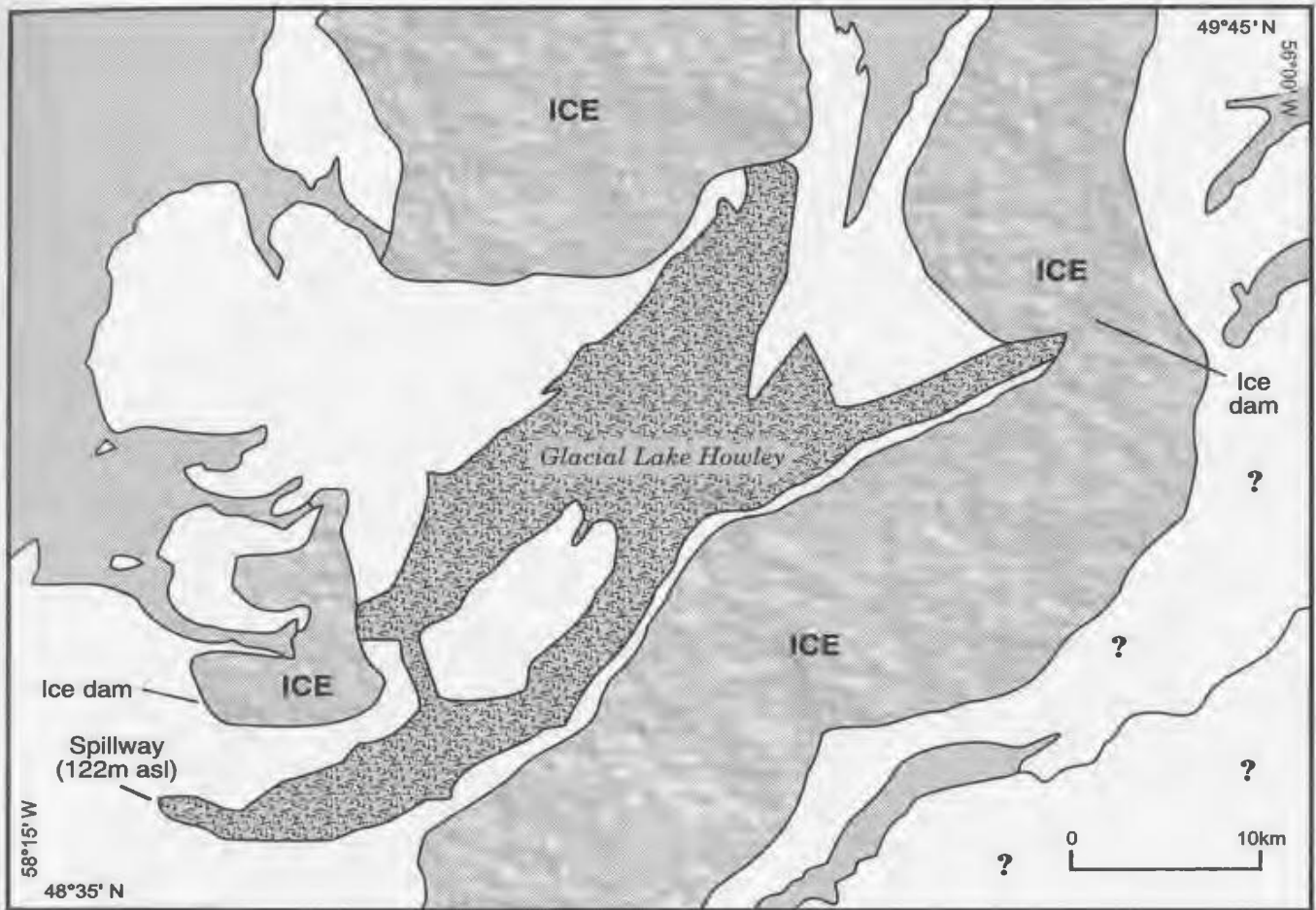
**Figure 7 - 3:** Maximum reconstruction of glacial Lake Howley (after Batterson *et al.*, 1993).

the extent of the lake along topographic contours into those areas that had not been extensively mapped at that time.

Lake extent was based largely on sedimentological and geomorphological descriptions from exposures along the margins of the proposed glacial Lake Howley. Liverman and St. Croix (1989b) described sections in the upper Indian Brook valley near Gillards Lake as interbedded gravel and diamicton, and beds of rhythmically bedded silt and fine-sand containing dropstones. They interpreted the sections as representing deposition within an ice-contact lake.

Lundqvist (1965) described a section on the watershed between Birchy Lake and Indian River at 104 m as composed of lacustrine sediments. Liverman (personal communication, 1995) visited the site in 1989 and described rippled sand and rhythmically bedded silt and clay overlain by gravel and coarse-sand. The lower part of the sequence is interpreted to have been deposited in a proglacial lacustrine environment. No diamicton interbeds or dropstones were noted in this exposure. Lundqvist (1965) interpreted this section to represent a small ice-contact lake in the Indian Brook valley. The location of the section on the drainage divide between Birchy Lake and the Indian Brook valley implies an ice dam must have been present to the east to preclude eastward drainage. Liverman and St. Croix (1989b) described deltaic sediments at Baie Verte Junction, at about 60 m asl, deposited by water flowing to the west, opposite to the modern drainage direction. This evidence indicates that an ice dam did not exist to the west of the watershed section.

The pattern of differential isostatic rebound across the area is difficult to assess, as the only firm data points are the marine limit estimates on the coast.

Estimates exist of 60 m asl for Corner Brook, 40 m asl at Stephenville (Brookes, 1974), and 75 m asl for the Springdale area (Tucker, 1974a), and the times of deglaciation are thought to be similar for both the northeast and west coasts. The effect of isostatic rebound likely increases from southwest to northeast. A lake shoreline formed shortly after deglaciation would probably now show a tilt up to the northeast.

If the Humber River gorge and the Birchy Lake valley were dammed, the lake would drain through the lowest available point on the basin edge. This is the drainage divide at the southwestern end of Grand Lake, which currently lies at 122 m asl. This divide consists of a low valley between Grand Lake Brook (flowing east into Grand Lake) and Ahwachenjeech Brook, a tributary of the southward flowing Harrys River. Aerial photographs (Figure 7-4) show a single, well-defined channel, 170-400 m wide, with a gradient of 1:95, extending about 11.5 km south from Grand Lake towards Harrys River (Plate 7-2). Grant (1991) recognised the extension of this large proglacial channel down the Harrys River valley, entering St. George's Bay at Stephenville Crossing. This feature is interpreted as a spillway resulting from overflow of an enlarged Grand Lake. The 18 m difference between the elevation of this overflow at 122 m asl and the deltas at 140 m asl at the north end of Grand Lake may be due to a combination of differential isostatic rebound or erosion. Sediments interpreted as lacustrine, with a surface elevation of about 120 m asl, were described from the sand pit along the Grand Lake road. The sediments show that glacial Lake Howley extended west of the modern lake margin, current flow was westward away from the lake, and the lake surface was at least 120 m asl. The palaeo-channel becomes well-
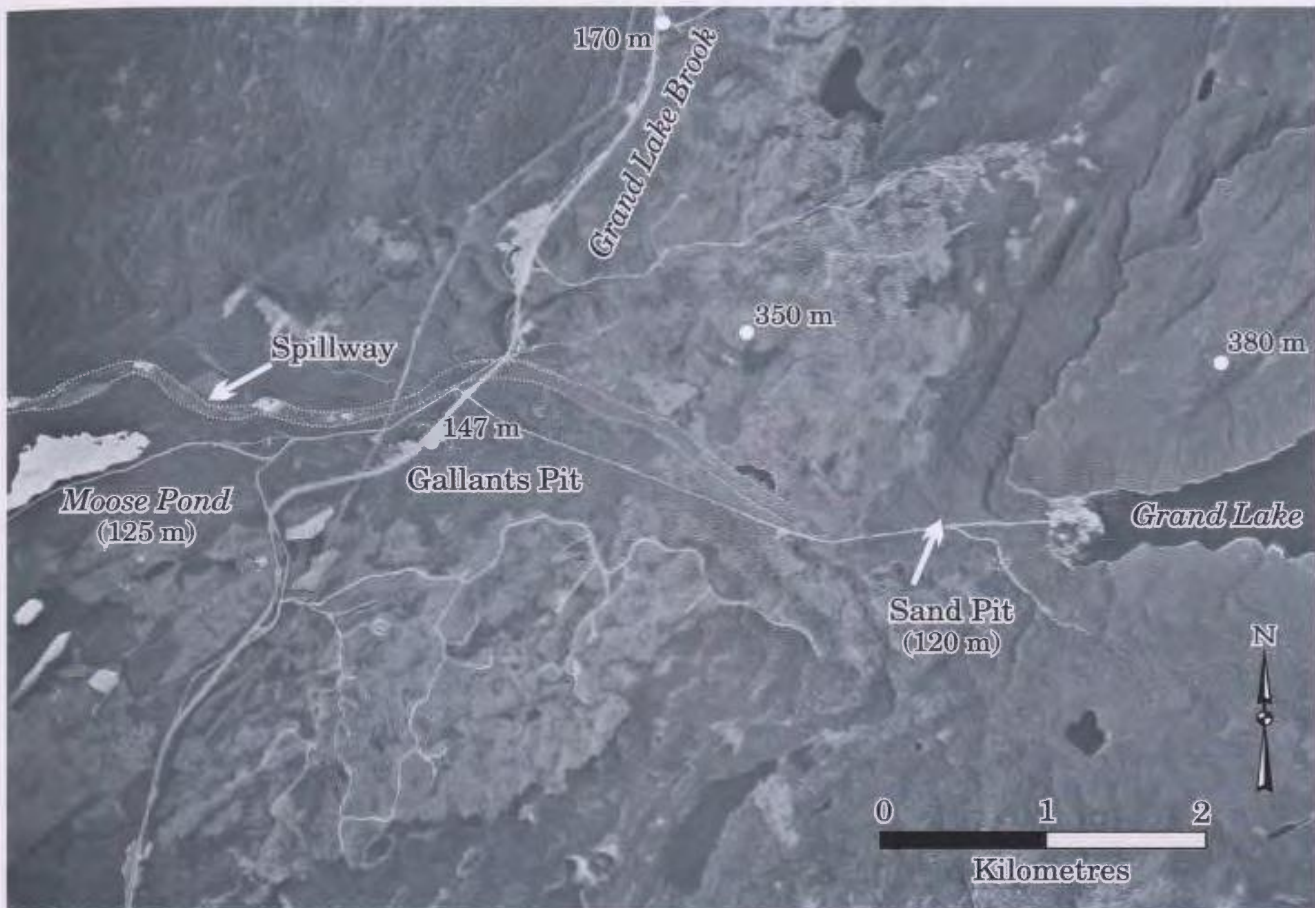
**Figure 7-4:** Vertical aerial photograph of part of the spillway (shown as dotted lines) from glacial Lake Howley, extending from the southwestern end of Grand Lake towards Moose Pond.

**Plate 7-2:**
View of Harrys River spillway looking northeast from near Moose Pond.
The channel here is about 400 m wide. Elevation of the channel at this
point is 110 m asl. It was produced by drainage from glacial Lake Howley
during deglaciation of the Grand Lake valley.

established west of the sand pit, indicating the sand was deposited close to the outlet of the lake.

Sediment interpreted as proglacial outwash was described from the Gallants Pit along the channel margin. Other poorly exposed deposits of sand and gravel are found along the western margins of Grand Lake, up to an elevation of about 135 m asl. No sections were found exposing glaciofluvial sediments capped by till or other features (e.g., eskers) indicative of subglacial deposition, and these sediments are thus interpreted as sandur deposits. The sandur was produced by melting ice at the western end of Grand Lake, as suggested by Brookes (1974) and Grant (1991). The channel is incised into these sediments and therefore must post-date them. The channel does not cross the regional topographic gradients that would indicate sub-glacial water flow under pressure (Rothlisberger, 1972), and does not have an undulating longitudinal profile typical of tunnel valleys (e.g., Gilbert, 1990; Brennard and Shaw, 1994). Although the channel crosses the low divide between Grand Lake Brook and Ahwachenjeech Brook, it slopes away from glacial Lake Howley.

Tunnel valleys are recognised by an anabranching network of channels incised into bedrock or sediment, an undulating linear profile, a channel path against the regional gradient, glacial or glaciofluvial deposits, particularly eskers, within the channel, and the truncation of subglacially produced glacial landforms by the channel (Mooers, 1989; Gilbert, 1990; Shaw, 1983; Brennard and Shaw, 1993). The channel at the western end of Grand Lake is incised into sediment and bedrock, but shows none of the other characteristics normally associated with tunnel valleys. Formation as a proglacial channel thus is more likely than a subglacial origin.

Ice retreated rapidly from the western end of Grand Lake following a period of ice-contact sedimentation. This is shown by the lack of sediment along the shores of Grand Lake, except in the raised deltas at the mouths of many of the modern streams.

The reconstruction of Batterson *et al.* (1993) can no longer be supported in total. Field mapping in the upper Humber River valley (Batterson and Taylor, 1994) showed no evidence of high level deltas, or the presence of lacustrine sediments. In the Cormack area, surface sediments commonly are diamictons of local provenance. Towards Alder Pond, adjacent to the Humber River, diamictons are overlain by fluvial sand. In the Adies Pond area, a pronounced esker ridge overlies diamicton. The esker, which was also mapped by Grant (1989b), shows that ice retreated up the valley.

An ice-contact delta with a surface elevation of 46 m asl at the mouth of Deer Lake, exposed during road construction in 1994-1995 is also incompatible with the reconstruction presented by Batterson *et al.* (1993), which shows the ice dam seaward of this position.

Ice flow data also supports ice cover extending southward beyond the upper Humber River basin. Southward-directed striations are found at the north end of Sandy Lake. Similarly, southward striations are found on Birchy Ridge, and also on the highlands east of Glide Lake, which crosscut striations formed by the regional westward flow from The Topsails. Southward oriented striations in the Sandy Lake basin are only found on the north and west side.

### Minimum reconstruction

A minimum reconstruction is that glacial Lake Howley occupied only the area of the modern Grand Lake basin. The ice-contact delta at the mouth

of Deer Lake, and eskers near Adies Pond and adjacent to the Humber River show that ice retreated up the Humber River valley towards the Long Range Mountains. The Humber River valley therefore was filled with ice during the glacial Lake Howley phase in Grand Lake. The surface of glacial Lake Howley therefore was controlled by the elevation of the outflow at the western end of the lake. Some of the high level beaches recorded on the west side of the lake may have been cut during this early phase of lake development.

Glacial Lake Howley developed rapidly during deglaciation as ice retreated across the Grand Lake basin. Glacial Lake Howley likely was a time-transgressive feature and had a continually changing geometry in response to wasting ice in the Grand Lake-Sandy Lake lowlands. The description represents an unstable, rather than a stable configuration.

As ice retreated northward up the valley from the delta at Deer Lake (Figure 7-5), it exposed the South Brook valley allowing drainage from glacial Lake Howley (Figure 7-6). The lake surface dropped to about 145 m asl, the elevation of the col at the southern end of South Brook. This would allow formation of the prominent deltas found south of Hinds Brook along the east side of Grand Lake at this elevation.

Raised deltas on the east side of Grand Lake increase in surface elevation from 128 m asl at Lewaseechjeech Brook at the western end of Grand Lake to about 145 m north of Hinds Brook. This represents an increase of 0.22 m km$^{-1}$ towards the northeast. This value does not necessarily represent isostatic tilt, because individual deltas are likely progressively younger towards the northeast. However, the rate is similar to a 0.20 m km$^{-1}$ increase between Stephenville and Springdale, calculated from known palaeo-sea level data (Grant 1989a; Scott *et al.*, 1991; Forbes *et al.*, 1993).
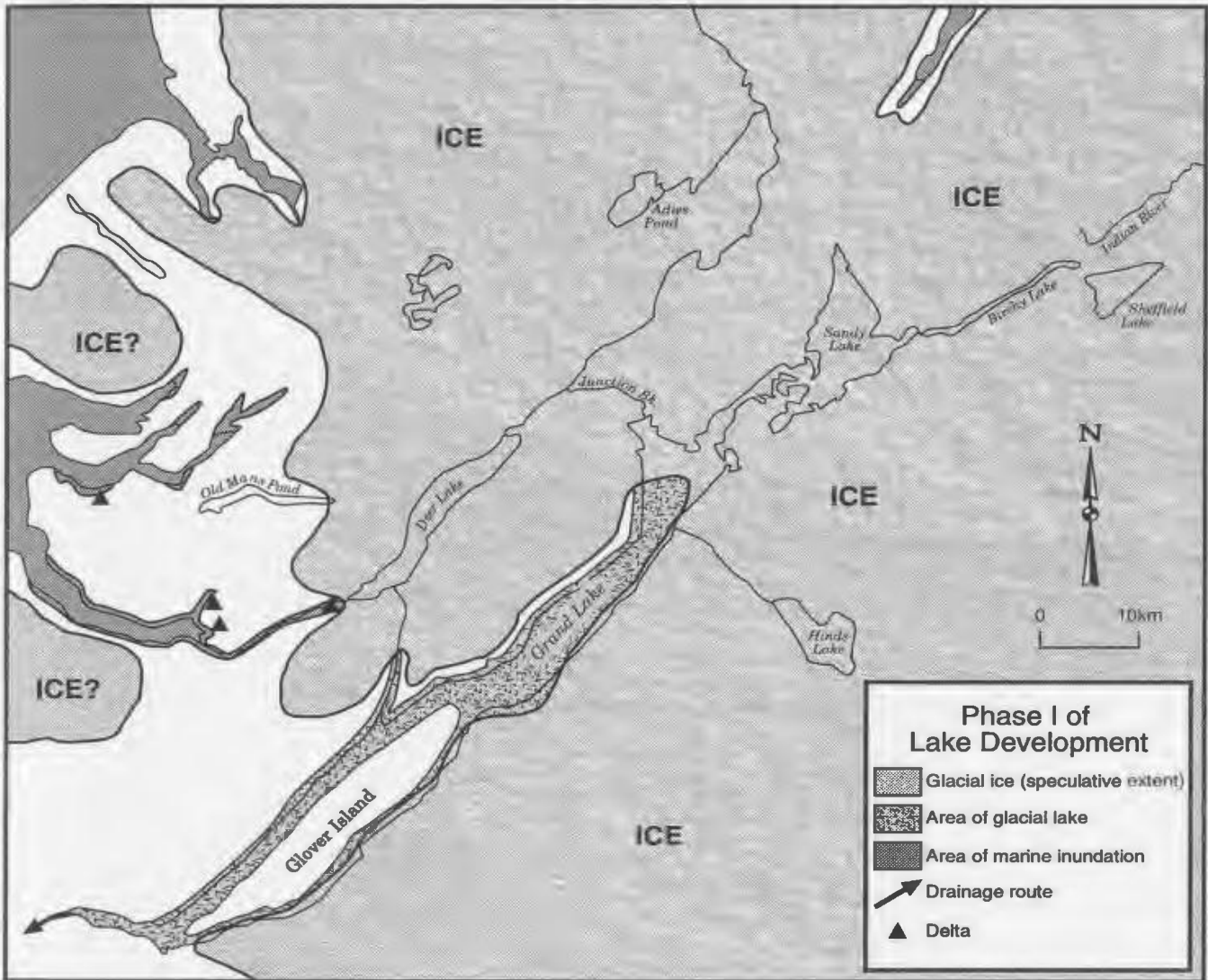
**Figure 7 - 5:** Minimum reconstruction of glacial Lake Howley.
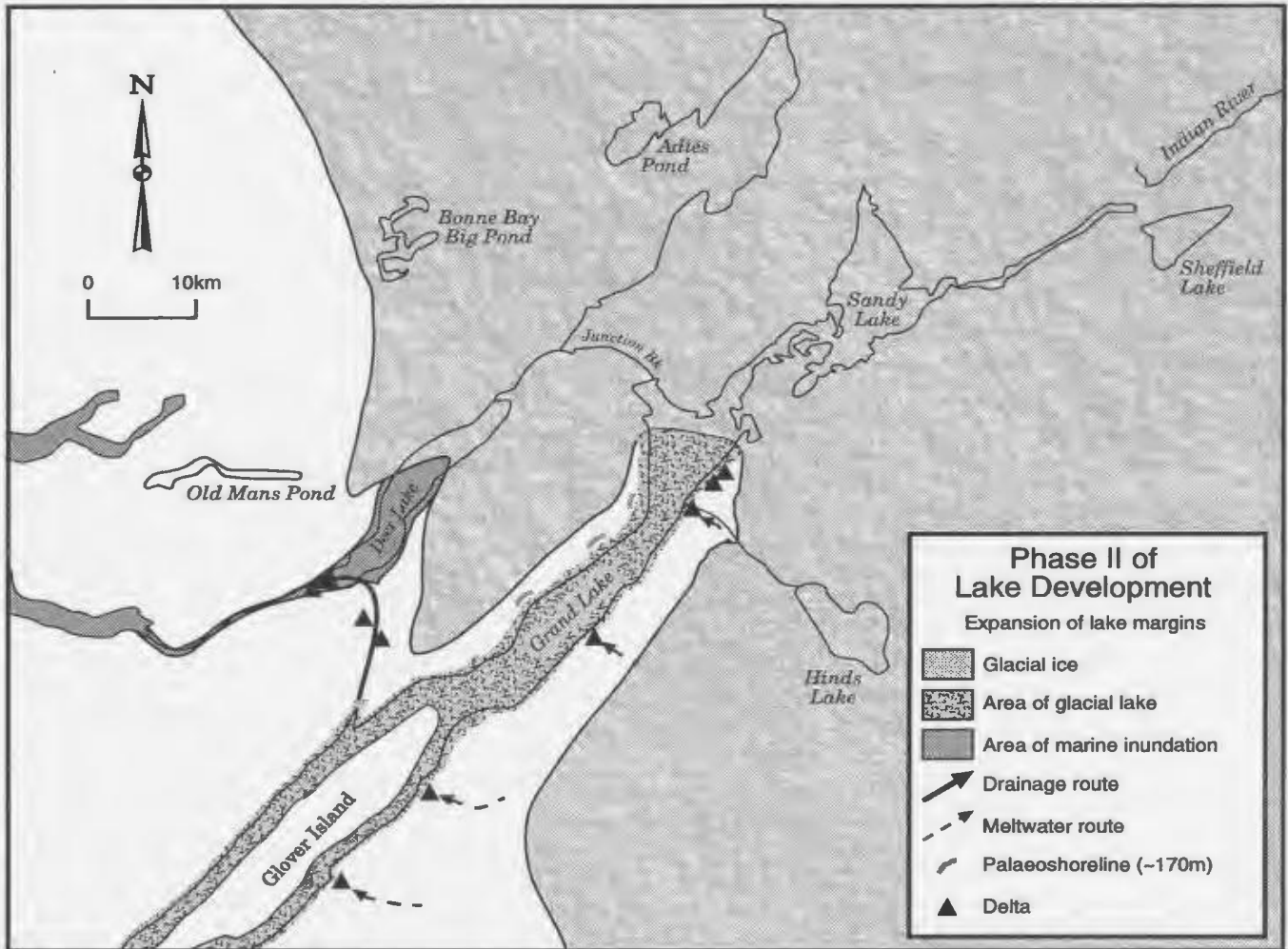
**Figure 7- 6:** Phase II of lake development. Expansion of lake margins. The deltas in the South Brook valley were formed at an intermediate stage between Phase I and Phase II.

The next low point farther up-valley is between the Glide Lake highlands and Birchy Ridge, now occupied by the modern outflow of Grand Lake through Junction Brook. This area must have been dammed by ice. The distribution of meltwater channels on the Glide Lake highlands, and the southern part of Birchy Ridge suggests melting of ice on highlands north and south of Junction Brook. Ice retreat up the valley was rapid, indicated by the similar elevation of the delta at the mouth of Deer Lake and those at the head of the lake. As ice retreated across the Junction Brook lowland it allowed drainage of glacial Lake Howley (Figure 7-7), through a spillway currently occupied by Junction Brook.

Junction Brook flows through a narrow, steep sided, flat-bottomed channel incised into bedrock, up to 450 m wide and 40 metres deep that descends steeply about 30 metres over 4.3 km (Plate 7-3). It has two small tributaries, both of which are less than 1 km long. Junction Brook likely was formed as ice retreated northward, and its formation accompanied a drop in lake level from 145 m (controlled by the South Brook col), to the pre-modern dam level of about 75 m asl, a drop of 70 m. Some lake drainage may also have been through the tributary south of Junction Brook, which is also incised in its lower reaches.

An estimate of potential discharge through the Junction Brook spillway may be calculated through application of the Manning equation. The Manning equation states:

$$u = \underline{\frac{1.009}{n}}. R^{2/3}. \sqrt{slope}$$
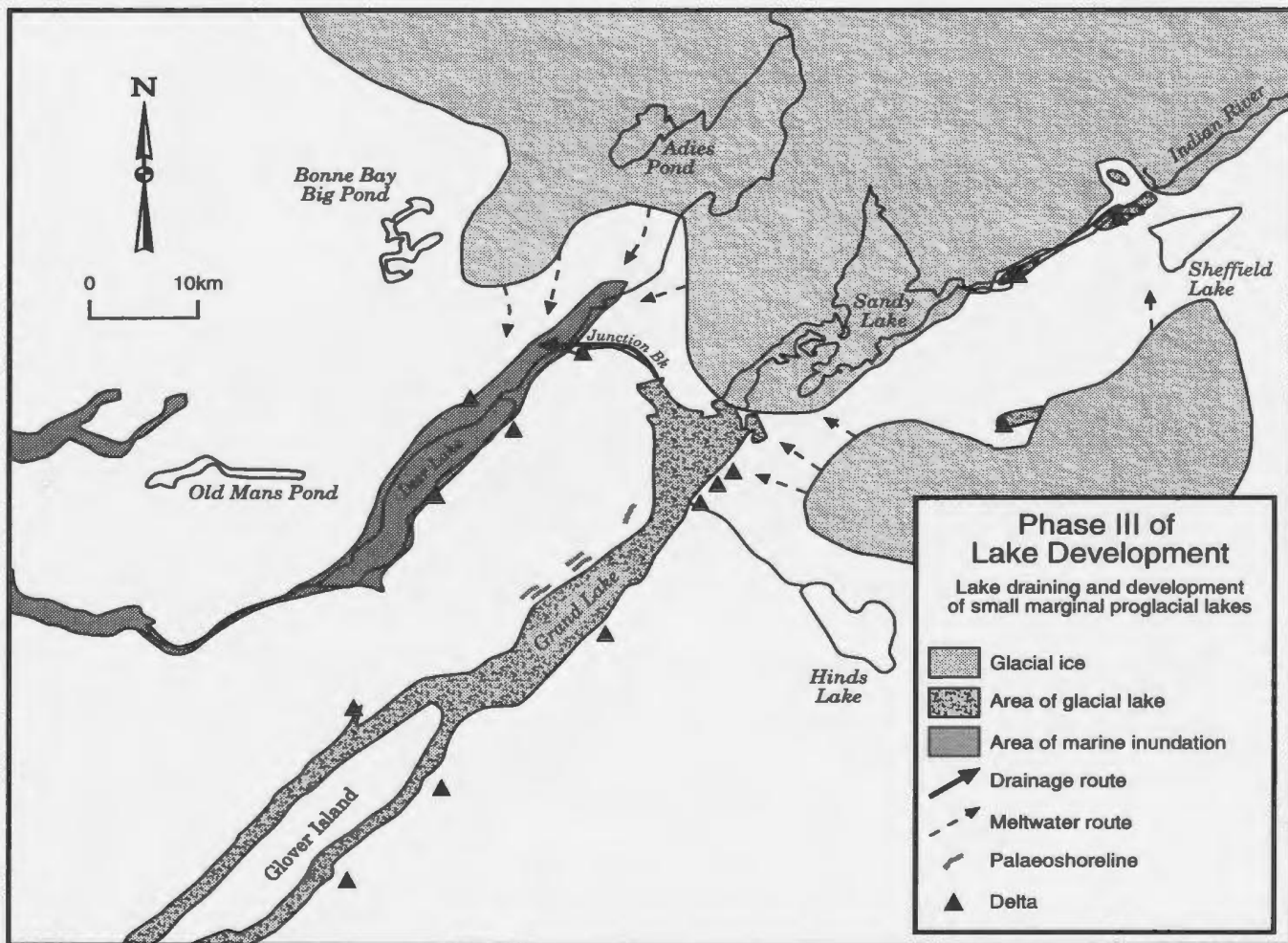
**Figure 7 - 7:** Phase III of lake development. Lake draining and development of small marginal proglacial lakes.

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**Plate 7-3:**
Oblique aerial photograph of the Junction Brook valley, looking southward towards Grand Lake. Junction Brook is a spillway produced by drainage of glacial Lake Howley. It was the modern outlet for Grand Lake until dammed for hydro-electric power generation in 1925.

where u=stream velocity, n=Manning number, R=hydraulic radius of the channel.

The Manning number takes into account the form of the channel (straight or meandering), and the sediment within the channel (clay, sand, gravel). The Junction Brook channel is generally straight with a gravel base, producing a Manning number of 0.05. The cross sectional area of the channel at the upstream end is about 2500 m$^2$, giving a value for R of 13.8. The slope is calculated to be 0.0070. Assuming the channel was cut instantaneously and maintained bank-full levels, this gives a velocity of 4.1 m sec$^{-1}$, and a maximum discharge of 10200 m$^3$ sec$^{-1}$. The surface area of the proglacial lake described under the minimum reconstruction is about 365 km$^2$. A drop in water level of 71 m produces a volume of 2.59 x 10$^{10}$ m$^3$, not accounting for the effect of isostasy or basin geometry, or the slope of the basin margins. Given the maximum discharge of 102000 m$^3$ sec$^{-1}$, a lake with the volume calculated would drain in approximately 29 days.

The peak discharge calculated for glacial Lake Howley is comparable to observed discharges on modern glacier dammed lakes (Walder and Costa, 1996). The discharge is small compared to rates calculated for glacial Lake Agassiz discharge that commonly exceeded 100,000 m$^3$ sec$^{-1}$ (Teller and Thorleifson, 1987; Teller, 1987).

The channel was not cut instantaneously and is unlikely to have maintained bank-full levels during its development, and thus the assumptions used in these calculations are not realistic. However, this exercise shows that the channel was cut over a short period of time and the whole lake could have drained in less than a month. The effect of introducing

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such a large volume of water (and sediment) to the Humber river system is discussed below.

The minimum view suggests that events in the Birchy Lake valley are not associated with the development of glacial Lake Howley. The presence of rhythmically bedded silts and clays in the Gillards Lake basin and in the canal connecting Indian Brook and Birchy Lake could individually be interpreted as ice-marginal ponding, as suggested by Liverman and St. Croix (1989b) and Lundqvist (1965), respectively. Ice that occupied the northern end of Grand Lake may have separated Birchy Lake from Grand Lake. Ice-disintegration is shown by the ice flow data on the west side of the lake, the dead-ice topography in the Howley area, and an esker mapped west of Howley. The age of these features is unknown. Hummocks in the Howley area contain clasts derived from The Topsails, suggesting this as the source area. There is no evidence to support the view that ice from the Long Range Mountains ice cap extended as far east as Howley.

### Intermediate reconstruction

This view accepts the reconstruction for the northern part of the Grand Lake basin, but suggests connection with the Birchy Lake valley during the waning stages of glacial Lake Howley (Figure 7-8). As ice retreated northward from the Junction Brook area it may have allowed connection of the Grand Lake and Birchy Lake systems. Much of the evidence used to support the minimum view may also be applied to this intermediate reconstruction.

The rhythmically bedded silt and clay in the Gillards Lake area are up to 160 m asl. Liverman and St. Croix (1989b) cite the lack of associated deltas or strandline features, and the height of the Gillards Lake section above the
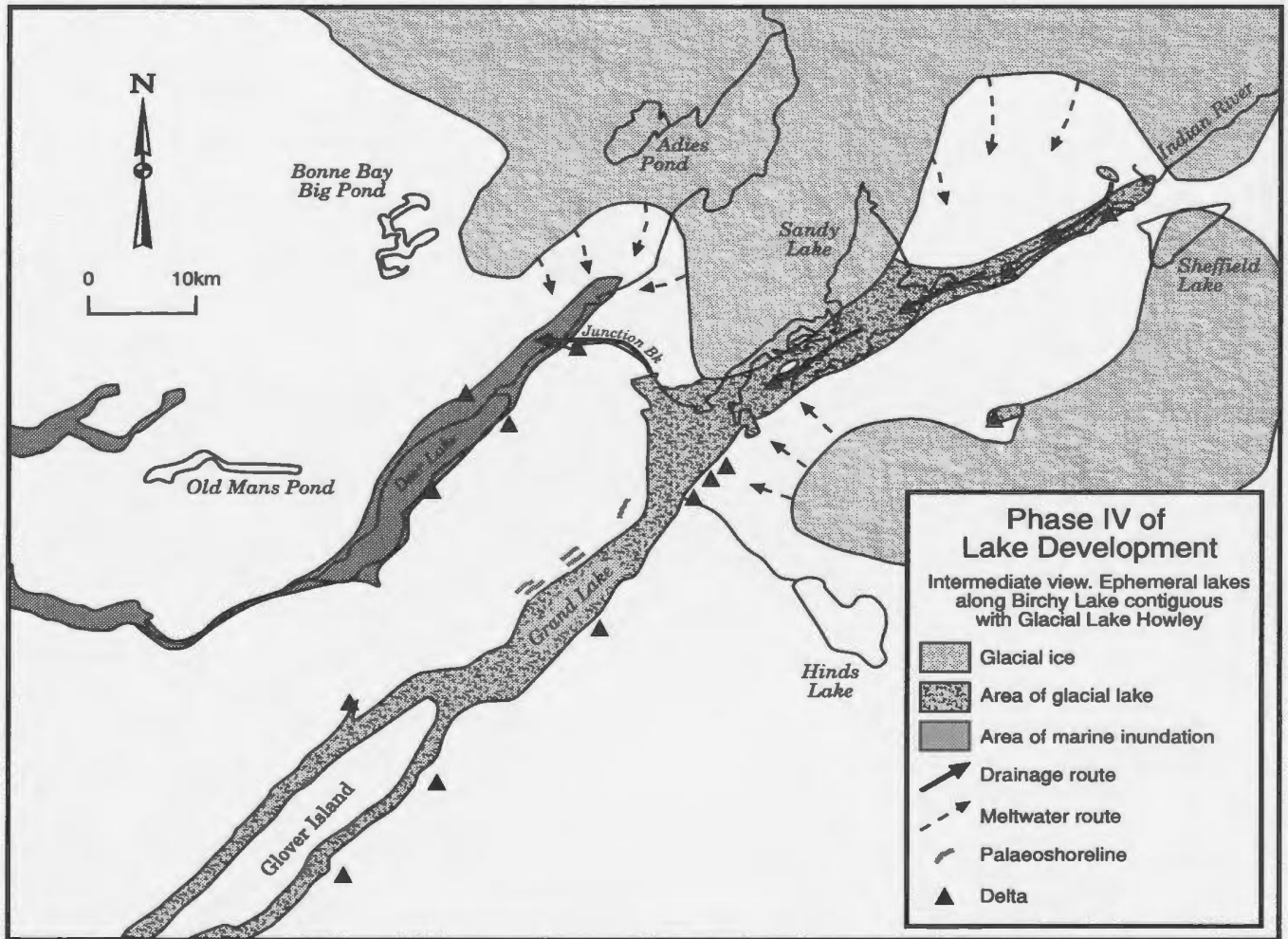
**Figure 7 - 8:** Phase IV of lake development. Intermediate view.

valley to argue for deposition in an ice-marginal lake produced by ice in the Birchy Lake valley. The elevation difference between glaciolacustrine sediments at Gillards Lake and the eastern shore of Grand Lake might be explained by differential isostatic rebound (Figure 7-2). The presence of rhythmites on the watershed at 104 m asl between Indian Brook and Birchy Lake shows the existence of standing water. This is well above the known marine limit for the adjacent coast. The rhythmites are thin, planar-bedded, contain no diamicton lenses or beds, dropstones, and show no evidence of faulting or contortion that suggests deposition was in an ice-proximal environment. The ice dam that formed the lake was east of Birchy Lake. This is shown by westward palaeo-current indicators from a gravel pit near Baie Verte junction described by Liverman and St. Croix (1989b). This is opposed to the modern eastward drainage. Southward striations showing flow from the Baie Verte Peninsula into the Indian Brook valley have also been recognised by Grant (1974) and Liverman and St. Croix (1989a, 1989b). Apart from an ice dam to the east, higher water levels at the modern watershed require either an ice dam, or a continuous water body to the west. The absence of other reported rhythmites to the west may suggest the former. Modern colluvial activity along Birchy Lake has likely reworked or covered sediments deposited during deglaciation. Flat-topped deltas are found at the mouths of Sheffield Brook (115 m asl), at the northern end of Birchy Lake, and Voyins Brook (105 m asl) at the southern end of Birchy Lake. Neither has exposed sections, and determination of a deltaic origin is on morphological grounds. Limited evidence suggests higher water levels in Birchy Lake during deglaciation.

Isostatic rebound is expected to produce a northwestward tilt on raised marine (and by implication lacustrine) features (see earlier discussion). The

raised deltas identified along Birchy Lake at 110-115 m asl may therefore reasonably be associated with sediments or features at some elevation lower than this in the Grand Lake basin.

Support for the former connection of the modern Grand Lake and Sandy Lake basins comes from the extensive sand and gravel deposits found along the north shore of Grand Lake, up to about 100 m asl, and along The Main Brook area connecting the two lake basins. Palaeo-flow indicators generally support fluvial transport towards the Junction Brook area. Although much of this area has been mapped as ice-contact sediments by Grant (1989b) this is not supported by field evidence. In particular, several of the features mapped as eskers were not verified in the field. Connection of the Sandy Lake and Birchy Lake basins during regional deglaciation is not as readily apparent.

### Discussion

The maximum view of glacial Lake Howley proposed by Batterson *et al.* (1993) is considered unlikely on the basis of field work in the upper Humber River valley, and the identification of an ice-contact delta at the mouth of Deer Lake. Evidence from raised deltas at 100-115 m asl, and the presence of rhythmically bedded silt and clay on the Indian Brook - Birchy Lake drainage divide at 104 m asl shows that higher lake level than present occurred in the Birchy Lake valley during deglaciation. An ice dam to the east of Baie Verte junction impounded the lake at the eastern end.

The evidence for a separate ice dam in the western part of the Birchy Lake basin is not conclusive. No eskers or other ice-contact features have been identified to suggest ice retreated up the valley. Similarly, no channels

connecting an independent lake in the Birchy Lake valley with glacial Lake Howley have been found. Finally, the elevation of sediments and features in the two basins is similar. These factors suggest that the connection of the Birchy Lake and Grand Lake basins, at least in the final phases of glacial Lake Howley is reasonable. As such, the intermediate reconstruction is the one favoured here.

Acceptance of the intermediate reconstruction produces a long, narrow lake, up to 135 km long and 10 km wide, with a surface area of 650 km$^2$. This is considerably smaller than the 1850 km$^2$ suggested by Batterson *et al.* (1993). A lake of this size, draining exclusively through the Junction Brook spillway would drain in approximately 52 days.

**Phase 4: Marine Inundation**

A period of higher relative sea levels on an isostatically depressed coastline followed deglaciation of the Humber River valley. Along the margins of the Humber Arm constructional features such as marine terraces and deltas are found up to an elevation of about 60 m asl. This marine limit is marked by a delta in the Hughes Brook valley, and wave cut terraces at about the same elevation near Humbermouth. Marine shells are found in fine-grained sediments along the modern inner coast. The highest, and farthest inland are shell fragments found along Goose Arm Brook at 50 m asl, and dated at 13,070 ± 90 yrs BP (TO-3624) (Table 6-1). Marine shells are found at the eastern end of the Humber River gorge, indicating that marine inundation occurred through this part of the basin. Fine-grained sediments are common below about 30 m asl inland of the gorge, and deltas are found at the mouth of Deer Lake and at the head of the lake between Nicholsville and Junction

Brook. The Junction Brook delta was likely formed during outflow from glacial Lake Howley.

Ice retreated up the lower Humber River valley, accompanied by marine inundation. It initially stalled at the head of the Humber Arm, producing the delta at Humbermouth, that was subsequently incised as ice retreated through the Humber River gorge. Marine shells in the adjacent Wild Cove valley were radiocarbon dated at 12.5 ka, providing a minimum age for deglaciation for this area. A delta at the head of Wild Cove with a surface elevation of 51 m asl also shows deglaciation about this time.

Retreat of ice through the lower Humber River valley stalled at the mouth of modern Deer Lake, where it formed an ice-contact delta. Further retreat of the ice, and the accompanying marine inundation led to the formation of the deltas at the head of Deer Lake. Ice retreated rapidly from this area, as the deltas show no indication of formation in an ice-proximal environment.

Subsequent isostatic rebound resulted in lowered sea level, and the development of deltas in the lower Humber River valley at 33 m asl, such as the one on which the community of Pasadena is located. No equivalent delta surfaces were found in the Humber Arm (c.f., Flint, 1940).

Marine inundation and subsequent isostatic adjustment accompanied development and final drainage of glacial Lake Howley. They are both time transgressive events, discussed in more detail below.


**Timing of glacial Lake Howley**

The sea level curve developed for the Bay of Islands area allows an estimation of the age of the deltas at Deer Lake. Projection of these deltas at 45

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m asl onto the proposed relative sea level curve provides an estimated age of about 12.6 ± 0.2 ka. The effects of differential isostatic uplift across the basin are uncertain, although the northeastward isostatic tilt suggests delta formation may have been some time (several hundred years?) later. The Deer Lake deltas are about 45 km inland from the modern coast, and on a line oblique to isobases proposed in existing models of relative sea level history (e.g., Grant, 1989a). Assuming the marine limit in the inner Humber Arm is 60 m asl (elevation of Hughes Brook delta), and the marine limit at Springdale is 75 m asl (Springdale deltas), this would suggest a rise of 0.1 m km$^{-1}$ between Corner Brook and Springdale. Deglaciation at Corner Brook (~13.1 ka) was likely earlier than at Springdale (~12.5 ka). Isostatic tilt was therefore steeper, up to 0.2 m km$^{-1}$.

The deltas at the head of Deer Lake, 45 km from the modern coast, therefore correspond to a position on the RSL curve at 41.5 to 36.5 m asl, giving a date of 12.4 to 12.2 ka. This age estimate corresponds to the date of marine shells in the Humber River gorge, and in the Wild Cove valley, both of which have statistically similar dates of 12.2 to 12.5 ka.


**Effects of catastrophic drainage in the lower Humber River valley**

Glacial Lake Howley drained through two outlets, apart from the Harrys River exit. The first, through the South Brook valley, lowered water levels from up to 170 m (based on the elevation of strandlines on the west side of the lake), to 145 m the level of the col at the southern end of South Brook. The areal extent of the early phase of the lake is unclear. No deltas equivalent to the high beaches on the west side have been located on the east side of Grand Lake. The lake may therefore have been of limited extent. It is

possible that this early phase extended into the modern South Brook valley. A large flat-topped, steep sided feature, interpreted to be an ice-contact delta on the basis of morphology and sediment type (bedded sand and gravel, plus diamicton beds), is found in the central part of the valley with a surface elevation of 150 m asl. Exposure was from a single backhoe test pit that showed planar bedded sand and gravel with beds dipping southeastward down the valley. Two small deltas are also found on the western side of the valley, at surface elevations are about 140 m asl for a delta immediately west of the 150 m delta (site 91232; Appendix A), and 145 m asl for a delta about 2 km north (site 89006; Appendix A). Both are poorly exposed, and show inclined beds of sand and gravel dipping into the valley. Further evidence for standing water in the South Brook valley is the presence of greater than 2 m of structureless clayey silt at 90 m asl (sites 91226 and 91230; Appendix A). Other small exposures of sand and gravel, overlying diamicton are found on the eastern flanks of the South Brook valley.

The South Brook valley contains fragmentary evidence for standing water, in the form of deltas and fine grained sediment. The location of an ice dam in the South Brook valley is uncertain. The direction of dipping beds in the 155 m delta indicates deposition from the north, and any proglacial lake may have accompanied retreat of ice up the lower Humber River valley. The lack of exposures through the valley makes this conclusion speculative.

The effects of discharge through the South Brook valley are unclear. The lower part of the valley contains a well-defined terrace grading southward up the valley. Sediments contain clasts derived from The Topsails. Similarly, a channel is incised through the ice-contact delta at the mouth of

Deer Lake. It may be speculated that the terrace gravel and the eroded channel are the result of lake drainage through the South Brook valley.

Final draining of glacial Lake Howley through the Junction Brook lowlands was catastrophic, and introduced an estimated volume of water of 2.6 to 4.5 x $10^{10}$ m$^3$ over a period of 30-50 days, into an isostatically depressed inner coastal environment with sea level about 45 m higher than present. Lake drainage formed the Junction Brook spillway. Flow was subsequently into a raised postglacial sea. The spillway is thus the only subaerially-exposed erosional feature. Other erosional features may exist on the floor of modern Deer Lake. A geophysical survey designed to examine lake bottom topography and stratigraphy failed due to mechanical difficulties.

The major effect of lake outflow was depositional. The Junction Brook area has a surface veneer of sandy gravel and large (up to 300 cm diameter) granite boulders, presumably deposited as the outflow lost its competence to transport. Deposition of the sediments, and the associated delta, trapped most of the coarse-grained sediment from lake discharge. Fine-grained sediment was transported as turbid underflow with or without overflow-interflow through the lower Humber River valley. A short core taken on a reconnaissance seismic mapping and sampling program in the Humber Arm and Bay of Islands (Shaw *et al.*, 1995) revealed a reddish brown buttery clay that may be derived from the Deer Lake basin. The clay contains low foraminifera counts, with early colonizer species (*Cassidulina reniforme* and *Elphidium excavatum*) (Vilks *et al.*, 1989; MacLean *et al.*, 1992; Scott *et al.*, 1984). The lower part of this core is undated, but may have been deposited during outflow from glacial Lake Howley. The proximity of the core site to the mouth of the Humber River, and the presence of red sedimentary bedrock in

the Carboniferous Deer Lake basin that is drained by the Humber River supports this conclusion. The high percentage of clay through the lower 60 cm of the core suggests deposition by suspension settling, and the consistency of sediment texture suggests rapid deposition. The low proportion of foraminifera tests contained within the clay, and the tolerance ranges of species identified, suggest a high freshwater component to the water. The clay was deposited some time before 5.4 ka.

The extent of this clay unit in the Humber Arm and Bay of Islands is uncertain. A near-surface, thin, reddish clay unit with a sparse palynofloral assemblage was mapped in the Bay of Islands (A. Aksu, personal communication, Department of Earth Sciences, Memorial University of Newfoundland, 1998). The clay sediments identified by Aksu and Shaw *et al.* (1995) are similar, and may represent the same discharge event.

Ericson *et al.* (1981) and Barranco *et al.* (1989) described red marine sediments (brick red lutites) in the Laurentian Channel - Gulf of St. Lawrence area that were derived from Permo-Carboniferous red sediments in New Brunswick, Nova Scotia and Prince Edward Island. Bartlett and Molinsky (1972) reported red sediments with low micro-fossil concentrations from the Laurentian Channel. All the sediments represent periods of high sedimentation associated with deglaciation.

Cumming (1991) described rapidly deposited (about 200 years based on $^{14}C$ dating), fine-grained marine sediments with sparse microfauna or microflora in cores from Clode Sound in eastern Newfoundland. The stratigraphy was similar succession to that described in the Humber Arm. Sommerville (1996) described glacial lake sediments from the Terra Nova

River valley that drains into Clode Sound. No correlation between the two events has been established.

## Discussion of the implications of marine inundation and glacial Lake Howley for regional deglaciation

The existence of a proglacial lake, some time before 12.3 to 12.6 ka, in the interior of Newfoundland during deglaciation of the west coast has several important implications for the established Quaternary history and stratigraphy of the west coast, particularly the St. George's Bay region.

The presence of a spillway at the western end of Grand Lake implies that meltwater could flow westward without obstruction, and thus that the Stephenville area was deglaciated before 12.3 to 12.6 ka. This is incompatible with the timing of the Robinsons Head readvance Brookes (1977a). Discussion of the evidence and timing of the Robinsons Head readvance is warranted, although it is outside the Humber River basin. These arguments are summarized in Batterson *et al.* (1993, 1995) and Brookes (1995).

The culmination of the Robinsons Head readvance in the Stephenville area is interpreted at about 12.6 ka based on a $^{14}$C date of from a section near Kippens (Table 6-1). The extent of the Robinsons Head moraine has been described by Brookes (1970a, 1974, 1977a, 1987) as extending from Highlands in the south, around St. George's Bay, to just west of Romaines Brook in the north. Robinsons Head Drift is described as "a coarse, loosely-structured till of englacial and supraglacial origin" (Brookes, 1974, p. 22), and ice-contact stratified drift, with the outer limits marked by a kame moraine consisting of "stratified gravel and sand with minor silt and small irregular bodies of till" (Brookes, 1974, p. 22). The Robinsons Head Drift was first described by

MacClintock and Twenhofel (1940) and along with the underlying St. George's Bay delta and St. George's River Drift has become established as the accepted Quaternary stratigraphic sequence in southwestern Newfoundland (e.g., Brookes, 1970a, 1974, 1977a, 1987; Grant 1987, 1989; Proudfoot et al., 1988). Brookes (1977a) suggests the Robinsons Head readvance was climatically induced. Supportive arguments for a regional correlation with the Robinsons Head Drift event (Brookes, 1977a) were from a late Wisconsinan readvance on the Cabot Strait coast of Newfoundland (Brookes, 1975), the Highland Front Morainic system in southeastern Canada (Gadd et al., 1972), the Pineo Ridge moraine (Borns, 1973), and the Inner Port Huron moraine (Evenson et al., 1976). Each of these features was dated at about 12.6-12.7 ka, although the cause of readvance at some localities may not have been climate related (Brookes, 1977a).

Of the cases cited by Brookes (1977a) the Port Huron stade remains the best dated. The readvance of three lobes in the Great Lakes region, the Huron, Michigan and Ontario/Erie lobes, produced a series of moraines (e.g., Port Huron moraine in Michigan, and Wyoming - Banks moraine in Ontario (Karrow, 1989), as well as a series of small moraines on the Niagara Peninsula (Dreimanis and Goldthwait, 1973; Barnett, 1979)). It also deposited a regional correlated till unit, named the St. Joseph Till (Cooper and Clue, 1974) from the Huron Lobe, the Oak Creek Formation from the Michigan Lobe (Eschman and Mickelson, 1986), and the Halton Till (Karrow, 1959) from the Ontario Lobe. Although the regional correlation of the readvance of three separate lobes suggests a climatic link, the large distances (~400 km) and short time period (200-300 years) suggests surging may have been the cause (Hansel et al., 1985). A further argument against a climatic link is that while this part of the

Laurentide Ice Sheet was advancing, sectors to the east and west of the Great Lakes basin were retreating (Dyke and Prest, 1987).

The Highland Front moraine system of Gadd *et al.* (1972) on the southern margin of the Champlain Sea was formed about 12.5 ka, by southward flowing ice from the retreating Laurentide ice sheet. However, Parent and Ochietti (1988) consider the so-called Highland Front moraine system to be a grouping of unrelated features, including bedrock controlled ridges, diachronous moraines, eskers, and deltas. Even assuming its existence, there is no stratigraphic evidence for a readvance in this area (LaSalle *et al.*, 1977; Gadd, 1978), and the feature is considered to represent a halt in the general recession of the ice sheet (Gadd *et al.*, 1972; Chauvin *et al.*, 1985). The Pineo Ridge moraine in Maine has been re-dated at about 13.0-13.2 ka (Smith, 1985), with ice being well inland by about 12.6 ka (Borns *et al.*, 1985). Several other moraines have been identified in the Maritimes dating around 12.6 ka. In the Baie des Chaleurs, the Elmtree Interlobate moraine dates around 12.5 ka (Bobrowsky *et al.*, 1987). Rappol (1989) describes moraines in the St. John River valley from the local Appalachian Ice Divide prior to 11.0 ka, and Stea *et al.* (1992) described advance of ice from the Scotian Ice Divide and Antigonish Highlands in the 12.0 to 13.0 ka period that may be correlated with Robinsons Head readvance. However, none of these features has been linked with climatic forcing, and no cooling event that may trigger a readvance has been recorded from palaeo-ecological sources.

It is perhaps significant that all the moraines dating in the 11.5 - 13.0 ka range are found adjacent to the coast, at a time when the main Laurentide Ice Sheet was downwasting. The drawdown of ice into marine basins and the influence of falling relative sea levels may have been the trigger for re-

activation of local ice fronts, rather than any climatic trigger. In contrast to the Younger Dryas event, which is recorded in mountain (e.g., Clapperton, 1993; Magny and Ruffaldi, 1995; Williamson *et al.*, 1993; Reasoner *et al.*, 1993), as well as coastal areas (Bergstrom, 1995; Cwynar and Levesque, 1995; Anderson and Macpherson, 1994), the advances at about 12.5 ka are only recorded adjacent to coasts and are not recorded in mountain areas such as the Rockies.

The extent and timing of the Robinsons Head readvance is problematic. The date of the readvance at 12.6 ka is based on a single radiocarbon date from a section at Kippens interpreted to represent deposition within a kame. In contrast, a section at Romaines, 3.5 km west of Kippens yielded dates of 13,100 ± 180 yrs BP (GSC-4095, *Mya truncata* shells) and 13,345 ± 230 yrs BP (S-3074, whale bone) from silts overlying sediments interpreted as being associated with the Robinsons Head readvance (Grant, 1987, 1991; Proudfoot *et al.*, 1988). This suggests that the area may have been ice free at the proposed time of the existence of glacial Lake Howley.

The section at Kippens contains shell fragments dated as GSC-2295 found in a sand bed within kame gravel (Brookes, 1977a), which are described as "...unevenly stratified gravels, with many cobbles and boulders" (Brookes, 1970a, p. 136). It seems likely that the assignment of an ice-contact origin was based primarily on local geomorphology. A date of 13,300 ± 810 yrs BP (GSC-2063) from the same horizon as GSC-2295 was rejected by Brookes (1977a) due to the large error bar. Batterson and Janes (1997) interpreted the Kippens section (Plate 7-4) as representing initial ice-proximal glaciomarine sedimentation, followed by delta progradation produced by glacial retreat or a shallowing sea. Whole marine shells (*Hiatella arctica*) were found in upper foreset gravel, and subsequently dated at 12,600 ± 120 yrs BP (GSC-5942).
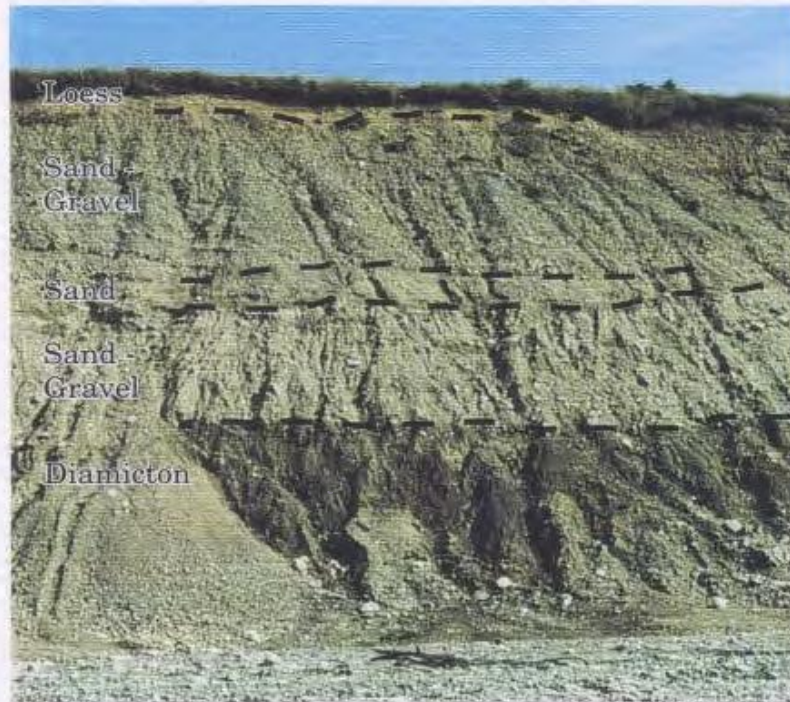
**Plate 7-4:**
A 20 metre-high coastal exposure near Kippens west of Stephenville. A stratigraphy of diamicton, overlain by sand-gravel, sand, sand-gravel, and cliff top loess was interpreted by Brookes (1974) to indicate basal till overlain by ice contact sediment (excluding the loess), dated at 12.6 ka based on marine shells within the sand bed. The section has been interpreted by Batterson and Janes (1996) as a deglacial sequence of till, followed by delta progradation produced by glacial retreat or a shallowing sea.

Marine shells from an adjacent exposure found within marine muds at 8 m asl, below a marine to freshwater transition, were dated at 12,610 ± 100 yrs BP (TO-6138) (Table 6-1).

The western extent of the morainic topography around St. George's Bay interpreted as being associated with the Robinsons Head readvance is at Romaines. Batterson and Janes (1997) interpreted the sediments as having been deposited into a gypsum karst depression. Marine silt found in the upper part of the section contains marine macro fauna, including two marine shell samples and a whale bone, previously dated at 13,100 ± 180 yrs BP (GSC-4095), 12,800 ± 130 yrs BP (GSC-4858) and 13,345 ± 230 yrs BP (S-3047) respectively (Grant, 1989b; McNeely and Jorgensen, 1993) (Table 6-1). Marine shells (*Mya truncata*) with a diamicton found within the Romaines Brook valley at 37 m asl were dated at 13,680 ± 100 yrs BP (TO-6137).

The section had been previously interpreted as showing kame deposits of the Robinsons Head readvance overlain by silts (Brookes, 1970a). The radiocarbon dates from Romaines suggest the area was ice free before about 13 ka. This is in contrast to Brookes' (1977a) interpretation of the Kippens section. Grant (in Blake, 1988, p 6-7) considered three alternative explanations for this discrepancy: the disappearance of ice from the area; reworking from a lower stratigraphic unit; or a meltwater effect on the $^{14}$C dates. In a later discussion of the site, Grant (in McNeely and Jorgensen, 1993, p. 14-15) considered the reworking scenario unlikely because the shells are intact, and suggested that an average date on the marine silts overlying the interpreted Robinsons Head readvance sediments is about 13 ka.

The apparent dichotomy between the sedimentologic evidence and the numerous depressions that characterize the surface morphology of the

northern coast of St. George's Bay, interpreted by Brookes (1970a) as kettle holes, is resolved by interpretation of the depressions as sinkholes resultant from gypsum karst (Grant, 1989b; Batterson and Janes, 1997). Gypsum is exposed on the surface near Romaines Brook and is also exposed farther east in the Flat Bay area. Bedrock exposures are absent between Kippens and Romaines Brook.

Liverman and Bell (1996) have re-examined some of the sections between Bank Head and Highlands, including the type section for the Robinsons Head readvance at Robinsons Head. In contrast to the tripartite stratigraphy described by MacClintock and Twenhofel (1940) and Brookes (1969, 1974), Liverman and Bell (1996) record a complex stratigraphy with numerous lateral and vertical shifts in sediment type was found. Liverman and Bell (1996) proposed that sediments in the southern part of St. George's Bay were deposited as grounding line fans from a calving ice mass. No readvance is implied in this interpretation.

Batterson et al. (1993) used a date of 13,100 ± 220 yrs BP (GSC-5302) (Table 6-1) on non-calcareous bulk organics from a small lake at the south end of the South Brook valley (Thane Anderson, Geological Survey of Canada, personal communication, 1994) to further discuss the timing of the inland deglaciation. However, a *Salix* twig from the base of this core was subsequently dated at 9,540 ± 90 yrs BP (TO-5707). Although this promotes further discussion of the reliability of bulk organic dates using conventional techniques, it provides little additional information on the timing of glacial Lake Howley.

The area near Stephenville Crossing (Figure 7-9), where drainage from Grand Lake likely reached the sea, has no well described or dated sections that show that the outlet would have been ice-covered at the time of glacial Lake

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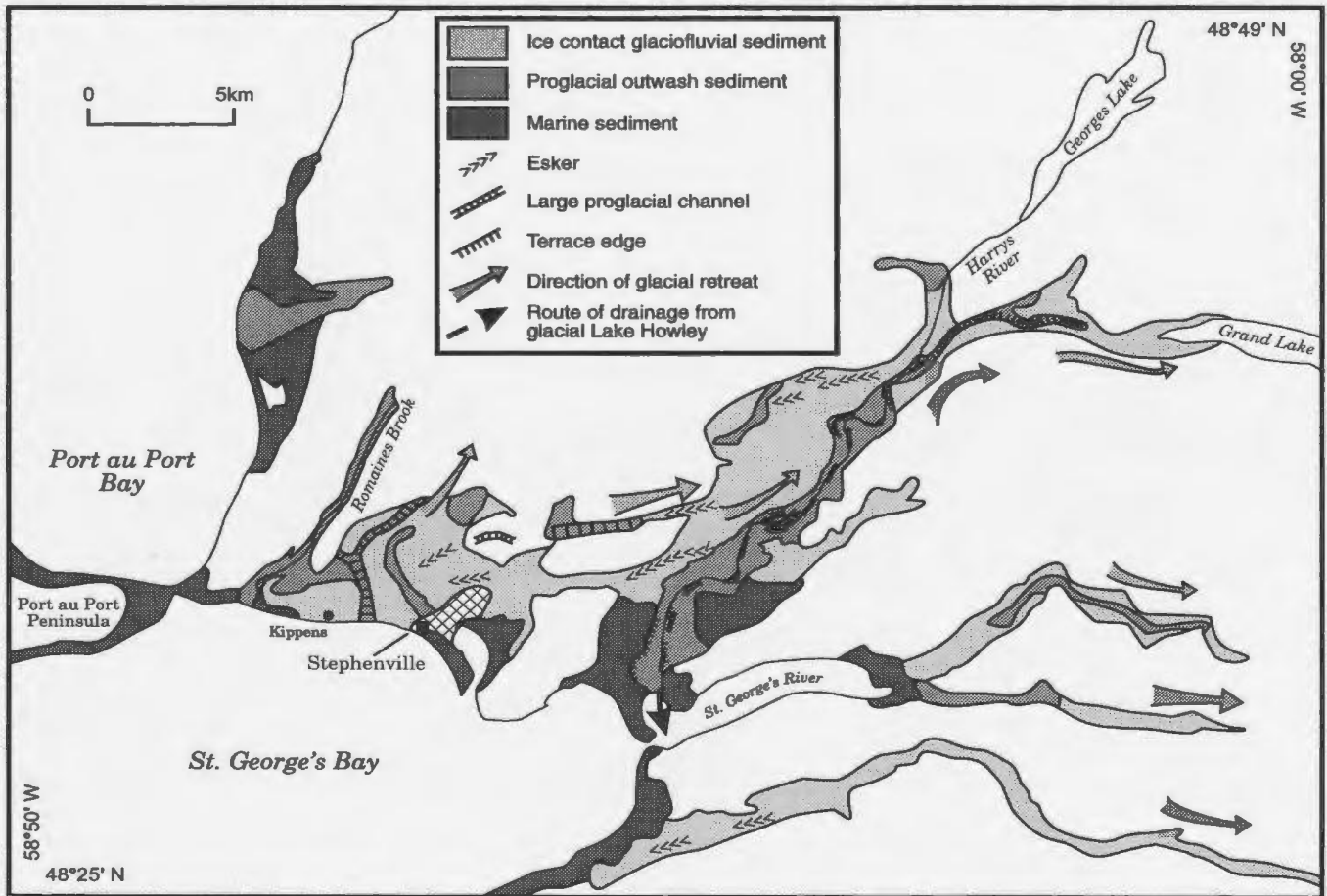
**Figure 7 - 9:** Drainage route of glacial Lake Howley towards St. George's Bay.

Howley. The route of drainage from Grand Lake to the coast is marked by a large proglacial channel. Brookes (1974) showed an esker following a similar course to the channel, and makes no reference to the large meandering channel identified by Grant (1991).

The timing of deglaciation at the northwest and northern margins of the Humber River basin must also be considered in discussions of glacial Lake Howley. Pink till derived from Carboniferous sediments in the Deer Lake basin have been described from Bonne Bay (Brookes, 1974, 1995; Liverman and Batterson, 1995). This shows that ice must have flowed across the Deer Lake basin. Ice flow data from the Humber River basin supports this conclusion. The oldest date from Bonne Bay is 12,100 ± 160 yrs BP (GSC-4158) (Table 6-1). Brookes (1995) argued that Bonne Bay area was not deglaciated until 12.1 ka, which precludes the existence of glacial Lake Howley prior to 12,200 BP. Radiocarbon dates on marine organisms provide *minimum* dates on deglaciation, although it is commonly assumed that these relate to marine limit features, and by implication date actual deglaciation. To make this conclusion, careful sedimentological examination and interpretation is required, demonstrating that the sediments in which the organisms are found are indeed the lateral equivalent to marine limit deltas. Radiocarbon dates (11.0 to 12.0 ka; Table 6-1) from the Springdale-Halls Bay area were used to date the numerous ice-contact deltas found at the coast (Tucker, 1974a; Grant, 1974). Using similar arguments to Brookes (1995), these dates would preclude the existence of a large deglaciated area inland prior to 12,200 BP. Subsequent discoveries of marine fauna dated at 12,470 ± 300 yrs BP (TO-2305) up to 10 kilometres inland of the marine features at the modern coast clearly demonstrate that the original interpretation was incorrect, and that the dates

relate to a later stage in deglaciation (Scott *et al.*, 1991). At Goose Arm, a date of 10,600 ± 100 yrs BP (GSC-4400) at 6 m asl was interpreted as a minimum date for a glacial stand at this position (Grant in McNeely and McCuaig, 1991, p. 17). However, marine shells were later found in Goose Arm Brook at 50 m asl and dated at 13,150 ± 90 yrs BP (TO-3264) (Batterson *et al.*, 1993). This provides a new minimum date for deglaciation of the area. Goose Arm is about 13 km west of the Deer Lake watershed, about half the distance between Bonne Bay and the Deer Lake watershed. The date of 12,220 ± 90 yrs BP (TO-2885) on marine shells in the Humber River gorge shows that the western end of the Humber River basin was ice free before this time.

The dates from the Humber River gorge and from Goose Arm are difficult to reconcile with the assertion by Brookes (1974, 1995) that Bonne Bay was not deglaciated until 12.1 ka. Faced with a similar predicament at Lark Harbour where the date on a delta there was substantially younger than for a delta at a similar elevation at Cox's Cove, Brookes (1974) suggested that ice lingered in the constricted valley at Lark Harbour; similar reasoning can be suggested for the Bonne Bay area. The radiocarbon dates and the lack of evidence showing ice-proximal conditions suggest that the Deer Lake-Grand Lake basin was ice free before 12.2 ka.

In the absence of similar detailed sedimentological studies, it is suggested that dates in Bonne Bay, and other areas (including the Stephenville and Bay of Islands areas) should be interpreted as minimum dates only.

Glacial Lake Howley was dependent on the presence of ice dams in the Humber River gorge and the Indian Brook valley, and maintenance of the Harrys Brook outlet at 122 m asl. These constraints were unlikely to remain

for an extended period, and the life span of the lake was probably short. The thin lacustrine sediments in the Birchy Lake canal section support this conclusion. Thicker fine-grained sediments in the South Brook valley also tentatively are identified as lacustrine. The surface sediment in much of the Sandy Lake - Birchy Lake region is sand and gravel (Grant, 1989b), suggesting any lacustrine deposits have been either eroded or buried by subsequent fluvial activity.

The scarcity of lacustrine sediments in the basin indicates a short lived lake that drained rapidly. This conclusion is supported by the absence of successively lower shoreline features, and the lack of terracing of the Grand Lake outlet. If the Indian Brook valley ice dam collapsed prior to the Humber gorge ice dam, then a set of strandline features related to the elevation of the Indian Brook-Birchy Lake drainage divide should have been preserved. The absence of a secondary shoreline indicates that drainage followed the collapse of the Humber gorge dam.

Previous studies have suggested that deglaciation of the Humber River basin followed an orderly retreat from the coast towards remnant ice centres on west coast highlands, beginning about 14.0-13.0 ka BP (Prest *et al.*, 1968; Dyke and Prest, 1987; Grant, 1989a). An alternative style of deglaciation has been presented here that shows that a large, low elevation basin in the interior was deglaciated, possibly at a similar time to ice retreat to coastal positions from offshore. Due to isolation from marine influence, modern mean summer temperatures are higher, and precipitation and snowfall lower within the Deer Lake - Grand Lake basin than in areas near the coast (Banfield, 1981; Department of Environment and Lands, 1992). Assuming similar patterns existed during deglaciation, isolation from marine influence

may have been an important control on melting rates, with ice more persistent in coastal areas. The presence of a large pro-glacial lake shows that deglaciation was underway before 12.2 ka, possibly as early as 13.0 ka, throughout the Deer Lake - Grand Lake basin and that drainage outlets to the southwest were also ice free at this time. Following retreat of ice through the lower Humber River valley raised post glacial sea levels resulted in flooding of large areas of the basin. Glacier ice was restricted to isolated remnants. Grant (1974) described the final stage of deglaciation as being multiple remnant ice caps derived from the major Newfoundland ice sheet by "a process of shrinkage, separation and migration". The pattern described here is an intermediate stage between this final configuration, and that of the glacial maximum. Early deglaciation of the Deer Lake - Grand Lake basin is required to enable separation of distinct Northern Peninsula, The Topsails, and Baie Verte ice caps (c.f. Grant, 1974).

# Chapter 8

# Summary of Major Findings and Suggestions for Further Research

This thesis focused on three areas of study; the mapping and detailed description of surficial sediments; the determination of palaeo-ice flow using erosional and depositional evidence; and definition of the relative sea level history. These topics are integrated to provide a Quaternary history. The major findings of this research are presented below:

1. The entire Humber River basin was glaciated. Striated bedrock surfaces and exotic clast rock types were found on the highest hills within, and along the margins of the basin. Diamictons were fresh, and striated bedrock surfaces unweathered. The tills were deposited during the Late Wisconsinan.

2. Diamictons found across the Humber River basin mostly were deposited as lodgement and melt-out tills, or their secondary derivatives. Depositional environments were defined on the basis of sedimentary structures, and clast fabrics. Evidence of deformation was found in sections south of Pasadena dump. The clastic dykes found within the middle diamicton at the Pasadena dump exposures, and similar features near Deer Lake, are relatively unusual features. They have not been reported elsewhere in Newfoundland.

3. Initial advance of glaciers was from a Long Range Mountain ice cap southward into the upper Humber River valley, and then flowing into the Deer Lake basin. The southwestern extent of this flow is uncertain. Southward-directed striations are found near Stephenville and farther south, but there are insufficient data to link these features to the advance from the Long Range Mountains.

4. The next phase of ice flow was from an ice centre on The Topsails. In the Hinds Lake area, ice flow was northwestward, whereas flow on the high plateau to the east was northeastward, thus providing data on the northeastern part of the dispersal centre. Topsails-centred ice crossed the Glide Lake highlands and Deer Lake, flowing toward the coast. Ice flow from The Topsails did not cross into the upper Humber River valley, which contained ice from the Long Range Mountains throughout the Late Wisconsinan. In the north, ice crossed Sandy Lake and Birchy Lake and flowed toward the coast into White Bay or Hall's Bay (Figure 5-1), whereas in the southwest, ice flow was directed toward St. George's Bay or through Serpentine Lake. These flow patterns provide a sequence of ice flows that differs from existing models, but explain the striation, clast fabrics and clast provenance data.

5. The distribution of eskers, meltwater channels and hummocky moraine suggests areas of ice wastage. The presence of hummocks in the central and eastern parts of the basin suggests that ice retreated across the highlands west of the Humber River valley, and stagnated within the upper Humber River valley, on the Glide Lake highlands, in the lowlands around Howley, and on The Topsails. These areas also contain meltwater channels. A

radial pattern of meltwater channels also suggests that wasting ice was located on the southern end of Birchy Ridge, on the highlands between the Glide Lake and Deer Lake valleys, overlooking the South Brook valley, and on The Topsails southwest of Hinds Brook. These remnant ice centres remained active, at least for a short period, as indicated by the striation patterns. In the Glide Lake - Pynn's Brook area, till found overlying glaciofluvial sand-gravel suggests a local readvance down the Pynn's Brook valley.

6. The spatial and elevational distribution of features indicating deposition within a body of standing water, well above marine limit, in the Grand Lake basin suggests formation within a single glacial lake. At its maximum extent, this lake occupied most of the basin, including Grand Lake, and likely Sandy Lake and Birchy Lake. Lake level was controlled by discharge through the southwestern end into Harrys River, and configuration of the lake was controlled by retreating ice through Deer Lake and Sandy Lake. The elevation of shoreline features increases northeastward from 128 m to 150 m asl, due to differential isostatic rebound. The name 'glacial Lake Howley' was proposed for this body of water (Batterson *et al.*, 1993).

7. Glacial Lake Howley drained through a spillway now occupied by Junction Brook, as ice retreated across the lowland between Glide Lake highlands and Birchy Ridge. Drainage through the Junction Brook spillway lowered lake levels by up to 71 m, representing a volume of 2.6-4.1 x $10^{10}$ $m^3$ of water. Discharge through this channel is estimated at a maximum of 10,200 $m^3$ $sec^{-1}$. This would drain the lake within a 1-2 month period, depending on the actual configuration of the lake.

8. Marine limit on the coast is about 60 m asl, based on the elevation of a delta in the Hughes Brook valley. This is 10 m higher than published records of marine limit for the Humber Arm area.

9. A protracted episode of standing water in the Deer Lake basin at elevations below 50 m asl resulted in the formation of deltas along the basin margins, and deposition of rhythmically bedded sediments within deeper parts of the basin. Although sedimentology, the lack of macro- or micro-fauna, or microflora, and a poorly defined geochemical signature cannot confirm a marine origin, the elevation with respect to marine limit and the presence of a relict population of the marine fish *Microgadus tomcod* in modern Deer Lake, suggest that a marine origin is more likely than lacustrine.

10. Discharge from drainage of glacial Lake Howley would have introduced large quantities of water and sediment into the Deer Lake basin. It is speculated most of the coarse-grained material was deposited in the Junction Brook delta formed during marine inundation of the Deer Lake basin. Fine-grained sediment was transported through the lower Humber River valley and into the Humber Arm. This mechanism may explain the presence of a well-sorted, reddish brown clay layer containing a sparse micro-faunal assemblage described by Shaw *et al.* (1995)

11. Radiocarbon dating of marine shells in the Humber Arm and tributaries was used to construct a relative sea level curve for the area. It is a Type B (Quinlan and Beaumont, 1981) curve, showing rapid relative sea level fall from a marine limit of 60 m dated at about 13.1 ka, falling below modern

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sea level at about 10.0 ka, reaching a sea level lowstand at -6 m at about 7.9 ka and recovering since then.

12. The relative sea level curve developed from the Humber Arm, was used to date the deltas at the head of Deer Lake at 12.3 to 12.6 ka. These deltas were formed subsequent to lake drainage. Glacial Lake Howley was formed sometime before these dates.

13. Draining of a lake through the Harrys River valley before 12.3-12.6 ka is not compatible with the established chronology for the St. George's Bay area of western Newfoundland. It is argued that the extent and/or timing of the Robinsons Head readvance should be re-evaluated.

14. The style of deglaciation presented here differs from previously accepted models for this part of eastern Canada (Prest *et al.*, 1968; Dyke and Prest, 1987; Grant, 1989a). Rather than a gradual retreat from the coast to remnant ice centres on topographic highs, a style is suggested in which a large, low elevation basin in the interior was deglaciated early, possibly at a similar time to ice retreat to coastal positions from offshore. Early deglaciation of the Deer Lake - Grand Lake basin is required to enable separation of distinct Northern Peninsula, Topsail Hills, and Baie Verte ice caps (c.f., Grant, 1974).

## Further Research

The following are several areas where further work is required:

1. The depositional environment of fine-grained sediments in the

lower Humber River valley remains speculative. In this thesis they were interpreted as glaciomarine sediments deposited during marine inundation of the Humber River valley. However, the sediments contained only rare foraminifera, no macrofossils, no microflora, and had no distinct geochemical signature. A detailed examination of these sediments is warranted to determine:

a) criteria that may be used to differentiate fine-grained sediments deposited in marine or freshwater environments.

b) whether a marine to freshwater transition can be determined from a detailed examination of sections at, for instance, Wild Cove, or from drill core from the Steady Brook area, where thick sediment is found.

A detailed micro-faunal or micro-floral examination may be considered. Alternatively, the use of strontium isotopes (e.g., Reinhardt, 1996) or carbon isotopes (e.g., Winkler, 1994) may be applicable to the problem in the Humber Arm.

2. Geophysical surveys of the sub-bottom profiles and stratigraphy of Deer Lake and Grand Lake are required. Bathymetry of these lakes also are currently unavailable. Water depths and steepness of basin sidewalls will require a Huntec deep-towed or equivalent system, thus limiting the types of suitable boats. The potential for a long sedimentologic record within these basins, either glaciolacustrine in Grand Lake or marine in Deer Lake, should be sufficient encouragement for a survey to be undertaken.

3. The implications of glacial Lake Howley have been discussed in detail. A major conclusion is that the existing chronology of southwestern Newfoundland needs to be re-examined if the Grand Lake basin was ice free at

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about 12.5 ka. This would preclude the possibility of Robinsons Head readvance ice covering the Harrys River lowland, the drainage route for the lake. Recent work by Liverman and Bell (1996) and Batterson and Janes (1997) bears on this discussion, but considerably more study, involving detailed section descriptions, is required to resolve this problem.

4. A new relative sea level curve for the Humber Arm area has increased data concerning the sea level history of western Newfoundland. The data do not readily fit to the existing geophysical models that were developed to explain sea level change in Newfoundland (e.g., Quinlan and Beaumont, 1981, 1982). A new synthesis of the data are required, perhaps adopting the approach of Lambeck *et al.* (1996) to determine the pattern of crustal recovery from the influence of the Laurentide ice sheet and an independent Newfoundland ice cap.

5. The presence of a proposed early southward ice flow requires further investigation. Evidence of southward flow exists in the erosional record from the Northern Peninsula to Cape Ray, with supporting fabric data from the Corner Brook area. The source of this flow is unknown, and the reasons for coast-parallel flow unclear. Alternative hypotheses, including piedmont glaciation onto the coastal platform or southward ice occupying the Esquiman channel require testing.

6. The hypothesis of west coast refugia remains unresolved. Grant (1987) and Brookes (1977b) suggested the presence of nunataks on some west coast uplands. Cosmogenic radionuclide investigations demonstrated that Gros Morne (one of the proposed nunataks) was likely ice-covered during the

Lake Wisconsinan (Gosse and Grant, 1993). Complete glacial coverage in the Late Wisconsinan must be reconciled with the biological data that suggests refugia, e.g., the distribution of the land-snail *Cepaea hortensis* on the west coast (Maunder and Batterson, in prep.). The location of this refugium (if any) is speculative, but may not be in the west coast highlands.

7. Other areas of interest are: detailed mapping in the South Brook valley, which connects the Grand Lake basin with the lower Humber River valley. The early phase of glacial Lake Howley drained through the South Brook valley; sedimentological descriptions and mapping of the valley connecting the western end of Grand Lake to the Harrys River valley; and detailed mapping and sedimentology of deltas at the head of Deer Lake.

## Concluding statement

As with any project dealing with an area subject to relatively little previous work, the result of research is to produce a framework for future investigations. This thesis work has provided additions to the scientific knowledge of the Humber River basin that may be used for a wide range of practical applications. It has also provided an impetus to further research concerning the Quaternary history of western Newfoundland, particularly the examination of the stratigraphy and sea level history of St. George's Bay and the problem of refugia on west coast highlands or coastal margins. Numerous opportunities for future work have been presented and will hopefully be undertaken by other Quaternarists, both to test the hypotheses presented in this thesis and to find answers to the unresolved issues. Continued scientific investigations are anticipated and encouraged.

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# Appendix A

# Site and Sample Description

The following listing provides data on individual sites examined across the Humber River basin. Data is presented in the following format:

Yr -                    The year in which data was collected (1991, 1992, 1993, 1994).

Site -                  The site number assigned during field work.

NTS -                   The National Topographic System map number.

East -                  The easting on the Universal Transverse Mercator Grid, Zone 21.

North -                 The northing on the Universal Transverse Mercator Grid, Zone 21.

Elev -                  The elevation of the site above sea level. This was either estimated from a topographic map (accuracy ± 5 m), or from an altimeter (accuracy ± 2 m).

Sed -                   The sediment type found at a site, designated by the following letters: D (diamicton), S (sand), SC (silt-clay), SG (sand and gravel), SS (sand-silt).

Munsell Colour -        The moist colour of sediment using the Munsell Soil Color Chart is shown first. The dry colour of sediment using the Munsell Soil Color is shown beneath.

Sand -                  The percentage of sand found within sediment matrix.

Silt -                  The percentage of silt found within sediment matrix.

Clay -                  The percentage of clay found within sediment matrix.

Mean -                  The graphic mean of particle sizes, derived from Folk and Ward (1957), expressed in ø sizes.

S.D. -    The inclusive graphic standard deviation of sediments, as a
          measure of sorting, derived from Folk and Ward (1957) and
          expressed in ø sizes.

Sample -  The sample number assigned to a sediment or pebble
          sample. Pebble data is compiled in Appendix 3.

$S_1$ -   The principal eigenvalue from clast fabric analysis. It
          describes the strength of the strongest cluster.

$S_3$ -   The eigenvalue of the weakest cluster (i.e., perpendicular to
          the principal eigenvector).

Comments  Site description, including brief section description, where
          applicable

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 89-6 | 12A13 | 454350 5424620 | 145 | SG | | | | | | | | Interbedded sand, gravelly sand, diamicton. Beds dip at 8° towards 120°. Some normal faulting. Ice wedge cast. |
| 91-1 | 12A13 | 433870 5422980 | 79 | | | | | | | | | Striae 258 ± 4. |
| 91-2 | 12A13 | 432930 5421720 | 238 | | | | | | | | | Striae 284 ± 6. |
| 91-3 | 12A13 | 433970 5421830 | 235 | | | | | | | | | Striae 270 ± 3. Striae 214 ± 5. |
| 91-4 | 12A13 | 433920 5422100 | 229 | D | 2.5Y 7/2 2.5Y 8/2 | 48.8 | 31.9 | 19.3 | 2.33 4.62 | 914000 | 0.57 0.12 | Light grey diamicton. Sandy to silty matrix. Massive. |
| 91-5 | 12A13 | 434150 5422880 | 58 | SG | | | | | | 914001 | | Sandy gravel. Matrix coarse sand. |
| 91-6 | 12A13 | 434870 5422070 | 82 | D | 5Y 6/3 10YR 8/2 | 67.3 | 28.4 | 4.3 | 1.16 3.66 | 914081 | 0.85 0.04 | Silty to fine sandy diamicton overlain by sandy gravel. Striae at west end pit 295 ± 5. |
| 91-7 | 12A13 | 435840 5421820 | 61 | GS | | | | | | 914002 | | Interbedded gravelly sand and gravel. |
| 91-8 | 12A13 | 435860 5421950 | 30 | S | | | | | | | | Mostly f-c sand. Faulted. Planar interbedded. Beds dip at 24° toward 118°. |
| 91-9 | 12A13 | 435130 5422520 | 21 | GS | | | | | | | | Dawe's Pit. See Chapter 4. |
| 91-10 | 12A13 | 434500 5423900 | 37 | GS | | | | | | | | 3 m pebbly to gravelly sand. Edge of terrace. |
| 91-11 | 12A13 | 435050 5424400 | 1 | | | | | | | | | Striae 243 ± 2. |
| 91-12 | 12A13 | 435040 5424600 | 2 | SC | | | | | | | | 6 m exposure. Silt, clay and fine sand. |
| 91-13 | 12A13 | 434860 5424620 | 7 | SC | | | | | | 914005 | | 7 m silt-clay. |
| 91-14 | 12A13 | 434510 5424660 | 7 | D | 10YR 4/2 10YR 6/2 | 44.4 | 37.6 | 18.0 | 3.82 3.91 | 914006 | 0.64 0.16 | 7 m diamicton. Matrix fine sand to silt. |
| 91-15 | 12A13 | 434250 5424760 | 2 | | | | | | | | | Striae 244 ± 3. |
| 91-16 | 12A13 | 434020 5424790 | 8 | D | 2.5Y 6/4 2.5Y 8/2 | 54.2 | 39.4 | 6.4 | 2.02 4.4 | 914007 | | 9 m+ diamicton over bedrock. Matrix fine sand and silt. |
| 91-17 | 12A13 | 433840 5424930 | 2 | | | | | | | | | Striae and grooves. 255 ± 3. |
| 91-18 | 12A13 | 433560 5425400 | 8 | SC | 5YR 5/3 | | | | | 914008 | | 6 m pebbly sand; 5-7 mm calcite cement; Interbedded silt, clay and fine sand. Bedrock striated 246 ± 6. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S1 S3 | Comments |
|------|-----|-----------|--------|-----|---------------|------|------|------|-----------|--------|-------|----------|
| 91-19 | 12A13 | 433570 5425680 | 15 | SC | | | | | | | | 8 m of silt-clay overlying 12 m sandy gravel, separated by calcite cement. |
| 91-20 | 12A13 | 440270 5423700 | 12 | GS | 2.5YR 4/2 | | | | | 914009 | | 15 cm gravelly sand. Overlies 1.2 m+ clay and silt. |
| 91-21 | 12A13 | 439500 5424120 | 76 | PS | 2.5Y 4/4 2.5Y 7/2 | 73.3 | 23.9 | 2.9 | 1.9 3.34 | 914010 | | Pebbly sand. |
| 91-22 | 12A13 | 437700 5425070 | 37 | SG | | | | | | | | Sand and gravel. |
| 91-23 | 12A13 | 437300 5424960 | 37 | D | 10YR 5/4 2.5Y 7/4 | 65.3 | 27.2 | 7.4 | 1.4 3.92 | 914011 | | 1 m. Sandy diamicton. |
| 91-24 | 12A13 | 437020 5424780 | 18 | SG | | | | | | | | Sandy gravel overlain by 1 m of gravelly sand. |
| 91-25 | 12A13 | 435770 5424650 | 18 | SG | 5YR 5/2 10YR 7/3 | 67.0 | 25.7 | 7.3 | 0.84 5.29 | 914012 | | Wild Cove section. See Chapter 4. |
| 91-25 | 12A13 | 435770 5424650 | 18 | SG | 7.5YR 6/4 10YR 7/3 | 71.6 | 24.1 | 4.4 | 2.8 3.82 | 914013 | | |
| 91-26 | 12A13 | 435660 5424590 | 30 | G | | | | | | | | Exposure 12 m high. Silty gravel. |
| 91-27 | 12A13 | 435590 5426480 | 156 | D | 10YR 6/4 10YR 8/3 | 37.3 | 46.9 | 15.8 | 1.14 4.91 | 914015 | 0.83 0.06 | Diamicton. |
| 91-28 | 12A13 | 435680 5426410 | 128 | | | | | | | | | Striae 225 ± 4; 280 ± 3. |
| 91-29 | 12H04 | 435920 5427950 | 49 | SG | | | | | | | | 2 to 5 m planar bedded sand and gravel. |
| 91-30 | 12A13 | 435030 5427260 | 43 | SG | | | | | | | | Interbedded coarse to medium sand and sandy pebble gravel. |
| 91-31 | 12H04 | 435250 5428020 | 49 | D | 10YR 4/3 7.5YR 7/4 | 49.0 | 37.3 | 13.7 | 2.93 4.28 | 914138 | | Diamicton, grades laterally to sand-gravel. |
| 91-32 | 12A13 | 431600 5426330 | 79 | D | 10YR 4/3 2.5Y 7/4 | 69.2 | 26.1 | 4.7 | 1.06 3.63 | 914016 | | Diamicton. Overlies interbedded sand and gravel. |
| 91-33 | 12A13 | 431100 5425680 | 2 | D | 10YR 5/1 10YR 7/1 | 60.7 | 33.2 | 6.1 | 2.74 3.25 | 914017 | 0.58 0.08 | 30 m terrace. Diamicton. Silt and fine sand. Overlain by sand and gravel. |
| 91-34 | 12A13 | 429530 5425030 | 55 | | | | | | | | | Striae 244 ± 4. |
| 91-35 | 12A13 | 429350 5427230 | 204 | | | | | | | | | Striae 260 ± 2. |
| 91-36 | 12A13 | 429020 5426970 | 152 | D | 2.5Y 4/2 10YR 7/2 | 76.2 | 12.1 | 11.7 | -0.19 3.89 | 914018 | 0.79 0.02 | 1.8 m thick diamicton. Overlain by 1.2 m brown diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91-36 | 12A13 | 429020 5426970 | 152 | D | 7.5YR 4/2 10YR 7/2 | 65.8 | 23.2 | 11.1 | 0.4 4.12 | 914019 | 0.79 0.02 | |
| 91-37 | 12A13 | 429050 5427710 | 146 | | | | | | | | | Striae 254 ± 10. |
| 91-38 | 12A13 | 433050 5420850 | 155 | | | | | | | | | Striae 274 ± 3. |
| 91-39 | 12A13 | 433450 5420600 | 149 | GS | 2.5Y 6/2 2.5Y 7/2 | 85.3 | 13.7 | 1.0 | 0.31 2.79 | 914020 | | 6 m gravelly sand. |
| 91-40 | 12A13 | 433450 5420600 | 137 | D | 2.5Y 6/4 10YR 7/1 | 63.6 | 28.9 | 7.5 | 0.97 4.14 | 914021 | 0.52 0.06 | Upper 2 of 7 m visible. Diamicton. |
| 91-41 | 12A13 | 433400 5420400 | 177 | | | | | | | | | Striae 292 ± 4. 6 m exposure gravelly sand overlies diamicton. |
| 91-42 | 12A13 | 434150 5417900 | 207 | | | | | | | | | Striae 318 ± 6. |
| 91-43 | 12A13 | 427350 5421050 | 198 | | | | | | | | | Striae 310 ± 4. |
| 91-44 | 12A13 | 427650 5419375 | 219 | D | 5Y 6/1 5Y 7/1 | 51.3 | 20.5 | 28.2 | 2.93 4.49 | 914022 | 0.92 0.03 | 2 m diamicton. |
| 91-45 | 12A13 | 428400 5419775 | 223 | | | | | | | | | Striae 296 ± 2. |
| 91-46 | 12A13 | 433250 5419200 | 226 | GS | 2.5Y 6/4 2.5Y 8/2 | 73.6 | 21.7 | 4.7 | -0.86 3.52 | 914023 | | Gravelly sand. |
| 91-47 | 12A13 | 433050 5416175 | 284 | | | | | | | | | Striae 320 ± 6. |
| 91-48 | 12A13 | 432950 5416050 | 287 | D | 5Y 6/2 5Y 7/1 | 48.4 | 36.4 | 15.3 | 2.04 4.47 | 914024 | 0.64 0.08 | 5 m diamicton. |
| 91-49 | 12A13 | 439070 5405600 | 387 | | | | | | | | | Striae 316 ± 3. |
| 91-50 | 12A13 | 440940 5404370 | 351 | D | 5Y 6/2 5Y 7/2 | 63.5 | 29.9 | 6.6 | 0.65 3.86 | 914025 | 0.71 0.08 | 3 m diamicton. |
| 91-51 | 12A13 | 438190 5406670 | 363 | D | 5Y 6/3 2.5Y 7/2 | 59.9 | 24.7 | 15.4 | 2.73 3.99 | 914026 | | 1.5 m diamicton. |
| 91-52 | 12A13 | 437350 5409650 | 341 | D | 5Y 6/3 5Y 7/2 | 51.2 | 36.0 | 12.8 | 2.6 4.29 | 914027 | | 2 m diamicton. |
| 91-53 | 12A13 | 438370 5411380 | 299 | D | 2.5Y 4/2 2.5Y 7/2 | 77.6 | 19.0 | 3.4 | -0.61 3.41 | 914028 | 0.73 0.06 | 6 m diamicton. |
| 91-54 | 12A13 | 437960 5421560 | 45 | D | 5YR 4/3 5YR 5/3 | 24.9 | 18.6 | 56.4 | 5.9 4.4 | 914029 | 0.77 0.09 | 1 m+ of gravelly sand; 1 m diamicton, interbedded with silt-clay with rare pebbles; and 1.5 m sand. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91-55 | 12A13 | 437860 5421570 | 31 | S | | | | | | | | 3 m well sorted, rippled sand. |
| 91-56 | 12A13 | 438030 5421840 | 37 | | | | | | | | | Striae 208-028. |
| 91-57 | 12A13 | 432730 5416170 | 308 | | | | | | | | | Striae 324 ± 2. |
| 91-58 | 12A13 | 432450 5417150 | 287 | | | | | | | | | Striae 320 ± 4. |
| 91-59 | 12A13 | 432670 5418190 | 311 | | | | | | | | | Striae 322 ± 3. |
| 91-60 | 12A13 | 438860 5415830 | 421 | D | 2.5Y 5/4 2.5Y 7/2 | 80.1 | 19.0 | 0.9 | 0.65 3.09 | 914030 | 0.85 0.05 | 7 m diamicton. |
| 91-61 | 12A13 | 438380 5414180 | 445 | D | | | | | | | | Silt - fine sand diamicton. |
| 91-62 | 12A13 | 438710 5411800 | 360 | D | 2.5Y 6/4 2.5Y 7/2 | 83.3 | 14.2 | 2.5 | 0.75 2.99 | 914031 | 0.51 0.12 | Hummock, 50 m diameter. 7m diamicton. |
| 91-63 | 12A13 | 437860 5413000 | 366 | D | 2.5Y 5/4 2.5Y 7/2 | 84.4 | 14.5 | 1.1 | 0.43 2.98 | 914032 | | 4 m diamicton. |
| 91-64 | 12A13 | 436850 5415710 | 323 | D | 5Y 6/3 5Y 7/3 | 57.6 | 36.0 | 6.4 | 3.15 3.26 | 914033 | | 1.5-2 m diamicton. |
| 91-65 | 12A13 | 435190 5418390 | 274 | | | | | | | | | Striae 297 ± 3. |
| 91-66 | 12A13 | 435570 5418470 | 232 | D | 2.5Y 5/4 2.5Y 7/4 | 83.9 | 14.2 | 1.9 | 0.17 3.02 | 914034 | 0.57 0.12 | 4 m diamicton. |
| 91-67 | 12A13 | 432800 5415700 | 280 | | | | | | | | | Striae 310 ± 3. |
| 91-68 | 12A13 | 428570 5411620 | 302 | | | | | | | | | Striae 300 ± 2. |
| 91-69 | 12H04 | 455170 5428550 | 29 | S | 5YR 4/3 5YR 5/3 | 85.9 | 10.2 | 3.9 | 2.33 1.85 | 914035 | | 0-2 m bedrock; 6 m m-c sand; 1 m silt-clay and interbedded fine sand; 1.5 m sandy gravel. |
| 91-70 | 12H04 | 455320 5428430 | 29 | SC | 5YR 4/3 | | | | | 914037 | | 2 m rhythmically bedded silt-clay. Reddish brown. |
| 91-71 | 12H04 | 454370 5429070 | 31 | SG | | | | | | | | Grooves 204 ± 4. 4 m sandy pebbly gravel. |
| 91-72 | 12H04 | 453340 5428960 | 24 | SG | | | | | | | | Interbedded sandy gravel and granules. |
| 91-73 | 12H04 | 450530 5427550 | 61 | D | 10YR 4/3 10YR 6/4 | 91.8 | 7.0 | 1.2 | -1.37 2.7 | 914038 | | 2 m diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91-74 | 12H04 | 449150 5427520 | 21 | SG | | | | | | | | 30 cm sandy gravel; 50-80 cm interbedded c, m, f sand, 5-50 cm pebbly diamicton, 5 cm well sorted c sand and >15 cm gravelly sand. |
| 91-75 | 12A13 | 433610 5416140 | 287 | | | | | | | | | Striae 310 ± 2. |
| 91-76 | 12A13 | 436020 5412940 | 314 | | | | | | | | | Grooves 310 ± 3. Grooves 245 ± 3. |
| 91-77 | 12A13 | 435300 5410880 | 375 | | | | | | | | | Striae 308 ± 3. |
| 91-78 | 12A13 | 434340 5404350 | 256 | D | 5Y 5/3 5Y 6/4 | 70.6 | 21.4 | 8.1 | 0.62 3.71 | 914039 | | 1 m diamicton. |
| 91-79 | 12A13 | 434510 5413170 | 317 | | | | | | | | | Grooves 310 ± 2. |
| 91-80 | 12A13 | 458500 5421620 | 311 | D | 5Y 5/3 2.5Y 7/2 | 77.1 | 15.3 | 7.6 | 0.87 3.09 | 914040 | 0.73 0.12 | Diamicton. |
| 91-81 | 12A13 | 458870 5420460 | 256 | D | 2.5Y 6/4 10YR 3/2 | 62.5 | 28.1 | 9.4 | 1.57 4 | 914041 | | 3 m diamicton. |
| 91-82 | 12A13 | 455950 5418410 | 293 | D | 10YR 3/3 2.5Y 7/4 | 78.3 | 18.3 | 3.4 | 0.62 2.94 | 914042 | 0.79 0.03 | 2 m very dark greyish brown diamicton. Sharp contact over >1 m dark greyish brown diamicton. |
| 91-82 | 12A13 | 455950 5418410 | 293 | D | 5Y 5/3 2.5Y 7/2 | 49.6 | 32.2 | 18.2 | 3.42 4.02 | 914043 | | |
| 91-83 | 12H04 | 460730 5427920 | 274 | | | | | | | | | Grooves 308 ± 3. |
| 91-84 | 12H04 | 459100 5427480 | 259 | D | 10YR 4/3 2.5Y 7/2 | 78.0 | 13.1 | 9.0 | -1.69 3.55 | 914044 | | 75 cm diamicton. |
| 91-85 | 12A13 | 457180 5424900 | 170 | D | 5YR 4/6 7.5YR 6/6 | 87.6 | 11.3 | 1.1 | -0.86 2.9 | 914045 | | Diamicton. |
| 91-86 | 12A13 | 456220 5423370 | 154 | D | 2.5Y 5/2 2.5Y 7/2 | 51.5 | 31.1 | 17.4 | 1.27 5.46 | 914046 | | 75 cm diamicton. |
| 91-87 | 12A13 | 453430 5416050 | 126 | D | 5Y 5/3 5Y 7/2 | 82.0 | 13.1 | 4.9 | -0.12 3.08 | 914047 | | 12 m exp., 4-5 m diamicton.; 6-8 m interbedded gravelly sand, sandy gravel, and diamicton. |
| 91-87 | 12A13 | 453430 5416050 | 126 | SG | 5Y 4/2 5Y 7/3 | 98.6 | 1.4 | 0.0 | | 914048 | | |
| 91-88 | 12A13 | 453850 5417260 | 180 | SG | 5Y 4/2 5Y 6/3 | 95.5 | 4.5 | 0.0 | | 914049 | | Sandy gravel. |
| 91-89 | 12A13 | 454820 5417980 | 200 | D | 5Y 4/2 5Y 5/3 | 64.8 | 24.7 | 10.4 | -0.09 4.18 | 914050 | 0.89 0.02 | 3 m diamicton. |
| 91-90 | 12A13 | 454020 5418140 | 150 | D | 5Y 5/3 2.5Y 6/4 | 77.3 | 19.2 | 3.5 | 0.7 3.23 | 914051 | | 8 m diamicton. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|---------|----------|
| 91-91 | 12A13 | 454320 5418930 | 120 | D | 5Y 4/2 5Y 5/3 | 57.5 | 28.1 | 14.5 | 1.21 4.85 | 914052 | | 2 m exposure. >0.5 m olive grey diamicton. Overlain by 0.8-1.0 m diamicton. Reddish brown. |
| 91-91 | 12A13 | 454320 5418930 | 120 | D | 5YR 4/3 7.5YR 6/4 | 35.1 | 33.0 | 32.0 | 4.54 4.26 | 914053 | | |
| 91-92 | 12A13 | 454350 5419200 | 150 | SG | | | | | | | | 3 m sand-gravel. Grades laterally into sandy diamicton. |
| 91-93 | 12A13 | 454460 5419520 | 155 | SG | | | | | | | | 5 m sandy gravel to gravelly sand. |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | 10YR 4/2 7.5YR 7/4 | 66.4 | 24.6 | 9.0 | 1.47 4.24 | 914054 | 0.79 0.05 | Dark brownish grey diamicton; olive grey diamicton; dark reddish brown diamicton. Striae and grooves 205 ± 5 |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | 5Y 4/2 2.5Y 6/2 | 57.0 | 31.3 | 11.7 | 1.98 4.08 | 914055 | 0.73 0.12 | |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | 5YR 4/2 7.5YR 6/4 | 58.6 | 30.9 | 10.5 | 2.27 4.05 | 914056 | 0.74 0.1 | |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | | | | | | 914054a | 0.92 0.01 | |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | | | | | | 914055a | 0.72 0.13 | |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | | | | | | 914056a | 0.75 0.09 | |
| 91-94 | 12A13 | 455640 5426570 | 65 | D | | | | | | 914056b | 0.69 0.04 | |
| 91-95 | 12H04 | 460680 5436930 | 91 | D | 10YR 5/4 10YR 3/3 | 65.3 | 29.7 | 5.0 | -0.31 4.45 | 914057 | | Diamicton. |
| 91-96 | 12H04 | 460650 5436920 | 91 | SS | 10YR 4/2 7.5YR 6/4 | 16.6 | 75.3 | 8.1 | 4.31 3.53 | 914058 | | Fine sand and silt with some pebbles and cobbles. |
| 91-97 | 12A13 | 454600 5419930 | 145 | D | | | | | | 914059 | | 2-3 m diamicton. |
| 91-98 | 12A13 | 454930 5420950 | 135 | D | 5Y 4/2 2.5Y 6/4 | 70.5 | 25.4 | 4.0 | 0.41 3.85 | 914060 | 0.82 0.04 | 2 m diamicton. |
| 91-99 | 12A13 | 454620 5422830 | 140 | GS | | | | | | | | 4 m pebbly sand. See site 91235. |
| 91-100 | 12A13 | 454390 5422480 | 220 | D | 10YR 4/2 10YR 6/4 | 69.7 | 23.8 | 6.5 | 0.41 3.85 | 914061 | | 1 m diamicton. |
| 91-101 | 12A13 | 455060 5424650 | 85 | S | | | | | | | | 2.5 m sand, with layers of manganese stain and cemented sand and silty clay. |
| 91-102 | 12A13 | 455200 5425330 | 86 | S | 7.5YR 5/4 7.5YR 6/4 | 65.8 | 32.7 | 1.4 | 3.98 1.15 | 914062 | | 2 m fine sand. |

6

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 91-103 | 12H04 | 460410 5437270 | 33 | GS | | | | | | | | 7 m interbedded gravelly sand and sandy gravel. |
| 91-104 | 12A13 | 455480 5426320 | 84 | D | 10YR 5/3 10YR 7/3 | 57.5 | 24.6 | 18.0 | 3.78 5.01 | 914063 | 0.67 0.14 | 6 m exposure. Diamicton. Overlain by interbedded v. f - m sands and diamicton. |
| 91-104 | 12A13 | 455480 5426320 | 84 | D | | | | | | 914063a | 0.9 0.04 | |
| 91-105 | 12A13 | 455420 5426180 | 88 | D | 2.5Y 5/2 10YR 7/3 | 65.3 | 28.1 | 6.6 | 0.52 4.21 | 914064 | 0.76 0.07 | 7 m exposure. Greyish brown diamicton; 45 cm sand, manganese stained and gravelly sand; 1.2 m diamicton, and 0-3m sand- gravel. |
| 91-105 | 12A13 | 455420 5426180 | 88 | D | 5YR 4/3 7.5YR 6/4 | 57.0 | 32.5 | 10.4 | 3.12 3.82 | 914065 | 0.78 0.07 | |
| 91-106 | 12A13 | 451690 5416330 | 570 | | | | | | | | | Striae 315 ± 2. |
| 91-107 | 12A13 | 449540 5416440 | 529 | | | | | | | | | Striae 310 ± 2. |
| 91-108 | 12A13 | 448940 5416490 | 558 | | | | | | | | | Striae 315 ± 2. |
| 91-109 | 12A13 | 446970 5417150 | 492 | | | | | | | | | Striae 318 ± 2. |
| 91-110 | 12A13 | 446270 5417320 | 480 | | | | | | | | | Striae 310 ± 3. |
| 91-111 | 12A13 | 450920 5416550 | 505 | D | | | | | | 914066 | | Diamicton. Thin. |
| 91-112 | 12A13 | 454770 5415630 | 420 | | | | | | | | | Striae 268 ± 2, 290 ± 2, 310 ± 2. |
| 91-113 | 12A13 | 455230 5415530 | 335 | D | | | | | | 914067 | | Erratics collected from hilltop. |
| 91-114 | 12A13 | 454930 5415580 | 354 | | | | | | | | | Striae 250 ± 5. |
| 91-115 | 12A13 | 440870 5421330 | 205 | SG | | | | | | | | Interbedded c sand/granule, f-m sand, and sandy gravel. |
| 91-116 | 12A13 | 444320 5420420 | 380 | | | | | | | | | Striae 282 ± 3. |
| 91-117 | 12A13 | 444270 5421470 | 380 | SG | 10YR 4/3 2.5Y 7/4 | 86.4 | 11.9 | 1.8 | -1.71 2.66 | 914068 | | 6 m high terrace. Interbedded granule/pebble gravel and sandy gravel. |
| 91-118 | 12A13 | 449680 5421660 | 380 | | | | | | | | | Striae 262 ± 3. |
| 91-119 | 12A13 | 450730 5422480 | 397 | | | | | | | | | Striae 272 ± 4. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|---------|----------|
| 91-120 | 12A13 | 449880 5421670 | 378 | D | 10YR 4/3 10YR 7/6 | 86.3 | 12.0 | 1.8 | -1.84 2.87 | 914069 | | Thin diamicton. |
| 91-121 | 12A13 | 452650 5423230 | 350 | D | 10YR 4/3 10YR 6/3 | 60.4 | 24.9 | 14.7 | 1.12 5 | 914070 | | Thin diamicton. Striae 280 ± 3. |
| 91-122 | 12A13 | 454030 5423150 | 247 | D | 2.5Y 7/2 10YR 4/2 | 55.2 | 34.3 | 10.6 | 1.43 4.61 | 914071 | | 1 m diamicton. |
| 91-123 | 12A13 | 454740 5423120 | 135 | GS | | | | | | | | 1 m interbedded granule gravel, gravelly sand, sand, and diamicton |
| 91-124 | 12A13 | 439750 5418560 | 530 | | | | | | | | | Striae 272 ± 3 to 282 ± 3. |
| 91-125 | 12A13 | 439400 5418510 | 460 | D | 10YR 4/4 10YR 6/4 | 69.0 | 25.1 | 5.9 | -1.3 4.3 | 914072 | | 75 cm diamicton. |
| 91-126 | 12A13 | 437570 5418320 | 435 | D | | | | | | 914073 | | Pebbles collected from road. |
| 91-127 | 12H04 | 454260 5432650 | 31 | D | 5YR 4/4 5YR 5/4 | 56.5 | 38.1 | 5.5 | 3.78 2.71 | 914074 | | 4 m interbedded sandy gravel, diamicton and sand. |
| 91-128 | 12H04 | 454220 5432590 | 26 | | | | | | | | | Striae 322 ± 6. |
| 91-129 | 12H04 | 452870 5431890 | 107 | | | | | | | | | Grooves 244 ± 4. |
| 91-130 | 12H04 | 452660 5431760 | 110 | | | | | | | | | Striae 244 ± 10. Striae 282 ± 5. |
| 91-131 | 12H04 | 452330 5431470 | 91 | | | | | | | | | Striae 224 ± 3. Striae 335 ± 7. |
| 91-132 | 12H04 | 451900 5431100 | 46 | | | | | | | | | Grooves 270 ± 4. |
| 91-133 | 12H04 | 451420 5430680 | 43 | GS | 5YR 4/3 5YR 6/6 | 95.7 | 3.3 | 1.0 | -0.21 2.21 | 914075 | | 5 m interbedded sand and pebbly sand. |
| 91-134 | 12H04 | 451770 5431030 | 43 | SG | 5YR 3/4 7.5YR 5/6 | 90.7 | 8.6 | 0.7 | 1.22 2.51 | 914076 | | Partially cemented sandy gravel exposed in stream bed. |
| 91-135 | 12H04 | 453750 5432270 | 43 | D | 5YR 3/4 5YR 5/6 | 76.0 | 18.9 | 5.2 | 0.62 3.98 | 914077 | | 0.5 m diamicton overlying rotted bedrock. |
| 91-136 | 12B09 | 417500 5391350 | 120 | S | | | | | | | | 12 m well sorted medium sand. |
| 91-137 | 12B09 | 413760 5492180 | 146 | S | | | | | | | | 12 m gravelly sand and boulder gravel. |
| 91-138 | 12A13 | 437950 5421850 | 13 | SG | | | | | | | | Humber gorge section. See Chapter 4. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91-139 | 12A13 | 436550 5421540 | 15 | S | | | | | | | | 2-3 m very fine sand; 50-75 cm bed open work gravel; 1 m planar sandy gravel, and pebble gravel. |
| 91-140 | 12A13 | 436750 5402300 | 488 | | | | | | | | | Grooves 308 ± 3. |
| 91-141 | 12A13 | 435930 5401130 | 466 | D | 10YR 5/8 10YR 6/4 | 76.1 | 20.5 | 3.4 | 0.84 3.2 | 914082 | 0.77 0.03 | 6 m diamicton. |
| 91-142 | 12A13 | 437880 5405100 | 357 | D | 5Y5/3 5Y 7/2 | 38.7 | 55.9 | 5.4 | -0.41 4.38 | 914083 | 0.67 0.05 | 4 m diamicton. |
| 91-143 | 12H04 | 461850 5446850 | 53 | SG | 5YR 3/3 5YR 6/4 | 91.7 | 5.8 | 2.5 | -1.7 2.49 | 914084 | | Sandy gravel. |
| 91-144 | 12H04 | 461800 5445200 | 47 | S | 5YR 4/3 5YR 6/4 | 99.4 | 0.6 | 0.0 | | 914085 | | 5 m exposure. 4 m interbedded medium to coarse sand/granules. Overlain by 1 m sandy gravel. |
| 91-145 | 12H04 | 460650 5443500 | 9 | SC | 5YR 4/3 5YR 7/4 | 11.8 | 27.1 | 61.1 | 7.93 2.53 | 914086 | | 12 m exposure. 1 m pebble gravel; 2 m planar f and v fine sand; 3 m interbedded silt, clay and sand; and 1.5 m pebbly sand. |
| 91-145 | 12H04 | 460650 5443500 | 9 | S | 5YR 5/4 5YR 6/4 | 99.9 | 0.1 | 0.0 | | 914087 | | |
| 91-146 | 12H04 | 456850 5443550 | 274 | D | | | | | | 914088 | | Pebble sample from road surface. |
| 91-147 | 12H04 | 455600 5441850 | 183 | D | 10YR 4/4 10YR 6/4 | 74.4 | 17.5 | 8.1 | -0.08 3.67 | 914089 | | 2 m diamicton. |
| 91-148 | 12H04 | 458350 5445900 | 137 | | | | | | | | | Striae 250 ± 3. |
| 91-149 | 12H04 | 458300 5446100 | 128 | D | 5YR 4/4 7.5YR 6/4 | 56.3 | 37.0 | 6.8 | 1.77 4.43 | 914090 | | 75 cm diamicton. |
| 91-150 | 12H04 | 454650 5441500 | 183 | D | 5YR 3/4 10YR 6/4 | 81.5 | 14.1 | 4.4 | 1.15 3.05 | 914091 | | 2 m exposure. 50 cm+ sand. Overlain by 1.2 m diamicton. |
| 91-150 | 12H04 | 454650 5441500 | 183 | S | 7.5YR 4/4 7.5YR 7/4 | 78.6 | 19.6 | 1.7 | 3.06 1.68 | 914092 | | |
| 91-151 | 12H04 | 454800 5441550 | 180 | | | | | | | | | Striae 258 ± 6. |
| 91-152 | 12H04 | 455950 5442300 | 177 | GS | 10YR 4/4 10YR 7/3 | 78.8 | 19.4 | 1.8 | 0.8 3.29 | 914093 | | 6 m exposure, basal 3.5 m obscured. >50 cm gravelly sand. Overlain by 2 m sandy gravel. |
| 91-152 | 12H04 | 455950 5442300 | 177 | SG | 7.5YR 4/4 7.5YR 6/6 | 77.7 | 19.5 | 2.9 | -1.17 3.45 | 914094 | | |
| 91-153 | 12H04 | 456650 5441350 | 123 | D | 5YR 4/4 7.5YR 6/4 | 86.3 | 9.1 | 4.6 | -0.21 3 | 914095 | | 2m sandy diamicton. |
| 91-154 | 12H04 | 456600 5440100 | 27 | | | | | | | | | Grooves 252 ± 2. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 91-155 | 12H04 | 455850 5439850 | 76 | D | 5YR 4/4 7.5YR 6/4 | 59.5 | 31.6 | 8.9 | 2.01 4.05 | 914096 | | 75 cm diamicton. |
| 91-156 | 12H04 | 457250 5448540 | 165 | | | | | | | | | Striae 270 ± 2. |
| 91-157 | 12H04 | 456900 5448790 | 189 | | | | | | | | | Striae 292 ± 3. |
| 91-158 | 12H04 | 456560 5448950 | 223 | D | | | | | | 914097 | | Pebble sample. |
| 91-159 | 12H04 | 463510 5451050 | 168 | | | | | | | | | Striae 242 ± 4. |
| 91-160 | 12H04 | 460610 5448970 | 195 | | | | | | | | | Grooves 224 ± 2. |
| 91-161 | 12H04 | 459870 5448970 | 213 | | | | | | | | | Striae 240 ± 3. |
| 91-162 | 12H04 | 463170 5450610 | 143 | D | 5YR 4/6 5YR 6/6 | 66.3 | 27.7 | 6.0 | 2.49 3.36 | 914098 | | 2 m diamicton. |
| 91-163 | 12H04 | 462720 5450250 | 119 | D | 2.5YR 4/4 2.5YR 6/6 | 48.3 | 33.8 | 17.9 | 3.67 3.91 | 914099 | 0.74 0.07 | Same as site 89059. 7 m exposure. 2 m + reddish grey diamicton; 3 m reddish brown diamicton. |
| 91-163 | 12H04 | 462720 5450250 | 119 | D | 5YR 5/3 7.5YR 6/4 | 49.3 | 35.7 | 15.0 | 3.82 3.58 | 914100 | 0.69 0.07 | |
| 91-163 | 12H04 | 462720 5450250 | 119 | D | | | | | | 914099a | 0.67 0.09 | |
| 91-163 | 12H04 | 462720 5450250 | 119 | D | | | | | | 914100a | 0.61 0.1 | |
| 91-164 | 12H04 | 455110 5452840 | 174 | D | 7.5YR 5/4 7.5YR 7/4 | 59.2 | 28.6 | 12.2 | 2.26 4.21 | 914101 | | 1.5 m diamicton. |
| 91-165 | 12H04 | 459480 5449980 | 213 | D | 7.5YR 4/4 10YR 7/4 | 65.7 | 28.1 | 6.3 | 2.71 3.27 | 914102 | | 2 m diamicton. |
| 91-166 | 12H04 | 461750 5449410 | 152 | D | 7.5YR 5/4 7.5YR 8/2 | 68.5 | 27.3 | 4.2 | 2.34 3.45 | 914103 | | 2 m diamicton. |
| 91-167 | 12H04 | 440450 5428870 | 213 | D | 10YR 5/3 10YR 6/4 | 48.1 | 42.3 | 9.6 | 3 3.93 | 914104 | | 2 m diamicton. |
| 91-168 | 12H04 | 438670 5428620 | 152 | D | | | | | | | | 1.5 m diamicton. |
| 91-169 | 12A13 | 437400 5428380 | 98 | D | 5Y 5/3 2.5Y 7/2 | 69.6 | 22.2 | 8.2 | 0.85 4.15 | 914105 | | 3-6 m diamicton. |
| 91-170 | 12H04 | 436640 5428980 | 46 | SG | | | | | | | | 12 m exposure, mostly slumped. Interbedded sand, gravelly sand and sandy gravel. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-----------|----------|
| 91-171 | 12H04 | 437180 5430190 | 37 | SG | | | | | | | | 4 m terrace. Interbedded sands and sandy pebble gravel. |
| 91-172 | 12H04 | 438380 5432870 | 43 | S | | | | | | | | 4 m exposure interbedded sand and pebble sand. |
| 91-173 | 12H04 | 437650 5430880 | 46 | S | | | | | | | | Hughes Brook section. See Chapter 4. |
| 91-174 | 12H04 | 436910 5430790 | 46 | S | | | | | | | | 12 m exp. Slumped. Interbeds of cross bedded f sand, sandy gravel and sandy granule gravel. |
| 91-175 | 12H04 | 437450 5431520 | 64 | | | | | | | | | Striae 236 ± 3. |
| 91-176 | 12H04 | 437570 5433870 | 152 | D | 7.5YR 6/4 5YR 4/3 | 51.1 | 40.9 | 8.0 | 3.24 3.52 | 914106 | 0.82 0.04 | 2 m diamicton. |
| 91-177 | 12H04 | 434560 5437350 | 183 | D | 10YR 6/3 10YR 4/2 | 61.1 | 25.2 | 13.7 | 2.47 4.26 | 914107 | 0.59 0.12 | 6 m exposure. 2 m diamicton. Overlain by 4 m diamicton. |
| 91-177 | 12H04 | 434560 5437350 | 183 | D | 10YR 7/3 10YR 4/3 | 75.8 | 15.1 | 9.1 | 0.23 3.8 | 914108 | 0.64 0.08 | |
| 91-178 | 12H04 | 434270 5437680 | 122 | SG | | | | | | | | 4 m interbedded sand, and sandy pebble gravel. Beds dip 20° to 280°. |
| 91-179 | 12H04 | 434110 5439350 | 137 | D | 5Y 7/3 5Y 5/3 | 61.5 | 24.7 | 13.9 | 0.68 4.73 | 914109 | | 4 m diamicton. |
| 91-180 | 12H04 | 437200 5434820 | 183 | D | 5Y 7/3 5Y 5/3 | 37.8 | 41.3 | 20.9 | 3.91 4.25 | 914110 | | 2 m diamicton. |
| 91-181 | 12H04 | 436350 5421650 | 15 | SC | 5YR 6/3 2.5YR 3/4 | 5.3 | 37.1 | 57.7 | 8.85 3.39 | 914111 | | 15 m exposures. Planar bedded sand and sandy gravels; 1 m planar f sand; and sandy gravel. |
| 91-182 | 12A13 | 437970 5421850 | 15 | S | | | | | | | | 1 m gravelly sand overlain by 1 m rippled sand. |
| 91-183 | 12A13 | 438280 5422040 | 15 | SC | 5YR 4/3 | | | | | 914112 | | Reddish brown silty clay. Overlain by interbedded f and v fine sands, and sand and gravel. |
| 91-184 | 12A13 | 440980 5423430 | 40 | D | 2.5Y 7/2 5Y 4/2 | 78.5 | 18.8 | 2.8 | -0.64 3.55 | 914113 | | 1.5 m diamicton. |
| 91-185 | 12A13 | 443400 5425270 | 20 | SC | 5YR 6/3 5YR 4/3 | 1.4 | 36.0 | 62.6 | 8.18 1.76 | 914114 | | 2 m reddish brown silty clay interbedded with f sand. |
| 91-186 | 12A13 | 445900 5425770 | 37 | SG | | | | | | | | 2 m fine sand overlain by 50 cm sandy gravel. |
| 91-187 | 12A13 | 448120 5426920 | 45 | D | 2.5Y 7/2 5Y 5/3 | 61.7 | 34.2 | 4.2 | 0.95 3.96 | 914115 | 0.6 0.06 | 3 m interbedded f and m sands; thin sandy gravel. In places 2 m diamicton, overlain by 2-3 m inter-bedded sand and sandy pebble gravel. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-----------|----------|
| 91-188 | 12A13 | 446650 5426640 | 15 | SC | 5YR 6/3 5YR 4/3 | 32.1 | 50.4 | 17.5 | 5.64 2.2 | 914116 | | Silt-clay, reddish brown. Overlain by 15 m gravelly sand. |
| 91-189 | 12A13 | 447440 5426400 | 30 | SG | | | | | | | | 3 m interbedded f and m sands, and sandy gravel. |
| 91-190 | 12H04 | 448380 5427500 | 46.2 | SG | | | | | | | | Sandy gravel. |
| 91-191 | 12H04 | 462350 5430650 | 330 | D | 10YR 6/4 10YR 4/3 | 73.0 | 18.6 | 8.4 | -1.25 4.06 | 914117 | | 1 m diamicton. |
| 91-192 | 12H04 | 457760 5432170 | 13 | SC | 5YR 6/3 5YR 4/3 | 1.6 | 34.5 | 64.0 | 8.27 1.89 | 914118 | | 3 m exposure. 1 m reddish brown silty clay. Overlain by 2 m sandy gravel. |
| 91-192 | 12H04 | 457760 5432170 | 13 | SL | 5YR 6/3 5YR 4/3 | 7.9 | 87.9 | 4.2 | 5.46 1.28 | 924051 | | |
| 91-193 | 12H04 | 462900 5437820 | 320 | D | 10YR 6/3 7.5YR 4/4 | 74.3 | 23.2 | 2.5 | 0.71 3.79 | 914119 | 0.79 0.02 | 6 m diamicton. |
| 91-194 | 12H04 | 461390 5436320 | 152 | SS | 10YR 6/3 7.5YR 4/4 | 61.8 | 20.9 | 17.3 | -1.91 3.54 | 914120 | | 6 m sandy gravel. Same as Site 91240 |
| 91-195 | 12H04 | 461950 5436630 | 146 | SG | | | | | | | | 2 m interbedded fine, medium sands, granule gravel and sandy gravel. |
| 91-196 | 12H04 | 463330 5436230 | 195 | D | 7.5YR 6/4 5YR 4/3 | 60.0 | 32.4 | 7.6 | 2.44 3.95 | 914121 | | 2 m diamicton. |
| 91-197 | 12H04 | 462970 5430870 | 287 | D | 10YR 6/3 10YR 4/3 | 79.0 | 18.4 | 2.6 | 0.05 3.47 | 914122 | | 3-4 m exposure. 2 m diamicton. Overlain by 2-3 m sandy gravel. |
| 91-197 | 12H04 | 462970 5430870 | 287 | SG | 10YR 6/4 10YR 3/3 | 91.1 | 8.4 | 0.5 | -0.59 3.15 | 914123 | | |
| 91-198 | 12H04 | 462800 5434280 | 229 | D | 7.5YR 6/4 5YR 4/3 | 62.6 | 23.2 | 14.2 | 2.51 4.29 | 914124 | | 2 m diamicton. |
| 91-199 | 12H04 | 457180 5430750 | 52 | GS | | | | | | | | 1 m pebbly sand overlying 7 m of soft sandstone bedrock. |
| 91-200 | 12H04 | 461890 5439980 | 15 | GS | | | | | | | | 1 m gravel. |
| 91-201 | 12H04 | 461740 5439560 | 31 | GS | | | | | | | | 3 m terrace. Granule gravel to pebbles. |
| 91-202 | 12A13 | 441870 5425150 | 9 | S | | | | | | | | 8 m interbedded m-c sand cross beds. |
| 91-203 | 12A13 | 442840 5425530 | 9 | SC | 5YR 6/3 5YR 4/3 | 1.8 | 73.6 | 24.7 | 6.7 1.62 | 914125 | | 10 m exposure. 7 m slumped. Shows silty clay; 50 cm pebbly sand, and 50 cm f sand. |
| 91-204 | 12H04 | 440320 5437900 | 300 | D | 5Y 6/3 5Y 4/2 | 67.7 | 21.8 | 10.5 | 0.56 4.37 | 914126 | | 2 m diamicton. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 91-205 | 12H04 | 440070 5440240 | 105 | D | 2.5Y 6/4 10YR 4/3 | 66.2 | 28.1 | 5.7 | 1.52 3.65 | 914127 | | 2 m diamicton. |
| 91-206 | 12H04 | 440910 5439490 | 98 | SG | | | | | | | | 4 m sandy gravel. |
| 91-207 | 12H04 | 444450 5439230 | 100 | D | 2.5Y 6/4 2.5Y4/2 | 66.8 | 23.3 | 10.0 | 0.83 4.16 | 914128 | | 2 m diamicton. |
| 91-208 | 12H04 | 447100 5439170 | 100 | D | 2.5Y 6/2 2.5Y4/2 | 62.8 | 22.8 | 14.4 | 0.63 4.81 | 914129 | | Diamicton. |
| 91-209 | 12H04 | 447600 5439150 | 93 | SG | | | | | | | | 2 m sandy gravel. |
| 91-210 | 12H04 | 449140 5439950 | 160 | D | 10YR 6/3 10YR 3/3 | 68.4 | 14.7 | 16.9 | 0.4 4.36 | 914130 | 0.56 0.09 | Two diamictons. |
| 91-210 | 12H04 | 449140 5439950 | 160 | D | 7.5YR 6/2 5YR 4/3 | 47.6 | 41.6 | 10.8 | 2.09 5.02 | 914131 | 0.67 0.05 | |
| 91-211 | 12H04 | 453800 5436970 | 143 | D | 7.5YR 6/4 5YR 4/3 | 64.5 | 33.0 | 2.5 | 1.15 4.32 | 914132 | | 1.5 m diamicton. |
| 91-212 | 12H04 | 450220 5437170 | 210 | D | 10YR 7/4 7.5YR 4/4 | 81.4 | 17.2 | 1.4 | 1.41 3.01 | 914133 | | 2 m diamicton. |
| 91-213 | 12A13 | 432250 5422870 | 110 | | | | | | | | | Striae 274 ± 4. |
| 91-214 | 12A13 | 431450 5422540 | 76 | | | | | | | | | Grooves 256 ± 3. |
| 91-215 | 12A13 | 431030 5422970 | 15 | GS | 10YR 6/4 10YR 5/3 | 78.5 | 14.9 | 6.6 | 2.25 3.13 | 914134 | | 15 m exposure. 3 m+ pebbly sand, 20 cm gravelly sand; 300 cm diamicton; 30 cm interbedded sand, silt and diamicton; 30 cm sandy gravel; 150 cm sand; 350 cm sandy gravel. |
| 91-215 | 12A13 | 431030 5422970 | 15 | D | 2.5YR 6/0 2.5YR 4/0 | 52.1 | 37.2 | 10.7 | 2.39 4.08 | 914135 | 0.68 0.1 | |
| 91-215 | 12A13 | 431030 5422970 | 15 | SG | 10YR 7/3 10YR 4/3 | 95.4 | 3.1 | 1.5 | -0.6 2.98 | 914136 | | |
| 91-216 | 12A13 | 433430 5423340 | 46 | | | | | | | | | Striae 285 ± 15. |
| 91-217 | 12A13 | 429400 5415750 | 339 | | | | | | | | | Striae 310 ± 2. |
| 91-218 | 12A13 | 427480 5416020 | 305 | D | 5Y 6/3 5Y 5/3 | 57.9 | 27.1 | 15.0 | 1.86 4.4 | 914137 | | 2 m diamicton. |
| 91-219 | 12A13 | 436400 5424600 | 50.2 | D | 10YR 7/3 7.5YR 5/4 | 66.8 | 27.9 | 5.4 | 0.89 4.77 | 914139 | | 0.2 m+ diamicton. Overlain by 3.4 m of interbedded sand and gravel. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 91-220 | 12A13 | 437350 5424900 | 40.7 | D | 10YR 6/4 10YR 4/4 | 65.0 | 29.9 | 5.1 | 0.79 4.16 | 914140 | 0.76 0.05 | Wild Cove section. See Chapter 4. |
| 91-220 | 12A13 | 437350 5424900 | 40.7 | S | 10YR 6/3 10YR 4/3 | 83.5 | 11.2 | 5.3 | 2.8 1.89 | 914141 | | |
| 91-220 | 12A13 | 437350 5424900 | 40.7 | SC | 10YR 6/3 7.5YR 5/4 | 13.1 | 74.6 | 12.3 | 5.45 2.77 | 914142 | | |
| 91-221 | 12A13 | 437800 5425060 | 53.2 | SG | 10YR 5/4 7.5YR 3/2 | 91.1 | 7.9 | 1.0 | -1.8 1.87 | 914143 | | 1.5 m+ interbedded gravel and sandy gravel. Overlain by 1.5 m sandy gravel. |
| 91-222 | 12A13 | 438980 5424300 | 62.2 | D | 10YR 6/3 10YR 4/3 | 75.2 | 20.5 | 4.2 | 0.85 3.5 | 914144 | 0.65 0.07 | 3.5 m+ diamicton. |
| 91-223 | 12A13 | 439430 5424130 | 71.2 | D | 10YR 6/4 10YR 4/3 | 73.9 | 21.1 | 5.1 | 2.13 3.43 | 914145 | 0.61 0.05 | 3.2 m+ diamicton. |
| 91-224 | 12A13 | 455450 5426300 | 103 | D | 7.5YR 6/6 7.5YR 4/4 | 67.7 | 21.7 | 10.6 | 2.01 4.04 | 914146 | 0.77 0.07 | See also 91104. Diamicton. |
| 91-225 | 12A13 | 455140 5426280 | 125 | D | 7.5YR 6/4 5YR 4/3 | 60.1 | 21.9 | 18.0 | 2.57 4.39 | 914147 | 0.73 0.05 | 2 m+ diamicton. |
| 91-226 | 12A13 | 455470 5424950 | 79.7 | SC | 7.5YR 6/4 5YR 4/4 | 18.8 | 48.1 | 33.1 | 6.26 3.13 | 914148 | | Interbedded sands, silts and pebbly sands. Some silt-clay beds. |
| 91-226 | 12A13 | 455470 5424950 | 79.7 | SG | 10YR 6/4 10YR 4/4 | 91.6 | 6.6 | 1.8 | 1.77 1.55 | 914149 | | |
| 91-227 | 12A13 | 456340 5424850 | 112 | D | 7.5YR 6/4 5YR 4/4 | 54.5 | 32.9 | 12.6 | 3.61 3.6 | 914150 | 0.89 0.04 | 50 cm+ sand. Overlain by 2.5 m diamicton. |
| 91-227 | 12A13 | 456340 5424850 | 112 | S | 7.5YR 5/4 5YR 4/4 | 84.8 | 11.3 | 3.8 | 1.38 3.09 | 914151 | | |
| 91-228 | 12A13 | 457030 5425170 | 152 | GS | 10YR 6/3 7.5YR 4/4 | 88.9 | 9.2 | 1.9 | 0.43 2.76 | 914152 | | 1 m gravelly sand. Overlain by 3 cm silt and 2 m sandy gravel. |
| 91-228 | 12A13 | 457030 5425170 | 152 | SG | 7.5YR 6/4 5YR 4/4 | 76.9 | 17.2 | 5.8 | -0.61 3.89 | 914153 | | |
| 91-229 | 12A13 | 456450 5424350 | 136 | SG | 7.5YR 5/4 7.5YR 4/4 | 95.0 | 3.8 | 1.2 | -2.38 3.01 | 914154 | | 3 m interbedded sands and sandy gravels. Beds dip 30° towards 310°. |
| 91-230 | 12A13 | 455400 5424100 | 88.7 | SC | 7.5YR 6/4 7.5YR 4/4 | 5.8 | 57.1 | 37.1 | 7.19 1.78 | 914155 | | Generally over 2 m+ silt-clay, brown. Overlain by 80 cm gravelly sand. |
| 91-231 | 12A13 | 456050 5423370 | 129 | GS | 7.5YR 6/4 5YR 5/4 | 87.8 | 10.0 | 2.2 | 0.98 2.51 | 914156 | | 1.5 m+ pebbly sand. Overlain by 50 cm silty diamicton, and 1 m diamicton. |
| 91-231 | 12A13 | 456050 5423370 | 129 | D | 7.5YR 5/4 5YR 4/4 | 63.0 | 26.7 | 10.3 | 0.98 4.28 | 914157 | 0.84 0.05 | |
| 91-231 | 12A13 | 456050 5423370 | 129 | D | 5YR 6/4 5YR 4/4 | 36.0 | 47.6 | 16.4 | 5.43 2.53 | 914158 | | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S$_1$ S$_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91-232 | 12A13 | 455700 5422650 | 150 | GS | 7.5YR 5/4 7.5YR 4/6 | 97.6 | 1.9 | 0.5 | -0.99 2.26 | 914159 | | Interbedded sand and gravel and diamicton. Gravel beds dip 25° to 130°. |
| 91-233 | 12A13 | 455530 5421790 | 133 | D | 2.5Y 7/2 10YR 5/3 | 50.9 | 31.7 | 17.4 | 2.43 4.49 | 914160 | 0.8 0.04 | 1.5 m diamicton. Brown. Overlain by 1.5 m sandy diamicton. |
| 91-233 | 12A13 | 455530 5421790 | 133 | D | 2.5Y 6/2 10YR 4/2 | 79.9 | 17.3 | 2.8 | -0.23 3.28 | 914161 | | |
| 91-234 | 12A13 | 455330 5420630 | 135 | SG | 10YR 4/2 10YR 3/3 | 93.1 | 5.7 | 1.3 | -0.81 2.48 | 914162 | 0.62 0.06 | 3 m sandy gravel. |
| 91-235 | 12A13 | 454620 5422830 | 140 | SG | 10YR 5/4 10YR 3/3 | 98.1 | 1.7 | 0.2 | -1.36 1.94 | 914163 | | See site 91099. 3 m interbedded gravelly sand, sandy gravel and gravel. |
| 91-236 | 12A13 | 454420 5417450 | 154 | SG | 5Y 7/2 5Y 5/2 | 87.0 | 10.6 | 2.4 | -1.57 2.49 | 914164 | | 50 cm+ sandy gravel; 1.2 m olive diamicton; 1.2 m brown diamicton. |
| 91-236 | 12A13 | 454420 5417450 | 154 | D | 5Y 7/2 5Y 5/3 | 59.3 | 26.3 | 14.4 | 0.89 4.42 | 914165 | 0.67 0.05 | |
| 91-236 | 12A13 | 454420 5417450 | 154 | D | 2.5Y 6/4 5Y 4/2 | 48.7 | 32.5 | 18.8 | 1.93 5.34 | 914166 | 0.69 0.04 | |
| 91-237 | 12A13 | 454350 5417330 | 152 | GS | 2.5Y 7/2 5Y 4/2 | 80.0 | 16.5 | 3.5 | 0.32 3.01 | 914167 | | 30 cm+ gravelly sand. Overlain by 1 m sandy gravel, and 2 m sandy gravel. |
| 91-237 | 12A13 | 454350 5417330 | 152 | SG | 2.5Y 6/2 5Y 4/2 | 89.1 | 8.4 | 2.5 | 0.26 2.96 | 914168 | | |
| 91-237 | 12A13 | 454350 5417330 | 152 | SG | 2.5Y 6/4 10YR 5/4 | 87.4 | 11.2 | 1.5 | -1.74 2.84 | 914169 | | |
| 91-238 | 12H04 | 461660 5436920 | 140 | SS | 10YR 6/3 10YR 3/3 | 67.8 | 27.9 | 4.3 | 2.96 3.11 | 914170 | | 2.5 m gravelly sand. Overlain by <1 cm manganese layer, and 30 cm diamicton. |
| 91-239 | 12H04 | 461920 5436600 | 161 | SG | 10YR 6/3 10YR 6/4 | 69.8 | 28.2 | 1.9 | 3.87 1.43 | 914171 | | 1 m+ sand and sandy gravel. Overlain by 2 m diamicton. |
| 91-239 | 12H04 | 461920 5436600 | 161 | D | 7.5YR 6/4 5YR 4/3 | 27.7 | 37.3 | 35.1 | 4.48 4.58 | 914172 | 0.67 0.13 | |
| 91-240 | 12H04 | 461390 5436320 | 163 | SG | 10YR 5/2 7.5YR 3/2 | 86.0 | 10.3 | 3.7 | -1.32 2.47 | 914173 | | Same as site 91194. 6 m sandy gravel. |
| 91-241 | 12H04 | 461930 5447720 | 66.5 | D | 10YR 6/3 10YR 4/3 | 48.6 | 36.2 | 15.2 | 1.11 4.63 | 914174 | 0.47 0.17 | 2.5 m diamicton, reddish brown to greenish grey. |
| 91-242 | 12H04 | 461030 5447670 | 86 | D | 10YR 6/3 7.5YR 3/2 | 66.1 | 27.1 | 6.8 | -0.05 4.96 | 914175 | 0.72 0.08 | 4 m sandy diamicton. |
| 91-243 | 12H04 | 460170 5447470 | 94 | S | 7.5YR 6/4 7.5YR 5/4 | 87.8 | 10.3 | 1.8 | 2.44 1.72 | 914176 | | 2 m+ interbedded f and f-m sand. Overlain by 1 m sandy gravel. |
| 92-1 | 12H03 | 475230 5451130 | 50 | D | 5YR 6/3 5YR 4/4 | 74.8 | 25.0 | 0.3 | 1.71 3.02 | 924000 | | Diamicton at base 5 m test pit. Surface disturbed |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-2 | 12H03 | 489370 5432060 | 310 | | | | | | | | | Striae 252 ± 3. |
| 92-3 | 12H03 | 487150 5430520 | 337 | | | | | | | | | Striae 251 ± 3. |
| 92-4 | 12H03 | 465710 5454940 | 128 | SG | | | | | | | | 3-4 m exposure, slumped. Sandy gravel. |
| 92-5 | 12H03 | 465870 5454600 | 138 | SG | | | | | | | | 6 m exposure. m-c sand and pebble gravel. |
| 92-6 | 12H03 | 465830 5454440 | 162 | D | | | | | | 924001 | | Striae 254 ± 6. Clasts taken from surface. |
| 92-7 | 12H03 | 467030 5452330 | 80 | D | 10YR 6/4 2.5YR 4/4 | 63.4 | 31.3 | 5.4 | 2.43 3.39 | 924002 | 0.7 0.09 | 1 m+ diamicton. |
| 92-8 | 12H03 | 468360 5450890 | 13 | D | 2.5YR 5/4 2.5YR 3/4 | 52.0 | 43.0 | 5.1 | 3.66 2.45 | 924003 | 0.72 0.04 | 1 m+ diamicton. Overlain by 1 m boulder gravel. |
| 92-9 | 12H03 | 468350 5450860 | 13 | D | 2.5YR 5/4 2.5YR 3/4 | 73.6 | 25.9 | 0.5 | 2.81 2.14 | 924004 | 0.7 0.08 | 1 m+ diamicton. |
| 92-10 | 12H03 | 470560 5452030 | 8 | SS | 5YR 6/3 5YR 4/2 | 12.9 | 86.5 | 0.6 | 5.35 1.11 | 924005 | | 2-5 m exposure at base sandy gravel terrace. Interbedded sand and silt. |
| 92-10 | 12H03 | 470560 5452030 | 8 | SL | 5YR 6/3 5YR 4/2 | 6.2 | 85.9 | 8.0 | 6.42 1.27 | 924006 | | |
| 92-11 | 12H03 | 490150 5445620 | 88 | SG | | | | | | | | M-c sand and granule gravel. |
| 92-12 | 12H03 | 489700 5445800 | 89 | S | | | | | | | | 2.5 m well sorted m-c cross-bedded sand. |
| 92-13 | 12H03 | 481130 5449290 | 90 | S | | | | | | | | Veneer gravelly sand. |
| 92-14 | 12H03 | 492850 5446180 | 102 | GS | | | | | | 924007 | 0.66 0.05 | Hummock 25 m diameter. Gravelly sand. |
| 92-15 | 12H03 | 494880 5446920 | 100 | SG | | | | | | 924008 | | Hummock 75 m diameter. 4 m exposure, slumped. 1 m+ sandy gravel overlain by 1 m gravelly sand. |
| 92-16 | 12H03 | 496750 5447530 | 101 | SG | 10YR 6/3 10YR 4/3 | 97.6 | 2.5 | 0.0 | -1.58 2.42 | 924009 | | Hummock 60 m diameter. 1.5 m sandy gravel. |
| 92-17 | 12H03 | 498770 5448430 | 100 | SG | | | | | | 924010 | | Hummock 75 m diameter. 3.5 m sandy gravel. |
| 92-18 | 12H03 | 478470 5451960 | 55 | D | 5YR 6/3 5YR 4/3 | 79.7 | 20.2 | 0.1 | 1.15 2.9 | 924011 | 0.48 0.12 | 2 m+ sandy diamicton; 60 cm reddish brown diamicton; and 80 cm sand. |
| 92-18 | 12H03 | 478470 5451960 | 55 | D | 2.5YR 5/4 5YR 3/4 | 65.2 | 33.3 | 1.5 | 1.61 3.39 | 924012 | 0.66 0.05 | |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------|------|-----|------|------|------|------|------|------|------|------|
| 92-18 | 12H03 | 478470 5451960 | 55 | S | 2.5YR 5/4 2.5YR 3/4 | 99.1 | 0.9 | 0.0 | 0.52 1.41 | 924013 | | |
| 92-19 | 12H03 | 463870 5451070 | 155 | D | 7.5YR 7/2 10YR 4/3 | 60.3 | 38.8 | 0.9 | 2.18 3.25 | 924014 | | 2 m diamicton. |
| 92-20 | 12H03 | 464480 5451730 | 162 | D | 10YR 6/3 5YR 4/3 | 71.0 | 28.2 | 0.8 | 1.59 3 | 924015 | 0.81 0.06 | 2 m diamicton. |
| 92-21 | 12H03 | 465500 5452530 | 119 | D | 10YR 6/3 7.5YR 4/4 | 71.3 | 27.5 | 1.2 | 1.37 3.3 | 924016 | 0.72 0.03 | 2 m diamicton. |
| 92-22 | 12H03 | 465760 5452830 | 118 | D | | | | | | | | 1 m reddish brown diamicton. |
| 92-23 | 12H03 | 466180 5452560 | 100 | SG | 10YR 6/3 10YR 4/3 | 86.8 | 13.2 | 0.0 | -0.45 3.02 | 924017 | | 75 cm sandy gravel - gravelly sand. |
| 92-24 | 12H03 | 466590 5452050 | 90 | D | 7.5YR 7/2 5YR 4/3 | 70.8 | 27.9 | 1.3 | 1.82 3.13 | 924018 | 0.72 0.05 | 2 - 2.5 m sandy diamicton. More gravelly towards surface. |
| 92-25 | 12H03 | 468190 5450170 | 10 | D | | | | | | | | Diamicton; sand; 1.5 m sandy gravel. |
| 92-26 | 12H03 | 467090 5448820 | 8 | SS | 5YR 6/3 5YR 4/3 | 29.0 | 65.1 | 6.0 | 5.02 1.83 | 924019 | | 10 m exposure. Slumped. Interbedded silts, clays, fine and medium sands. |
| 92-27 | 12H03 | 466720 5448580 | 42 | SG | | | | | | | | 4 m+ interbedded m, c sands, and granule gravel; 2.5 m interbedded pebble-cobble gravels, and sandy gravels; 1.5 m interbedded f, very f and m sands, and sandy pebble gravels. |
| 92-28 | 12H03 | 466260 5448000 | 27 | SG | | | | | | | | 16.5 m terrace slumped. Interbedded m-c sands and gravelly sands. |
| 92-29 | 12H03 | 470000 5447840 | 40 | SG | 5YR 6/3 5YR 4/3 | | | | | 924020 | | Interbedded m-c sands, and sandy gravels. |
| 92-30 | 12H03 | 470270 5448580 | 30 | SG | | | | | | | | 3-4 m exposure interbedded f, rippled sand and sandy gravel. |
| 92-31 | 12H03 | 471140 5451080 | 17 | S | | | | | | | | 3 m interbedded f and m sands. Overlain by planar bedded, sandy granule gravel. |
| 92-32 | 12H03 | 474450 5451880 | 30 | SG | | | | | | | | 3 m rippled f sand. Overlain by 2m+ sandy gravel. |
| 92-33 | 12H03 | 472350 5447020 | 84 | D | 7.5YR 7/2 5YR 4/3 | 71.3 | 28.6 | 0.0 | 1.82 2.65 | 924021 | 0.66 0.04 | 3 m diamicton. |
| 92-34 | 12H03 | 473200 5447550 | 85 | D | 10YR 7/3 10YR 4/3 | 78.4 | 21.2 | 0.4 | 0.88 2.86 | 924022 | | Gravelly sand over 1 m+ diamicton. Overlain by 1 m gravelly sand. |
| 92-34 | 12H03 | 473200 5447550 | 85 | GS | 10YR 6/3 10YR 4/3 | 94.2 | 5.8 | 0.0 | -0.47 2.49 | 924023 | | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-35 | 12H03 | 477200 5447150 | 92 | D | 10YR 7/3 7.5YR 4/4 | 82.9 | 17.0 | 0.0 | 1.16 2.67 | 924024 | | 1 m+ sandy diamicton. |
| 92-36 | 12H03 | 478890 5448650 | 90 | D | 10YR 7/3 10YR 4/3 | 84.4 | 15.4 | 0.2 | 0.86 2.58 | 924025 | 0.64 0.07 | Junction Brook pit. North side 1.5 m exp. Sandy gravel over 1 m+ diamicton. |
| 92-37 | 12H03 | 491360 5446180 | 98 | S | 10YR 7/3 10YR 4/3 | 92.5 | 7.1 | 0.4 | 1.22 2.26 | 924026 | | 1 m+ interbedded f sands, very f sand, and m-c sand beds; 80 cm sandy boulder gravel. |
| 92-38 | 12H03 | 495070 5450060 | 94 | GS | 10YR 7/3 7.5YR 4/4 | 99.5 | 0.5 | 0.0 | -0.32 1.63 | 924027 | | 1 m pebbly sand. |
| 92-39 | 12H03 | 495040 5453840 | 90 | D | 7.5YR 7/2 5YR 4/3 | 58.4 | 41.3 | 0.4 | 1.9 3.87 | 924028 | | 3 m diamicton. |
| 92-40 | 12H03 | 496760 5453450 | 95 | S | 7.5YR 6/4 5YR 4/3 | 93.0 | 6.7 | 0.3 | 1.52 1.6 | 924029 | | Sand. |
| 92-41 | 12H03 | 470120 5445020 | 152 | | | | | | | | | Striae 345 ± 3. |
| 92-42 | 12H03 | 473220 5445300 | 142 | | | | | | | | | Striae 354 ± 3. |
| 92-43 | 12H03 | 475700 5439410 | 300 | | | | | | | | | Striae 282 ± 3. Striae 020-200 ± 4. No age relationship. |
| 92-44 | 12H03 | 476700 5436520 | 292 | | | | | | | | | Striae 197 ± 3. Striae 287 ± 4. 197 crosses 287. |
| 92-45 | 12H03 | 476820 5436750 | 260 | | | | | | | | | Grooves. 294 ± 5. Striae. 240-060 ± 3. |
| 92-46 | 12H03 | 476480 5438630 | 298 | | | | | | | | | Striae 177 ± 3. Striae 286 ± 2. 177 crosscuts 286. |
| 92-47 | 12H03 | 475470 5439100 | 290 | | | | | | | | | Striae 262 ± 3. |
| 92-48 | 12H03 | 475800 5438340 | 315 | | | | | | | | | Striae, grooves 184 ± 4. |
| 92-49 | 12H03 | 475830 5437850 | 312 | | | | | | | | | Striae 179 ± 3. |
| 92-50 | 12H03 | 475750 5437530 | 295 | | | | | | | | | Striae 177 ± 3. Striae & grooves 289 ± 5. 177 crosses 289. |
| 92-51 | 12H03 | 474250 5437080 | 272 | | | | | | | | | Striae 170 ± 7. |
| 92-52 | 12H03 | 474280 5433630 | 222 | | | | | | | | | Striae 176 ± 4. |
| 92-53 | 12H03 | 473860 5437700 | 254 | | | | | | | | | Striae 204 ± 2. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-54 | 12H03 | 474820 5438030 | 308 | | | | | | | | | Striae 185 ± 3. Striae 289 ± 2. |
| 92-55 | 12H03 | 470770 5436040 | 153 | | | | | | | | | Grooves 200 ± 3. |
| 92-56 | 12H03 | 470020 5444760 | 168 | D | 7.5YR 7/2 5YR 4/3 | 75.6 | 23.3 | 1.2 | 1.22 3.12 | 924229 | 0.79 0.05 | 1 m diamicton. |
| 92-57 | 12H03 | 478250 5442570 | 300 | D | 10YR 6/3 10YR 4/3 | 82.3 | 17.1 | 0.7 | 0.52 3 | 924030 | | Poorly exposed. Sandy diamicton. |
| 92-58 | 12H03 | 479730 5438970 | 250 | D | 7.5YR 7/2 7.5YR 4/2 | 79.0 | 20.0 | 1.0 | -0.37 3.52 | 924031 | 0.71 0.06 | 1 m diamicton. |
| 92-59 | 12H03 | 477070 5438130 | 265 | D | 10YR 6/2 10YR 4/2 | 77.6 | 20.0 | 2.5 | -0.5 3.5 | 924032 | 0.82 0.08 | 1.5 m diamicton. |
| 92-60 | 12H03 | 474420 5435130 | 260 | D | 10YR 6/2 10YR 3/2 | 62.6 | 35.4 | 1.9 | -0.31 3.93 | 924033 | 0.68 0.06 | 1 m+ grey diamicton. Overlain by brown diamicton. |
| 92-60 | 12H03 | 474420 5435130 | 260 | D | 10YR 6/3 7.5YR 4/2 | 66.0 | 32.1 | 1.9 | 0.93 3.68 | 924034 | 0.66 0.09 | |
| 92-61 | 12H03 | 474180 5433470 | 218 | D | 10YR 6/3 10YR 3/3 | 75.3 | 24.6 | 0.1 | 0.45 3.2 | 924035 | 0.78 0.03 | 2 m diamicton. |
| 92-62 | 12H03 | 474320 5432040 | 263 | D | 10YR 6/2 10YR 3/3 | 55.0 | 44.0 | 1.1 | 1.16 3.61 | 924036 | 0.88 0.04 | 2 m diamicton. |
| 92-63 | 12H03 | 474200 5439070 | 220 | D | 10YR 6/2 10YR 3/2 | 50.4 | 42.4 | 7.2 | 1.28 3.84 | 924037 | 0.75 0.02 | 1 m+ dark brown diamicton. Overlain by 25 cm light brown diamicton and 1 m gravelly sand. |
| 92-63 | 12H03 | 474200 5439070 | 220 | D | 10YR 6/3 10YR 3/3 | 63.0 | 32.2 | 4.8 | 1.23 3.87 | 924038 | | |
| 92-63 | 12H03 | 474200 5439070 | 220 | GS | 10YR 5/3 10YR 3/2 | | | | | 924039 | | |
| 92-64 | 12H03 | 463580 5430040 | 318 | | | | | | | | | Striae 266 ± 3. |
| 92-65 | 12H03 | 463650 5429860 | 303 | | | | | | | | | Striae 267 ± 3. |
| 92-66 | 12H03 | 463870 5429750 | 290 | | | | | | | | | Striae 266 ± 3. |
| 92-67 | 12H03 | 464820 5429600 | 282 | | | | | | | | | Striae and grooves 270 ± 2. |
| 92-68 | 12H03 | 486030 5436450 | 225 | | | | | | | | | Grooves 322 ± 6. |
| 92-69 | 12H03 | 487580 5434750 | 220 | | | | | | | | | Grooves 314 ± 2. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|------|----------|
| 92-70 | 12H03 | 491030 5427500 | 373 | | | | | | | | | Striae 297 ± 5. |
| 92-71 | 12H03 | 489380 5432010 | 310 | | | | | | | | | Striae 320 ± 5. |
| 92-72 | 12H03 | 489440 5432060 | 310 | | | | | | | | | Striae and grooves. 310 ± 4. Striae 258 ± 3. 310 crosses 258. |
| 92-73 | 12H03 | 488820 5442480 | 90 | GS | 7.5YR 6/4 7.5YR 5/4 | 99.9 | 0.1 | 0.0 | | 924040 | | 15-20 m exp. Slumped. 5 m+ interbedded m, f and c sands and gravelly sands; 5 m+ gravelly sand. |
| 92-74 | 12H03 | 488480 5441950 | 90 | GS | | | | | | | | 10 m exp. Slumped. 1 m+ gravelly sand.; 1.5 m interbedded f, m-c, c sands and sandy gravel. |
| 92-75 | 12H03 | 488050 5441480 | 90 | GS | | | | | | | | 6 m exp. Slumped. 2 m+ interbedded gravelly sand, f, m, and c sands. |
| 92-76 | 12H03 | 487900 5441280 | 90 | GS | | 99.6 | 0.4 | 0.0 | | 934041 | | 2 m+ interbedded f sand, m-c sand, c sand and gravelly sands. |
| 92-77 | 12H03 | 487800 5441230 | 90 | GS | | | | | | | | 2 m+ interbedded f sand, m-c sand, c sand and gravelly sands. |
| 92-78 | 12H03 | 485820 5439030 | 90 | S | 7.5YR 5/4 7.5YR 3/4 | 99.0 | 1.0 | 0.0 | | 934042 | | 3 m+ sand. Silt-clay interbeds. |
| 92-78 | 12H03 | 485820 5439030 | 90 | SL | | | | | | 934043 | | |
| 92-78 | 12H03 | 485820 5439030 | 90 | SL | | | | | | 934044 | | |
| 92-79 | 12H03 | 485280 5438220 | 90 | GS | | 99.8 | 0.2 | 0.0 | | 934045 | | 18 m exp. Slumped. Interbedded f, c, m sand and gravelly sand; 3 m+ interbedded sandy gravel, m-f sand, and pebbly sand. |
| 92-80 | 12H03 | 466650 5432320 | 265 | | | | | | | | | Striae 286 ± 3. Striae 263 ± 4. 286 crosses 263. |
| 92-81 | 12H03 | 466950 5431980 | 250 | | | | | | | | | Striae 292 ± 5. |
| 92-82 | 12H03 | 491950 5443630 | 98 | SG | | | | | | | | 4 m interbedded sandy gravel and c-m sands. |
| 92-83 | 12H03 | 489200 5441850 | 130 | SG | | | | | | | | Ridge 6 m high and 25 m wide. Trends 250-070. Interbedded f, m-c sands and gravelly sand. |
| 92-84 | 12H03 | 487250 5439970 | 125 | GS | | | | | | | | 15 m exposure, mostly slumped. 2 m+ interbedded f and m sands; discontinuous gravelly sand. |
| 92-85 | 12H03 | 485480 5437570 | 140 | SS | 10YR 7/2 10YR 4/2 | 12.0 | 85.8 | 2.2 | 5.35 1.24 | 924041 | | 8 m exposure. Slumped. F sand and silt and cobbles, overlain by fine sands. |
| 92-86 | 12H03 | 486500 5436860 | 300 | | | | | | | | | Striae 320 ± 3. Striae 252 ± 7. 252 crosses 320. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-87 | 12H03 | 487250 5436350 | 335 | | | | | | | | | Striae 260 ± 3. Striae 300 ± 3. 260 crosses 300. |
| 92-88 | 12H03 | 489680 5434750 | 340 | | | | | | | | | Striae 310 ± 3. |
| 92-89 | 12H03 | 489960 5435060 | 360 | D | 10YR 6/1 10YR 4/2 | 70.3 | 29.3 | 0.5 | 1.83 2.91 | 924042 | 0.79 0.03 | 5 m exp. Bottom 2 m slumped. Sandy diamicton plus lenses.; sandy diamicton, and diamicton |
| 92-89 | 12H03 | 489960 5435060 | 360 | D | 7.5YR 6/2 7.5YR 4/2 | 74.0 | 25.6 | 0.5 | 1.04 3.36 | 924043 | 0.6 0.07 | |
| 92-89 | 12H03 | 489960 5435060 | 360 | D | 10YR 6/2 10YR 4/2 | 73.3 | 26.4 | 0.4 | 0.93 3.09 | 924109 | 0.58 0.06 | |
| 92-90 | 12H03 | 490720 5433220 | 325 | | | | | | | | | Grooves 300 ± 3. |
| 92-91 | 12H03 | 487100 5435350 | 220 | SG | | | | | | | | 4 m exposure. Hummock. Sandy pebble gravel with sand lenses. |
| 92-92 | 12H03 | 487200 5434960 | 230 | SG | | | | | | | | 4 m exposure, lower 2 m slumped. Sandy gravel. |
| 92-93 | 12H03 | 487720 5434370 | 260 | D | 10YR 6/2 10YR 3/2 | 78.8 | 20.7 | 0.4 | 1.23 2.74 | 924044 | 0.78 0.06 | 1 m diamicton. |
| 92-94 | 12H03 | 487780 5434320 | 265 | GS | 7.5YR 6/2 7.5YR 4/2 | 85.2 | 14.8 | 0.0 | 0.35 2.86 | 924045 | | Gravelly sand. |
| 92-95 | 12H03 | 488850 5433040 | 287 | GS | | | | | | | | Hummock. Gravelly sand. |
| 92-96 | 12H03 | 489210 5431930 | 320 | D | 10YR 6/2 10YR 4/2 | 79.3 | 20.7 | 0.0 | 0.99 2.8 | 924046 | 0.78 0.05 | 3 m diamicton. |
| 92-97 | 12H03 | 490450 5427970 | 365 | D | 10YR 6/2 10YR 3/2 | 78.2 | 21.1 | 0.7 | 0.55 3.01 | 924047 | 0.84 0.03 | 2 m diamicton. |
| 92-98 | 12H03 | 490220 5428150 | 370 | | | | | | | | | Striae 312 ± 3. |
| 92-99 | 12H03 | 488820 5490030 | 370 | GS | 10YR 6/2 10YR 4/2 | 83.3 | 16.7 | 0.0 | -0.22 3.05 | 924048 | | 2 m gravelly sand. |
| 92-100 | 12H03 | 488780 5429170 | 360 | SG | | | | | | | | Hummock. 5 m sandy boulder gravel. |
| 92-101 | 12H03 | 468270 5435550 | 212 | | | | | | | | | Striae and grooves 215 ± 5. |
| 92-102 | 12A13 | 435120 5422580 | 40 | SC | 5YR 5/3 5YR 3/3 | 24.7 | 61.6 | 13.7 | 5.25 2.31 | 924049 | | Dawe's Pit. See Chapter 4. |
| 92-103 | 12H04 | 437650 5430880 | 58 | GS | | | | | | | | See site 91173. Interbedded sands and gravelly sands. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-104 | 12H04 | 449120 5427550 | 25 | SL | 5YR 6/3 5YR 4/3 | 3.2 | 89.1 | 7.7 | 6.16 1.11 | 924050 | | Interbedded c sands, granule gravel and sandy gravels. F sand and silt at base. |
| 92-105 | 12A13 | 455700 5427520 | 45 | SG | | | | | | | | 3 m interbedded sands and sandy gravels. |
| 92-106 | 12A13 | 455720 5426350 | 50 | SG | | | | | | | | 6 m interbedded sandy gravel, f-m, f, and gravelly sand beds. |
| 92-107 | 12H04 | 462740 5440180 | 30 | S | 5YR 6/3 5YR 4/3 | 63.4 | 36.6 | 0.0 | 3.72 1.17 | 924052 | | 1 m interbedded f sand, very f sand and silt. Overlain by sandy gravel. |
| 92-108 | 12H03 | 465300 5442670 | 40 | SG | | | | | | | | 1 m+ sandy gravel. |
| 92-109 | 12H03 | 465050 5442570 | 28 | SG | | | | | | | | 4 m interbedded m-f, c-m, c sand-granule gravels, and sandy gravels. |
| 92-110 | 12H03 | 499940 5443530 | 240 | GS | 10YR 5/3 7.5YR 3/4 | 95.8 | 4.2 | 0.0 | -1.22 2.26 | 924053 | | 5 m exposure Slumped. Gravelly sand. |
| 92-111 | 12H03 | 499470 5443720 | 235 | D | 10YR 7/2 10YR 5/3 | 84.9 | 14.9 | 0.3 | 1.41 2.65 | 924054 | | 1 m+ sandy diamicton. Overlain by 1 m sandy gravel. |
| 92-112 | 12H03 | 498380 5444400 | 205 | D | 10YR 7/2 10YR 5/2 | 81.4 | 18.2 | 0.4 | 0.72 2.79 | 924055 | 0.58 0.06 | 4 m sandy diamicton. |
| 92-113 | 12H03 | 495460 5445120 | 145 | SG | | | | | | | | 50 cm+ m-c sand. Overlain by 80 cm sandy gravel. |
| 92-114 | 12H03 | 494820 5444920 | 140 | SG | | | | | | | | Ridge. 1 m+ gravelly sand. Overlain by 1 m sandy gravel. |
| 92-115 | 12H04 | 437940 5453600 | 205 | D | | | | | | 924056 | | Striae 253 ± 8. |
| 92-116 | 12H04 | 435480 5446640 | 26.5 | SS | 5YR 5/4 | 35.4 | 54.9 | 9.7 | 4.67 2.83 | 924057 | | Silty clay to clayey silt. |
| 92-116 | 12H04 | 435480 5446640 | 26.5 | SS | 5YR 4/3 | 38.1 | 53.2 | 8.7 | 4.76 2.54 | 924083 | | |
| 92-117 | 12H04 | 456170 5450100 | 210 | | | | | | | | | Striae 238 ± 3. |
| 92-118 | 12H04 | 455550 5449230 | 218 | | | | | | | | | Striae 255 ± 5. |
| 92-119 | 12H04 | 447020 5451580 | 220 | D | 10YR 6/3 10YR 4/3 | 71.9 | 27.9 | 0.2 | 2.24 2.64 | 924058 | | 50 cm+ diamicton. |
| 92-120 | 12H04 | 447480 5449630 | 260 | D | 7.5YR 6/4 5YR 4/3 | 75.3 | 24.4 | 0.3 | 1.09 3.22 | 924059 | | 1.5 m sandy diamicton. |
| 92-121 | 12H04 | 451550 5455080 | 190 | D | 7.5YR 6/4 7.5YR 3/4 | 82.9 | 16.9 | 0.2 | 0.7 2.82 | 924060 | | 1 m diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-122 | 12H04 | 449520 5453680 | 155 | D | 10YR 5/3 10YR 3/3 | 75.7 | 23.0 | 1.3 | -0.25 3.78 | 924061 | | 2 m diamicton. |
| 92-123 | 12H04 | 447320 5455040 | 265 | | | | | | | | | Striae 255 ± 3. |
| 92-124 | 12H04 | 446380 5454180 | 70 | S | 7.5YR 6/4 5YR 4/3 | 86.8 | 13.2 | 0.0 | 2.06 1.88 | 924062 | | 4 m exp. Sand; 10 cm diamicton.; gravelly sand. |
| 92-124 | 12H04 | 446380 5454180 | 70 | D | 5YR 6/4 5YR 4/3 | 62.9 | 36.7 | 0.3 | 1.99 3.19 | 924063 | | |
| 92-124 | 12H04 | 446380 5454180 | 70 | GS | 7.5YR 6/4 7.5YR 3/4 | 88.3 | 11.7 | 0.1 | -0.08 2.83 | 924064 | | |
| 92-125 | 12H04 | 444420 5452670 | 45 | | | | | | | 924065 | | Brachiopods and some bivalves sample. |
| 92-126 | 12H04 | 444240 5452780 | 65 | D | 10YR 6/3 7.5YR 4/4 | 80.7 | 19.1 | 0.2 | 1.01 2.86 | 924066 | | 1 m diamicton. |
| 92-127 | 12H04 | 445120 5450780 | 38 | | | | | | | 924067 | | Brachiopods and bivalves sample. |
| 92-128 | 12H04 | 438360 5435050 | 85 | D | 10YR 6/3 10YR 4/3 | 71.1 | 28.6 | 0.3 | 0.33 3.42 | 924068 | | 1 m diamicton. |
| 92-129 | 12H04 | 438070 5434600 | 78 | SG | | | | | | | | 1.5 m f sand and granule gravel. |
| 92-130 | 12H04 | 436980 5435130 | 262 | | | | | | | | | Striae and grooves 304 ± 3. |
| 92-131 | 12H04 | 431380 5439520 | 310 | | | | | | | | | Striae and grooves 305 ± 6. |
| 92-132 | 12H04 | 431180 5439620 | 308 | | | | | | | | | Striae 334 ± 3. |
| 92-133 | 12H04 | 431080 5440020 | 295 | | | | | | | | | Striae 295 ± 3. |
| 92-134 | 12H04 | 430740 5440170 | 248 | | | | | | | | | Striae and grooves 290 ± 3. Striae 315 ± 3. 315 crosses 290. |
| 92-135 | 12H04 | 430450 5440180 | 255 | | | | | | | | | Striae 308 ± 4. |
| 92-136 | 12H04 | 430770 5439500 | 322 | | | | | | | | | Striae and grooves 290 ± 4. |
| 92-137 | 12H04 | 430340 5439250 | 310 | | | | | | | | | Striae 296 ± 3. Striae 327 ± 4. 327 crosses 296. |
| 92-138 | 12H04 | 429960 5438970 | 310 | | | | | | | | | Striae and grooves 280 ± 3. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-139 | 12H04 | 428210 5438130 | 268 | | | | | | | | | Striae and grooves 264 ± 4. |
| 92-140 | 12H04 | 427880 5437890 | 270 | | | | | | | | | Striae 266 ± 3. |
| 92-141 | 12H04 | 427000 5437250 | 230 | | | | | | | | | Striae 254 ± 3. |
| 92-142 | 12H04 | 431800 5439170 | 255 | | | | | | | | | Striae 292 ± 5. Striae 260 ± 3. Striae 224 ± 4. Oldest 292, youngest 224. |
| 92-143 | 12H04 | 438120 5444650 | 280 | | | | | | | | | Striae 274 ± 4. |
| 92-144 | 12H04 | 438200 5444850 | 280 | | | | | | | | | Striae 270 ± 8. Striae 215 ± 15. 270 crosses 215. |
| 92-145 | 12H04 | 439480 5446030 | 185 | D | 2.5Y 7/2 2.5Y 5/2 | 58.8 | 40.4 | 0.9 | 0.96 3.59 | 924069 | 0.53 0.07 | 4 m diamicton. |
| 92-146 | 12H04 | 439430 5446500 | 150 | | | | | | | | | Striae 255 ± 3. Striae 289 ± 3. 289 crosses 253. |
| 92-147 | 12H04 | 439650 5446870 | 135 | D | 10YR 7/2 2.5Y 5/2 | 60.8 | 39.0 | 0.2 | 0.3 3.45 | 924070 | 0.68 0.09 | 1 m+ diamicton. Overlain by 3 m sandy diamicton. |
| 92-147 | 12H04 | 439650 5446870 | 135 | D | 10YR 6/2 2.5Y 4/2 | 74.5 | 23.9 | 1.6 | -0.07 3.42 | 924071 | 0.56 0.07 | |
| 92-148 | 12H04 | 439860 5447200 | 95 | SG | | | | | | | | 2 m+ gravelly sand; 5-20 cm f sand and silt; 2.5 m sandy gravel. |
| 92-149 | 12H04 | 439930 5447470 | 90 | GS | 10YR 6/3 10YR 4/3 | 87.9 | 12.2 | 0.0 | 1.16 2.54 | 924072 | | 4 m exposure gravelly sand. |
| 92-150 | 12H04 | 439950 5447690 | 90 | D | 10YR 6/3 10YR 3/3 | 63.3 | 34.4 | 2.4 | 2.05 3.3 | 924073 | | 1 m diamicton. |
| 92-151 | 12H04 | 444120 5443970 | 165 | D | 10YR 7/2 10YR 4/2 | 69.9 | 29.1 | 1.1 | 0.96 3.36 | 924074 | | 2 m diamicton. |
| 92-152 | 12H04 | 448870 5443870 | 240 | D | 2.5Y 4/2 | 60.5 | 38.7 | 0.8 | 0.2 3.85 | 924075 | 0.77 0.05 | 5 m exposure, slumped. Diamicton. |
| 92-153 | 12H04 | 446200 5443670 | 160 | D | 2.5Y 4/2 | 74.5 | 24.7 | 0.9 | 0.31 3.34 | 924076 | | 20 cm+ grey diamicton; 1.5 m brown diamicton. |
| 92-154 | 12H04 | 443250 5442830 | 152 | D | 2.5Y 4/2 | 69.5 | 30.3 | 0.1 | 1.03 3.46 | 924077 | | 2 m diamicton. |
| 92-155 | 12H04 | 440800 5442250 | 132 | GS | | | | | | | | Gravelly sand - sandy gravel. |
| 92-156 | 12H04 | 440170 5442150 | 130 | SG | | | | | | | | 1 m+ sandy gravel; 30 cm granules and c sand.; 1 m sand. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-157 | 12H04 | 439670 5442200 | 172 | | | | | | | | | Striae 250 ± 4. |
| 92-158 | 12H04 | 438680 5447550 | 40 | SS | 5YR 4/3 | 23.1 | 68.3 | 8.6 | 5.03 1.83 | 924078 | | 6 m sandy gravel, with 2 cm interbed of f sand, very f sand and silt. |
| 92-159 | 12H04 | 439180 5447570 | 60 | D | 10YR 6/3 10YR 4/3 | 78.5 | 21.0 | 0.5 | 0.27 3.07 | 924079 | | 1 m diamicton. |
| 92-160 | 12H04 | 438340 5447700 | 40 | SG | | | | | | | | 1 m+ sandy gravel. Overlain by 1 m gravelly sand. |
| 92-161 | 12H04 | 437730 5447800 | 20 | SC | 5YR 4/3 | 3.3 | 88.6 | 8.2 | 5.91 1.15 | 924080 | | 10-15 m terrace. 70 cm+ silt-clay; 80 cm sandy gravel. |
| 92-162 | 12H04 | 437500 5447950 | 10 | SC | 5YR 4/2 | 3.6 | 91.5 | 4.9 | 5.91 1.05 | 924082 | | 3 m silt-clay. Shell sample. |
| 92-163 | 12H04 | 435150 5447150 | 42 | D | 10YR 7/2 10YR 5/3 | 42.5 | 53.6 | 4.0 | 1.73 3.96 | 924084 | 0.89 0.04 | 4 m diamicton. |
| 92-164 | 12H04 | 435880 5447550 | 30 | SC | 5YR 4/3 | 9.8 | 87.7 | 2.5 | 5.21 1.17 | 924085 | | 1 m+ silty clay. |
| 92-165 | 12H04 | 436660 5447980 | 50 | D | 5YR 6/4 5YR 4/3 | 55.8 | 40.3 | 3.9 | 2.03 3.5 | 924086 | | 1 m diamicton. Overlain by 60 cm sandy gravel. |
| 92-166 | 12H04 | 436920 5448300 | 72 | D | 7.5YR 6/4 7.5YR 4/4 | 70.9 | 28.6 | 0.5 | 2.54 2.62 | 924087 | | 1.5 m diamicton. |
| 92-167 | 12H03 | 469770 5438270 | 145 | D | 5YR 6/3 5YR 3/3 | 62.3 | 37.5 | 0.3 | 2.09 2.94 | 924088 | | 50 cm diamicton. |
| 92-168 | 12H03 | 469140 5443430 | 240 | D | 5YR 6/3 5YR 4/3 | 76.4 | 23.5 | 0.2 | 1.55 2.76 | 924089 | | 50 cm diamicton. |
| 92-169 | 12H04 | 460350 5435670 | 120 | D | 2.5YR 5/4 2.5YR 3/4 | 56.1 | 43.6 | 0.3 | 1.72 3.14 | 924090 | | 1.5 m diamicton. |
| 92-170 | 12H04 | 460720 5435920 | 160 | D | 10YR 6/3 10YR 3/3 | 67.7 | 30.4 | 1.9 | 0.47 3.85 | 924091 | | 1 m sandy diamicton. |
| 92-171 | 12H03 | 463700 5436270 | 220 | D | 5YR 6/3 5YR 3/3 | 62.2 | 37.2 | 0.6 | 1.97 3.17 | 924092 | 0.88 0.04 | 2 m diamicton. |
| 92-172 | 12H03 | 464250 5436180 | 198 | S | | | | | | | | 75 cm well sorted f sand. Contains diamicton interbeds. |
| 92-173 | 12H03 | 465030 5436120 | 187 | SG | | | | | | | | 4 m exposure Slumped. 1 m + pebble gravel overlain by 1 m sand overlain by sandy gravel. |
| 92-174 | 12H03 | 465980 5435980 | 158 | SG | | | | | | | | 50 cm+ gravelly sand overlain by 1 m sandy gravel. |
| 92-175 | 12H03 | 467430 5435800 | 150 | D | 5YR 6/3 5YR 3/3 | 61.8 | 36.9 | 1.3 | 1.41 3.53 | 924093 | | 1.5 m diamicton. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-176 | 12H03 | 469150 5436080 | 175 | D | 7.5YR 5/4 5YR 3/3 | 70.9 | 28.6 | 0.5 | 0.64 3.27 | 924094 | 0.57 0.04 | 4 m diamicton. |
| 92-177 | 12H03 | 465730 5435830 | 168 | SG | | | | | | | | 10 cm + sandy gravel. Overlain by 25 cm fine sand. Overlain by 50 cm sandy gravel. |
| 92-178 | 12H03 | 483120 5434820 | 100 | D | 7.5YR 7/2 7.5YR 4/2 | 70.8 | 27.0 | 2.3 | 1 3.54 | 924095 | | 20 m exp. Slumped. 50 cm+ diamicton.; 1 m f sand grading down into 30 cm silt and clay; 6 m interbedded sandy gravel. |
| 92-178 | 12H03 | 483120 5434820 | 100 | SC | 7.5YR 7/2 7.5YR 4/2 | 32.5 | 62.0 | 5.6 | 4.95 1.98 | 924096 | | |
| 92-178 | 12H03 | 483120 5434820 | 100 | D | 5YR 6/3 5YR 3/3 | 73.9 | 24.8 | 1.3 | 1.25 3.38 | 924097 | | |
| 92-178 | 12H03 | 483120 5434820 | 100 | SG | 7.5YR 6/2 7.5YR 3/2 | 92.8 | | | | 934038 | | |
| 92-178 | 12H03 | 483120 5434820 | 100 | D | 5YR 5/3 5YR 3/3 | 74.7 | 19.8 | 5.5 | 1.55 3.47 | 934039 | 0.59 0.17 | |
| 92-179 | 12H03 | 482630 5433970 | 100 | SG | | 99.9 | 0.1 | 0.0 | | 934037 | | 30 m exposure Slumped. 10 m+ sandy gravel. |
| 92-180 | 12H03 | 482120 5433030 | 90 | | | | | | | | | Grooves 208 ± 4. |
| 92-181 | 12H03 | 481780 5432720 | 90 | | | | | | | | | Striae 214 ± 3. |
| 92-182 | 12H03 | 481750 5432630 | 100 | SG | | | | | | | | 13 m exposure. Sandy gravel. Bedrock at base striated 208 ± 4. |
| 92-183 | 12H03 | 481530 5432250 | 100 | SG | | 99.9 | 0.1 | 0.0 | | 934036 | | Conglomerate overlain by sandy gravel and gravelly sands. |
| 92-184 | 12H03 | 480520 5430380 | 100 | GS | | 99.3 | 0.7 | 0.0 | | 934035 | | 10 m exposure Slumped. Gravelly sand. |
| 92-185 | 12H03 | 477750 5427770 | 95 | SG | | 99.9 | 0.1 | 0.0 | | 934034 | | 6 m exposure Slumped. Interbedded gravelly sand and sandy gravel. |
| 92-186 | 12A13 | 443630 5425350 | 20 | SC | 5YR 4/3 | 0.6 | 77.0 | 22.5 | 6.63 1.54 | 924098 | | 1 m+ silt-clay. |
| 92-187 | 12H04 | 437150 5448070 | 29 | SC | 5YR 4/3 | 25.5 | 50.6 | 24.0 | 5.59 2.75 | 924099 | | 1 m+ silty clay. |
| 92-188 | 12H04 | 436920 5448320 | 65 | | | | | | | | | Striae 206 ± 6. Striae 126 ± 4. 126 crosses 206. |
| 92-189 | 12H04 | 437320 5448770 | 100 | D | 5YR 6/3 5YR 4/3 | 54.2 | 43.4 | 2.5 | 1.53 3.73 | 924100 | 0.6 0.1 | 1.5 m+ diamicton. Overlain by 2.5 m sand and pebble sand. |
| 92-190 | 12H04 | 439630 5451200 | 50 | SC | 5YR 4/3 | 4.6 | 48.5 | 46.9 | 7.39 2.08 | 924101 | | 1 m+ silt-clay. Reddish brown. Overlain by 4 m sandy gravel. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-191 | 12H04 | 437280 5450250 | 150 | D | 5YR 6/3 5YR 4/3 | 55.0 | 39.6 | 5.4 | 2.81 3.11 | 924102 | 0.85 0.04 | 4 m diamicton. Reddish brown. |
| 92-192 | 12H04 | 436920 5451240 | 180 | D | 7.5YR 6/4 7.5YR 4/4 | 80.2 | 19.6 | 0.3 | 1.43 2.75 | 924103 | | 2 m diamicton. Brown. |
| 92-193 | 12H04 | 437220 5452870 | 180 | D | 10YR 8/2 10YR 5/2 | 56.5 | 42.1 | 1.4 | 1.59 3.5 | 924104 | 0.74 0.06 | 3 m diamicton. Greyish brown. |
| 92-194 | 12H03 | 489270 5444220 | 90 | SS | 5YR 3/3 | 20.8 | 79.1 | 0.2 | 4.67 1.11 | 924105 | | 6 m exp. Slumped. F-m rippled sand; interbedded m-c sands, and sandy pebble gravels; rippled very f sand and silt.; rippled m-f sand. |
| 92-195 | 12H03 | 489660 5431200 | 330 | D | 10YR 6/2 10YR 3/2 | 73.7 | 26.2 | 0.1 | 1.17 3.03 | 924106 | 0.53 0.05 | 1.5 m+ sandy diamicton. Overlain by 1.5 m diamicton. |
| 92-195 | 12H03 | 489660 5431200 | 330 | D | 10YR 6/3 10YR 3/2 | 82.3 | 17.7 | 0.0 | -0.06 3.07 | 924107 | 0.88 0.03 | |
| 92-196 | 12H03 | 489540 5430420 | 355 | D | 10YR 6/2 10YR 3/2 | 83.5 | 16.5 | 0.0 | -0.28 3.04 | 924108 | | 1 m diamicton. |
| 92-197 | 12H04 | 462950 5430880 | 290 | D | 7.5YR 6/2 7.5YR 3/2 | 80.2 | 19.2 | 0.6 | -0.25 3.51 | 924110 | 0.83 0.05 | 2 m diamicton. |
| 92-198 | 12H03 | 471780 5437120 | 145 | D | 5YR 5/3 5YR 3/2 | 55.9 | 43.2 | 1.0 | 0.69 3.55 | 924111 | 0.57 0.11 | 1 m diamicton. |
| 92-199 | 12H03 | 474180 5438680 | 197 | SG | | | | | | | | 4 m sandy gravel. |
| 92-200 | 12H03 | 473800 5438830 | 200 | D | 10YR 6/2 10YR 3/2 | 71.0 | 24.5 | 4.5 | -0.16 3.42 | 924112 | | 3 m diamicton. |
| 92-201 | 12H03 | 485850 5454560 | 132 | D | 7.5YR 6/2 7.5YR 4/2 | 63.2 | 36.6 | 0.3 | 2.34 3.08 | 924113 | 0.61 0.05 | Pit 3 m deep. 1.5 m+ diamicton. Overlain by 1.5 m diamicton. |
| 92-201 | 12H03 | 485850 5454560 | 132 | D | 10YR 6/3 7.5YR 4/2 | 54.2 | 44.7 | 1.2 | 1.85 3.79 | 924114 | 0.53 0.14 | |
| 92-202 | 12H03 | 484620 5453340 | 132 | D | 5YR 6/3 5YR 4/3 | 66.5 | 31.9 | 1.6 | 2.43 2.77 | 924115 | 0.46 0.1 | 2.5 m diamicton. |
| 92-203 | 12H03 | 483780 5452140 | 122 | D | 5YR 6/3 5YR 3/3 | 67.6 | 30.9 | 1.5 | 1.61 3.48 | 924116 | 0.73 0.11 | 2 m diamicton. Gravelly sand lens in middle of unit. |
| 92-204 | 12H03 | 482020 5451880 | 90 | GS | 5YR 5/3 5YR 3/3 | 90.7 | 9.3 | 0.0 | 1.66 2.08 | 924117 | 0.5 0.07 | 3 m gravelly sand. |
| 92-205 | 12H03 | 472350 5445750 | 140 | D | 5YR 6/3 5YR 4/3 | 41.4 | 57.3 | 1.3 | 2.29 3.85 | 924118 | 0.78 0.06 | 2.5 m diamicton. |
| 92-206 | 12H03 | 474170 5444020 | 128 | D | 5YR 5/3 5YR 3/3 | 66.2 | 33.4 | 0.5 | 1.67 3.26 | 924119 | 0.72 0.06 | 50 cm+ diamicton. Overlain by 2 m diamicton. |
| 92-206 | 12H03 | 474170 5444020 | 128 | D | 5YR 6/3 5YR 3/3 | 53.0 | 46.6 | 0.4 | 3.54 1.93 | 924120 | | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 92-207 | 12H03 | 473170 5442320 | 160 | D | 7.5YR 7/2 7.5YR 4/2 | 45.5 | 53.4 | 1.1 | 3.8 2.28 | 924121 | 0.64 0.09 | 1 m+ brown diamicton. Overlain by 2 m reddish brown diamicton. |
| 92-207 | 12H03 | 473170 5442320 | 160 | D | 5YR 6/3 5YR 4/3 | 66.5 | 32.6 | 0.8 | 2.05 3.03 | 924122 | 0.61 0.06 | |
| 92-208 | 12H03 | 472950 5441000 | 150 | D | 7.5YR 6/2 5YR 4/2 | 51.4 | 48.4 | 0.3 | 1.17 4.01 | 924123 | | Dark reddish grey diamicton. Overlain by 1 m dark reddish brown diamicton. |
| 92-208 | 12H03 | 472950 5441000 | 150 | D | 5YR 5/3 5YR 3/3 | 51.9 | 47.1 | 1.1 | 2.29 3.28 | 924124 | 0.86 0.05 | |
| 92-209 | 12H03 | 472450 5440480 | 162 | D | 5YR 6/3 5YR 3/3 | 68.5 | 30.3 | 1.2 | 2.47 2.87 | 924125 | 0.57 0.09 | 2.8 m diamicton. |
| 92-210 | 12H04 | 461470 5436350 | 150 | D | 10YR 6/3 10YR 3/3 | 69.8 | 29.7 | 0.5 | -0.32 3.69 | 924126 | 0.51 0.12 | Ridge. 2.5 m+ diamicton. |
| 92-211 | 12H04 | 461220 5436300 | 150 | D | 7.5YR 6/2 7.5YR 3/2 | 81.2 | 18.3 | 0.5 | 1.07 2.8 | 924127 | 0.51 0.07 | 1.3 m+ brown. diamicton.; 1.2 m grey diamicton. |
| 92-211 | 12H04 | 461220 5436300 | 150 | D | 5YR 6/1 5YR 4/1 | 69.2 | 27.4 | 3.4 | 0.95 3.96 | 924128 | | |
| 92-212 | 12H04 | 462500 5436150 | 160 | D | 7.5YR 6/4 5YR 3/3 | 48.9 | 50.7 | 0.5 | 2 3.53 | 924129 | 0.84 0.04 | 2.5 m+ diamicton. |
| 92-213 | 12H03 | 477820 5451680 | 75 | D | 7.5YR 6/4 7.5YR 4/4 | 80.1 | 18.7 | 1.2 | 1.23 2.83 | 924130 | 0.49 0.22 | 1.5 m+ sandy diamicton. Brown. Overlain by 70 cm sandy gravel. |
| 92-214 | 12H03 | 477970 5450250 | 100 | D | 7.5YR 7/2 7.5YR 4/4 | 77.9 | 21.2 | 1.0 | 1.84 2.61 | 924131 | 0.55 0.17 | Ridge. 2 m sandy diamicton. |
| 92-215 | 12H03 | 480860 5452730 | 90 | D | 7.5YR 7/2 5YR 4/3 | 76.3 | 23.2 | 0.5 | 1.64 2.83 | 924132 | 0.54 0.1 | Ridge. 2.5 m sandy diamicton. |
| 92-216 | 12H03 | 481260 5452080 | 90 | D | 7.5YR 7/2 5YR 4/3 | 78.8 | 21.1 | 0.2 | 2.12 2.16 | 924133 | 0.52 0.08 | 2 m diamicton. |
| 92-217 | 12H03 | 493250 5449130 | 120 | D | 7.5YR 7/2 5YR 4/3 | 70.0 | 29.1 | 0.9 | 2.21 3.02 | 924134 | 0.67 0.1 | 2 m diamicton. |
| 92-218 | 12H03 | 492950 5448720 | 122 | D | 7.5YR 6/2 7.5YR 4/2 | 66.4 | 32.7 | 1.0 | 2.48 2.78 | 924135 | 0.69 0.05 | 2.5 m diamicton. |
| 92-219 | 12H03 | 492750 5448450 | 115 | D | 7.5YR 6/2 7.5YR 4/2 | 72.0 | 27.4 | 0.6 | 1.62 3.21 | 924136 | 0.49 0.1 | 2.5 m diamicton. |
| 92-220 | 12H03 | 471980 5437370 | 140 | D | 5YR 6/2 5YR 3/2 | 43.1 | 54.5 | 2.4 | 0.82 5.65 | 924137 | 0.71 0.05 | 2 m diamicton. |
| 92-221 | 12H04 | 446180 5443320 | 175 | D | 2.5Y 6/2 2.5Y 4/2 | 56.3 | 36.5 | 7.2 | 2.4 3.6 | 924138 | 0.73 0.02 | 1 m+ dark greyish brown diamicton. Overlain by 1.5 m sandy diamicton. Dark greyish brown. |
| 92-221 | 12H04 | 446180 5443320 | 175 | D | 2.5Y 6/2 2.5Y 4/2 | 70.6 | 26.4 | 3.1 | 0.77 3.43 | 924139 | 0.74 0.04 | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92-222 | 12H04 | 432950 5438030 | 142 | D | 2.5Y 6/2 10YR 4/2 | 55.7 | 41.2 | 3.2 | 2.91 3.07 | 924140 | 0.65 0.07 | 2 m diamicton. |
| 92-223 | 12H04 | 458420 5448030 | 150 | | | | | | | | | Striae and grooves 285 ± 3. |
| 92-224 | 12H04 | 455720 5454860 | 200 | D | 5YR 6/3 5YR 4/3 | 60.7 | 36.8 | 2.6 | 2.46 3.3 | 924141 | | 2 m diamicton. |
| 92-225 | 12H04 | 456950 5454270 | 178 | SG | | | | | | | | 1 m+ sandy gravel. |
| 92-226 | 12A13 | 442840 5425530 | 9 | SC | | 2.1 | 65.5 | 32.5 | 6.84 1.99 | 924142 | | |
| 93-1 | 12H06 | 471890 5467500 | 255 | | | | | | | | | Striae 227 ± 3. Striae 090 ± 3. 090 x by 227. |
| 93-2 | 12H06 | 471090 5468920 | 327 | | | | | | | | | Striae 267 ± 4. |
| 93-3 | 12H06 | 471180 5468400 | 320 | D | 5YR 5/6 5YR 3/4 | 84.5 | 15.3 | 0.2 | -1.31 3.21 | 934000 | | Striae 275 ± 5. 1 m+ diamicton. |
| 93-4 | 12H06 | 471550 5468140 | 297 | | | | | | | | | Striae 256 ± 3. |
| 93-5 | 12H06 | 472680 5466950 | 182 | D | 5YR 7/4 5YR 3/4 | 67.3 | 30.6 | 2.2 | 2.24 3.16 | 934001 | 0.69 0.08 | 3 m diamicton. |
| 93-6 | 12H06 | 481350 5467300 | 71 | | | | | | | | | Grooves 215 ± 3. Grooves 158 ± 6. 158 x by 215. |
| 93-7 | 12H06 | 476850 5466730 | 90 | | | | | | | | | Striae 208 ± 8. Striae 336 ± 10. 336 x by 208. |
| 93-8 | 12H03 | 480370 5429680 | 90 | D | 7.5YR 7/2 7.5YR 3/2 | 86.1 | 10.4 | 3.5 | -0.84 3.29 | 934002 | | 10m exposure. Gravelly sand, reddish brown silt-clay on clasts; sandy gravel, and 30 cm diamicton. |
| 93-8 | 12H03 | 480370 5429680 | 90 | D | 7.5YR 7/2 5YR 3/3 | 72.9 | 15.2 | 11.9 | -3.22 2.38 | 934003 | | |
| 93-8 | 12H03 | 480370 5429680 | 90 | SG | | | | | | 934004 | | |
| 93-9 | 12H03 | 478750 5428450 | 90 | SG | | | | | | 934005 | | Grindstone Point section. See chapter 4. |
| 93-9 | 12H03 | 478750 5428450 | 90 | SS | 5YR 7/1 7.5YR 3/4 | 59.4 | 36.9 | 3.6 | 3.62 2.17 | 934006 | | |
| 93-9 | 12H03 | 478750 5428450 | 90 | S | | 99.1 | 0.9 | 0.0 | | 934007 | | |
| 93-10 | 12A14 | 477210 5426720 | 90 | SG | | | | | | 934008 | | 30 m exposure Lower 15 m slumped. 1 m+ sandy gravel.; 60 cm interbedded m-f sands and gravelly sand; 60 cm cemented c sand and gravelly sand. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 93-11 | 12A14 | 476220 5425180 | 90 | D | 7.5YR 6/2 7.5YR 3/2 | 86.5 | 10.6 | 3.0 | -0.11 2.93 | 934009 | | 12 m exposure Slumped. 1.2 m+ sandy diamicton; 1.2 m sandy gravel; 1.1 m diamicton. |
| 93-11 | 12A14 | 476220 5425180 | 90 | SG | | 98.7 | 1.3 | 0.0 | | 934010 | | |
| 93-11 | 12A14 | 476220 5425180 | 90 | D | 5YR 7/2 5YR 3/3 | 76.4 | 20.8 | 2.7 | -0.2 3.13 | 934011 | 0.56 0.01 | |
| 93-11 | 12A14 | 476220 5425180 | 90 | D | 7.5YR 7/2 7.5YR 4/2 | 65.3 | 27.3 | 7.5 | 1.14 4.04 | 934012 | 0.51 0.21 | |
| 93-12 | 12A14 | 475820 5424420 | 90 | SG | 7.5 6/4 5YR 3/3 | 93.0 | 3.7 | 3.2 | -0.33 2.15 | 934013 | | 12m exposure Slumped. 2 m+ sandy gravel; 40-80 cm interbedded f, m, c, sand; 5 m sandy gravel. |
| 93-13 | 12A14 | 473020 5421120 | 90 | SL | 7.5YR 7/2 7.5YR 3/4 | 8.1 | 90.4 | 1.5 | 5.57 1.53 | 934014 | | Little Pond Brook section. See Chapter 4. |
| 93-13 | 12A14 | 473020 5421120 | 90 | SS | 5YR 6/2 5YR 4/3 | 24.4 | 75.5 | 0.1 | 4.86 1.24 | 934015 | | |
| 93-14 | 12H03 | 473540 5429690 | 150 | SG | 2.5Y 7/4 2.5Y 4/2 | 83.1 | 16.1 | 0.8 | -2.78 3.74 | 934029 | | Beach ridges on hillside. Beaches at 54.5m, 67m, and 88.5m above lake level. Uppermost beach is sandy gravel. |
| 93-15 | 12A14 | 469820 5426680 | 90 | SC | 5YR 5/2 5YR 3/3 | 35.3 | 39.8 | 25.0 | 5.44 3.26 | 934016 | | 8 m exposure 3 m+ silty sand. Overlain by 2 m gravelly sand, and 1m+ diamicton. |
| 93-15 | 12A14 | 469820 5426680 | 90 | D | 5YR 5/3 7.5YR 3/4 | 63.9 | 26.5 | 9.7 | 1.06 4.64 | 934017 | | |
| 93-16 | 12A14 | 465250 5420570 | 90 | SG | | 99.9 | 0.1 | 0.0 | | 934018 | | 12m exposure in terrace. Interbedded sandy gravel and gravelly sand. Possible beaches 141m asl |
| 93-17 | 12A14 | 468550 5416230 | 90 | SG | | | | | | 934019 | | 20m exposure Slumped. >1m pebbly sand. Overlain by 1.2m sandy gravel. |
| 93-18 | 12H03 | 487250 5439970 | 125 | S | | 99.9 | 0.1 | 0.0 | 2.3 0.8 | 934020 | | Alder Brook section. See Chapter 4. |
| 93-19 | 12H03 | 490430 5432500 | 210 | D | 5YR 7/1 5YR 4/1 | 68.6 | 31.2 | 0.2 | 1.28 3.11 | 934021 | 0.48 0.16 | 1 m+ dark grey diamicton. Overlain by 2 m dark reddish brown diamicton. |
| 93-19 | 12H03 | 490430 5432500 | 210 | D | 5YR 6/1 5YR 3/2 | 80.7 | 19.1 | 0.2 | 0.93 2.68 | 934022 | 0.57 0.13 | |
| 93-20 | 12H03 | 486580 5434880 | 380 | D | 5YR 6/1 5YR 4/2 | 85.9 | 13.8 | 0.4 | 0.47 2.63 | 934023 | 0.59 0.16 | 5m exposure. 3m diamicton. Overlain by 10 cm sand and 1 m+ diamicton. |
| 93-21 | 12H03 | 487620 5433840 | 350 | D | 7.5YR 6/4 7.5YR 3/4 | 80.2 | 19.8 | 0.0 | 0.8 2.82 | 934024 | | 4.5 m diamicton. |
| 93-22 | 12H03 | 486660 5445610 | 90 | GS | 7.5YR 6/4 7.5YR 3/4 | 96.9 | 3.1 | 0.0 | | 934025 | | 10 m exposure Slumped. 5m+ gravelly sand. Overlain by 2.5 m is interbedded c, m, f sand. |
| 93-22 | 12H03 | 486660 5445610 | 90 | SL | | | | | | 934026 | | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-23 | 12H03 | 485450 5445370 | 90 | SG | | 99.6 | 0.4 | 0.0 | | 934027 | | 35 m exposure. Slumped. 16 m interbedded c, m, f sand, overlain by 16 m sand and gravel. |
| 93-24 | 12H03 | 484250 5446150 | 90 | GS | | | | | | | | 5 m exposure 2 m+ sand overlain by 1 m pebbly sand. |
| 93-25 | 12H03 | 480850 5447430 | 90 | SG | | 99.8 | 0.2 | 0.0 | | 934028 | | 15 m exposure. Slumped. Upper 3 m shows sand over sandy gravel over interbedded c sand + granules, c and m sand. |
| 93-26 | 12H03 | 480030 5435430 | 150 | | | | | | | | | Beaches at elevation 144 m and 172 m asl. |
| 93-27 | 12H03 | 480310 5438260 | 150 | | | | | | | | | Beach at 56 m above lake. |
| 93-28 | 12A14 | 469220 5416770 | 90 | D | 10YR 7/3 10YR 3/4 | 69.7 | 23.3 | 7.0 | 0.65 4.03 | 934030 | 0.61 0.12 | 10 m exposure. Diamicton. Overlain by 2 m sandy diamicton. |
| 93-28 | 12A14 | 469220 5416770 | 90 | D | 5YR 6/4 5YR 3/3 | 62.9 | 30.4 | 6.7 | 1.65 4.01 | 934031 | | |
| 93-29 | 12A14 | 470550 5418270 | 90 | GS | | 97.8 | 2.2 | | | 934032 | | 12 m exposure 1 m+ sandy diamicton. Overlain by 4 m gravelly sand. |
| 93-29 | 12A14 | 470550 5418270 | 90 | D | 5YR 6/2 5YR 3/4 | 75.1 | 21.4 | 3.5 | 0.37 3.39 | 934033 | | |
| 93-30 | 12A14 | 475250 5423400 | 140 | | | | | | | | | Delta. Surface 53 m above lake. Possible higher surface 83 m above lake. |
| 93-31 | 12H03 | 479950 5428950 | 140 | | | | | | | | | Delta surface 43 m above lake. |
| 93-32 | 12H03 | 484700 5436200 | 130 | | | | | | | | | Delta surfaces, some unclear and dissected, 31m, 43m, 74m above lake. |
| 93-33 | 12H03 | 480270 5436120 | 140 | | | | | | | | | Beach terraces at 62m. |
| 93-34 | 12H03 | 468420 5450900 | 30 | SG | | | | | | | | Rocky Brook section. See chapter 4. |
| 93-35 | 12A13 | 437230 5424880 | 50 | D | 10YR 7/3 10YR 3/6 | 69.3 | 25.6 | 5.1 | 1.07 3.72 | 934046 | 0.82 0.08 | 2 m diamicton. |
| 93-36 | 12A13 | 436420 5424580 | 55 | GS | | | | | | | | 4 m interbedded sands and gravelly sand. |
| 93-37 | 12A13 | 435120 5422500 | 30 | SG | | | | | | 934047 | | Same as site 92037 |
| 93-37 | 12A13 | 435120 5422500 | 30 | SG | | | | | | 934048 | | |
| 93-37 | 12A13 | 435120 5422500 | 30 | SC | 10R 6/3 2.5YR 2/4 | 3.9 | 28.9 | 67.2 | 8.23 1.78 | 934049 | | |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-38 | 12A13 | 427620 5423000 | 10 | | | | | | | 934050 | | 5.5 m+ interbedded clays, fine sands and gravelly sand. Shell sample. |
| 93-38 | 12A13 | 427620 5423000 | 10 | SC | 2.5YR 6/2 2.5YR 4/2 | 7.1 | 55.3 | 37.6 | 7.24 2.11 | 934051 | | |
| 93-39 | 12H06 | 471100 5469070 | 325 | | | | | | | | | Striae 272 ± 3. |
| 93-40 | 12H06 | 470950 5469170 | 335 | | | | | | | | | Striae 257±3. Striae 210 ± 4. 210 crossed by 257. |
| 93-41 | 12H06 | 470730 5470050 | 380 | | | | | | | | | Striae 270 ± 3. |
| 93-42 | 12H06 | 470740 5470700 | 430 | | | | | | | | | Striae 205 ± 4. Striae 235 ± 4. 205 crossed by 235. |
| 93-43 | 12H06 | 470380 5471650 | 445 | | | | | | | | | Striae 222 ± 3. |
| 93-44 | 12H06 | 470460 5471750 | 435 | D | 10Y 7/1 10YR 4/2 | 69.2 | 27.8 | 3.0 | 1.17 3.87 | 934052 | | 1 m+ diamicton. |
| 93-45 | 12H06 | 470820 5470350 | 305 | D | 10YR 6/2 10YR 4/2 | 89.6 | 9.9 | 0.5 | 0.3 2.48 | 934053 | 0.61 0.08 | 2.5 m sandy diamicton. |
| 93-46 | 12H06 | 473870 5468850 | 130 | SG | | | | | | | | Esker. Sandy gravel. |
| 93-47 | 12H06 | 469000 5477140 | 510 | | | | | | | | | Striae and grooves. 230 ± 10. |
| 93-48 | 12H06 | 469050 5478390 | 435 | | | | | | | | | Grooves 185 ± 4. |
| 93-49 | 12H06 | 468850 5479280 | 420 | D | | | | | | 934054 | | Striae and grooves. 205 ± 5. Pebble sample taken from surface. |
| 93-50 | 12H06 | 470650 5480540 | 470 | | | | | | | | | Striae 205 ± 3. |
| 93-51 | 12H06 | 472370 5482600 | 347 | SG | | | | | | | | 3 m exposure, slumped. Sandy gravel. |
| 93-52 | 12H06 | 471600 5481770 | 355 | | | | | | | | | Grooves 200-020. |
| 93-53 | 12H06 | 473600 5475600 | 395 | D | | | | | | 934055 | | Pebble sample. |
| 93-54 | 12H06 | 475860 5475140 | 220 | D | | | | | | 934056 | | Pebble sample. |
| 93-55 | 12H06 | 491880 5466870 | 125 | D | 7.5YR 5/4 7.5YR 3/4 | 73.0 | 25.0 | 2.0 | -0.03 3.61 | 934057 | | 1 m+ diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-56 | 12H06 | 492340 5467830 | 118 | | | | | | | | | Grooves 185. |
| 93-57 | 12H06 | 492570 5468320 | 108 | | | | | | | | | Grooves 192-012. |
| 93-58 | 12H06 | 497800 5471080 | 270 | | | | | | | | | Striae 210 ± 5. |
| 93-59 | 12H06 | 497920 5471160 | 270 | | | | | | | | | Striae 200 ± 3. |
| 93-60 | 12H06 | 498370 5470890 | 270 | | | | | | | | | Striae 210 ± 4. |
| 93-61 | 12H06 | 496930 5470500 | 240 | D | | | | | | 934058 | | Pebble sample. |
| 93-62 | 12H06 | 495520 5468840 | 240 | D | | | | | | 934059 | | Pebble sample. |
| 93-63 | 12H06 | 492750 5469670 | 90 | | | | | | | | | Striae 215 ± 4. |
| 93-64 | 12H06 | 489320 5458450 | 220 | D | | | | | | 934060 | | Pebble sample. |
| 93-65 | 12H06 | 489320 5457780 | 240 | | | | | | | | | Striae 200 ± 6. |
| 93-66 | 12H06 | 488630 5460450 | 139 | | | | | | | | | Striae 200 ± 5. |
| 93-67 | 12H06 | 490580 5461020 | 210 | D | 7.5YR 6/0 7.5YR 3/2 | 49.7 | 36.9 | 13.4 | 2.02 4.68 | 934061 | 0.65 0.1 | 2 m exposure. Upper 80-100 cm road fill. Beneath is 1 m+ diamicton. |
| 93-68 | 12H06 | 491140 5461870 | 228 | D | | | | | | 934062 | | 1 m+ diamicton. |
| 93-69 | 12H06 | 496370 5466480 | 254 | | | | | | | | | Grooves 272 ± 3. |
| 93-70 | 12H06 | 481060 5467070 | 72 | | | | | | | | | Striae 214 ± 5. Striae 270 ± 3. 214 crosses 270. |
| 93-71 | 12H06 | 480550 5466770 | 70 | | | | | | | | | Grooves and striae 203 ± 3. |
| 93-72 | 12H06 | 495260 5470570 | 160 | | | | | | | | | Grooves 345 ± 5. |
| 93-73 | 12H06 | 496620 5471650 | 172 | | | | | | | | | Striae 195 ± 5. |
| 93-74 | 12H06 | 498120 5473600 | 183 | | | | | | | | | Grooves and striae 230 ± 3. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-75 | 12B09 | 419800 5391130 | 90 | SG | | | | | | | | 15 m exposure, slumped. 1 m+ sandy gravel. |
| 93-76 | 12B09 | 417500 5391350 | 107 | S | | | | | | | | 5 m+ sand. Cross-bedded and faulted units included. |
| 93-77 | 12H06 | 497520 5476300 | 150 | D | 7.5YR 6/4 7.5YR 4/4 | 71.7 | 25.7 | 2.6 | 0.79 3.6 | 934064 | 0.74 0.07 | 1.5 m diamicton. |
| 93-78 | 12H06 | 497020 5479070 | 80 | D | | | | | | 934065 | | Pebble sample. |
| 93-79 | 12H03 | 474320 5450780 | 50 | GS | | | | | | | | 1.5 m+ sand overlain by 1.2 m gravelly sand |
| 93-80 | 12H06 | 491900 5456900 | 153 | D | 5YR 6/3 5YR 3/4 | 60.6 | 37.1 | 2.3 | 1.91 3.54 | 934066 | 0.7 0.11 | 1.5 m diamicton. |
| 93-81 | 12H06 | 497520 5463770 | 185 | D | | | | | | 934067 | | Pebble sample. |
| 93-82 | 12H06 | 499130 5467090 | 155 | D | 2.5YR 6/0 2.5YR 3/0 | 45.0 | 32.6 | 22.4 | 1.9 4.79 | 934068 | 0.52 0.19 | 2 m grey diamicton. Overlain by 50 cm brown diamicton. |
| 93-82 | 12H06 | 499130 5467090 | 155 | D | 2.5YR 6/2 5YR 2.5/1 | 50.3 | 36.7 | 13.0 | 3.06 4.14 | 934069 | | |
| 93-83 | 12H07 | 505130 5480030 | 242 | | | | | | | | | Striae 184 ± 3. Striae 112 ± 8. 184 crosses 112. |
| 93-84 | 12H11 | 499550 5489730 | 192 | | | | | | | | | Striae 210 ± 3. Striae 118 ± 3. 210 crosses 118. |
| 93-85 | 12H11 | 497800 5491750 | 250 | | | | | | | | | Striae 205 ± 3. |
| 93-86 | 12H10 | 500320 5484030 | 142 | | | | | | | | | Striae 085 ± 4. |
| 93-87 | 12H03 | 465800 5454930 | 120 | D | | 41.2 | 45.2 | 13.6 | 3.88 3.72 | 934070 | 0.7 0.11 | 3 m + diamicton. Overlain by 1 m f-m, mod -well sorted sand. |
| 93-88 | 12H11 | 489220 5486620 | 170 | SS | | 36.4 | 56.0 | 7.6 | 4.94 2.26 | 934071 | | 15 cm structureless sand/silt. Overlain by 60 cm diamicton. |
| 93-88 | 12H11 | 489220 5486620 | 170 | D | 2.5Y 6/2 2.5Y 3/2 | 75.0 | 24.7 | 0.3 | 0.43 3.58 | 934072 | | |
| 93-89 | 12H11 | 490230 5488670 | 125 | | | | | | | | | Striae 152 ± 3. |
| 93-90 | 12H11 | 491080 5485690 | 90 | D | 7.5YR 6/0 5YR 4/1 | 69.0 | 28.5 | 2.5 | 1.49 3.67 | 934073 | | 30 cm+ diamicton. Overlain by 1 m sand and gravel. |
| 93-91 | 12H11 | 491480 5484200 | 80 | GS | 10R 5/4 10R 3/3 | 90.4 | | | | 934074 | | 80 cm gravelly sand. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S₁ S₃ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-92 | 12H06 | 485820 5474970 | 80 | D | 10R 6/3 10R 3/4 | 53.5 | 45.2 | 1.3 | 2.79 2.87 | 934075 | | Ridge. 1 m+ diamicton. Overlain by 1 m gravelly sand. |
| 93-93 | 12H10 | 500250 5484170 | 140 | D | 10R 6/2 10R 3/2 | 81.7 | | | | 934076 | | 4 m exp. Slumped. 2 m+ sandy diamicton. |
| 93-94 | 12H10 | 500520 5487070 | 145 | D | 5YR 6/2 5YR 3/2 | 88.7 | | | | 934077 | 0.48 0.24 | 2 m diamicton. |
| 93-95 | 12H06 | 486530 5475930 | 80 | D | 10R 6/3 10R 3/6 | 88.5 | 10.6 | 1.0 | 0.04 2.64 | 934078 | | 50 cm+ diamicton. Overlain by 5-10 cm reddish brown sandy silt and 50 cm gravelly sand. |
| 93-95 | 12H06 | 486530 5475930 | 80 | SS | 10R 4/8 10R 4/4 | 27.4 | 63.7 | 8.9 | 3.73 3.52 | 934079 | | |
| 93-95 | 12H06 | 486530 5475930 | 80 | GS | 10R5/6 10R 3/6 | 99.1 | 0.9 | 0.0 | | 934080 | | |
| 93-96 | 12H06 | 488550 5479740 | 87 | D | 10R 6/3 10R 3/3 | 69.9 | 28.9 | 1.3 | 1.58 3.21 | 934081 | | 50 cm grey diamicton. Overlain by 50 cm gravelly sand. |
| 93-96 | 12H06 | 488550 5479740 | 87 | GS | 5YR 5/4 5YR 3/3 | 87.3 | 12.7 | 0.0 | 0.93 2.27 | 934082 | | |
| 93-97 | 12H06 | 489880 5481800 | 92 | D | 5YR 6/3 5YR 3/3 | 78.1 | 19.9 | 2.0 | 0.18 3.4 | 934083 | | Hummock. 30 cm+ sandy diamicton; 20 cm red sandy gravel; 40 cm red grey to grey diamicton. |
| 93-97 | 12H06 | 489880 5481800 | 92 | D | 10R 6/3 10R 3/4 | 80.9 | 18.4 | 0.8 | -0.28 3.51 | 934084 | | |
| 93-97 | 12H06 | 489880 5481800 | 92 | D | 5YR 6/2 5YR 3/1 | 65.7 | 34.3 | 0.0 | 2.39 2.68 | 934085 | | |
| 93-98 | 12H11 | 490550 5482930 | 90 | D | 2.5YR 5/4 2.5YR 3/4 | 79.8 | 18.7 | 1.5 | 1.07 2.77 | 934086 | | 50 cm+ reddish diamicton. Overlain by 1m sandy gravel. |
| 93-98 | 12H11 | 490550 5482930 | 90 | SG | 7.5YR 5/6 5YR 3/3 | 99.0 | 1.0 | 0.0 | | 934087 | | |
| 93-99 | 12H11 | 491700 5483350 | 80 | SG | | 99.6 | 0.4 | 0.0 | | 934088 | | 3m interbedded sandy gravel and sand. |
| 93-100 | 12H07 | 500270 5480080 | 292 | | | | | | | | | Grooves and striae 072 ± 4. |
| 93-101 | 12H07 | 500870 5477630 | 230 | D | 5YR 6/4 5YR 3/4 | 66.1 | 31.4 | 2.6 | 1.57 3.36 | 934089 | 0.8 0.04 | 1.5m diamicton. |
| 93-102 | 12H07 | 504900 5478030 | 185 | D | 2.5Y 7/2 2.5Y 4/4 | 56.1 | 36.5 | 7.4 | -0.01 4.71 | 934090 | 0.7 0.08 | 2m diamicton. |
| 93-103 | 12H07 | 503130 5474850 | 200 | D | | | | | | | | Drumlin. 1 m+ diamicton; 40 cm sandy diamicton; 2 m+ sandy diamicton. |
| 93-104 | 12H07 | 502540 5474200 | 200 | D | 2.5Y 5/2 2.5Y 3/2 | 70.4 | 26.9 | 2.8 | 1.24 3.34 | 934091 | | 5 m diamicton. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 93-105 | 12H07 | 502170 5472650 | 160 | D | 10YR 6/2 10YR 3/2 | 73.0 | 26.4 | 0.6 | 0.94 3.17 | 934092 | 0.63 0.03 | 3.5 m exposure, slumped. 1.5 m+ sandy diamicton. |
| 93-106 | 12H07 | 511870 5457720 | 125 | SG | | | | | | | | 1 m+ interbedded sand and sandy gravel. |
| 93-107 | 12H07 | 511220 5455300 | 280 | SG | | | | | | | | 1 m+ sandy gravel. |
| 93-108 | 12H07 | 518370 5459580 | 440 | D | | | | | | | | veneer sandy diamicton. |
| 93-109 | 12H07 | 520550 5458400 | 380 | D | | | | | | | | 50 cm+ diamicton |
| 93-110 | 12H07 | 517320 5458130 | 270 | SG | | | | | | | | 5 m sandy gravel. |
| 93-111 | 12H07 | 515460 5458480 | 210 | | | | | | | | | Possible delta. |
| 93-112 | 12H07 | 517030 5461330 | 90 | SS | | | | | | | | 30 cm+ fine sand to silt. Overlain by 80 cm diamicton. Overlain by 50 cm sandy gravel. |
| 93-113 | 12H07 | 521500 5465250 | 160 | D | | | | | | | | 6 m diamicton. |
| 93-114 | 12H07 | 521660 5465370 | 150 | GS | | | | | | | | 6 m gravelly sand. |
| 93-115 | 12H06 | 466400 5455170 | 110 | D | 7.5YR 6/2 7.5YR 3/2 | 80.2 | 18.1 | 1.7 | 1.21 2.89 | 934093 | | 3 m diamicton. Overlain by 60 cm gravelly sand. |
| 93-116 | 12H06 | 466620 5455290 | 110 | GS | | | | | | | | 4 m exposure, slumped. Gravelly sand. |
| 93-117 | 12H06 | 471040 5458950 | 108 | D | 10YR 6/2 10YR 3/4 | 78.8 | 19.5 | 1.7 | -0.35 2.86 | 934094 | | 75 cm+ diamicton. |
| 93-118 | 12H06 | 471520 5460000 | 122 | D | 10YR 6/2 10YR 3/4 | 63.0 | 30.3 | 6.7 | 0.72 3.82 | 934095 | | 1.5 m diamicton. |
| 93-119 | 12H06 | 471550 5461050 | 120 | GS | | | | | | | | 3 m interbedded sands and gravelly sand. |
| 93-120 | 12H06 | 472160 5462950 | 130 | D | 10YR 6/2 10YR 3/4 | 80.2 | 15.1 | 4.8 | 0.56 3.09 | 934096 | | 1 m+ diamicton. |
| 93-121 | 12H06 | 473470 5461830 | 92 | D | 10YR 6/1 10YR 3/2 | 76.7 | 17.9 | 5.5 | 1.66 3.23 | 934097 | | 1 m+ diamicton. |
| 93-122 | 12H03 | 488300 5433120 | 320 | D | | 91.8 | | | | 934103 | 0.7 0.06 | 4m sandy diamicton. |
| 93-123 | 12H06 | 474900 5468100 | 110 | GS | | 99.1 | 0.9 | 0.0 | | 934104 | | Esker. 5 m+ interbedded c., m. and f., sand; 9 cm v. fine sand to silt, and 150 cm gravelly sand. |

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| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | S1 S3 | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-------|----------|
| 93-123 | 12H06 | 474900 5468100 | 110 | SS | 5YR 6/3 5YR 3/3 | 12.9 | 79.6 | 7.6 | 5.67 1.58 | 934105 | | |
| 93-123 | 12H06 | 474900 5468100 | 110 | S | | 99.7 | 0.3 | 0.0 | | 934106 | | |
| 93-124 | 12H06 | 474450 5468620 | 102 | D | 2.5YR 4/8 2.5YR 3/4 | 80.9 | 16.6 | 2.5 | 0.79 3.55 | 934107 | | 1 m+ diamicton. |
| 93-125 | 12H06 | 486810 5456030 | 142 | D | 5YR 6/2 5YR 4/2 | 59.4 | 32.2 | 8.5 | 2.01 4.27 | 934108 | 0.51 0.12 | Ridge. 3 m+ diamicton. |
| 93-126 | 12H06 | 487880 5455890 | 133 | D | 10YR 7/2 10YR 4/3 | 65.3 | 32.4 | 2.3 | 1.81 3.47 | 934109 | 0.59 0.09 | 2m diamicton. |
| 93-127 | 12H06 | 489370 5458030 | 230 | D | 10YR 7/2 10YR 4/3 | 56.3 | 37.0 | 6.7 | 1.56 4.06 | 934110 | 0.62 0.15 | 180 cm diamicton. |
| 93-128 | 12H06 | 488950 5459170 | 179 | D | 5YR 3/4 5YR 3/2 | 67.9 | 30.4 | 1.7 | 0.45 3.61 | 934111 | 0.73 0.07 | Ridge. 50 cm+ brown red diamicton; 50 cm brown diamicton, and 50 cm reddish brown diamicton. |
| 93-128 | 12H06 | 488950 5459170 | 179 | D | 7.5YR 7/2 7.5YR 4/2 | 72.8 | 25.7 | 1.5 | 1.37 3.34 | 934112 | | |
| 93-128 | 12H06 | 488950 5459170 | 179 | D | 2.5YR 5/4 2.5YR 3/4 | 60.7 | 34.5 | 4.9 | 2.27 3.43 | 934113 | | |
| 93-129 | 12H06 | 491060 5465820 | 120 | D | 5YR 6/3 5YR 4/3 | 62.1 | 37.1 | 0.8 | 1.89 3.49 | 934114 | 0.58 0.1 | 2m diamicton. |
| 93-130 | 12H06 | 493250 5465670 | 228 | D | 10YR 6/2 10YR 4/4 | 50.1 | 36.5 | 13.4 | 2.28 4.38 | 934115 | 0.57 0.14 | 1.5 m diamicton. |
| 93-131 | 12H06 | 494730 5466600 | 270 | D | 2.5Y 5/2 2.5Y 4/2 | 57.9 | 30.2 | 11.9 | 2.46 4.01 | 934116 | 0.49 0.1 | 270 cm diamicton. |
| 93-131 | 12H06 | 494730 5466600 | 270 | D | 2.5Y 6/2 2.5Y 3/2 | 52.5 | 39.2 | 8.3 | 1.5 4.17 | 934117 | | |
| 93-132 | 12H06 | 496250 5466450 | 247 | D | 10YR 5/3 10YR 3/2 | 55.1 | 31.9 | 12.9 | 2.18 4.35 | 934118 | 0.46 0.18 | 150 cm. Diamicton. |
| 93-133 | 12H06 | 498030 5466570 | 187 | D | 2.5Y 6/0 2.5Y 2/0 | 48.1 | 34.6 | 17.4 | 2.5 4.33 | 934119 | 0.58 0.08 | 70 cm+ grey diamicton. Overlain by 150 cm reddish grey diamicton. |
| 93-133 | 12H06 | 498030 5466570 | 187 | D | 10YR 6/2 10YR 4/2 | 50.2 | 35.1 | 14.7 | 2.31 4.4 | 934120 | 0.62 0.08 | |
| 93-133 | 12H06 | 498030 5466570 | 187 | D | 7.5YR 6/0 7.5YR 4/0 | 27.8 | 54.2 | 18.1 | 3.54 4.32 | 934121 | | |
| 93-134 | 12H06 | 491840 5466870 | 130 | D | 5YR 4/6 5YR 3/3 | 74.6 | 22.2 | 3.3 | 1.3 3.39 | 934122 | 0.46 0.1 | 180 cm diamicton. |
| 93-135 | 12H06 | 493930 5470070 | 130 | D | 2.5YR 4/2 2.5YR 2/2 | 84.5 | 14.2 | 1.3 | 0.81 2.65 | 934123 | | 160 cm diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|------|-----|-----------|--------|-----|----------------|------|------|------|-----------|--------|-----------|----------|
| 93-136 | 12H06 | 495670 5470420 | 160 | D | 2.5YR 6/2 2.5YR 4/2 | 29.4 | 61.3 | 9.3 | 5.29 1.93 | 934124 | | 190 cm. 25 cm grey-green sandstone; 50 cm reddish brown diamicton.; 50 cm sandy diamicton. |
| 93-136 | 12H06 | 470420 5495670 | 160 | D | 5YR 6/2 5YR 4/2 | 87.7 | | | | 934125 | 0.58 0.15 | |
| 93-137 | 12H06 | 496470 5471670 | 178 | D | 10YR 6/2 10YR 4/2 | 68.9 | 26.6 | 4.6 | 1.78 3.41 | 934126 | 0.62 0.06 | 130 cm diamicton. |
| 93-138 | 12H06 | 497500 5473070 | 178 | D | 10YR 6/3 10YR 4/3 | 64.0 | 32.9 | 3.1 | 1.66 3.52 | 934127 | 0.49 0.18 | 260 cm diamicton. |
| 93-139 | 12H07 | 503660 5474790 | 210 | D | 10YR 5/2 10YR 3/2 | 86.5 | | | | 934128 | 0.59 0.08 | Ridge. 1 m diamicton. |
| 93-140 | 12H07 | 506080 5475820 | 182 | D | 2.5Y 4/4 2.5Y 3/2 | 88.4 | | | | 934129 | | Ridge. 160 cm diamicton. |
| 93-141 | 12H07 | 503140 5474870 | 200 | D | 10YR 6/2 10YR 4/2 | 22.6 | 51.6 | 25.9 | 4.29 4.4 | 934130 | 0.62 0.04 | Drumlin. 320 cm+ diamicton. Overlain by 140 cm sandy diamicton, and sandy diamicton. |
| 93-141 | 12H07 | 503140 5474870 | 200 | D | 10YR 6/2 10YR 3/2 | 70.9 | 27.3 | 1.9 | 1.76 3.17 | 934133 | 0.69 0.14 | |
| 93-141 | 12H07 | 503140 5474870 | 200 | D | 10YR 6/2 10YR 3/3 | 71.1 | 27.5 | 1.5 | 1.65 3 | 934134 | | |
| 93-142 | 12H07 | 502340 5469890 | 140 | D | 10YR 7/1 10YR 4/1 | 95.8 | 4.2 | 0.0 | | 934131 | 0.51 0.11 | 350 cm gravelly sand. |
| 93-143 | 12H07 | 505060 5462100 | 110 | D | 10YR 7/2 10YR 4/2 | 64.4 | 32.6 | 3.0 | 2.65 2.91 | 934132 | 0.72 0.1 | 320 cm diamicton. |
| 93-144 | 12H06 | 475020 5464650 | 101 | D | 10YR 6/2 10YR 3/2 | 75.3 | 21.7 | 3.0 | 1.34 2.91 | 934135 | 0.53 0.11 | 290 cm diamicton. |
| 93-145 | 12H06 | 476920 5466970 | 100 | D | 10YR 7/1 10YR 3/3 | 71.5 | 24.2 | 4.3 | 1.61 3.34 | 934136 | 0.51 0.16 | 210 cm. Diamicton. |
| 93-146 | 12H06 | 473980 5468820 | 130 | D | | 82.2 | 16.5 | 1.4 | 1.78 2.32 | 934137 | 0.57 0.12 | Hummock. 160 cm+ sandy diamicton. Overlain by 130 cm gravelly sand. |
| 93-147 | 12H06 | 474470 5469170 | 115 | D | 2.5YR 4/8 2.5YR 3/6 | 84.2 | 14.1 | 1.7 | 0.42 2.86 | 934138 | 0.62 0.17 | 170 cm diamicton. |
| 93-148 | 12H06 | 475540 5471680 | 100 | D | 2.5YR 5/6 2.5YR 3/4 | 91.3 | 8.0 | 0.7 | 0.24 2.14 | 934139 | 0.76 0.08 | 200 cm gravelly sand. |
| 93-149 | 12H03 | 480700 5453720 | 80 | D | 10R 6/2 10R 4/2 | 73.7 | 22.3 | 4.0 | 2.15 3.2 | 934140 | 0.48 0.13 | 340 cm diamicton. |
| 93-150 | 12H06 | 481070 5455100 | 70 | D | 7.5YR 8/2 7.5YR 5/3 | 69.7 | 26.3 | 4.0 | 2.01 3.36 | 934141 | 0.52 0.12 | 210 cm diamicton. |
| 93-151 | 12H06 | 481650 5456730 | 63 | D | 10R 6/4 10R 4/6 | 84.3 | 13.6 | 2.1 | 1.48 2.32 | 934142 | 0.54 0.14 | Ridge. 250 cm diamicton. |

| Site | NTS | East North | Elev m | Sed | Munsell colour | Sand | Silt | Clay | Mean S.D. | Sample | $S_1$ $S_3$ | Comments |
|------|-----|------------|--------|-----|----------------|------|------|------|-----------|--------|-----------|----------|
| 93-152 | 12H06 | 482530 5456370 | 88 | D | 7.5YR 7/2 7.5YR 4/2 | 70.1 | 28.6 | 1.2 | 1.32 3.39 | 934143 | | 100 cm diamicton. |
| 93-156 | 12A13 | 446900 5404350 | 580 | | | | | | | | | Striae / grooves 290 ± 4. |
| 93-157 | 12H04 | 460900 5444050 | 20 | GS | 7.5YR 5/2 7.5YR 3/4 | 98.5 | 1.5 | 0.0 | | 934098 | | North Brook section. See chapter 4. |
| 93-157 | 12H04 | 460900 5444050 | 20 | GS | | 99.2 | 0.8 | 0.0 | | 934099 | | |
| 93-157 | 12H04 | 460900 5444050 | 20 | S | | 99.8 | 0.2 | 0.0 | | 934100 | | |
| 93-157 | 12H04 | 460900 5444050 | 20 | SC | | | | | | 934101 | | |
| 93-157 | 12H04 | 460900 5444050 | 20 | SS | | | | | | 934102 | | |
| 93-174 | 12B09 | 416300 5390260 | 244 | D | 7.5YR 5/0 7.5YR 3/0 | 73.0 | 25.3 | 1.7 | 1.01 3.47 | 934063 | 0.75 0.08 | 2 m diamicton. |
| 94-3 | 12A13 | 434320 5422900 | 35 | D | | | | | | 944007 | 0.78 0.06 | 5 m+ diamicton, overlain by 7 m sand, and 3 m gravelly sand. |

# Appendix B

# Overburden Thickness

The following listing provides data on overburden thickness across the Humber River basin, and is presented in the following format:

Place - Location where data was collected.

East - The easting on the Universal Transverse Mercator Grid, Zone 21.

North - The northing on the Universal Transverse Mercator Grid, Zone 21.

NTS - The National Topographic System map number.

Depth - Depth of overburden in metres.

Comments - Description of sediment encountered, or other pertinent data include by driller or drill core logger. The following abbreviations are used: H.F. refers to Humber Falls Formation; R.B. refers to Rocky Brook Formation; sdst - sandstone; conglom - conglomerate; slst - siltstone

Source - Source from which data was derived. References are found in the reference list. Water well data refers to the 1995 Department of Environment Report titled 'Water Well Data for Newfoundland and Labrador 1950-1994'.

Sources identified by a map number followed by a number in parentheses e.g., 12H(709), are from assessment reports filed with the Geological Survey, Newfoundland Department of Mines and Energy, St. John's. All files are non- confidential, and may be attained by writing to the Publications and Information Section, or telephoning (709) 729-6193.

Sources designated WST refer to drillcore data provided by the Provincial Department of Works, Services and Transportation.

| Place | NTS | East | North | Depth | Comments | Source |
|-------|-----|------|-------|-------|----------|--------|
| Cormack | 12H06 | 466431 | 5453338 | 3 | gravel | Water well data |
| Cormack | 12H06 | 471750 | 5461200 | 7 | sand | Water well data |
| Cormack | 12H06 | 470741 | 5459207 | 2 | clay | Water well data |
| Cormack | 12H06 | 468450 | 5456500 | 9 | clay | Water well data |
| Cormack | 12H06 | 474075 | 5463700 | 6 | clay | Water well data |
| Cormack | 12H06 | 468850 | 5458000 | 8 | gravel | Water well data |
| Cormack | 12H06 | 466150 | 5452000 | 4 | clay | Water well data |
| Cormack | 12H06 | 471669 | 5461477 | 4 | gravel | Water well data |
| Cormack | 12H06 | 471126 | 5461337 | 15 | clay (13) over gravel | Water well data |
| Cormack | 12H06 | 468612 | 5458214 | 3 | gravel | Water well data |
| Cormack | 12H06 | 464250 | 5455300 | 50 | sand and gravel (13) over sand | Water well data |
| Cormack | 12H06 | 466441 | 5455245 | 5 | clay, sand, gravel | Water well data |
| Cormack | 12H06 | 466418 | 5455227 | 5 | clay, sand, gravel | Water well data |
| Cormack | 12H06 | 464250 | 5455175 | 11 | clay | Water well data |
| Cormack | 12H06 | 468500 | 5458015 | 2 | gravel | Water well data |
| Cormack | 12H06 | 468450 | 5457325 | 10 | gravel | Water well data |
| Cormack | 12H06 | 468491 | 5458470 | 3 | gravel | Water well data |
| Cormack | 12H06 | 468474 | 5458437 | 6 | gravel | Water well data |
| Cormack | 12H06 | 468907 | 5458376 | 3 | clay | Water well data |
| Cormack | 12H06 | 468922 | 5458361 | 0 | | Water well data |
| Cormack | 12H06 | 471850 | 5461155 | 7 | sand | Water well data |
| Cormack | 12H06 | 471850 | 5461150 | 18 | gravel | Water well data |
| Cormack | 12H06 | 471427 | 5461234 | 20 | gravel | Water well data |
| Cormack | 12H06 | 466415 | 5453463 | 2 | clay | Water well data |
| Cormack | 12H06 | 468175 | 5456500 | 10 | clay | Water well data |
| Cormack | 12H06 | 469100 | 5458450 | 10 | clay | Water well data |
| Cormack | 12H06 | 473250 | 5462900 | 12 | gravel | Water well data |
| Cormack | 12H06 | 473000 | 5462800 | 9 | clay | Water well data |
| Cormack | 12H06 | 473250 | 5463350 | 5 | gravel | Water well data |
| Cormack | 12H06 | 468450 | 5458200 | 8 | gravel | Water well data |
| Cormack | 12H06 | 468650 | 5457700 | 9 | clay | Water well data |
| Cormack | 12H06 | 468372 | 5459295 | 40 | sand | Water well data |
| Cormack | 12H06 | 470875 | 5461075 | 5 | clay | Water well data |
| Cormack | 12H06 | 467550 | 5456725 | 3 | gravel | Water well data |
| Cormack | 12H06 | 472475 | 5462075 | 4 | clay | Water well data |
| Cormack | 12H06 | 468915 | 5458045 | 6 | clay | Water well data |
| Cormack | 12H06 | 468925 | 5458030 | 9 | topsail | Water well data |
| Cormack | 12H06 | 468916 | 5458040 | 10 | topsoil | Water well data |
| Cormack | 12H06 | 468286 | 5457673 | 6 | gravel | Water well data |
| Cormack | 12H06 | 468282 | 5457682 | 10 | gravel | Water well data |
| Cormack | 12H06 | 471236 | 5461401 | 6 | clay | Water well data |
| Cormack | 12H06 | 471212 | 5461398 | 5 | clay | Water well data |
| Cormack | 12H06 | 471161 | 5461375 | 21 | clay | Water well data |
| Cormack | 12H06 | 471245 | 5461467 | 6 | clay | Water well data |
| Cormack | 12H06 | 468550 | 5456550 | 9 | gravel | Water well data |
| Corner Brook | 12A13 | 399658 | 5434689 | 13 | gravel | Water well data |
| Corner Brook | 12A13 | 434093 | 5417765 | 8 | gravel | Water well data |
| Corner Brook | 12A13 | 412950 | 5399800 | 25 | sand (7) over gravel | Water well data |

| Place | NTS | East | North | Depth | Comments | Source |
|---|---|---|---|---|---|---|
| Corner Brook | 12A13 | 433969 | 5417661 | 90 | sand | Water well data |
| Corner Brook | 12A13 | 433756 | 5417704 | 19 | clay | Water well data |
| Deer Lake | 12H03 | 466540 | 5448491 | 40 | sand | Water well data |
| Deer Lake | 12H03 | 470000 | 5447500 | 10 | gravel (8) over clay | Water well data |
| Deer Lake | 12H03 | 465150 | 5446200 | 5 | sand/clay | Water well data |
| Howley | 12H03 | 491664 | 5446438 | 15 | gravel (13) over sand | Water well data |
| Humber Village | 12A13 | 444602 | 5426912 | 5 | clay | Water well data |
| Humber Village | 12A13 | 444151 | 5426075 | 27 | sand | Water well data |
| Pasadena | 12H04 | 457400 | 5430890 | 85 | sand | Water well data |
| Pasadena | 12H04 | 457547 | 5431353 | 38 | clay (4) over sand | Water well data |
| Pynn's Brook | 12H04 | 460293 | 5437039 | 38 | sand. Salty at 74 m | Water well data |
| Pynn's Brook | 12H04 | 460933 | 5438280 | 5 | clay | Water well data |
| Pynn's Brook | 12H04 | 460505 | 5436946 | 62 | sand | Water well data |
| Pynn's Brook | 12H04 | 461005 | 5438649 | 5 | gravel | Water well data |
| Pynn's Brook | 12H04 | 460401 | 5437253 | 61 | gravel (6), sand (12), clay (14) over sand | Water well data |
| Reidville | 12H03 | 468750 | 5450260 | 25 | sand | Water well data |
| South Brook | 12H04 | 448009 | 5426998 | 58 | sand | Water well data |
| St. Judes | 12H03 | 466300 | 5443800 | 76 | sand | Water well data |
| Steady Brook | 12A13 | 450132 | 5428091 | 23 | sand (15) over gravel | Water well data |
| Cormack | 12H06 | 471050 | 5464750 | 6.7 | | 12H(573) |
| Cormack | 12H06 | 475100 | 5467800 | 6.8 | | 12H(576) |
| Cormack | 12H06 | 469300 | 5462100 | 6.3 | | 12H(582) |
| Alder Pond | 12H06 | 495600 | 5479350 | 8.4 | | 12H(583) |
| Adies Pond | 12H06 | 470850 | 5481800 | 9.8 | | 12H(584) |
| Sandy Lake | 12H06 | 499900 | 5464800 | 17.5 | | 12H(590) |
| Sandy Lake | 12H06 | 497600 | 5461000 | 9 | | 12H(592) |
| Sandy Lake | 12H06 | 498800 | 5461000 | 19 | | 12H(592) |
| Sandy Lake | 12H06 | 497000 | 5458000 | 15.3 | | 12H(593) |
| Cormack | 12H06 | 475000 | 5464700 | 5.2 | | 12H(597) |
| Sandy Lake | 12H06 | 495800 | 5458800 | 12.4 | | 12H(599) |
| Wigwam Brook | 12H06 | 495450 | 5474400 | 9.5 | 5YR 3/2. Limestone chips | 12H(709) |
| Wigwam Brook | 12H06 | 494640 | 5473950 | 3.4 | conglomerate and red mudstone chips | 12H(709) |
| Wigwam Brook | 12H06 | 494980 | 5474800 | 5.4 | H.F. sandstone and minor rhyolite | 12H(709) |
| Wigwam Brook | 12H06 | 495280 | 5474700 | 4 | | 12H(709) |
| Wigwam Brook | 12H06 | 495390 | 5474670 | 8.9 | | 12H(709) |
| Wigwam Brook | 12H06 | 495560 | 5474790 | 7.8 | | 12H(709) |
| Wigwam Brook | 12H06 | 495530 | 5474630 | 4.6 | | 12H(709) |
| Wigwam Brook | 12H06 | 495590 | 5474600 | 3 | | 12H(709) |
| Wigwam Brook | 12H06 | 496180 | 5475100 | 6 | granite and mudstone chips | 12H(709) |
| Wigwam Brook | 12H06 | 496610 | 5476740 | 4.8 | H.F. sandstone chips | 12H(709) |
| Wigwam Brook | 12H06 | 496390 | 5476650 | 5.8 | | 12H(709) |
| Wigwam Brook | 12H06 | 496230 | 5476460 | 4.7 | granite, rhyolite and H.F. sdst chips | 12H(709) |
| Wigwam Brook | 12H06 | 496460 | 5476360 | 5.1 | granite and H.F. sdst chips | 12H(709) |

| Place | NTS | East | North | Depth | Comments | Source |
|---|---|---|---|---|---|---|
| Wigwam Brook | 12H06 | 496630 | 5476540 | 4.7 | granite and H.F. sdst chips | 12H(709) |
| Wigwam Brook | 12H06 | 496910 | 5477000 | 3.7 | gabbro and H.F. sdst chips | 12H(709) |
| Wigwam Brook | 12H06 | 496830 | 5477320 | 5.1 | H.F. sdst, limestone and gabbro chips | 12H(709) |
| Wigwam Brook | 12H06 | 496300 | 5475320 | 5.8 | H.F. sdst, rhyolite, intrusive chips | 12H(709) |
| Wigwam Brook | 12H06 | 495880 | 5474380 | 4.9 | granite chips | 12H(709) |
| Wigwam Brook | 12H06 | 496500 | 5476850 | 6.5 | | 12H(709) |
| Wigwam Brook | 12H06 | 496520 | 5476810 | 6 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496550 | 5476770 | 6.1 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496570 | 5476720 | 5.5 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496470 | 5476890 | 8.9 | R.B. H.F., gabbro | 12H(709) |
| Wigwam Brook | 12H06 | 496450 | 5476940 | 14.2 | R.B., H.F., gabbro, granite, gneiss | 12H(709) |
| Wigwam Brook | 12H06 | 496420 | 5476980 | 15 | felsic volcanic, sdst, conglomerate | 12H(709) |
| Wigwam Brook | 12H06 | 496570 | 5477060 | 11 | H.F. sdst, conglom, felsic vol with qtz eyes | 12H(709) |
| Wigwam Brook | 12H06 | 496530 | 5476960 | 13.4 | H.F. sdst and conglomerate | 12H(709) |
| Wigwam Brook | 12H06 | 496420 | 5476890 | 11.1 | H.F. sdst and conglom, rhyolite, mudstone | 12H(709) |
| Wigwam Brook | 12H06 | 496380 | 5476860 | 14.2 | H.F. sdst, granite | 12H(709) |
| Wigwam Brook | 12H06 | 496460 | 5476920 | 9.3 | H.F. sdst, conglomerate | 12H(709) |
| Wigwam Brook | 12H06 | 496440 | 5476960 | 12.3 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496450 | 5477030 | 17.9 | H.F. sdst, mudstone | 12H(709) |
| Wigwam Brook | 12H06 | 496800 | 5477020 | 10.6 | H.F. sdst, conglomerate | 12H(709) |
| Wigwam Brook | 12H06 | 496840 | 5476990 | 7.7 | H.F. conglom, gabbro, limestone, granite | 12H(709) |
| Wigwam Brook | 12H06 | 496550 | 5477420 | 11.3 | H.F. sdst, mudstone | 12H(709) |
| Wigwam Brook | 12H06 | 496510 | 5477450 | 11.7 | Gabbro, H.F. sdst and conglom | 12H(709) |
| Wigwam Brook | 12H06 | 496980 | 5476910 | 22.4 | gabbro, granite, lmst, R.B., H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496940 | 5476940 | 18.9 | granite, gabbro, H.F. sdst, limestone | 12H(709) |
| Wigwam Brook | 12H06 | 496680 | 5476560 | 7.2 | granite, gabbro, sdst, mudstone | 12H(709) |
| Wigwam Brook | 12H06 | 493480 | 5473080 | 6.2 | | 12H(709) |
| Wigwam Brook | 12H06 | 493770 | 5472350 | 6.5 | H.F. sdst, granite, limestone | 12H(709) |
| Wigwam Brook | 12H06 | 493500 | 5472200 | 10.4 | H.F. sdst, granite, volcanics | 12H(709) |
| Wigwam Brook | 12H06 | 492960 | 5471010 | 9 | granite, gabbro, H.F. sdst, rhyolite | 12H(709) |

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| Place | NTS | East | North | Depth | Comments | Source |
|---|---|---|---|---|---|---|
| Wigwam Brook | 12H06 | 496440 | 5476490 | 3 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496040 | 5476400 | 7.6 | H.F. sdst, conglom; gabbro | 12H(709) |
| Wigwam Brook | 12H06 | 496070 | 5476360 | 10.5 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496110 | 5476320 | 7.9 | | 12H(709) |
| Wigwam Brook | 12H06 | 496140 | 5476290 | 7.9 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496170 | 5476210 | 9.6 | sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496200 | 5476160 | 11.1 | H.F. sdst, gabbro | 12H(709) |
| Wigwam Brook | 12H06 | 496330 | 5476030 | 8.3 | granite, H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 495760 | 5475770 | 7.4 | H.F. sdst, rhyolite, quartz (conglom?) | 12H(709) |
| Wigwam Brook | 12H06 | 496060 | 5475550 | 3.9 | sdst, gabbro, granite | 12H(709) |
| Wigwam Brook | 12H06 | 495900 | 5475130 | 3.1 | rhyolite | 12H(709) |
| Wigwam Brook | 12H06 | 495570 | 5475310 | 6 | conglom, R.B. slst, H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496590 | 5477340 | 11.7 | H.F. sdst, conglom | 12H(709) |
| Wigwam Brook | 12H06 | 496620 | 5477290 | 9 | H.F. sdst, granite, gabbro | 12H(709) |
| Wigwam Brook | 12H06 | 496650 | 5477250 | 10.6 | volcanics, H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496690 | 5477210 | 7.7 | granite, sdst | 12H(709) |
| Wigwam Brook | 12H06 | 496720 | 5477160 | 9 | H.F. sdst | 12H(709) |
| Wigwam Brook | 12H06 | 477200 | 5477370 | 14.4 | gabbro, H.F. sdst, granite, rhyolite. Red brown to grey red till | 12H(709) |
| Wigwam Brook | 12H06 | 497190 | 5477380 | 14.8 | gabbro, granite, H.F. sdst. Grey red sandy to red sandy clay till | 12H(709) |
| Wigwam Brook | 12H06 | 495630 | 5474730 | 5.8 | felsic volcanic | 12H(709) |
| Wigwam Brook | 12H06 | 495670 | 5474530 | 3.3 | granite, rhyolite, sdst | 12H(709) |
| Wigwam Brook | 12H06 | 494560 | 5475250 | 4.7 | gabbro, sdst | 12H(709) |
| Wigwam Brook | 12H06 | 494860 | 5475260 | 6.4 | H.F. sdst, biotite granite | 12H(709) |
| Wigwam Brook | 12H06 | 495710 | 5474590 | 5.7 | HF sdst, NB lmst, R.B. shale | 12H(709) |
| Wigwam Brook | 12H06 | 495690 | 5474510 | 3 | | 12H(709) |
| Wigwam Brook | 12H06 | 493480 | 5473080 | 8.1 | granite, gabbro, HF sdst | 12H(709) |
| Wigwam Brook | 12H06 | 493770 | 5472350 | 12 | granite, rhyolite, HF sdst, mafic volcanic | 12H(709) |
| Wigwam Brook | 12H06 | 493500 | 5472200 | 8 | HF sdst | 12H(709) |
| Wigwam Brook | 12H06 | 492960 | 5471010 | 6.3 | HF sdst, gabbro, RB mudstone. Sandy pale red 5Y 6/2 till | 12H(709) |
| Wigwam Brook | 12H06 | 496200 | 5475050 | 5 | granite, NB conglom | 12H(709) |
| Wigwam Brook | 12H06 | 496360 | 5475240 | 5 | | 12H(709) |
| Wigwam Brook | 12H06 | 496330 | 5475210 | 4 | | 12H(709) |
| Wigwam Brook | 12H06 | 495780 | 5474470 | 5.5 | gabbro, granite | 12H(709) |
| Wigwam Brook | 12H06 | 495840 | 5474430 | 7.4 | HF sdst, gabbro, slate, granite | 12H(709) |
| Wigwam Brook | 12H06 | 495880 | 5474420 | 6.9 | HF sdst, Gales Brook granite, NB conglom | 12H(709) |

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| Place | NTS | East | North | Depth | Comments | Source |
|---|---|---|---|---|---|---|
| Wigwam Brook | 12H06 | 495750 | 5474500 | 3.5 | | 12H(709) |
| Wigwam Brook | 12H06 | 495760 | 5474490 | 5.4 | red brown clay till | 12H(709) |
| Cormack | 12H06 | 465500 | 5455500 | 12.1 | | 12H(706) |
| Junction Brook | 12H03 | 478200 | 5448350 | 13.7 | | 12H(640) |
| Hinds Brook | 12H03 | 484660 | 5435550 | 2.1 | granite | 12H(226) |
| Hinds Brook | 12H03 | 484550 | 5435500 | 7.9 | clay, sand and andesite boulder | 12H(226) |
| Hinds Brook | 12H03 | 484550 | 5435270 | 8.5 | | 12H(226) |
| Hinds Brook | 12H03 | 484000 | 5434740 | 7.3 | | 12H(226) |
| Hinds Brook | 12H03 | 484200 | 5434720 | 3 | andesite bo and sand | 12H(226) |
| Hinds Brook | 12H03 | 484020 | 5434680 | 1.5 | | 12H(226) |
| Wigwam Brook | 12H06 | 497100 | 5476800 | 9.5 | average of 11 holes | 12H(1114) |
| Wigwam Brook | 12H06 | 496500 | 5476200 | 4.6 | average of 11 holes | 12H(1114) |
| Wigwam Brook | 12H06 | 493200 | 5472800 | 2.7 | average of 21 holes | 12H(549) |
| Glover Island | 12A12 | 442500 | 5394600 | 6.7 | average of 5 holes | 12A(638) |
| Glover Island | 12A12 | 442100 | 5394600 | 4.6 | average of 2 holes | 12A(638) |
| Glover Island | 12A12 | 441800 | 5394300 | 5.5 | average of 8 holes | 12A(638) |
| Glover Island | 12A12 | 444300 | 5396400 | 3.0 | average of 2 holes | 12A(638) |
| Glover Island | 12A12 | 445300 | 5397500 | 4.4 | average of 3 holes | 12A(638) |
| Corner Brook | 12A13 | 430800 | 5421680 | 4 | average of 10 holes. Mostly silt and sand | NGL 2019 |
| Deer Lake | 12H03 | 469250 | 5448200 | 2.5 | average 5 pits. No bedrock. | PWC, 1989 |
| Corner Brook | 12A13 | 429480 | 5422850 | 11.3 | average 5 holes. Sand and gravel | Golder, 1983 |
| Corner Brook | 12A13 | 429420 | 5422740 | 8 | average 5 holes. Sand and gravel | Golder, 1983 |
| Corner Brook | 12A13 | 431000 | 5423250 | 12.5 | average 5 holes. Sand and gravel | Geotechnical Associates, 1979 |
| Deer Lake | 12H03 | 469200 | 5448200 | 5 | average 6 holes | Golder, 1980 |
| Corner Brook | 12A13 | 430000 | 5422360 | 8.3 | average 8 holes. Sand, gravel, clay | Golder, 1991 |
| Corner Brook | 12A13 | 431330 | 5420900 | 4 | average 5 pits. Till | Golder, 1986 |
| Corner Brook | 12A13 | 427800 | 5419050 | 3.6 | average 3 holes. Till | Geotech, 1980 |
| Corner Brook | 12A13 | 431550 | 5420200 | 2.4 | average 24 holes. Till | Newfoundland Design, 1970 |
| Corner Brook | 12A13 | 430720 | 5421070 | 6.4 | grey till. Borehole 1 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430530 | 5420960 | 6.1 | grey till. borehole 5 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430660 | 5420770 | 6.4 | grey till. Borehole 10 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430470 | 5420780 | 4 | grey till. No rock. Borehole 12 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430580 | 5420550 | 6.7 | grey till. Borehole 19 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430670 | 5421270 | 3.4 | grey till. Borehole 22 | Newfoundland Design, 1968 |
| Corner Brook | 12A13 | 430370 | 5421220 | 4 | grey till. No rock. Borehole 24 | Newfoundland Design, 1968 |

| Place | NTS | East | North | Depth | Comments | Source |
|-------|-----|------|-------|-------|----------|--------|
| Corner Brook | 12A13 | 432950 | 5421750 | 4.7 | till. Average 3 boreholes | Geotechnical Associates, 1973 |
| Corner Brook | 12A13 | 433000 | 5421770 | 1.9 | till. Average 3 boreholes | Geotechnical Associates, 1973 |
| Corner Brook | 12A13 | 427150 | 5419550 | 4.6 | Till. No bedrock. Borehole 1 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427250 | 5419560 | 3.6 | Till. No bedrock. Borehole 2 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427400 | 5419540 | 3.6 | Till. No bedrock. Borehole 3 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427420 | 5419520 | 3.6 | Till. No bedrock. Borehole 4 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427680 | 5419550 | 4.6 | Till. No bedrock. Borehole 5 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427700 | 5419430 | 4.6 | Till. No bedrock. Borehole 6 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427820 | 5419580 | 4.6 | Till. No bedrock. Borehole 7 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 428000 | 5419570 | 4.6 | Till. No bedrock. Borehole 8 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 428160 | 5419630 | 3.6 | Till. No bedrock. Borehole 9 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 428280 | 5419620 | 4.6 | Till. No bedrock. Borehole 10 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427240 | 5419780 | 4.6 | Till. No bedrock. Borehole 11 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427350 | 5419860 | 4.6 | Till. No bedrock. Borehole 12 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427420 | 5419800 | 4.6 | Till. No bedrock. Borehole 13 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427480 | 5419750 | 4.6 | Till. No bedrock. Borehole 14 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427420 | 5419920 | 4.6 | Till. No bedrock. Borehole 15 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427150 | 5419270 | 4.6 | Till. No bedrock. Borehole 16 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427450 | 5419150 | 4.6 | Till. No bedrock. Borehole 17 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427660 | 5419170 | 4.6 | Till. No bedrock. Borehole 18 | Geotechnical Associates, 1980 |
| Corner Brook | 12A13 | 427920 | 5421000 | 3 | Till. No bedrock. Average 6 pits | NGL, 1989 |
| Corner Brook | 12A13 | 435840 | 5417880 | 4.3 | Till?. Borehole 1 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435740 | 5418050 | 3.4 | Till?. Borehole 2 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435660 | 5418180 | 6.1 | Till?. Borehole 3 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435620 | 5417300 | 1.2 | Till?. Borehole 4 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435550 | 5417420 | 4.3 | Till?. Borehole 5 | Geotechnical Associates, 1976 |

| Place | NTS | East | North | Depth | Comments | Source |
|-------|-----|------|-------|-------|----------|--------|
| Corner Brook | 12A13 | 435320 | 5417700 | 2.1 | Till?. Borehole 7 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435240 | 5417700 | 2.1 | Till?. Borehole 8 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435170 | 5417780 | 2.1 | Till?. Borehole 9 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 435000 | 5417920 | 1.8 | Till?. Borehole 10 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 434900 | 5419040 | 1.8 | Till?. Borehole 11 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 434720 | 5419130 | 1.5 | Till?. Borehole 12 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 434520 | 5419260 | 1.2 | Till?. Borehole 13 | Geotechnical Associates, 1976 |
| Corner Brook | 12A13 | 432750 | 5422850 | 15.8 | Borehole 2. No bedrock. Till? | WST, 1991 |
| Steady Brook | 12A13 | 437600 | 5422150 | 25.6 | 10m sandy gravel over silt- clay. 1963 hole showed 38 m. | WST, 1990 |
| Steady Brook | 12A13 | 437750 | 5422230 | 18.3 | No bedrock. Sandy gravel | WST, 1990 |
| Corner Brook | 12A13 | 435870 | 5421940 | 25.3 | 5.9m silty clay over sand and gavel over limestone | WST, 1991 |
| Corner Brook | 12A13 | 435850 | 5422030 | 27.3 | 10.9m silty clay over sand and sand-gravel over limestone | WST, 1991 |
| Little Rapids | 12A13 | 444170 | 5425570 | 20.4 | No bedrock. Clay. | WST, 1994 |
| Little Rapids | 12A13 | 447300 | 5426700 | 30.4 | Est. location. 3 m gravelly sand over clay | WST, 1994 |
| Little Rapids | 12A13 | 444220 | 5425480 | 12.9 | Borehole 1. Mostly sand. No bedrock. | WST, 1995 |
| Steady Brook | 12A13 | 443980 | 5425450 | 29.5 | Borehole 3. 15.2m sand and gravel over clay. No bedrock | WST, 1995 |
| Deer Lake | 12H03 | 471170 | 5451300 | 54.9 | 23m silty sand over 27m silt-clay over 5m sand-gravel. | Environment Canada, 1980 |
| Deer Lake | 12H03 | 471200 | 5451200 | 60.9 | No bedrock. silty clay to sandy clay | Environment Canada, 1980 |
| Steady Brook | 12A13 | 438700 | 5421950 | 120 | mostly silt-clay | Golder, 1983 |
| Howley | 12H03 | 491600 | 5443900 | 15.2 | mostly sand, some clay near base. Location est. | Murray and Howley, 1881 |
| Howley | 12H03 | 493500 | 5445500 | 13.1 | No bedrock. Sand/gravel. Location est. | Murray and Howley, 1881 |
| Howley | 12H03 | 492400 | 5443850 | 35.1 | 6 m clay overlain by sand-gravel. Location est. | Murray and Howley, 1918 |

# Appendix C

# Clast rock type determinations from diamicton samples

Data presented here is of clast rock type identification from 351 samples across the Humber River basin. Most samples are diamicton. A field description of sites from which samples were collected is found in Appendix A.

Clasts were identified in the field, and subdivided into rock type or, where positively identified, into source areas. Specific identification was dominantly to rock types outcropping on The Topsails, and terminology follows that of Whalen and Currie (1988). Where no source could be identified, only the rock type is recorded. The reader is referred to Chapter 1 for a complete discussion of the bedrock geology of the Humber River basin.

A total of 19,723 clasts were identified, and subdivided into 41 categories. In the following tables rock types or groups have been abbreviated. These are described below:

| | |
|---|---|
| Sample | The sample number assigned. See Appendix A for details. |
| Site | The site number assigned. See Appendix A for details. |

Clasts identified to a specific area

| | |
|---|---|
| Sq, Sm, Sp, Ssy | Topsails Intrusive Suite clasts with nomenclature taken from Whalen and Currie (1988). |
| Tps | Clasts from The Topsails but not assigned to a specific area. |
| Ss, Ssm, Ssf | Springdale Group clasts with nomenclature taken from Whalen and Currie (1988). |
| Oi, Oib, Oic, Oid | Ordovician granite and granodiorite with nomenclature taken from Whalen and Currie (1988). |
| Ohm | Rocks of the Hungry Mountain Complex with nomenclature taken from Whalen and Currie (1988). |
| MM | Mount Musgrave Group. Nomenclature from Williams and Cawood (1989). |
| HL | Hughes Lake Complex. Nomenclature from Williams and Cawood (1989). |

Rock types not assigned to a specific area:

| | |
|------|-------------------------|
| Shl | Shale |
| Slst | Siltstone |
| Sdst | Sandstone |
| Arks | Arkose |
| Cng | Conglomerate |
| Lst | Limestone |
| Dlmt | Dolomite |
| Scst | Schist |
| Gnss | Gneiss |
| Grnt | Granite |
| Gbr | Gabbro |
| Ultr | Ultramafics |
| Tuf | Tuff |
| Rhy | Rhyolite |
| Bslt | Basalt |
| Qzte | Quartzite |
| Mtsd | Metasediment |
| Mar | Marble |
| Amp | Amphibolite |
| Vl br | Volcanic breccia |
| Ac vl | Acid volcanic |
| Gngr | Granite/granodiorite |
| Prph | Porphyry |
| Qtz peb | Quartz pebble |
| Unk | Unknown |
| Tot | Total |

Sample and site data is found within Appendix A, except for the following. These are samples originally collected by Doug Vanderveer, Department of Mines and Energy, but pebble contents are identified as part of this research. All data is previously unpublished.

| Sample | Site # | NTS | Easting | Northing |
|--------|--------|-----|---------|----------|
| | | | | |
| 860725 | 80012 | 12H03 | 471800 | 5449680 |
| 860726 | 80012 | 12H03 | 471800 | 5449680 |
| 860727 | 80012 | 12H03 | 471800 | 5449680 |
| 860728 | 80020 | 12H03 | 477670 | 5452570 |
| 860729 | 80020 | 12H03 | 477670 | 5452570 |
| 860730 | 80023 | 12H03 | 480760 | 5452730 |
| 860731 | 80023 | 12H03 | 480760 | 5452730 |
| 860732 | 80024 | 12H03 | 481730 | 5451920 |
| 860734 | 80027 | 12H03 | 485860 | 5454540 |
| 860741 | 80128 | 12H06 | 491030 | 5456250 |
| 860742 | 80130 | 12H06 | 493300 | 5456680 |
| 860743 | 80130 | 12H06 | 493300 | 5456680 |
| 860744 | 86002 | 12H03 | 465930 | 5454970 |
| 860747 | 86001 | 12H03 | 472100 | 5449480 |
| 860749 | 80007 | 12H03 | 472870 | 5453770 |
| 864501 | 80128 | 12H06 | 491030 | 5456250 |
| 864502 | 80128 | 12H06 | 491030 | 5456250 |
| 864503 | 80128 | 12H06 | 491030 | 5456250 |
| 864504 | 80012 | 12H03 | 471800 | 5449680 |
| 864505 | 80012 | 12H03 | 471800 | 5449680 |
| 870001 | 80020 | 12H03 | 477670 | 5452570 |
| 870002 | 80020 | 12H03 | 477670 | 5452570 |
| 870003 | 80020 | 12H03 | 477670 | 5452570 |
| 870004 | 80020 | 12H03 | 477670 | 5452570 |
| 870005 | 80128 | 12H06 | 491030 | 5456250 |
| 870007 | 80128 | 12H06 | 491030 | 5456250 |
| 870008 | 80128 | 12H06 | 491030 | 5456250 |
| 870009 | 80012 | 12H03 | 471800 | 5449680 |
| 870010 | 80012 | 12H03 | 471800 | 5449680 |
| 870020 | 80130 | 12H06 | 493300 | 5456680 |
| 870021 | 80130 | 12H06 | 493300 | 5456680 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 860725 | 3 | 6 | 5 | | | | | 2 | | | | | 12 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | 29 |
| 860726 | | | 3 | | | | | 9 | | | 5 | | | | | | 16 | 3 | | | | | | | | | | | | | | | | | | | | | | 36 |
| 860727 | 4 | | 5 | | | | | 2 | | 12 | 2 | | 3 | | | | 6 | 2 | | | | | | | | | | | | | | | | | | | | | | 36 |
| 860728 | 5 | 1 | 1 | | | | | 3 | | 6 | | | | | | | | 47 | 1 | | | | | | | 1 | | | | | | | | | | | | | | 65 |
| 860729 | 8 | 5 | 6 | | | | 4 | 6 | | 12 | 5 | | | | | | | 29 | | | | | | | | 4 | | | | | | | | | | | | 1 | | 80 |
| 860730 | 10 | 1 | 3 | | | | | 1 | | 9 | 6 | | | | | | 10 | 18 | | | | | | | | 7 | | | | | | | | | | | | 1 | | 66 |
| 860731 | 19 | 2 | 5 | | | | | 8 | | 17 | 6 | | | | | | 2 | 17 | | | | | | | | 15 | | | | | | | | | | | | | | 91 |
| 860732 | 4 | | | | | | 1 | | | | 2 | | | | | | 2 | 94 | | | | | | | | 2 | | | | | | | | | | | | | | 105 |
| 860734 | 3 | | 3 | | | | | 4 | | 2 | | | | | | | 8 | 47 | | 3 | | | | | | 1 | | | | | | | | | | | | | | 71 |
| 860741 | | | | | | | | 3 | | | | | | | | | 46 | | | | | | | | | | | | | | | | | | | | | | | 49 |
| 860742 | | 4 | 1 | | | | | 7 | | 3 | | | 2 | | | | 9 | | | | | | | | | | | | | | | | | | | | | | | 26 |
| 860743 | | | 3 | | | | | 3 | | | | | 3 | | | | 11 | 6 | | | | | | | | | | | | | | | | | | | | | | 26 |
| 860744 | | | | | | | | | | | | | | | | | 21 | 16 | | | | | | | | | | | | | | | | | | | | | | 37 |
| 860747 | | | | | | | | | | | | | | | | | 31 | 3 | | | | | | | | | 1 | | | | | | | | | | | | | 35 |
| 860749 | | | | | | | | | | | | | | | | | 8 | 12 | | | | | | | 3 | | | | 1 | | | | | | | | | | | 24 |
| 864501 | 11 | 5 | 6 | | | | | 7 | | 13 | 11 | | | | | | 22 | 90 | | | | | | | | 1 | | | | | | | | | | | | 2 | | 168 |
| 864502 | 5 | | | | | | | 2 | | 2 | 6 | | | | | | 22 | 54 | | 2 | | | | | 2 | 7 | | | | | | | | | | | | | | 102 |
| 864503 | 12 | | 2 | | | | | 5 | | 10 | 11 | | | | | | 8 | 50 | | | | | | | | 2 | | | | | | | | | | | | 1 | | 101 |
| 864504 | 2 | 1 | 7 | | | | | 2 | | 26 | 18 | | | | | | 4 | 27 | | | | | | | 2 | 16 | | | 2 | | | | | | | | | | | 107 |
| 864505 | 4 | 5 | 17 | | | | | 11 | | 49 | 51 | | | | | | 8 | 29 | | | | | | | | 24 | | | | 1 | | | | | | | | | | 199 |
| 870001 | | | | | | | | | | | | | | | | | | 50 | | | | | | | | | | | | | | | | | | | | | | 50 |
| 870002 | 5 | | 1 | | | | | 13 | | | | | | | | | | 12 | | | | | | | | | 1 | | | 5 | | | | | | | | | | 37 |
| 870003 | | 2 | 4 | | | | | 15 | | | 3 | | | | | | | 6 | | | | | | | | | 8 | | | | | | | | | | | | | 38 |
| 870004 | | 3 | 1 | | | | | | 12 | | | | | | | | | 15 | | | | | | | | | | | | 8 | | | | | | | | | | 39 |
| 870005 | | | 1 | | | | | 6 | | | | | | | | | 18 | 8 | | | | | | | | | | 5 | | | | | | | | | | | | 38 |
| 870007 | | 6 | | | | | 6 | 12 | | | | | | | | | 22 | 11 | | | | | | | | | | | | | | | | | | | | | | 57 |
| 870008 | 7 | 1 | | | | | | | | | | | | | | | 19 | 22 | | | | | | | | 1 | | | | | | | | | | 1 | | | | 51 |
| 870009 | | 1 | 1 | | | | | 5 | | 4 | | | | | | | 13 | 21 | | | | | | | | | | | | | | | | | | | | | | 45 |
| 870010 | | 6 | 22 | | | | | 11 | | | | | | | | | | 1 | | | | | | | | | | | | 11 | | | | | | | | | | 51 |

530

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Gmt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Msd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
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| 870020 | | | | | | | | 21 | 12 | | | | | | | | 23 | 15 | | | | | | | | | | | | 14 | | | | | | | | | | 85 |
| 870021 | | 2 | | | | | | 10 | | 2 | | | | | | | | 22 | | | | | | | 12 | | | | | | | | | | | | | | | 48 |
| 914000 | | | | | | | | | | | | | | | | | 1 | 3 | | | 54 | | | | | | | | | | | | | | | | | | | 58 |
| 914001 | 1 | | | | | 1 | | | | 1 | 1 | | | 37 | | | | 5 | 4 | | | | | | | 1 | | | | | | | | | | | | | | 51 |
| 914002 | 1 | | | | | | | | | | 2 | 1 | | 3 | | | 4 | 6 | | | 39 | | | | | | | | | | | | | | | | | | | 56 |
| 914003 | 2 | | | | 1 | | | | | | | | | 29 | | | 3 | 4 | | | 2 | | | | | | | | | | | | | | | | | 5 | | 46 |
| 914004 | 2 | | | | | | | | | | | | | 24 | | | 4 | 8 | | | | | | | | 3 | | | | | | | | | | | | 4 | | 45 |
| 914006 | | | | | 3 | | | | | 2 | 2 | 1 | | | | | 14 | 12 | | | 3 | | | | 3 | 2 | | | 2 | | | 8 | | | | | | 38 | | 90 |
| 914007 | | | | | 1 | | | | | | | | | | | | 3 | 7 | | | 22 | | | | 2 | | | | | | | 2 | | | | | | 1 | | 38 |
| 914010 | 3 | | | | | | | | | | | | | 12 | | | | 12 | | | | | | | | 1 | | | 3 | | | | | | | | | 4 | | 35 |
| 914011 | 1 | | | | | | | | | | | | | 12 | | | | 11 | | | 1 | | | | | 2 | | | | | | | | | | | | 5 | | 32 |
| 914015 | | | | | | | | | | | | | | | | | | | | | 44 | | | | | | | | | | | | | | | | | | | 44 |
| 914016 | | | | | | | | | | | 1 | | | 10 | | 1 | | 27 | | | 2 | | | | | | | | | | | | | | | | | 5 | 5 | 51 |
| 914017 | | | | | 1 | | | | | | | | | 2 | | | | 9 | | | 28 | | | | | | | | | | | | | | | | | 5 | | 42 |
| 914018 | | | | | | | | | | | | | | 3 | | | | 28 | | | | | | | | | | 1 | | | | | | | | | | 5 | | 37 |
| 914019 | | | | | | | | | | | | | | | | | 35 | 17 | | | 1 | | | | | | | | | | | | | | | | | 2 | | 55 |
| 914020 | | | | | | | | | | | | | | 9 | | | | | | | 46 | | | | | | | | | | | | | | | | | 1 | | 56 |
| 914021 | | | | | | | | 2 | | | | | | 12 | | | | | | | 43 | | | | | | | | | | | | | | | | | | | 57 |
| 914022 | 2 | | | | | | | | | | | | | | | 36 | | 5 | | 1 | 20 | | | | 3 | 1 | | | 1 | | | | | | | | | 3 | | 72 |
| 914023 | | | | | | | | | | | | | | 10 | | | | | | | 31 | | | | | | 1 | | | | | | | | | | | 2 | | 44 |
| 914024 | | | | | | | | | | | | | | 9 | | | | | | | 49 | | | | | | | | | | | | | | | | | 1 | | 59 |
| 914025 | | | | | 3 | | | | | | | 1 | | | | | | | | | | | | | | | 1 | | | | | 43 | | | | | | 4 | | 52 |
| 914026 | | | | | 1 | | | | | | | 1 | | 36 | | | | | | | | | | | | 3 | 5 | | 3 | | | | | | | | | 5 | | 54 |
| 914027 | | | | | | | | | | | | | | 23 | | | | | | | | | | 20 | | | | | | | | | | | | | | 28 | | 71 |
| 914028 | | | | | | | | | | | | | | 26 | | | | | | | | | | 32 | | | | | | | | | | | | | | | | 58 |
| 914029 | | | | | | | | | | | | | | 31 | | | | 6 | | 8 | | | | | | | | | 1 | | | | | | | | | 7 | | 53 |
| 914030 | | | | | | | | | | | | | | | | | | 5 | | | | | | | | | | | | | | 45 | | | | | | 4 | | 54 |
| 914031 | | | | | | | | | | | | | | | | | | 6 | | | 1 | | | | | | | | | | | 50 | | | | | | 3 | | 60 |
| 914032 | | | | | | | | | | | | | | 42 | | | | | | | | | | 12 | | | | | | | | | | | | | | 2 | | 56 |
| 914033 | | | | | | | | | | | | | | | | | 11 | 36 | | | | | | | | 2 | 1 | | | | | | | | | | | | | 50 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlml | Scst | Gnss | Gml | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 914034 | 2 |  |  |  | 2 | 1 |  |  |  | 1 |  |  |  | 44 |  |  | 3 | 14 |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 72 |
| 914038 | 1 |  |  |  |  | 1 |  |  |  |  | 3 |  |  | 31 |  |  | 4 | 14 |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 58 |
| 914039 | 2 |  |  | 3 |  |  |  |  |  |  |  |  |  | 30 |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  | 1 |  |  |  | 5 |  | 49 |
| 914040 |  |  |  |  | 17 |  |  |  |  |  |  |  |  | 33 |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 54 |
| 914041 | 1 |  |  |  |  |  |  |  |  |  | 2 |  |  | 25 |  |  |  | 2 |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 4 |  | 36 |
| 914042 | 2 |  |  |  |  | 1 |  |  |  |  |  |  |  | 19 |  |  |  | 28 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 50 |
| 914043 | 2 |  |  | 3 |  | 2 |  |  |  |  |  |  |  | 18 |  |  | 6 | 20 |  |  |  |  |  |  | 7 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 59 |
| 914044 | 1 |  |  | 6 |  |  |  |  |  |  |  |  |  |  |  |  | 23 | 37 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 68 |
| 914045 | 3 |  |  | 7 |  | 5 |  |  |  |  |  |  |  | 3 |  |  | 4 | 17 |  |  |  |  |  |  |  | 2 |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 43 |
| 914046 | 2 |  |  |  |  | 1 | 1 |  |  |  |  |  |  | 2 |  |  | 11 | 26 |  |  |  |  |  |  |  | 3 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 49 |
| 914048 | 2 |  |  |  |  | 4 |  |  | 1 |  |  |  |  | 17 |  |  |  | 23 |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 52 |
| 914050 |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  | 11 | 11 | 20 |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 |
| 914052 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 28 | 25 |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 62 |
| 914053 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |  |  |  |  |  |  |  |  |  |  |  |  |  | 24 |  |  |  |  |  | 1 |  | 36 |
| 914054 | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  | 15 | 29 | 9 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 60 |
| 914055 | 1 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  | 20 | 38 | 12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 76 |
| 914056 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  | 16 | 31 | 12 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 62 |
| 914057 |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  | 8 | 33 | 13 |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 1 |  | 59 |
| 914059 | 4 |  |  |  |  | 3 |  | 1 |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |
| 914060 | 5 | 2 |  |  |  | 1 |  |  |  |  |  |  |  | 18 |  |  | 10 |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 42 |
| 914061 |  |  |  |  |  |  |  |  |  |  |  |  |  | 37 |  |  | 15 |  |  |  |  |  |  | 3 | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 69 |
| 914063 | 1 |  |  |  |  | 3 |  | 1 |  |  |  |  |  |  |  |  | 8 | 55 | 28 | 2 |  |  |  |  | 6 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 105 |
| 914064 | 4 |  |  |  |  | 1 |  | 4 |  |  |  |  |  | 2 | 1 |  | 3 | 20 |  |  |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 39 |
| 914065 |  |  |  |  |  | 3 |  | 2 |  |  |  |  |  |  |  |  | 7 | 17 | 11 |  |  |  |  |  | 3 |  | 2 |  |  |  |  |  |  |  |  |  |  | 2 |  | 47 |
| 914066 | 1 | 1 |  |  |  |  |  | 2 |  |  |  |  |  | 15 | 2 |  |  | 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 28 |
| 914067 | 7 |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 22 |
| 914068 | 10 | 1 |  | 1 | 12 |  |  |  |  |  |  |  |  | 25 |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 |
| 914069 | 8 | 1 |  | 3 |  |  |  |  |  |  |  |  |  | 29 |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 47 |
| 914070 | 18 | 6 |  | 10 |  |  |  |  |  |  |  |  |  | 6 |  |  | 11 | 14 | 6 |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 74 |
| 914071 | 8 | 1 |  |  |  | 1 |  |  |  |  | 1 |  |  | 1 |  |  | 3 | 12 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 30 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 914072 |  |  | 1 |  |  |  |  | 1 |  |  |  |  |  | 23 |  |  |  | 4 |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 | 35 |
| 914073 | 7 | 5 | 1 |  | 2 |  |  | 3 |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  | 3 |  | 3 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 31 |
| 914074 | 6 | 1 | 1 |  |  |  |  | 1 |  |  |  | 2 |  |  |  |  |  | 22 | 2 | 1 |  |  |  |  | 2 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 41 |
| 914076 | 5 | 4 | 8 | 2 |  | 3 |  | 1 |  | 3 |  | 3 |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  | 33 |
| 914077 |  |  | 1 |  | 5 |  | 1 | 2 |  |  | 1 |  |  |  | 2 |  | 7 | 16 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  | 38 |
| 914081 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 46 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 47 |
| 914082 |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 48 | 3 |  |  | 1 |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 64 |
| 914083 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 45 |  |  |  |  | 5 | 4 |  |  |  |  | 1 |  |  |  |  | 55 |
| 914084 | 5 | 8 | 7 | 3 |  |  |  |  |  | 1 |  | 2 |  |  |  |  |  | 15 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 | 50 |
| 914088 | 5 | 4 | 16 |  |  |  |  | 5 | 6 |  | 2 | 1 |  |  |  |  |  | 3 |  |  |  |  |  |  | 5 | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 |
| 914089 | 1 | 2 | 20 | 1 |  |  |  | 5 |  |  | 1 |  |  |  |  |  | 2 | 3 |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 46 |
| 914090 | 2 | 2 | 7 |  |  | 1 |  | 4 | 4 | 1 |  |  |  |  | 3 |  |  | 17 |  | 3 |  |  | 1 | 1 |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  |  |  | 48 |
| 914091 | 3 |  | 12 |  | 1 |  |  | 5 |  |  |  |  |  |  |  |  | 2 | 10 |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 5 | 40 |
| 914094 | 9 |  | 13 |  |  |  |  | 2 |  | 3 | 1 | 3 |  |  |  |  |  | 2 | 3 |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  |  | 10 | 48 |
| 914095 | 1 |  | 15 |  |  |  |  | 1 |  | 9 |  |  |  |  | 3 |  |  | 5 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 1 |  |  |  |  | 14 | 50 |
| 914096 |  |  | 9 | 8 |  |  |  |  |  |  |  |  |  |  | 2 |  | 2 | 14 |  | 2 |  |  |  |  |  | 1 |  |  |  | 2 |  |  |  | 1 |  |  |  | 5 | 2 | 47 |
| 914097 | 1 |  | 9 | 3 |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 1 |  |  |  |  |  |  |  |  |  | 4 | 21 |
| 914098 |  |  | 2 |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 11 | 9 |  |  |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  | 1 |  |  |  |  | 5 | 31 |
| 914099 | 1 |  | 1 |  |  | 2 |  | 3 |  |  |  |  |  |  | 2 |  | 12 | 14 | 4 | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 | 52 |
| 914100 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 43 | 8 |  |  | 14 |  |  | 2 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 69 |
| 914101 | 1 |  | 10 |  | 3 |  |  |  | 6 |  |  |  |  |  | 5 |  |  | 1 |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 7 | 36 |
| 914102 | 3 |  | 3 | 5 | 4 |  |  |  |  |  |  |  |  |  | 3 |  | 1 | 6 | 2 | 1 |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 1 | 1 |  |  |  |  | 31 |
| 914103 | 2 | 1 | 5 |  |  |  |  |  |  | 3 |  |  |  |  | 1 |  | 1 | 2 |  | 1 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 | 30 |
| 914104 | 6 |  | 5 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 | 2 |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 28 |
| 914105 |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 3 |  |  | 7 |  |  |  |  |  |  |  |  |  |  |  | 13 |  |  |  |  |  | 1 | 26 |
| 914106 | 5 |  | 11 |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 15 | 35 |
| 914107 |  |  |  |  |  |  |  |  |  |  |  |  | 21 |  |  | 13 | 1 | 23 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  | 5 | 2 | 67 |
| 914108 |  |  | 5 | 2 |  | 2 |  |  |  |  |  |  |  |  |  | 2 | 3 | 13 |  | 5 | 7 |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  | 7 | 6 | 55 |
| 914109 | 1 |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 1 |  |  | 2 |  |  |  |  |  |  |  | 20 | 3 |  |  |  | 1 |  |  |  |  |  |  | 2 | 7 | 38 |
| 914110 |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 6 |  |  | 13 |  |  |  |  | 1 |  |  |  |  |  | 5 |  |  |  |  |  |  | 2 | 30 |

533

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 914113 | 4 |  |  |  | 4 |  |  |  |  | 1 |  |  |  | 12 | 1 |  |  | 3 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 28 |
| 914115 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 38 |  |  |  |  |  | 2 |  | 40 |
| 914117 |  |  |  |  | 15 |  |  |  |  | 1 |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 |  |  |  |  |  |  |  | 33 |
| 914119 |  |  | 2 |  | 2 |  |  | 3 |  |  |  |  |  |  |  |  | 6 | 24 |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 | 42 |
| 914120 |  |  | 2 | 1 | 2 |  |  |  |  | 2 | 2 |  | 1 |  |  |  | 3 | 16 |  |  |  |  |  |  | 7 |  |  |  |  | 1 |  | 5 |  |  |  |  |  |  |  | 42 |
| 914121 |  |  | 2 |  | 6 |  |  |  |  |  |  |  |  |  |  |  |  | 23 |  |  |  |  |  |  | 6 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 38 |
| 914122 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  | 3 | 30 |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  | 38 |
| 914124 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  | 4 | 32 | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 | 49 |
| 914126 | 2 |  | 4 |  | 2 |  |  |  |  |  |  |  |  | 15 |  |  |  | 1 |  |  |  |  |  |  | 7 |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 34 |
| 914127 | 1 | 1 | 7 |  |  |  |  |  |  | 2 |  | 1 |  |  |  | 4 |  | 2 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 |  | 25 |
| 914128 |  |  | 8 |  | 7 |  |  | 3 |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 5 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  | 1 |  | 26 |
| 914129 |  | 2 | 6 |  | 2 |  |  |  |  |  |  |  |  |  |  | 14 |  | 10 |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  | 36 |
| 914130 | 5 | 4 | 3 |  |  | 2 |  |  | 1 |  |  |  |  |  |  | 8 | 1 | 1 |  |  |  |  |  |  | 6 |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 32 |
| 914131 |  |  | 5 |  | 6 |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  | 1 | 17 |  |  |  |  | 2 | 2 |  |  |  |  |  |  |  | 1 | 37 |
| 914132 |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 16 |  |  |  | 10 |  |  |  |  |  |  |  |  |  | 1 | 1 |  | 1 |  |  |  |  | 5 |  |  |  | 35 |
| 914135 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  | 2 |  |  | 17 |  | 7 |  |  |  |  |  | 2 |  |  |  | 2 |  |  |  |  | 3 |  | 41 |
| 914136 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 21 |  |  |  |  | 16 |  |  |  |  |  | 2 |  |  |  |  |  | 4 | 1 |  | 5 |  | 52 |
| 914137 |  |  | 3 |  | 6 |  |  | 2 |  |  |  |  |  | 11 |  |  | 1 | 5 |  |  |  | 1 |  | 3 | 7 | 1 |  |  | 1 |  |  |  |  |  |  |  |  | 7 |  | 48 |
| 914138 |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 |  | 3 | 2 | 10 |  |  | 20 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |  | 48 |
| 914139 |  |  |  |  | 7 |  |  |  |  |  |  |  |  |  |  |  | 2 | 18 |  |  | 10 | 11 |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  | 50 |
| 914140 | 3 |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 4 | 25 |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 |  |  |  |  |  | 2 |  | 46 |
| 914144 | 6 |  |  |  | 4 |  |  |  |  |  | 2 | 1 |  | 14 |  |  |  | 17 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 46 |
| 914145 | 2 | 1 |  |  | 2 |  |  |  |  |  |  |  |  | 19 |  |  |  | 23 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 |  | 51 |
| 914146 |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 | 45 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |  | 60 |
| 914147 |  |  |  |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  | 3 | 19 | 3 |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  | 1 | 1 | 8 |  | 39 |
| 914150 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 40 | 1 |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 54 |
| 914153 | 2 |  |  |  | 1 |  |  |  | 1 |  |  |  |  |  |  |  | 9 | 38 | 1 |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 1 |  | 56 |
| 914154 | 2 | 1 |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  | 5 | 23 | 2 |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 1 |  | 37 |
| 914157 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 | 44 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 | 1 |  | 63 |
| 914160 |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  | 3 | 20 | 34 | 1 |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 61 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 914161 |  |  |  |  | 4 |  |  |  |  |  |  |  | 18 |  |  |  | 4 | 18 |  |  |  |  |  | 3 | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 49 |
| 914162 |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 6 | 18 | 3 |  |  |  |  | 3 |  |  |  |  |  |  |  | 7 |  |  |  |  |  |  |  | 38 |
| 914165 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 7 | 16 |  | 1 |  |  |  | 37 |  |  |  |  |  |  |  | 13 |  |  |  |  |  |  | 1 | 75 |
| 914166 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 17 | 36 |  | 2 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 56 |
| 914172 |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 5 | 28 |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 14 |  |  |  |  |  |  | 1 | 50 |
| 914173 |  |  | 1 |  | 2 |  |  |  |  |  |  |  |  |  |  |  | 6 | 19 |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  |  |  | 33 |
| 914174 |  |  | 2 |  | 3 |  |  | 2 |  |  |  |  |  |  |  |  | 16 | 10 |  | 1 |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 3 |  | 3 |  |  | 4 | 45 |
| 914175 |  |  | 3 |  | 5 |  |  |  |  |  |  |  |  |  |  |  | 1 | 14 |  | 1 |  |  |  | 5 | 13 |  |  |  | 5 |  |  |  |  |  | 4 |  |  |  |  | 51 |
| 924000 | 3 | 8 | 6 |  |  | 2 |  | 4 |  | 10 |  |  |  |  |  |  | 2 | 10 | 3 |  |  |  |  | 1 | 8 | 2 |  |  |  |  |  |  |  | 3 | 1 | 3 |  |  | 1 | 67 |
| 924001 | 3 | 3 | 1 |  |  |  | 1 | 1 |  | 2 |  | 1 |  |  |  |  |  | 2 | 6 |  |  |  |  |  | 10 |  |  |  | 1 |  | 1 |  |  |  |  |  |  | 2 | 1 | 34 |
| 924002 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 | 30 |  |  |  |  |  |  | 4 | 2 |  |  | 3 |  | 2 |  |  | 1 |  |  |  | 1 |  | 52 |
| 924003 | 4 | 2 |  |  |  |  |  | 5 |  |  |  | 1 |  |  |  |  | 6 | 35 | 2 |  | 2 |  |  | 3 | 8 | 2 |  |  |  |  | 1 |  |  |  | 7 |  |  | 2 |  | 80 |
| 924004 |  | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 35 | 25 | 5 |  |  | 1 |  | 2 | 1 |  |  | 1 | 3 |  | 2 |  |  |  | 5 |  |  |  | 1 | 87 |
| 924007 | 5 | 21 | 2 |  |  | 3 |  | 3 |  | 16 |  |  |  |  |  |  |  | 2 | 2 |  |  |  |  | 2 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 59 |
| 924011 | 4 | 24 | 1 |  |  |  |  | 6 |  | 8 |  |  |  |  |  |  | 3 | 15 |  |  | 2 |  |  |  | 3 |  |  |  |  |  |  | 3 |  | 2 | 1 |  |  | 2 |  | 74 |
| 924012 | 2 | 2 | 2 |  |  |  |  | 1 |  | 1 |  | 1 |  |  |  |  | 4 | 25 |  |  | 2 |  |  |  | 6 | 1 |  |  | 3 |  |  |  |  | 1 |  |  |  |  |  | 51 |
| 924015 | 6 | 14 | 4 |  |  |  |  | 4 |  | 7 |  |  |  |  |  |  | 4 | 13 |  | 1 | 3 |  |  |  | 7 | 1 |  |  |  |  | 1 |  |  | 2 | 4 |  |  |  |  | 71 |
| 924016 | 1 | 12 |  |  |  |  |  | 3 |  | 5 | 1 |  |  |  |  |  | 17 | 23 |  |  |  |  |  |  | 3 | 3 |  |  |  |  |  |  |  | 3 | 2 |  |  |  |  | 73 |
| 924018 | 2 | 22 | 1 |  |  |  |  | 7 |  | 6 |  |  |  |  |  |  | 14 | 14 | 1 |  |  |  |  |  | 1 | 3 |  |  |  |  | 1 |  |  | 3 | 3 |  |  |  |  | 78 |
| 924021 | 2 | 11 |  |  |  |  |  | 6 |  | 11 |  |  |  |  |  |  | 7 | 19 |  |  |  |  |  |  | 11 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 69 |
| 924025 | 2 | 17 | 13 |  |  |  |  | 3 |  | 9 |  |  |  |  |  |  | 2 | 12 | 1 |  |  |  |  |  | 5 | 6 |  |  | 5 |  |  |  |  |  |  |  |  | 1 |  | 76 |
| 924029 | 2 | 4 | 5 |  |  |  |  | 2 |  | 6 |  |  |  |  |  |  | 4 | 24 |  |  |  |  |  |  | 2 | 6 |  |  |  | 1 |  |  |  | 2 |  |  |  | 1 |  | 59 |
| 924030 | 4 | 3 | 8 |  |  |  |  | 4 |  | 5 |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  | 8 | 3 |  |  |  | 3 |  |  |  | 2 |  |  |  |  | 9 | 58 |
| 924031 |  | 7 | 6 |  |  |  |  |  |  | 15 |  |  |  |  |  |  | 7 | 35 |  |  |  |  |  |  | 8 | 6 |  |  | 3 |  |  |  |  | 1 |  |  |  | 1 |  | 89 |
| 924032 | 3 |  |  |  |  |  |  | 1 |  | 4 |  |  |  |  |  |  |  | 53 |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 64 |
| 924033 | 3 |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  | 1 | 42 | 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 57 |
| 924034 | 10 | 5 |  |  |  |  |  | 5 |  | 5 |  |  |  |  |  |  |  | 29 | 8 |  |  |  |  |  |  | 5 |  |  |  | 3 |  |  |  |  |  |  |  |  |  | 70 |
| 924035 | 1 | 1 | 2 |  |  | 5 |  |  |  |  |  |  |  |  |  |  | 28 | 32 |  |  |  |  |  |  | 1 |  |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  | 72 |
| 924036 | 2 |  |  |  |  | 1 |  |  |  | 1 |  |  |  |  |  |  | 21 | 19 |  |  |  |  |  |  | 1 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 48 |
| 924037 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 27 | 26 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 54 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 924038 | 1 | 2 | 1 |  |  |  |  |  |  | 3 |  |  |  |  |  |  | 11 | 14 |  |  |  |  |  |  |  | 1 |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 34 |
| 924042 | 8 |  | 2 |  |  | 2 |  |  |  | 10 | 7 |  | 32 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  | 64 |
| 924043 | 5 | 11 | 1 |  |  |  |  |  |  | 17 | 11 |  | 21 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 4 |  |  |  |  |  |  |  |  |  | 71 |
| 924044 |  | 5 | 2 |  |  |  | 18 | 13 |  |  |  |  | 2 |  |  |  | 3 |  |  |  |  |  |  |  |  | 17 |  |  | 10 |  |  |  |  | 6 |  |  |  |  |  | 76 |
| 924045 | 7 | 15 | 2 |  |  |  |  |  |  | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 25 |  |  |  |  |  | 2 |  |  |  |  |  |  |  | 64 |
| 924046 | 8 | 7 |  |  |  |  |  | 3 | 2 | 5 |  |  | 4 |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 8 |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 40 |
| 924047 | 11 | 14 |  |  |  | 8 | 10 |  |  | 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 20 |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 70 |
| 924048 | 4 | 1 |  |  |  | 6 | 8 |  | 6 |  |  |  | 9 |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 36 |
| 924055 |  |  | 7 |  |  |  |  |  |  | 16 | 16 |  | 14 |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 1 | 59 |
| 924056 |  | 3 | 6 |  |  | 5 |  |  |  | 2 | 2 |  |  |  |  |  | 3 |  |  |  | 4 |  |  | 2 | 5 | 1 |  |  | 5 |  |  |  |  |  |  |  |  |  |  | 38 |
| 924058 | 1 | 2 | 2 |  |  | 3 |  |  |  | 3 | 1 |  |  |  |  |  | 6 |  |  |  |  |  |  | 2 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 22 |
| 924059 | 6 | 8 | 7 |  |  | 7 |  |  |  | 3 | 1 |  |  |  |  | 1 | 2 | 4 |  |  |  |  |  |  | 1 | 1 |  |  |  |  |  |  | 4 | 1 |  |  |  |  |  | 46 |
| 924061 |  | 11 | 2 |  |  |  |  | 4 |  | 5 | 4 |  |  |  |  |  | 12 | 2 | 3 |  |  |  |  |  | 5 | 2 |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  | 52 |
| 924068 | 1 | 3 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 11 |  | 4 |  | 3 |  |  |  |  |  | 8 |  |  |  |  |  |  | 1 |  | 32 |
| 924069 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 34 |  |  |  | 1 |  |  |  |  |  | 8 |  | 1 |  |  |  |  |  |  | 45 |
| 924070 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 31 | 1 |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  | 35 |
| 924071 | 2 | 5 | 2 |  |  | 3 |  |  |  |  |  |  |  |  |  | 2 | 1 | 5 |  |  | 10 |  |  |  | 1 | 2 |  |  |  |  | 15 |  |  |  |  |  |  |  |  | 48 |
| 924072 |  | 2 | 2 |  |  |  |  |  |  | 5 | 1 |  |  |  |  |  |  | 3 |  |  | 3 |  |  |  |  | 1 |  |  | 5 | 3 | 2 | 5 |  |  | 3 |  |  |  |  | 35 |
| 924074 | 1 | 10 | 6 |  |  |  |  | 8 |  | 7 | 1 |  |  |  |  | 18 |  | 9 |  |  |  |  |  |  | 2 | 4 |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 67 |
| 924075 |  | 4 |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 52 | 1 |  |  |  |  |  |  | 4 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 63 |
| 924077 | 3 | 6 | 2 |  |  |  |  | 1 |  | 8 | 4 |  | 1 |  |  |  |  | 27 |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 4 |  | 57 |
| 924079 |  | 2 | 1 |  |  |  |  | 5 |  | 4 | 2 |  |  |  |  |  |  | 14 |  |  | 26 |  |  |  | 3 |  |  |  |  |  |  |  | 3 |  |  |  |  | 3 |  | 63 |
| 924084 | 2 | 13 | 2 |  |  |  |  | 1 |  | 2 | 2 |  |  |  |  | 1 |  | 4 |  |  | 17 | 7 |  |  | 1 | 3 |  |  |  |  |  |  | 1 |  |  |  |  |  |  | 56 |
| 924088 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 57 |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 60 |
| 924089 |  | 5 | 2 |  |  | 1 |  |  |  | 7 | 6 |  |  |  |  |  |  | 16 |  |  |  |  |  |  | 1 | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  | 42 |
| 924093 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  | 56 |
| 924097 |  |  |  |  |  |  | 11 |  |  | 14 | 8 |  | 3 |  |  |  | 6 |  |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 53 |
| 924100 |  | 1 |  |  |  |  |  | 2 |  |  | 1 |  |  |  |  | 1 |  |  |  |  | 45 |  |  |  |  |  |  |  |  |  |  |  | 1 | 2 |  | 2 |  |  |  | 55 |
| 924102 | 4 | 7 | 1 |  |  |  |  | 4 |  | 9 | 4 |  | 1 |  |  |  | 2 | 5 |  |  | 23 |  |  |  | 3 |  |  | 1 |  |  |  |  |  | 2 |  |  |  |  |  | 66 |
| 924104 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 46 |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 47 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Gmt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
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| 924106 | 8 | 3 | 1 | | | | 11 | 3 | | 11 | | | 4 | | | | | | | | | | | | | 14 | | | | | | | | 2 | 2 | | | | | 59 |
| 924107 | 9 | 4 | 2 | | | | 5 | 1 | | 10 | | | 1 | | | | | | | | | | | | | 24 | | | | | | | | | 4 | | | | 1 | 61 |
| 924108 | 10 | 12 | 5 | | | | | 2 | | 2 | 1 | | 2 | | | | | | | | | | | | | 18 | | | | 5 | | | | | | | | | 2 | 59 |
| 924109 | 9 | 13 | 20 | | | | 6 | 1 | | 7 | 2 | | 13 | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | | 73 |
| 924113 | 1 | 1 | | | | | | | | 2 | 2 | | | | | | 20 | 26 | | 1 | | | | 1 | | | | | | | 1 | | | | | | | | | 55 |
| 924114 | 3 | | 1 | | | | 1 | 4 | | | 2 | | | | | | 12 | 32 | | 3 | | | | | | 4 | | | | | | | | | | | | 1 | | 63 |
| 924115 | 3 | 2 | | | | | | 5 | | 4 | | | | | | | 9 | 34 | | 5 | | | | | | 2 | | | | | | | | | | | | 1 | | 65 |
| 924116 | 2 | 3 | | | | | | 4 | | 2 | 1 | | | | | | 1 | 36 | | 7 | | | | | | 5 | | | | | | | | | | | | | | 61 |
| 924117 | 4 | | | | | | | 1 | | 6 | 8 | | | | | | 6 | 23 | | 1 | | | | | | 2 | | | | | | | | | 2 | | | | | 53 |
| 924118 | | | | | | | | | | | 2 | | | | | | 16 | 34 | | 1 | | | | | | | | | | 1 | | | | | | | | 1 | | 55 |
| 924119 | 2 | 1 | 5 | | | | 2 | | | 5 | 4 | | | | | | 1 | 38 | | | | | | | | 3 | | | | | | | | | | | | | | 61 |
| 924120 | 4 | | 2 | | | | | 2 | | 5 | 9 | | | | | | 6 | 25 | | | | | | | | 4 | | | | | | | | | | | | | | 57 |
| 924121 | 1 | 3 | | | | | 2 | | | 3 | 2 | | | | | | 4 | 35 | | | | | | | | 1 | | | | | | | | | | | | | | 51 |
| 924122 | 7 | | | | | | | 2 | | 5 | 2 | | | | | | 6 | 27 | | | | | | | | 8 | | | | 1 | | | | | | | | | | 58 |
| 924123 | | | 1 | | | | | | | 5 | 5 | | | | | | 9 | 38 | | | | | | | | 1 | | | | | | | | | | | | | | 58 |
| 924124 | | | 1 | | | | | | | | 2 | | | | | | 2 | 51 | | | | | | | | 1 | | | | | | | | | | | | | | 57 |
| 924125 | 3 | | | | | | 1 | | | 5 | 1 | | | | | | 7 | 34 | | | | | | | 1 | 4 | | | | | | | | | | | | 2 | | 58 |
| 924126 | | | | | | | | | | | 1 | | | | | | | 57 | | | | | | | | 2 | | | | | | | | | | | | 1 | | 61 |
| 924127 | | | 1 | | | | 1 | 1 | | | | | | | | | | 53 | | | | | | | | | 4 | | | | | | | | 1 | | | 1 | | 62 |
| 924128 | | | | | | | | | | | | | | | | | | 26 | | | | | | | | 1 | 21 | | | | | | | | | | | | | 48 |
| 924129 | 1 | | 3 | | | | | | | | 4 | | | | | | 13 | 36 | | | | | | | | 2 | | | 1 | | | | | | | 1 | | 1 | | 62 |
| 924130 | 14 | 5 | 1 | | | | | 7 | | 10 | 9 | | | | | | | 18 | | | | | | | | | | | | | | | | | | | | | | 64 |
| 924131 | 13 | 4 | | | | | | | | 11 | 13 | | | | | | 3 | 17 | | | | | | | | | | | | | | | | | | | | 1 | | 62 |
| 924132 | 17 | 5 | 4 | | | | | 3 | | 17 | 6 | | | | | | 4 | 21 | | | | | | | | 8 | | | | | | | | | | | | | | 85 |
| 924133 | 8 | 1 | 3 | | | | | 7 | | 9 | 13 | | | | | | 1 | 3 | | | | | | | | 4 | | | | | | | | | | | | | | 49 |
| 924134 | 3 | 3 | 2 | | | | | 2 | | 9 | 9 | | | | | | | 12 | | | | | | | | 3 | | | | | | | | | | | | | | 43 |
| 924135 | 2 | 2 | 1 | | | | | 5 | | 9 | 10 | | | | | | 3 | 7 | | | | | | | | 4 | | | | | | | | | | | | | | 43 |
| 924136 | 3 | | 5 | | | | | 2 | | 18 | 19 | | | | | | | | | | | | 1 | | | 7 | | | | | | | | | | | | | | 55 |
| 924137 | | | | | | | | | | | | | | | | | | 61 | | | | | | | | | | | | | | | | | | | | | | 61 |
| 924140 | | 1 | 7 | | | | | 3 | | 3 | 5 | 1 | | | | 5 | 10 | 22 | | | | | | | | 3 | | | | 5 | | | | | | 2 | | | | 67 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Gmt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qzpb | Unk | Tot |
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| 934000 | | | | | | | | | | | | | | | | | | 4 | | | | | | 66 | | | | | | 27 | | | | | | | | 3 | | 100 |
| 934001 | | | | | | | | | | | | | | | | | | 8 | | | | | | 38 | | | | | | 12 | 2 | | | | | | | 1 | | 61 |
| 934004 | 1 | | | | | | 7 | 34 | | 5 | | | | | | | | 1 | | | | | | | | | | | | | | | | 1 | | | | | | 49 |
| 934005 | 4 | | 1 | | | | 17 | 21 | | 6 | 1 | | 6 | | | | | | | | | | | 5 | 10 | | | 3 | 21 | 14 | | | | | | | 4 | | | 58 |
| 934008 | 39 | | | | | | 11 | 1 | | 2 | 2 | 10 | 1 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | 64 |
| 934009 | 4 | | 1 | | | | 12 | 54 | | 1 | 1 | | 2 | | | | | 3 | | | | | | | | | | 2 | | | | | | | | | | | | 80 |
| 934011 | 17 | | | | | | 25 | 34 | | 4 | 8 | | 3 | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | 93 |
| 934012 | 10 | 2 | 1 | | | | 31 | 32 | | 8 | 8 | | | | | | | 4 | | | | | | | | | | | | | | | | | | | | | | 96 |
| 934013 | 43 | 2 | | | | | 7 | 37 | | 1 | 1 | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | 94 |
| 934016 | 42 | | 1 | | | | 1 | 23 | | | | | | | | | | 8 | | | | | | | | | | 1 | | | | | | | | | | | | 76 |
| 934017 | 11 | | | | | | 8 | 13 | | 6 | 3 | 1 | | | | | | 39 | | | | | | | | | | | | | | | | | | | | | | 81 |
| 934018 | 10 | 1 | 1 | | | | 1 | 8 | | | | 4 | 2 | | | 1 | | 71 | | | | | | | | | | | | | | | | | | | | | | 99 |
| 934019 | 12 | 5 | | | | | 6 | 21 | | 6 | 9 | | 2 | | | | 3 | 1 | | | | | | | | | | 14 | | | | | | 1 | | | | | | 80 |
| 934020 | 7 | 3 | 22 | | | | 9 | 9 | | 4 | 5 | | 3 | | | 1 | | 2 | | | | | | | | | | | | | | | | | | | | | | 65 |
| 934021 | 3 | | | | | | 10 | 1 | | 30 | 2 | 10 | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | 59 |
| 934022 | | 4 | 4 | | | | 9 | | | 6 | 1 | | | | | | | | | | | | | | | 3 | | | | | | | | 3 | | | 2 | | 18 | 50 |
| 934023 | | | | | | | | | | 9 | 40 | | | | | | | 1 | | | | | | | 1 | | | | | 1 | | | | | | | | | | 55 |
| 934024 | 5 | | | | | | | | | 5 | 15 | 7 | | | | | | 3 | | | | | | | | | | | | 2 | | | | | | | 7 | | | 36 |
| 934025 | 2 | 7 | 1 | | | | 3 | 8 | | 2 | 3 | 17 | | | | | | 17 | | | | | | 2 | | | | | | | | | | | | | | 1 | | 63 |
| 934027 | 4 | 12 | | | | | | 1 | | 5 | | | | | | | | 41 | | | | | | 6 | 10 | 1 | | | 19 | | | | | | | | | | | 99 |
| 934028 | | 5 | 4 | | | | | | | 8 | 4 | 1 | | | | | | 17 | | | | | | 1 | | 1 | | 1 | 16 | 3 | | | | 2 | | | | | 1 | 64 |
| 934029 | | 1 | | | | | | | 2 | 2 | 4 | | | | | 5 | | 38 | | | | | | | | 1 | | | 2 | 6 | | | | 1 | | | | | 2 | 64 |
| 934030 | | 2 | | | | | | | | 1 | | | | | | 9 | | | | | | | | | | 1 | 3 | | 17 | 3 | | | | | | | 17 | | | 53 |
| 934032 | | | | | | | | | | | | | | | | 4 | 6 | | | | | | | | | | | 2 | 54 | 9 | | | | | | | | 1 | 4 | 80 |
| 934033 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | 2 | | 1 | 54 | 26 | | | | | | | | | 1 | 85 |
| 934034 | | | 1 | | | | | | | 3 | 2 | 4 | | | | 1 | 2 | | | | | | | | | 1 | | 2 | 25 | 12 | | | | 8 | | | | | | 58 |
| 934035 | | | 1 | | | | | | | 4 | 3 | | | | | 5 | 1 | | | | | | | | | 2 | | 1 | 40 | 17 | | | | 1 | | | | | 1 | 76 |
| 934036 | | 1 | | | | | | | | 24 | 6 | | | | | 3 | 1 | | | | | | | | | 3 | | 1 | 9 | 23 | | | | 3 | | | | | | 74 |
| 934037 | 6 | | 12 | | | | 25 | 6 | | 4 | 8 | 8 | 2 | | | 1 | 1 | | | | | | | | | | | 4 | | | | | | 6 | | | | | | 83 |
| 934038 | 8 | 1 | 18 | | | | 16 | 2 | | 19 | 6 | | 11 | | | | | 5 | | | | | | | | | | 1 | | | | | | 2 | | | | | | 89 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mlsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
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| 934039 | 6 | | | | | | 11 | 5 | | 12 | | 1 | 6 | | | | | 17 | | | | | | | | | | | | | | | | | | | | | | 58 |
| 934040 | 8 | 2 | 13 | | | | 2 | | | 27 | 18 | | 3 | | | 1 | | 5 | | | | | | | 1 | 1 | | | | | | | | | | | | | | 81 |
| 934041 | 7 | 3 | 17 | | | | 5 | 10 | | 28 | 5 | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 82 |
| 934045 | 2 | 1 | 21 | | | | 22 | 8 | | 5 | 4 | | | | | | | 3 | | | | | | | 3 | | | | | | | | | 4 | | | | | | 73 |
| 934046 | 3 | | | | | | | 2 | | | | | | | | | | 15 | | | | | 36 | | | | | | | 1 | | | | | | | | | | 57 |
| 934047 | | | | | | | | 2 | | | | | | | | | | 5 | | | | | 63 | 1 | 1 | | | | | 2 | | | | | | | | | | 74 |
| 934048 | 3 | | | | | | 1 | | | | | | | | | | | 4 | | | | | 63 | | | | | | | | | | | | | | | | | 71 |
| 934052 | | | | | | | | | | | | | | | | | | | | | | | | 71 | | | | | | | | | | | | | | | | 71 |
| 934053 | | | | | | | | | | | | | | | | | | | | | | | | 56 | | | | | | | | | | | | | | | | 56 |
| 934054 | | | | | | | | | | | | | | | | | | | | | | | | 41 | | | | | | | | | | | | | | | | 41 |
| 934055 | | | | | | | | | | | | | | | | | | | | | | | | 46 | | | | | | 8 | 2 | | | | | | | | | 56 |
| 934056 | | | | | | | | | | | | | | | | | | | | | | | | 64 | | | | | | | 2 | | | | | | | | | 66 |
| 934057 | | | | | | | | | | | | | | | | 5 | | 61 | | | | | | 2 | | | | | 1 | | 2 | | | | | | | | | 71 |
| 934058 | | | | | | | | | | | | | | | | 4 | | 51 | | | | | | | | | | | | | | | | | | | | | | 55 |
| 934059 | | | | | | | | | | | | | | | | 3 | | 52 | | | | | | | | | | | | 1 | | | | | | | | | | 56 |
| 934060 | 3 | 2 | 2 | | | | | | 2 | 2 | 2 | 1 | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | 16 |
| 934061 | | | | | | | | | | | | | | | | | 3 | 30 | | | | | | | | | | | | 22 | | | | | | | | | | 55 |
| 934062 | | | | | | | | 1 | | | | | | | | | | 8 | | | | | | | 11 | | | | | | 1 | | | | | | | | | 21 |
| 934063 | 1 | 3 | | | | | | 3 | | 1 | 4 | | | | | 7 | | 25 | | | | | | | | | | | | 20 | 2 | | | | | | | | | 66 |
| 934064 | | | | | | | | | | | | | | | | | | 15 | | | | | | | 37 | | | | | | | | | | | | | | | 52 |
| 934065 | | | | | | | | | | | | | | | | | | 15 | | | | | | | 54 | | | | 1 | | 2 | | | | | | | | | 72 |
| 934066 | 1 | 2 | 1 | | | | | | | 1 | 1 | | | | | | | 39 | | | | | | | | | | | | | | | | | | | | | | 45 |
| 934067 | | 5 | 5 | | | | | 9 | | 3 | 2 | 10 | 2 | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | 39 |
| 934068 | | | | | | | | | | 2 | 1 | | | | | | | 49 | | | | | | | | | | | | | | | | | | | | 1 | | 53 |
| 934068 | | | | | | | | | | 2 | 1 | | | | | | | 49 | | | | | | | | | | | | | | | | | | | | 1 | | 53 |
| 934069 | | | | | | | | | | | | | | | | | | 33 | | | | | | | 3 | 2 | | | 6 | 10 | | | | | | | | | | 54 |
| 934070 | | | | | | | | | | | | | | | | | | 30 | | | | | | | | 11 | | | 5 | 20 | 3 | | | | | | | | | 69 |
| 934073 | | | | | | | | | | | | | | | | | | 3 | | | | | | 33 | | | | | 4 | 2 | | | | 1 | | | | | | 43 |
| 934076 | | | | | | | | | | | | | | | | | | 18 | | | | | | 27 | | | | | | 13 | | | | | | | | | | 58 |
| 934083 | | | | | | | | | | | | | | | | 9 | | 5 | | | | | | 27 | | | | | 2 | 4 | 3 | | | | | | | | 7 | 57 |

539

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | HL | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Grnt | Gbr | Ultr | Tuf | Rhy | Bslt | Qzte | Mtsd | Mar | Amp | Acvl | Gngr | Prph | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 934086 | | | | | | | | | | | | | | | | | | 36 | | | | | | 49 | | | | | | | 3 | | | | | | | | | 88 |
| 934089 | | | | | | | | | | | | | | | | | | 39 | | | | | | | 16 | | | | | 6 | 1 | | | | | | 1 | | | 63 |
| 934090 | | | | | | | | | | | | | | | | 43 | 21 | | | | | | | | | | | | | | | | | | | | | | | 64 |
| 934091 | | | | | | | | | | 2 | | | | | | 64 | | | | | | | | | 1 | | | | | 2 | | | | | | | | | | 69 |
| 934092 | | 1 | | | | | | | | | | 2 | | | | 57 | | | | | | | | | 1 | | | | 3 | 6 | | | | | | | | | 2 | 72 |
| 934093 | | 1 | 1 | | | | | | | 1 | 5 | | | | | 37 | | | | | | | | | | | | | 7 | 3 | | | | | | | 2 | | | 57 |
| 934103 | | 14 | 5 | | | | | | | 11 | 2 | | | | | 5 | | | | | | | | | 2 | | | | 11 | 14 | | | | | 10 | | | | | 74 |
| 934108 | | | | | | | | | | | | | | | | | 32 | 9 | | | | | | | | | | | | | | | | | | | | | 8 | 49 |
| 934109 | | 1 | 1 | | | | | | | | | | | | | | 21 | 30 | | | | | | | | | | | | | | | | | | | | | 3 | 56 |
| 934112 | | | | | | | | | | 1 | | | | | | | 22 | 20 | | | | | | | | | | | 4 | | 1 | | | | | | | | | 48 |
| 934114 | | | | | | | | | | | | | | | | | 9 | 26 | | | | | | 7 | | | | | | | | | | | | | | | | 42 |
| 934115 | | 2 | | | | | | | | | | | | | | | 41 | 11 | | | | | | 13 | | | | | | | 1 | | | | | | | | | 68 |
| 934116 | | | | | | | | | | | | | | | | | 40 | | | | | | | | | | | | | | | | | | | | 1 | | | 41 |
| 934118 | | | | | | | | | | | | | | | | | 49 | 5 | | | | | | | | | | | 1 | | | | | | | | | | | 55 |
| 934119 | | | | | | | | | | | | | | | | | 54 | 2 | | | | | | | | | | | | | | | | | | | | | | 56 |
| 934122 | | | | | | | | | | | | | | | | | 1 | 47 | | | | | | | | | | | | | | | | | | | | | 10 | 58 |
| 934123 | | | | | | | | | | | | | | | | | | 57 | | | | | | 7 | 1 | | | | | | | | | | | | | | | 65 |
| 934125 | | | | | | | | | | | | | | | | | 23 | 19 | | | | | | 19 | | | | | | | 1 | | | | | | | | | 62 |
| 934126 | | | | | | | | | | | | | | | | | 29 | 35 | | | | | | 3 | | | | | | 3 | | | | | | | | | | 70 |
| 934127 | | | | | | | | | | | | | | | | | 9 | 47 | | | | | | | 1 | | | | | | | | | | | | | | | 57 |
| 934128 | | | 1 | | | | | | | | | | | | | | 4 | 1 | | | | | | | | | | | | 1 | | | | | | | | | | 7 |
| 934130 | | | | | | | | | | 1 | | 2 | | | | 13 | | | | | | | | | | | | | | | | | | | | | | | | 16 |
| 934131 | | | | | | | | | | 28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 17 | 45 |
| 934132 | | 1 | | | | | | | | 7 | | 8 | | | | | | 5 | | | | | | | | | | | 16 | | | | | | | | | | | 37 |
| 934133 | | | | | | | | | | | | | | | | 66 | | 3 | | | | | | | | | | | | | | | | | | | | | | 69 |
| 934134 | | | | | | | | | | | | | | | | 56 | | 1 | | | | | | | | | | | | | | | | | | | | | | 57 |
| 934135 | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | 3 | 1 | | | | | | | | | 6 |
| 934136 | | | | | | | | | | | | | | | | | | 5 | | | | | | 3 | | | | | | | | | | | | | | | | 8 |
| 934137 | | | | | | | | | | | | | | | | | | 59 | | | | | | 7 | | | | | | | 1 | | | | | | | | | 67 |
| 934138 | | | | | | | | | | | | | | | | | | 26 | | | | | | 32 | | | | | | | 1 | | | | | | | | | 59 |

| Sample | Sq | Sm | Sp | Ssy | Tps | Ss | Ssm | Ssf | Oi | Oib | Oic | Oid | Ohm | MM | TH | Shl | Slst | Sdst | Arks | Cng | Lst | Dlmt | Scst | Gnss | Gmi | Gbr | Utu | Tuf | Rby | Bslt | Qtzc | Mtsd | Mar | Amp | Acvl | Cngr | Prpb | Qtzpb | Unk | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 934139 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  | 39 |  |  |  |  |  |  | 9 |  |  |  |  |  | 1 |  | 1 | 55 |
| 934140 |  | 3 | 1 |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 37 | 15 |  |  |  |  |  |  | 3 |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  | 63 |
| 934141 |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 17 | 20 |  |  |  |  |  |  | 2 |  |  |  | 5 |  | 1 |  |  |  |  |  |  |  | 17 | 63 |
| 934142 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 | 25 |  |  |  |  |  |  |  |  |  |  | 40 |  |  |  |  |  |  |  |  |  |  | 70 |
| 924001A | 1 | 1 | 1 |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 3 | 1 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |

540

# NOTE TO USERS

Oversize maps and charts are microfilmed in sections in
the following manner:

# LEFT TO RIGHT, TOP TO BOTTOM, WITH
# SMALL OVERLAPS

## UMI
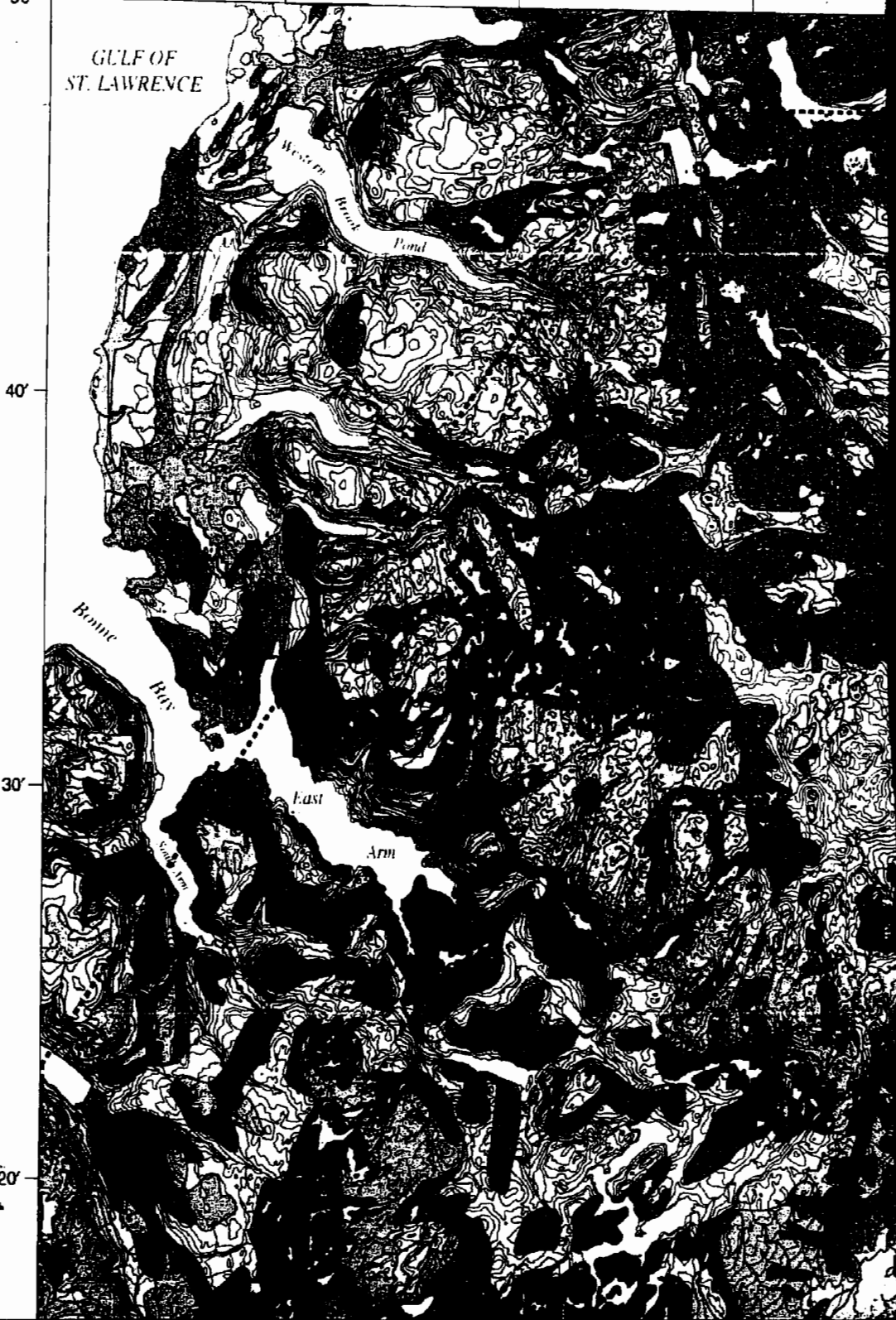
GULF OF
ST. LAWRENCE

Western Brook Pond

Bonne Bay

East Arm

58° 00'    50'    40'    57° 30'
49° 50'
40'
49° 30'
20'

LIMIT OF STUDY AREA

Sops Arm

Adies
85±
Pond

Sandy

Lake

WHITE

BAY

40'

Black Lake

49° 30'

171±

Sheffield Lake

20'

# SURFICIA

## O
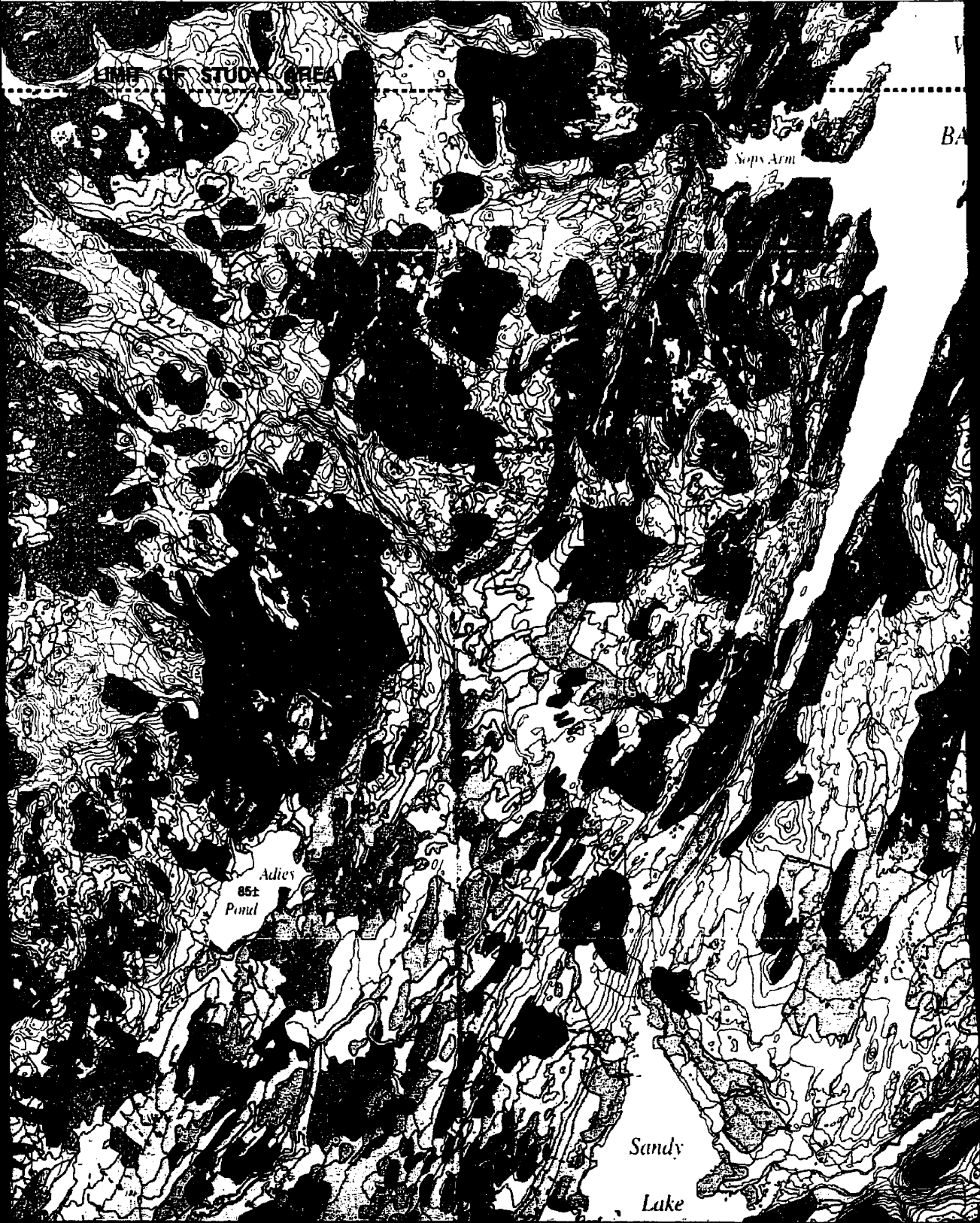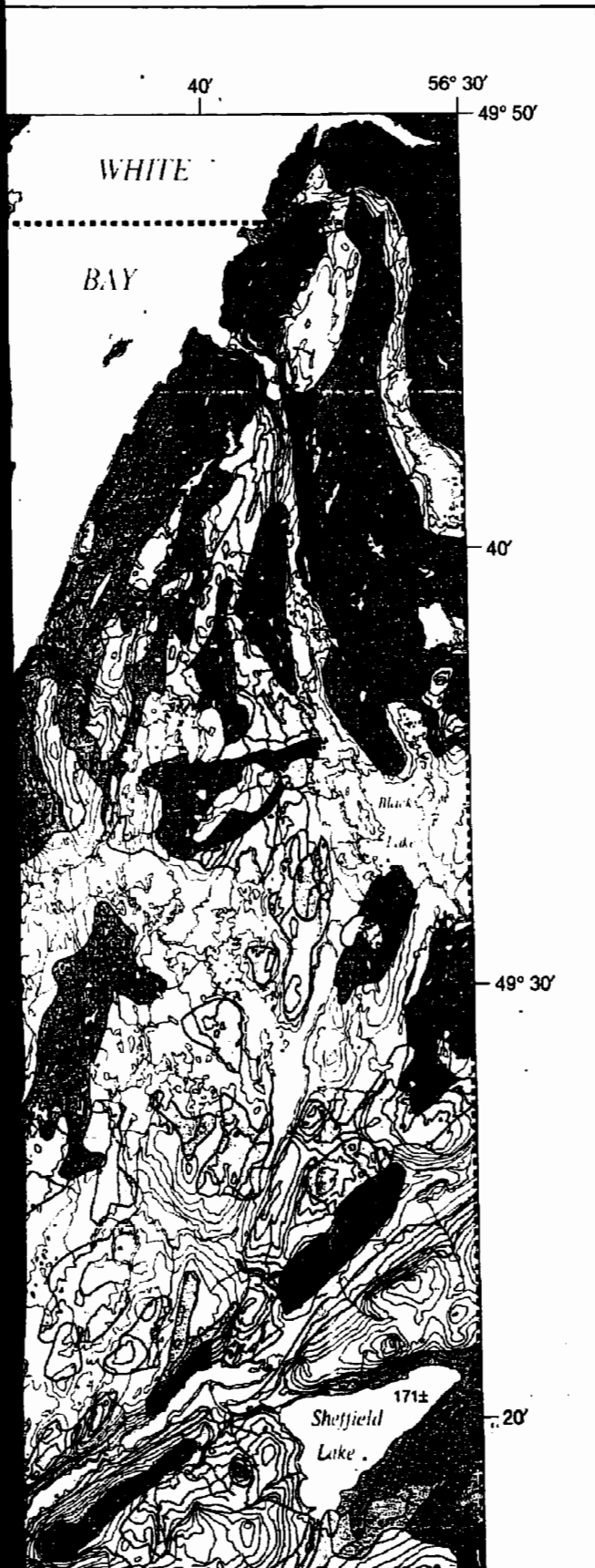
## HUMBER RIVER BASIN

(parts of NT

Scale

0        5        10

kil
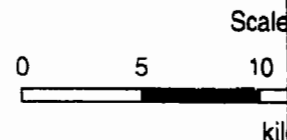
Contour interval ap
Elevations in metre

**LEGE**

**Exposed bedrock:** *exposed bedrock with little
till and other surficial sediment present but rare
controlled*

**Concealed bedrock:** *bedrock, mainly conceale
and bog (commonly less than 1.5 m thick) and
than 50 percent of the unit*

**Diamicton veneer:** *thin (less than 1.5 m) disco
sediment containing grain sizes from clay to bo
bedrock and thicker sediment cover common; di
matrix (sand size or finer), and 80% to 10% cla
dominated by sand with less than 20% silt and
clasts mostly granules (0.2 to 0.4 cm diameter),
topography variable and bedrock controlled*

**Eroded diamicton:** *continuous diamicton cover
between 1.5 and 15 m thick; diamicton of similar
sand and gravel are common at the surface with
blanket has been eroded by glacial meltwater*

**Hummocky diamicton:** *a blanket of diamicton,
topography and relief of 2 to 10 m; hummocks
contain poorly sorted sand and gravel; diamicto
commonly found in low areas between hummod
disintegration and stagnation during deglaciatio*

**Ridged diamicton:** *a blanket of diamicton, 1.5
streamlined elongate ridges 1.5 to 20 m high, an
tion to diamicton veneer; this unit was likely dep
of ridges either parallel or perpendicular to ice f*

**Glaciolacustrine sediment:** *a blanket of sedir
surface morphology; sediment is commonly poo
may be found in distinct beds; beds of sand and
fan deltas with smooth, inclined surfaces, or fla
channels; this unit was deposited in a proglacia*

# SURFICIAL GEOLOGY
## OF THE
## RIVER BASIN AND SURROUNDING AREAS
## (parts of NTS 12H and 12A)

Scale 1:250 000

| 5 | 10 | 15 | 20 | 25 |

kilometres

Contour interval approximately 30.5m (250 ft.)
Elevations in metres above sea level

## LEGEND

osed bedrock with little or no sediment or vegetation cover; patches of
diment present but rare; topography and relief variable, and bedrock

edrock, mainly concealed by vegetation; patches of till, sand and gravel,
s than 1.5 m thick) and exposed bedrock are common, but form less
unit

(less than 1.5 m) discontinuous sheet of diamicton (poorly sorted
in sizes from clay to boulders) overlying bedrock; patches of exposed
liment cover common; diamicton generally contains from 20% to 90%
er), and 80% to 10% clasts (greater than sand size); matrices generally
less than 20% silt and clay; maximum clast sizes from 1 to 2 m diameter, but
0.2 to 0.4 cm diameter), and pebbles (0.4 to 6.4 cm diameter); relief and
d bedrock controlled

tinuous diamicton cover commonly with a channeled surface topography
hick; diamicton of similar composition to diamicton veneer; where channeled,
mmon at the surface within channels; channeled areas form when a diamicton
d by glacial meltwater

: a blanket of diamicton, 1.5 to 15 m thick having irregular hummocky
f 2 to 10 m; hummocks are mainly composed of diamicton, but some may
and and gravel; diamicton is of similar composition to diamicton veneer; bog is
areas between hummocks; this unit was mainly deposited by ice
nation during deglaciation

blanket of diamicton, 1.5 to 20 m thick, with a topography consisting of
dges 1.5 to 20 m high, and 0.2 to 500 m long; diamicton is of similar composi-
er; this unit was likely deposited under actively flowing ice, with the long axis
or perpendicular to ice flow

ment: a blanket of sediment, 1.5 to 30 m thick having a smooth to irregular
ediment is commonly poor to well sorted sand and gravel, although silt-clay
t beds; beds of sand and gravel commonly are inclined; sediment comprises
inclined surfaces, or flat-topped deltas; irregular areas dissected by meltwater
deposited in a proglacial lake formed during deglaciation of the Grand Lake

d gravel: poor to well sorted sand and gravel, 1.5 to 50 m thick, having a
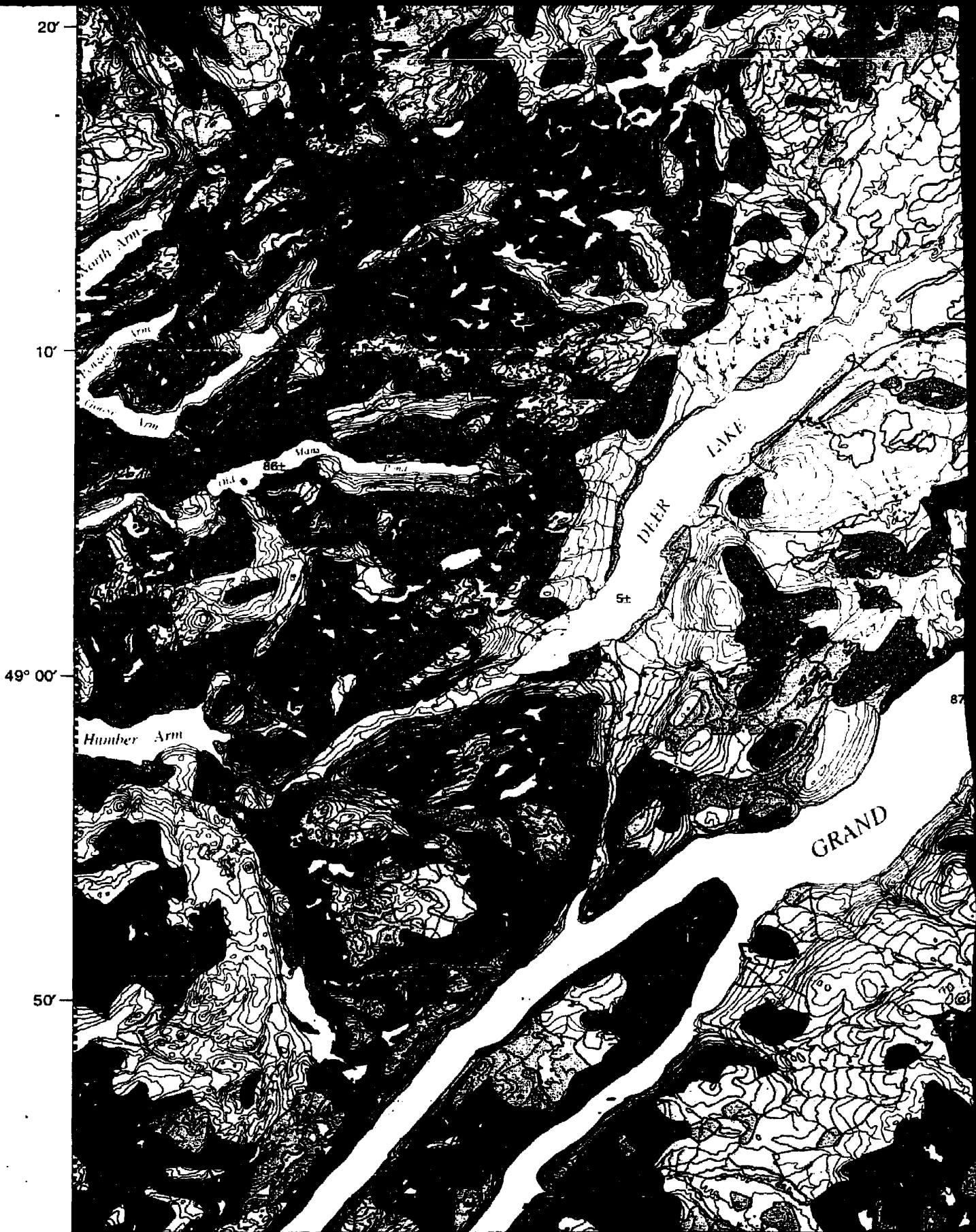
Sandy
Lake
87±

LAKE

87±

309±

Hinds
Lake
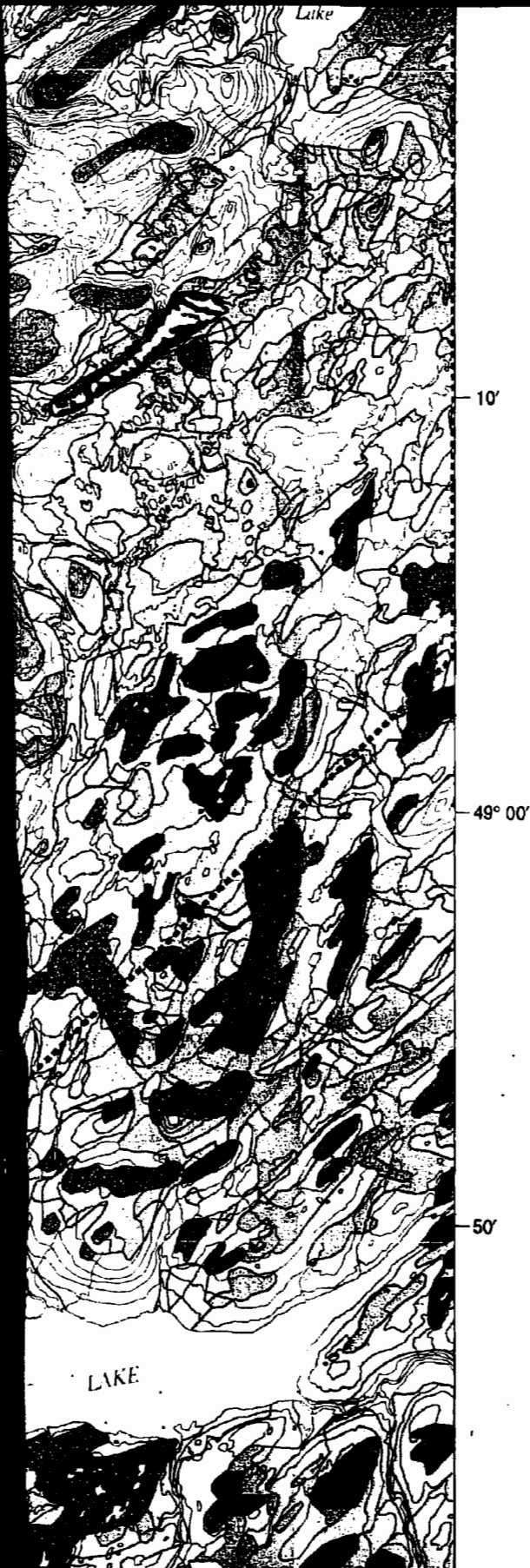
ND

152±      LAKE

NDIAN

**Glaciolacustrine sediment:** a blanket of sed
surface morphology; sediment is commonly po
may be found in distinct beds; beds of sand ar
fan deltas with smooth, inclined surfaces, or fl
channels; this unit was deposited in a proglaci
valley

**Glaciofluvial sand and gravel:** poor to well s
diverse surface topography; gravel is pebble to
unit includes eskers (sinuous, elongate ridges
to steep sided mounds up to 15 m high), and d
surface, 3 to 20 m thick, and up to 10 km long)

**Marine clay, sand, gravel and diamicton:** th
deposited in a marine or glaciomarine environr
50 m thick, found in marine terraces and raised
are found in ice distal glaciomarine deposits wi
all of these sediments have been raised to thei
relative sea level fall since deglaciation

**Fluvial:** low relief plains with channeled surfac
to well sorted gravel, sand, silt and clay, depos

**Colluvium:** a mixture of rock debris and uncor
forming aprons at the base of steep slopes

**Bog:** accumulations of degraded organic matte

**Note:** This map is a summary of the sur
largely compiled from detailed 1:50 000 scale s
text of the thesis refer to these maps. The read

### SYM

Moraines (large, small) ......
Meltwater channel (large, s
Crag-and-tail hill ..............
Esker (direction known, unk
Flute ................................

**Reference list**
This map was compiled from the following informa

BATTERSON, M.J. 1992. Surficial geology and lar
map sheet (NTS 12A/13). Newfoundland Departmer
92-13. Scale 1:50 000.

BATTERSON, M.J. 1994a. Surficial geology and la
sheet (NTS 12H/03). Newfoundland Department of
94-119. Scale 1:50 000.

BATTERSON, M.J. 1994b. Surficial geology and la
sheet (NTS 12H/04). Newfoundland Department of
94-120. Scale 1:50 000.

BATTERSON, M.J. 1994c. Surficial geology and la
sheet (NTS 12H/06). Newfoundland Department of
94-121. Scale 1:50 000.

LIVERMAN, D.G.E. and TAYLOR, D.M. 1991a. Sur
map area (NTS 12A). Newfoundland Department of

LIVERMAN, D.G.E. and TAYLOR, D.M. 1991b. Sur
area (NTS 12H). Newfoundland Department of Mine

**Figure 2-1.** Quaternary history, palaeo-geograph
and adjacent areas. Ph.D. thesis, Department of

Geology by: Martin Batterson

ict beds; beds of sand and gravel commonly are inclined; sediment comprises
h, inclined surfaces, or flat-topped deltas; irregular areas dissected by meltwater
s deposited in a proglacial lake formed during deglaciation of the Grand Lake

nd gravel: poor to well sorted sand and gravel, 1.5 to 50 m thick, having a
raphy; gravel is pebble to cobble sized_ and forms 50 to 95% of the sediment; the
sinuous, elongate ridges 3 to 15 m high, and up to 5 km long); kames (moderate
ls up to 15 m high), and outwash plains (plains with low relief, and a channeled
ck, and up to 10 km long)

ravel and diamicton: this unit consists of a wide range of sediment types,
e or glaciomarine environment; moderately to well sorted gravel and sand, up to
arine terraces and raised beaches; well sorted silt and clay, up to 90 m thick,
' glaciomarine deposits with most of the sediment lying below modern sea level;
s have been raised to their present elevation by isostatic rebound, resulting in
since deglaciation
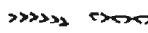
ins with channeled surfaces close to modern rivers, consisting of moderate
sand, silt and clay, deposited in modern river systems

e of rock debris and unconsolidated sediment deposited by mass movement
e base of steep slopes

of degraded organic matter deposited in poorly drained low-lying areas

ap is a summary of the surficial geology of the Humber River basin area. It was
n detailed 1:50 000 scale surficial mapping. Unit designations found within the
r to these maps. The reader is referred to the open file maps for details.

## SYMBOLS

Moraines (large, small) ...........................
Meltwater channel (large, small) .............
Crag-and-tail hill .....................................
Esker (direction known, unknown) ..........
Flute ......................................................

iled from the following information:

1992. Surficial geology and landform classification of the Corner Brook
/13). Newfoundland Department of Mines and Energy, Open file 12A/0616, Map
00.

1994a. Surficial geology and landform classification of the Deer Lake map
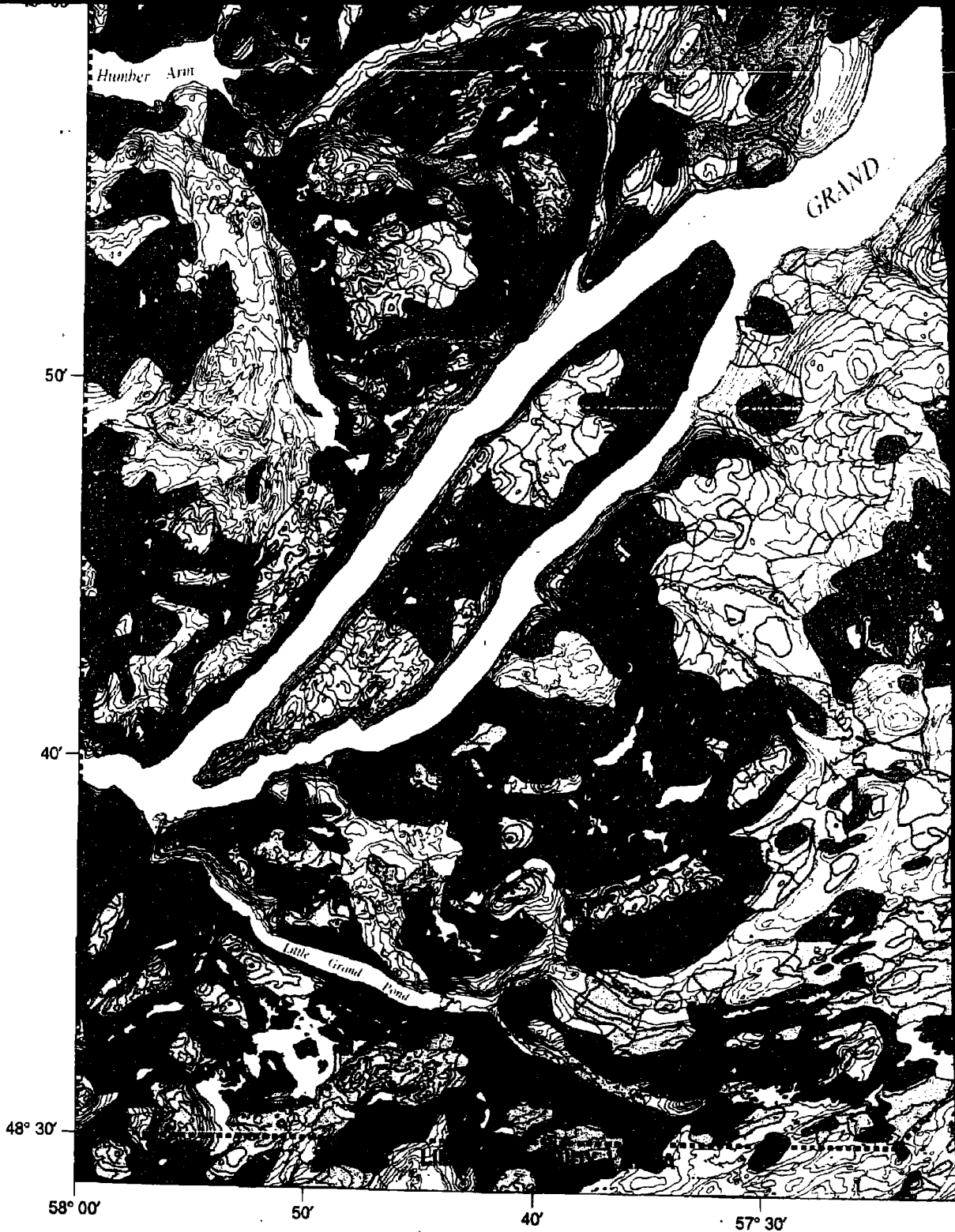). Newfoundland Department of Mines and Energy, Open File 12H/1287, Map
000.

1994b. Surficial geology and landform classification of the Pasadena map
. Newfoundland Department of Mines and Energy. Open file 12H/1288, Map
000.

1994c. Surficial geology and landform classification of the Cormack map
. Newfoundland Department of Mines and Energy, Open file 12H/1289, Map
000.

and TAYLOR, D.M. 1991a. Surficial geology of the Red Indian Lake
). Newfoundland Department of Mines and Energy, Map 94-236. Scale 1:250000.

and TAYLOR, D.M. 1991b. Surficial geology of the Sandy Lake map
wfoundland Department of Mines and Energy, Map 94-237. Scale 1:250 000.

ary history, palaeo-geography and sedimentology of the Humber River Basin
Ph.D. thesis, Department of Geography, Memorial University of Newfoundland.
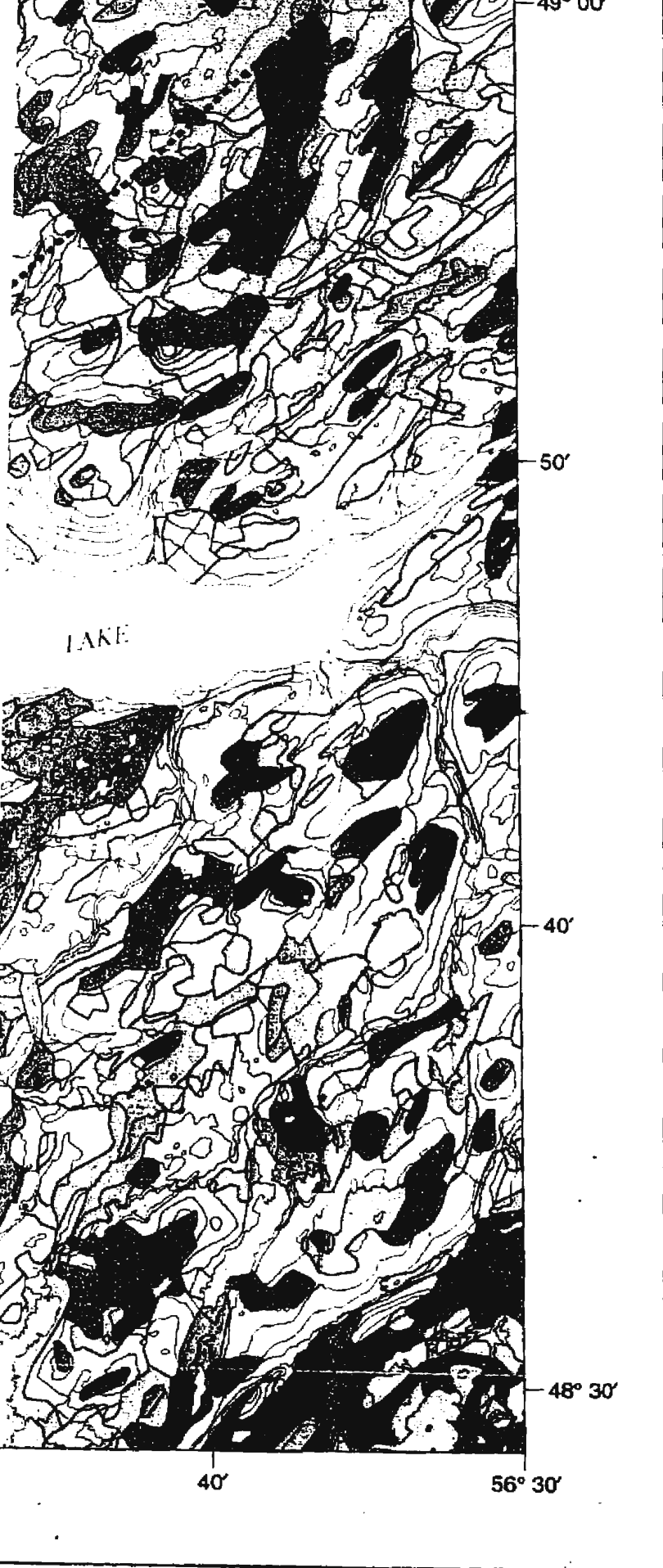
Batterson

87±

309±

*Hinds
Lake*

*LAKE*

152±

*INDIAN*

*RED*

20'            10'            57° 00'            50'

49° 00'

50'

LAKE

40'

48° 30'

40'    56° 30'

Crag-and-tail hill ..................
Esker (direction known, unkn...
Flute ·.................................

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sheet (NTS 12H/04). Newfoundland Department of...
94-120. Scale 1:50 000.

BATTERSON, M.J. 1994c. Surficial geology and la...
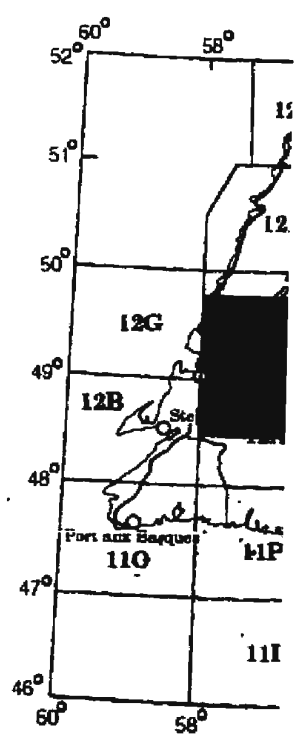sheet (NTS 12H/06). Newfoundland Department of...
94-121. Scale 1:50 000.

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map area (NTS 12A). Newfoundland Department of...

LIVERMAN, D.G.E. and TAYLOR, D.M. 1991b. Su...
area (NTS 12H). Newfoundland Department of Min...

**Figure 2-1.** Quatemary history, palaeo-geograp...
and adjacent areas. Ph.D. thesis, Department o...

Geology by: Martin Batterson

Cartography by: Tony Paltanavage, Geological



II

Crag-and-tail hill ......................................... ↩

Esker (direction known, unknown) .......... >>>>>> ◇◇◇◇

Flute ......................................................... ＼

st

s compiled from the following information:

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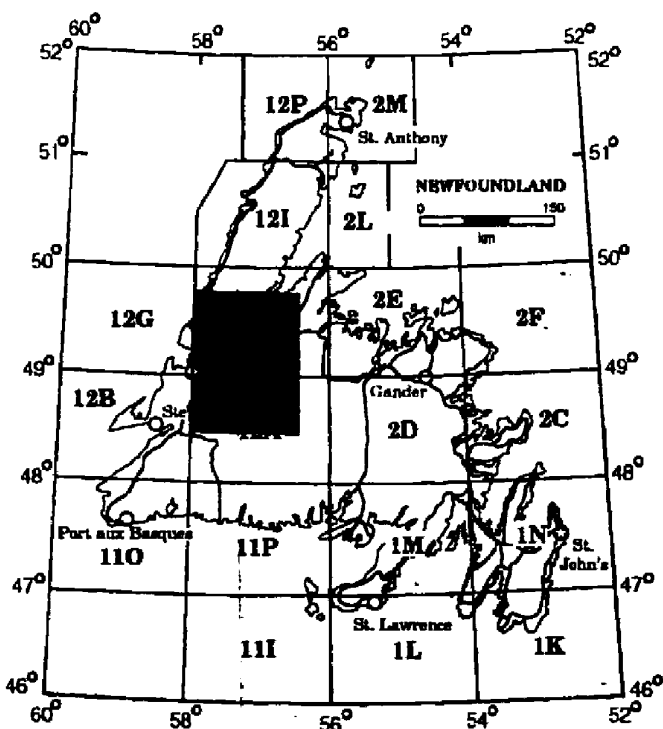2H/06). Newfoundland Department of Mines and Energy, Open file 12H/1289, Map
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Iartin Batterson

by: Tony Paltanavage, Geological Survey, Department of Mines and Energy.



INDEX MAP