STRATIGRAPHY AND CHRONOLOGY OF DEGLACIAL EVENTS AT HIGHLANDS, SOUTHERN ST. GEORGE'S BAY, SOUTHWEST NEWFOUNDLAND

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by

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Abstract

This thesis describes and interprets the sedimentology, geomorphology, and chronology of Quaternary deposits at Highlands, southern St. George's Bay, southwest Newfoundland. These deposits are critical in understanding the glacial and deglacial history of the region, and whether retreat was interrupted by a climatic reversal causing a readvance at ~12.6 ka BP across the lowlands around St. George's Bay.

The physiography of the Highlands area consists of a low-relief coastal plain backed to the east and south by the Long Range and Anguille mountains, respectively. The coastal plain is dominated by gravel near the coast, with till outcropping farther inland. The uplands are dominated by bedrock interspersed with till veneer. Late Wisconsinan ice, originating on the southern Long Range Mountains, covered the entire area and extended to a terminal position offshore in St. George' Bay. Striations and clast fabrics indicate that ice flow was generally west-northwestward and unconfined by topography. Deglacial ice flow was affected by topographic highs becoming diverted southwestward down Codroy Valley and south of Bald Mountain.

Retreat of ice across the lowlands occurred in a tidewater environment. Sediments exposed in the coastal sections relate to this retreat and were mostly deposited near the grounding-line on a subaqueous fan, as sediment and meltwater entered the sea via a subglacial jet. Two distinct sedimentary sequences relating to the surface topography occur along the coast. The coast is dominated by planar surfaces at 18 to 20 m asl and 24 to 26 m asl, interrupted by the Highlands ridge ranging from 34 m asl at the coast, to >60 m asl inland. Exposures through the planar surfaces consist generally of bedrock, overlain successively by diamicton, mud, sand, gravel, and sand and silt. These

represent a deglacial sequence from subglacial and proglacial deposition of the diamicton; to glaciomarine sedimentation of the mud and sand; and glaciofluvial/fluvial deposition of the gravel on outwash terraces. Sand and silt capping the coastal sections are interpreted as aeolian deposits.

Exposures through where Highlands ridge intersects the coast (Highlands section) consist of mud, overlain sequentially by sand and gravel; diamicton; gravel and gravelly sand; and sand and silt. This section represents the more proximal part of the grounding-line fan. Diamicton forms a continuous unit along the top of the Highlands section, grading laterally from structureless to stratified, and has characteristics of subglacial, proglacial, sediment gravity flow, and rainout depositional processes. At one site, a fossiliferous diamicton is interpreted to be deposited by a combination of sediment gravity flows, suspension settling from meltwater plumes and ice rafting, and traction currents. A radiocarbon date of 13 680 ± 90 BP (Beta-120124) on paired shells from this diamicton is interpreted to represent the date of its emplacement. This date lies within the range of all other dates (~13.1 to 14 ka BP) on marine organisms from sediments along the coast of southern St. George's Bay, and suggests that deposition of the diamicton was contemporaneous with sedimentation in all areas along the coast. Evidence to support a climatically induced readvance at ~12.6 ka BP was not found.

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I am very grateful to the Government of Newfoundland and Labrador, Department of Mines and Energy (Geological Survey) for offering me employment in their Quaternary mapping programs during the summers of 1996 through 1999. I thank Dr. David Liverman, the other member of my supervisory committee, for his time and effort. He initially introduced me to Quaternary field work in 1996, when I worked as his assistant in Goose Bay, Labrador. I also benefited greatly from working as a senior assistant under his supervision in 1998, when research for this thesis was carried out. Excellent field assistance was provided by Danny O'Dell and Mark Osmond. I thank Dr. Martin Batterson for his encouragement and interesting discussions on the Quaternary geology of the west coast, where I worked as his assistant during this past summer; and for reading various drafts of things I wrote over the last few months. Dave Taylor of the Geological Survey and Andrea Bassan were also very helpful and supportive. Terry Sears, Tony Paltanavange, and Dave Leonard of the Department of Mines and Energy cartographic laboratory were always helpful and responsive to my inquiries regarding diagrams and the use of lab facilities; Tony produced the excellent colour surficial maps (Figures 2.1, 2.2). Helen Gillespie of the Department of Earth Sciences (Memorial University) taught me how to use the Sedigraph and was very helpful with the grain size analyses.

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Chapter 1 Introduction and Background

1.1 Introduction

This thesis describes and interprets the sedimentology, geomorphology, and chronology of Quaternary deposits at Highlands, southern St. George's Bay, southwest Newfoundland. This region contains the thickest and most extensive exposures of unconsolidated sediments compared to anywhere on the island of Newfoundland. These exposures were studied initially in the 1930s (MacClintock and Twenhofel, 1940) and became the subject of more detailed analysis throughout the 1960s and 1970s (Brookes, 1969, 1970, 1972, 1974, 1975, 1977a,b). More recently, these sections have been reexamined (Liverman and Bell, 1996; Liverman et al. 1999; Batterson and Janes, 1997; Batterson and Sheppard, 2000; Bell et al. 1999; Bell et al. submitted; Sheppard et al. 1999; in press).

The deposits at Highlands are critical to the ongoing debate on the style of deglaciation, and whether overall retreat was punctuated by a climatically induced readvance across the lowlands around St. George's Bay. Resolution of the genesis of sediments and landforms at Highlands is considered an important step in understanding the deglacial history in western Newfoundland and northeastern North America (Atlantic Canada) because Highlands has been recognized as an area that provides evidence of a late-glacial readvance (Brookes, 1974).

1.2 Location and access

The study area lies on the southwest coast of Newfoundland, in southern St. George's Bay (Fig. 1.1). It is bounded in the south by the Anguille Mountains, to the

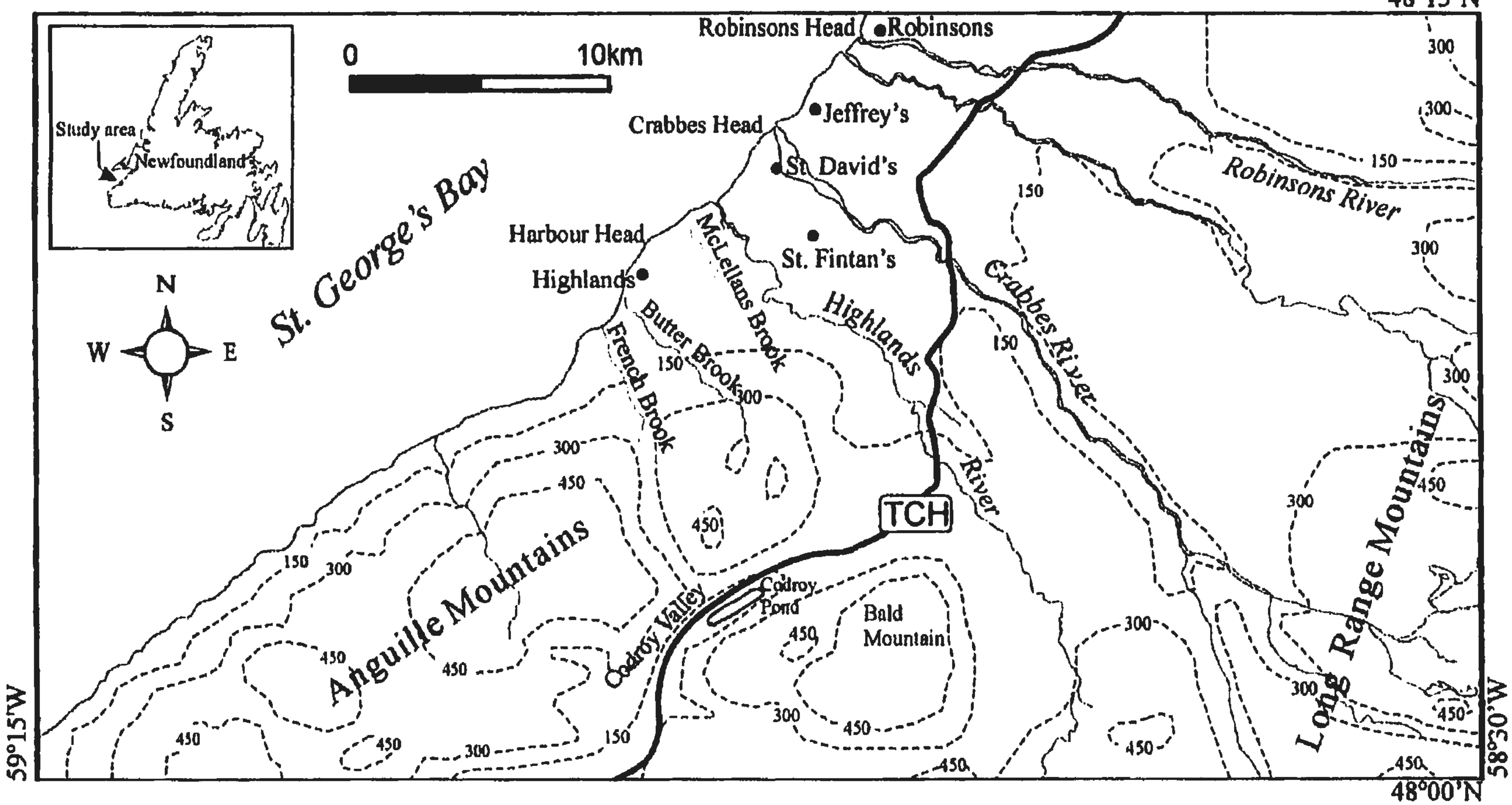

Figure 1.1 Location map of southern St. George's Bay. This study focuses on the area south of Crabbes River.

north by Crabbes River, and east by the Long Range Mountains. Access is limited in the interior of the Anguille and Long Range mountains, but elsewhere generally is good through a network of highway, community, and logging roads. Several communities occupy the coastal area including Highlands, St. Fintan's, St. David's, Jeffrey's, and Robinsons.

1.3 Physiographic setting

Southern St. George's Bay consists of three physiographic regions: Long Range Mountains, Anguille Mountains, and coastal lowlands. The Long Range Mountains rise from the lowlands in the southeast to their summits, where elevations reach 550 m above sea level (asl). These mountains are part of a continuous range that extend along the entire west coast of Newfoundland (Fig. 1.2). In the study area, the Long Range Mountains feed fluvial systems including Highlands and Crabbes rivers and several of their tributaries.

The Anguille Mountains abut the coastal lowlands in the south, trend northeast-southwest along the coast, and reach >530 m asl. The Codroy Valley, a northeast-southwest oriented trough, separates the Long Range and Anguille mountains south of the study area. Bald Mountain rises to ~530 m asl at its summit on the east side of Codroy Valley, adjacent to Codroy Pond. At the coast, the Anguille Mountains rise as steep vertical cliffs (up to 100 m asl) and are incised by several southeast-northwest oriented valleys containing minor brooks and streams that cascade into St. George's Bay. The uplands of the Long Range and Anguille Mountains are pre-Quaternary peneplain surfaces that tilt northwestward. These surfaces are correlative with others in New Brunswick, Nova Scotia, and other parts of Newfoundland (Grant, 1989).

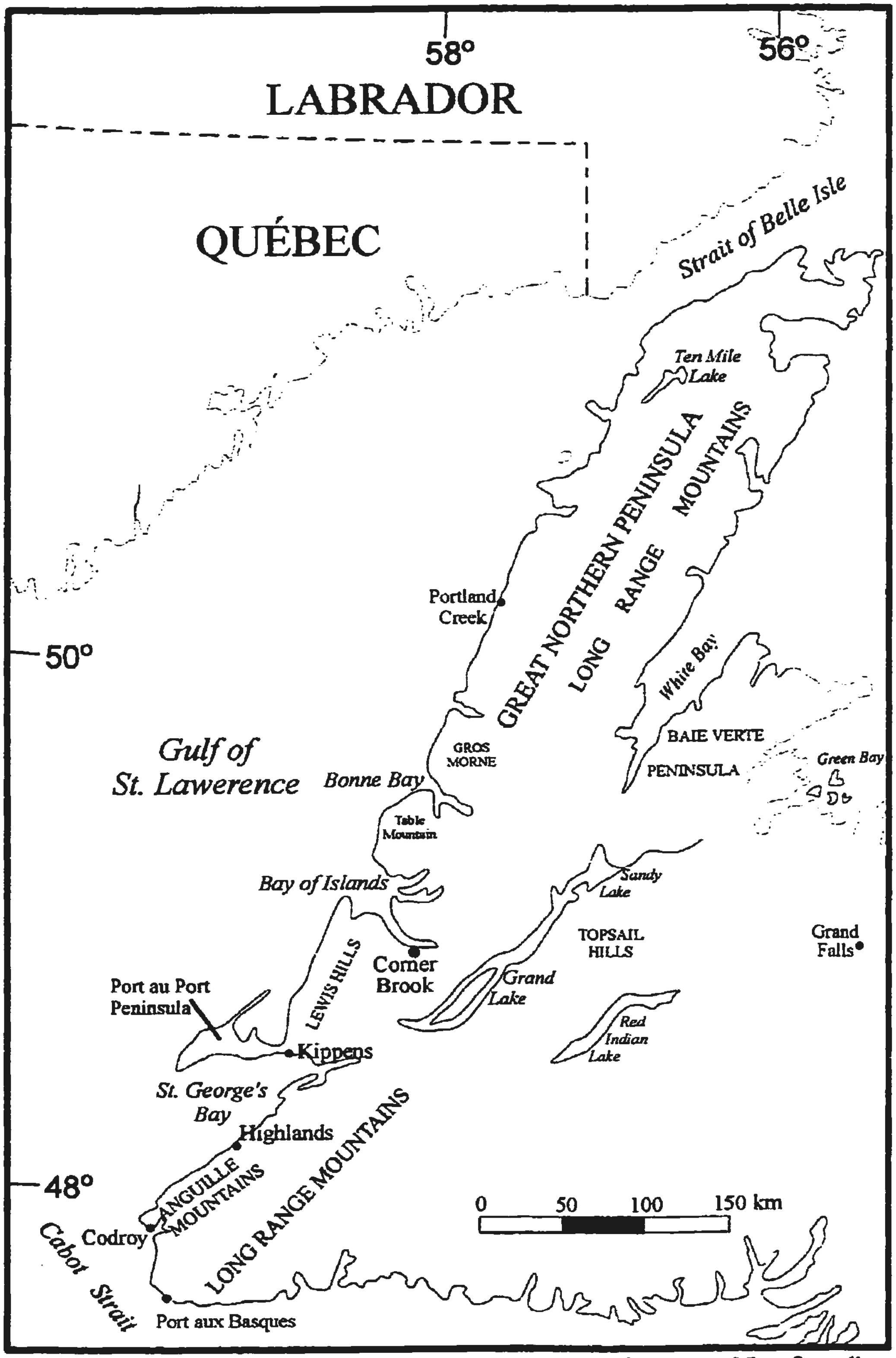

Figure 1.2 Map showing St. George's Bay in context of western Newfoundland.

The lowlands consist of a low-relief coastal plain grading toward St. George's Bay. They slope gently (10 to 15 m/km) from the Long Range Mountains, but more steeply (~20 m/km) from the northern flanks of the Anguille Mountains. Coastal cliffs composed of unconsolidated sediments extend from French Brook, northward along St. George's Bay, and in places are underlain by bedrock. Between French Brook and Crabbes River, these cliffs are up to 26 m asl. The most prominent feature on the lowlands occurs near McLellans Brook, consisting of a ~2 km-long, north-south oriented linear ridge that reaches >60 m asl. The lowlands are dissected by several southeast-northwest oriented valleys that contain Highlands and Crabbes rivers; and French, Butter, and McLellans brooks. In some places, these fluvial systems are incised down through sediment and bedrock.

1.4 Bedrock geology

Bedrock geology is important for determining clast provenance in surficial sediments. The distinctive nature of the sedimentary rocks of the Anguille Mountains and St. George's Bay Lowlands and the igneous and metamorphic rocks of the Long Range Mountains is useful in reconstructing ice-flow for the area (Fig. 1.3).

The northern parts of the Anguille Mountains, Bald Mountain, and Codroy Valley are composed of Mississippian (Carboniferous) rocks of the Friars Cove, Snakes Bight, and Kennels Brook formations (Anguille Group), whereas the southern part of the mountains consist of the Ship Cove, Woodville, and Highlands formations (Codroy Group). Rock types consist of grey, green-grey, and red sandstone; grey and black shale; thin grey, red, and interbedded grey and brown siltstone; and minor limestone and dolomite. The lowland areas include mainly Mississippian rocks of the Barachois

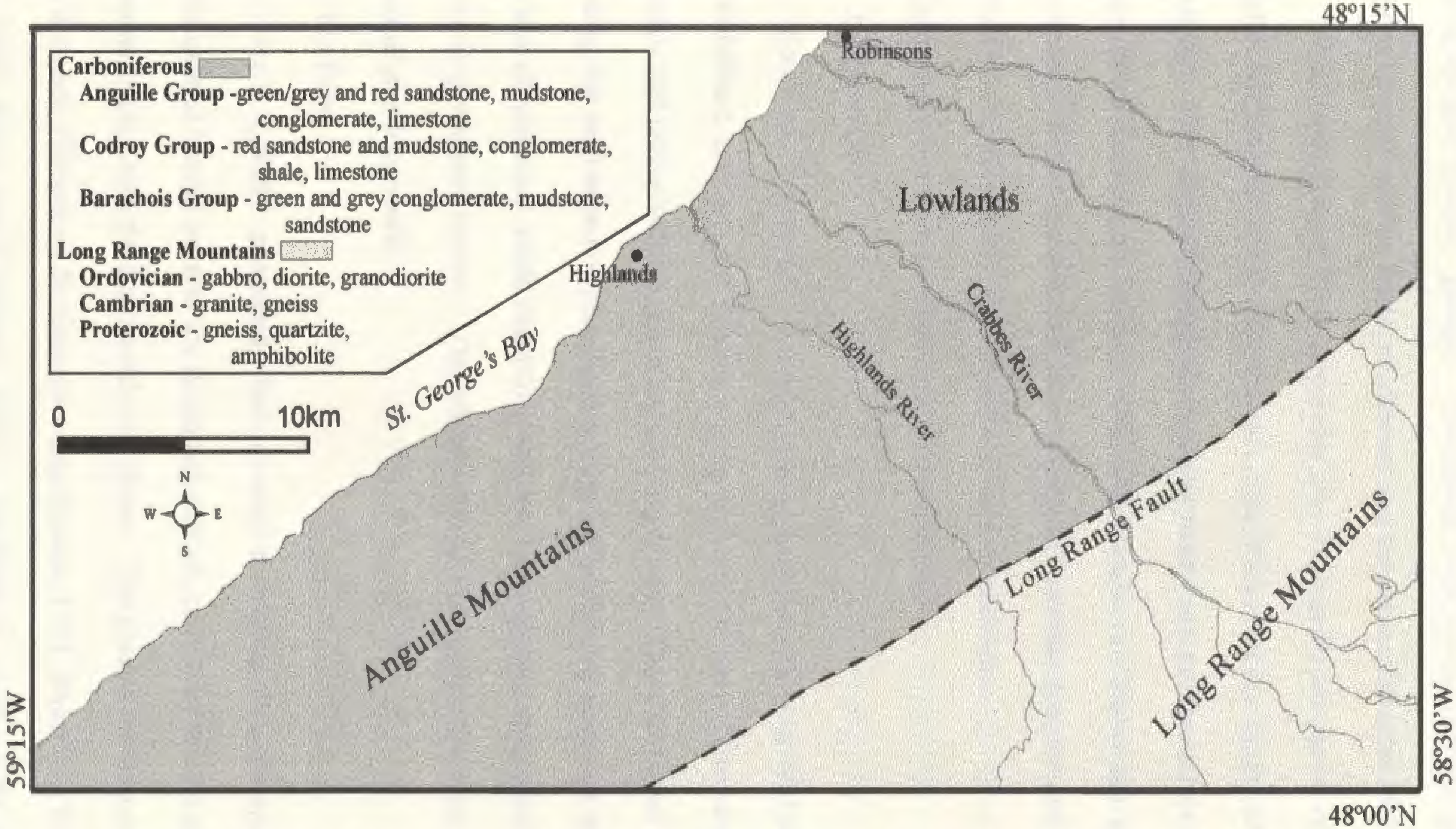

Figure 1.3 Simplified bedrock geology map of southern St. George's Bay (after Knight, 1982); Van Berkel and Currie, 1986).

(undivided) and Codroy groups. Dominant rock types include green-grey and red sandstone, conglomerate, shale, mudstone, and limestone (Knight, 1982).

The Long Range Fault separates the Carboniferous basin of the lowlands and Anguille Mountains from the igneous and metamorphic rock of the Long Range Mountains. The southern Long Range Mountains are composed of the Central Gneiss Terrane (Van Berkel and Currie, 1986) and consist of Ordovician gabbro, diorite, and granodiorite; biotite granite and leucogranite; Cambrian granite and calcareous gneiss; and Proterozoic granitoid gneiss, quartzite, and amphibolite.

1.5 Quaternary research in southwest Newfoundland

1.5.1 Introduction

Southern St. George's Bay is a critical area for studying the Quaternary history of Newfoundland, and several studies during the last 60 years have described the glacial, deglacial, and post-glacial depositional environments. There has been debate, particularly regarding the sedimentology and chronology of sediments exposed along the coast. An overview of previous work regarding the ice flow, stratigraphic, and relative sea level records is presented below. The objectives of this thesis are then considered in the context of previous work.

1.5.2 Ice-flow

Grant (1989) proposed that during the Late Wisconsinan glacial period, Newfoundland hosted several ice dispersal centres, as part of the Newfoundland Ice Cap, a separate entity from the Laurentide Ice Sheet. The glacial maximum ice limit extended some distance offshore in St. George's Bay (Grant, 1991; Shaw and Forbes, 1990; Forbes et al. 1993; Shaw and Courtney, 1997). Ice-flow in southern St. George's Bay was complex, with an early southward flow originating north of the study area followed by a late westward to northwestward flow from a dispersal centre on the Long Range Mountains (Brookes, 1974; Taylor, 1994; Liverman et al. 1999). Batterson and Sheppard (2000) document a southward flow across the Port au Port Peninsula, followed by a west-northwestward flow from the Long Range Mountains that crossed northern St. George's Bay to encroach on the south coast of the eastern Port au Port Peninsula. Other indicators of southward flow have been reported along the Great Northern Peninsula (Mihychuk, 1986; Grant, 1987; Proudfoot et al. 1988), and south of Corner Brook (Taylor, 1994). In each case, indicators represent the earliest recorded ice flow with no evidence for an ice free period between it and those showing the most recent flow. Batterson (1998) speculated that either Newfoundland ice was directed southward by ice occupying the Gulf of St. Lawrence, or that the southward flow represents Laurentide ice that impinged on the coastal fringe of the Island of Newfoundland. Liverman et al. (1999) proposed a similar idea for southern St. George's Bay.

Glacial retreat in southern St. George's Bay resulted in topographic control and ice became confined to valley areas (Brookes, 1974; Liverman et al. 1999). In the Codroy Valley, Liverman et al. (1999) recognized a southwestward flow crossing a northwestward flow, and Brookes (1975, 1977b) indicated that a southwestward flow extended into Cabot Strait at the mouth of Codroy Valley.

1.5.3 Stratigraphy

Retreat of ice from its maximum position during the Late Wisconsinan resulted in an extensive and complex assemblage of sediments being deposited at the coast. MacClintock and Twenhofel (1940), as part of a reconnaissance-level survey, described the coastal exposures between the Port au Port Peninsula and Anguille Mountains. They identified three sedimentary units: the St. George's River Drift, overlain successively by Bay St. George Delta and Robinsons Head Drift. These were interpreted to represent ice advance, retreat, and readvance phases, respectively, across the present coastline. These units were later formalized as a three-fold stratigraphic sequence and assigned ages by Brookes (1969, 1970, 1972, 1974, 1977b).

Brookes (1970, 1974) suggested that St. George's River Drift was deposited by Late Wisconsinan ice advancing into St. George's Bay, and consisted of 1 to 4.5 m of till and associated ice-contact stratified sediment directly overlying bedrock. At Highlands, this drift consists of 1 m of lodgement till overlying 3 m of Carboniferous sandstone (Fig. 1.4). Retreat of ice across the coast was related by Brookes (1969, 1974) to rising relative sea level and marine overlap of the isostatically depressed coastline up to ~45 m asl. Retreat occurred at ~13.4 ka BP, based on radiocarbon-dated shells at 5.5 m asl (Table 1.1) within 2 m of silt and clay bottomsets from the base of the Bay St. George Delta (Brookes, 1969). Sand and gravel foresets and gravel topsets formed the upper part of the Bay St. George Delta, although at Highlands, the foresets (up to 22 m asl) were overlain by Robinsons Head Drift (Brookes, 1974). Robinsons Head Drift was described by Brookes (1974) as consisting of a coarse, loosely structured till of englacial and supraglacial origin that was deposited during the Robinsons Head readvance, representing a distinct surge of ice from its inland position. At Highlands, Robinsons Head Drift consists of up to 10 m of pinkish lodgement till, forming an end moraine (Highlands ridge). Brookes (1974) suggested that this till indicated active ice flow across and into

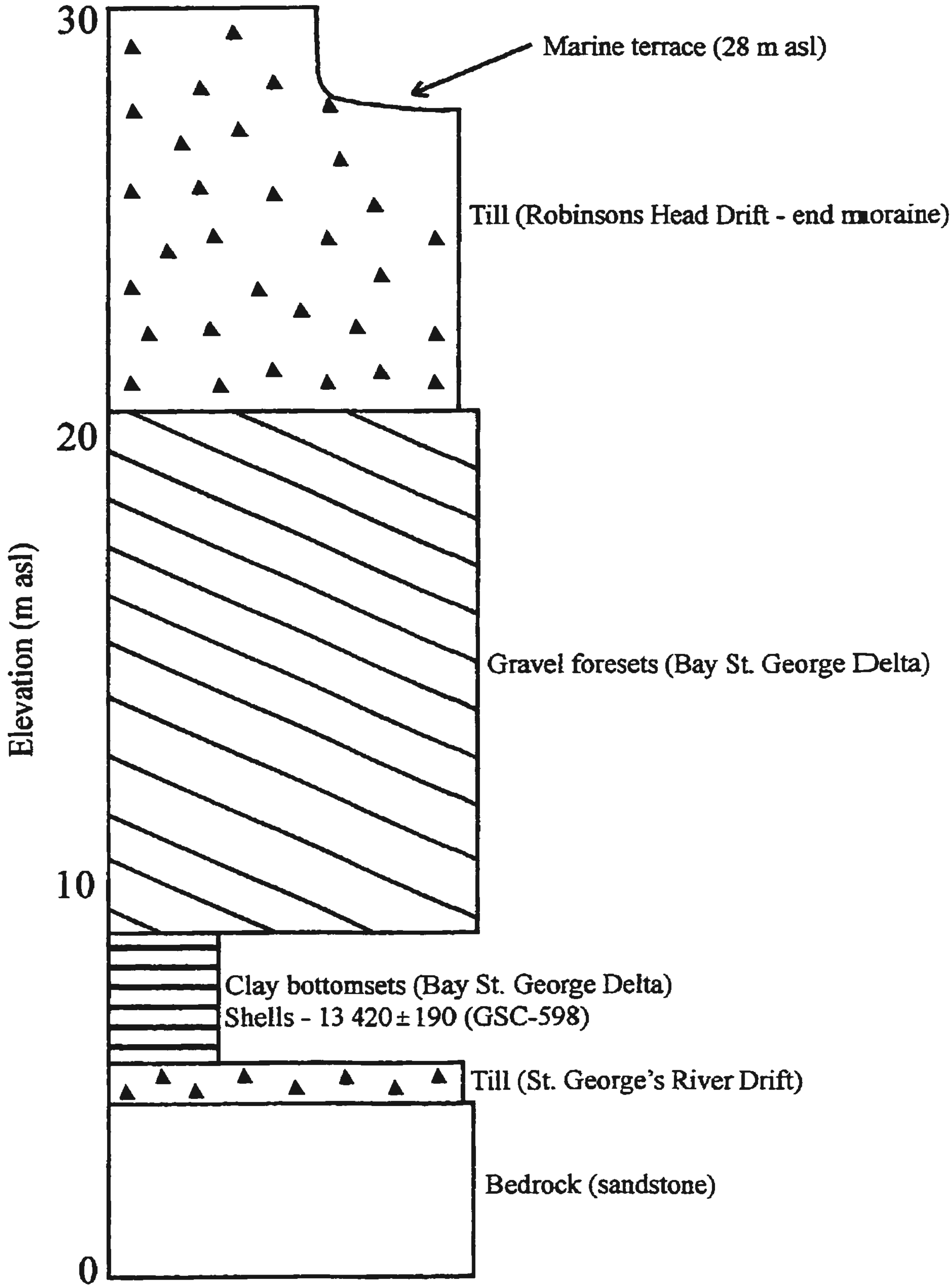

Figure 1.4 Stratigraphic sequence at Highlands as described by Brookes (1969, 1974).

Table 1.1. Radiocarbon dates on marine shells from mud in southern St. George's Bay.

Age	Lab number	Location	Elev. (m asl)	Material	Reference
13970 ± 200	TO-4536	Journois	10	*Portlandia arctica*	Liverman and Bell (1996)
13920 ± 120	TO-5717	Jeffrey's	22	*Portlandia arctica*	Bell et al. (submitted)
13700 ± 120	GSC-5700	Robinson's Head	12	*Hiatella arctica*	Liverman and Bell (1996)
13610 ± 110	TO-7455	Fischells	15	Marine shell	Bell et al. (submitted)
13600 ± 190	GSC-4270	Butter Brook (*)	10	*Hiatella arctica*	Liverman and Bell (1996)
13600 ± 170	GSC-6024	Heatherton	11-14	*Hiatella arctica*	Liverman and Bell (1996)
13500 ± 210	GSC-1200	Robinson's Head	35.4	*Hiatella arctica*	Brookes (1974)
13500 ± 120	GSC-4685	Harbour Head (*)	1-3	*Mya pseudoarenaria*	Liverman and Bell (1996)
13420 ± 190	GSC-598	St. George's Bay (*)	5.5	*Macoma calcarea*	Brookes (1974)
13070 ± 110	TO-7454	Middle Brook	10-12	Marine shell	Bell et al. (submitted)

* Location shown in Figure 3.9 and Figure 3.10; location of new dates collected in this study also illustrated.

marine sediments. A terrace in the moraine at 28 asl was interpreted by Brookes (1969) to be marine in origin, forming contemporaneous with construction of the moraine.

Chronological control of the Robinsons Head readvance was derived from a single radiocarbon date of 12 600 ± 140 BP (GSC-2295) on marine shells from interpreted ice-contact sediments in a coastal section at Kippens in northern St. George's Bay (Fig. 1.2; Brookes, 1977b). Brookes (1977b) also used geomorphological evidence to infer ice-contact conditions by interpreting near-coast depressions in that area as kettle holes. Batterson and Janes (1997) questioned the interpretation of the radiocarbon date, suggesting it represented the establishment of a glaciofluvial delta after ice retreated from that area, rather than a readvance. They also suggested that the coastal depressions in the Kippens area could be gypsum karst sinkholes.

The configuration of the Robinsons Head readvance ice margin in southern St. George's Bay was presented by Brookes (1974) as consisting of distinct lobes that extended across the coast at Highlands, Robinsons Head, and Bank Head (Fig. 1.5). Grant (1987) showed a lobate margin that spread out across the coast at Highlands and between Robinsons Head and Bank Head. Brookes (1974) suggested that interlobate areas were preserved as moraines, whereas Grant (1991) mapped ridges composed of glaciofluvial sand and gravel (outwash).

More recently, Liverman and Bell (1996) examined discrete sections along 40 km of coastline and presented an alternative interpretation of sediments in the coastal exposures. They suggested that deposition occurred along the margin of a tidewater

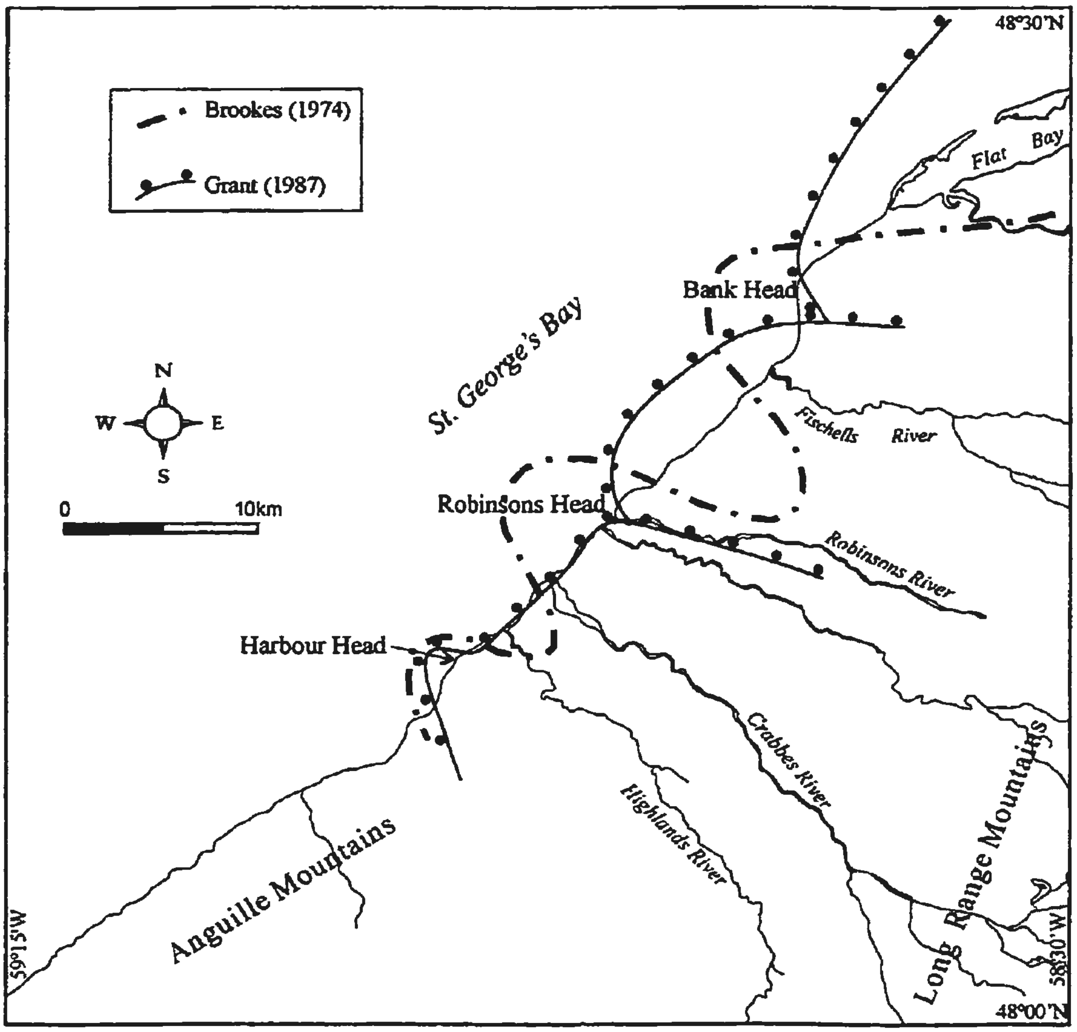

Figure 1.5 Proposed configurations of the Robinsons Head readvance ice margin in southern St. George's Bay.

glacier, where sediment and meltwater entered the sea via subglacial fluvial systems and constructed grounding-line fans (e.g. Powell, 1990; Lønne, 1995). The subglacial component of these fans was interpreted by Liverman and Bell (1996) to exist where ridges intersect the coast at Highlands, Crabbes Head, Robinsons Head, and Bank Head. Some of these ridges were also related to eskers and meltwater channels inland (Liverman and Bell, 1996; Bell et al. 1999; Bell et al. submitted). Adjacent to the ridges, planar surfaces at 18 to 20 m asl, 24 to 26 m asl, and 40 to 45 m asl were also identified (Liverman and Bell, 1996).

Liverman and Bell (1996) defined the sedimentary sequences based on the geomorphological contrasts along the coast (i.e. ridges and planar surfaces). Bell et al. (1999) indicated that where ridges intersect the coast, sediments generally consist of thick units of interbedded sand, gravel, and diamicton, overlain by diamicton and/or coarse gravel, and represented areas of direct meltwater and sediment input. Sediments associated with the Robinsons Head readvance were generally found only in sections through the ridges, although these sediments were suggested to represent minor grounding-line fluctuations during overall glacial retreat (Liverman and Bell, 1996). Sections through planar surfaces showed comparatively simple sequences, and were composed mainly of till (deposited during retreat across the coast), overlain successively by fossiliferous mud, and sand and planar-bedded gravel. These sedimentary sequences were interpreted to represent distal fan deposits that were subsequently capped by glaciofluvial outwash as relative sea level fell (Liverman and Bell, 1996; Bell et al. 1999). Overall, a tidewater glacier depositional environment required that all of the sediments along the coast be deposited rapidly during deglaciation without a significant landward retreat and subsequent readvance of the ice margin across the present coastline (Liverman and Bell, 1996). Rapid deposition was suggested by several radiocarbon dates that ranged from ~13.5 to 13.9 ka BP at various stratigraphic positions from the ridges along the coast (Table 1.1).

Liverman et al. (1999) suggested that the configuration of the deglacial ice margin could explain the contrast between sediments in the ridges and planar surfaces. As ice retreated across the coastline, the margin became pinned at points of direct sediment input (ridges), where calving bays became established along the ice margin. Areas outside the ridges remained covered by floating ice while ridges built up along the ice margin to above sea level. Continued retreat back from the coast resulted in ice-free conditions and development of the marine to glaciofluvial sedimentary sequences (planar surfaces) as relative sea level fell.

1.5.3.1 Regional implications of the Robinsons Head readvance

The Robinsons Head readvance is included in the Atlantic Canada lithostratigraphy that links glacial and deglacial events in the region (Grant, 1987, 1989). The Robinsons Head readvance is used as a benchmark to date other interpreted readvances at ~12.6 ka BP in southern Codroy Valley (Brookes, 1975) and on the Great Northern Peninsula (Grant, 1992). Brookes (1975) described stratified drift overlying till near the community of Codroy at the mouth of Codroy Valley. The drift was interpreted to be deposited by a readvance of a piedmont glacier down the valley following deglaciation and marine overlap of the coastline. Although robust shells from the base of the stratified (readvance) sediments provided a radiocarbon date of 13 800 ± 260 BP

(GSC-2113), the date of deposition was correlated with the Robinsons Head readvance by Brookes (1975), who suggested that ice likely overrode and incorporated "old" shells from marine sediments.

Grant (1992) identified the Piedmont Moraines between Bonne Bay and Portland Creek on the western Great Northern Peninsula as having been constructed by ice from the Long Range Mountains. He estimated the age of these moraines to lie between 12 and 12.8 ka BP. This age bracket was based on shells dating 12 to 12.6 ka BP from sediments deposited after ice retreated from the moraines; and shells dated 12.8 ka BP reworked into till that forms the moraine (Proudfoot and St. Croix, 1987). Formation of these moraines was considered coeval with deposition of Robinsons Head Drift sediments in St. George's Bay.

The Robinsons Head readvance is also linked to climatic events documented in Nova Scotia (Chignecto Phase; Stea et al. 1996; Stea, 1999), New Brunswick (Millville-Dungarvon Phase; Rampton et al. 1984), and Maine (Pineo Ridge readvance; Borns, 1977). The Robinsons Head readvance is distinguished because of its older age relative to more established late-glacial climatic reversals in Atlantic Canada. These include the Killarney Oscillation (KO) occurring between ~11.2 to 10.9 ka BP (Levesque et al., 1993a,b) and the Younger Dryas (YD) between ~11 to 10 ka BP (Grant, 1992; Anderson and Macpherson, 1994; Mott, 1994; Mayle and Cwynar, 1995).

Evidence for the KO and YD in Atlantic Canada is commonly based on pollen records, which tend to show decreases in loss-on-ignition percentages during the specified years (e.g. Levesque et al. 1993a; Anderson and Macpherson, 1994). The YD has been also identified through sedimentological evidence consisting of diamicton interpreted as till overlying organic deposits in Nova Scotia (Mott and Stea, 1994) and moraines composed of reworked marine sediments on the Great Northern Peninsula (Ten Mile Lake readvance; Grant, 1992). Pollen records in Newfoundland typically do not extend back far into the late-glacial period, so inferences regarding vegetation assemblages at 12.6 ka BP are difficult. Anderson and Macpherson (1994) illustrated increased ice coverage in Newfoundland at ~12.6 ka BP coincident with the Robinsons Head readvance, despite suggesting a gradual warming trend during the same interval (Fig. 1.6).

1.5.4 Sea level

Relative sea level patterns in Atlantic Canada are categorized into four different types (A, B, C, and D) based on the relative position of the location on the ice-marginal forebulge (Quinlan and Beaumont, 1981). Type A curves show continuous emergence with progressively younger dates at lower elevations. Type B is marked by initial emergence followed by submergence, with emergence greater than submergence. Types C and D show no evidence of emergence onshore, as sea-level was below present throughout deglaciation. The relative sea level history in southern St. George's Bay is not well understood, although the curve is characterized as Type B (Quinlan and Beaumont, 1981, 1982; Liverman, 1994).

Brookes (1974) initially established the marine limit for St. George's Bay at 45 m asl. This elevation is based on shells radiocarbon-dated 13 500 ± 210 BP (GSC-1200) at Robinsons Head from 35 m asl within interpreted delta bottomsets of the Bay St. George Delta (Table 1.1). In contrast, Liverman et al. (1999) suggested that sediments at

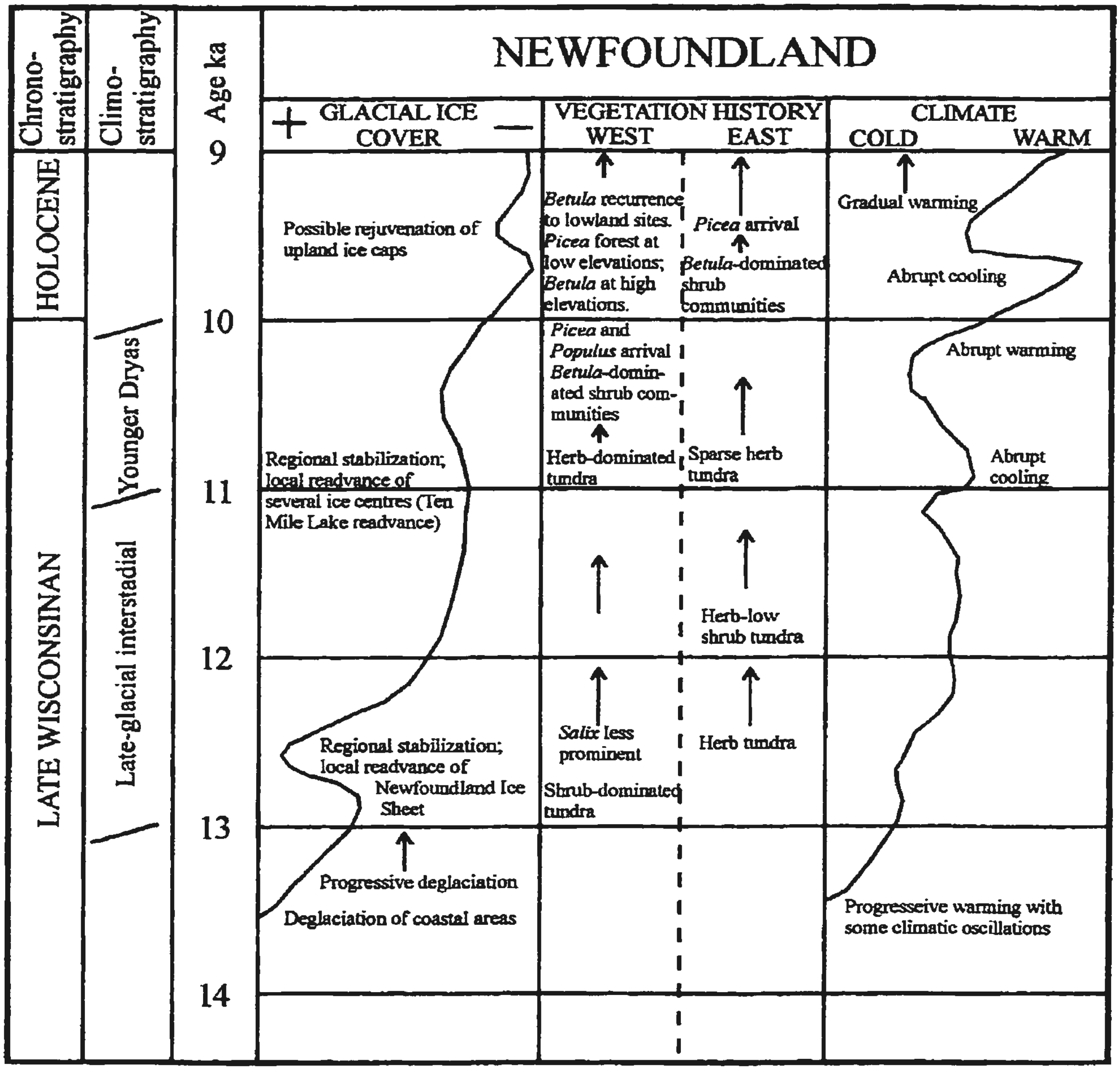

Figure 1.6 Summary diagram of deglacial events in Newfoundland (after Anderson and Macpherson, 1994).

Robinsons Head are not deltaic, and that marine limit can only be established to be greater than 38 m asl (the elevation of upper contact of the unit that contained the shells).

Based on the relative sea level curve for St. George's Bay (Forbes et al. 1993; Shaw and Forbes, 1995), the marine limit was established at 13.5 ka BP and sea-level fell below present at ~11.5 ka BP. An inflection in the curve at ~12.6 ka BP was interpreted to be caused by ice growth and/or stillstand during the Robinsons Head readvance, when relative sea level stood at ~28 m asl (Brookes, 1974, 1977b). Batterson (1998) and Batterson and Sheppard (2000) indicate that the curve could alternatively be modified to show a smooth transition from the marine limit to sea level fall below present at ~12 ka BP.

The St. George's Bay coastline spans across two coast-perpendicular (trending southeast-northwest) marine isobases, which define the deglacial marine limit (Grant, 1989). Southern St. George's Bay (south of Bank Head) lies in the 0 to 25 m asl range, whereas the northern part of the bay ranges between 25 and 50 m asl. Liverman (1994) indicated that the oldest radiocarbon dates from raised marine features are progressively younger on a northward transect along the west coast of Newfoundland. In southern St. George's Bay, 13 to 14 ka BP dates are the oldest, whereas north of Bank Head, the oldest dates range from 12.5 to 13 ka BP (Liverman, 1994). Bell et al. (submitted) show that radiocarbon dates from raised marine features in southern St. George's Bay range from ~13.1 to 14 ka BP.

Following relative sea level drop to below present, a lowstand at –25 m asl occurred between 9.5 and 10.5 ka BP (Forbes et al. 1993; Shaw and Forbes, 1995). This lowstand is shown by now-submerged deltas and wave-cut terraces farther out in the bay.

1.6 Objectives

The overall objective of this thesis is to provide a detailed record of the sedimentology, geomorphology, and chronology of deglaciation in southern St. George's Bay. MacClintock and Twenhofel (1940) and Brookes (1974) have identified Highlands as one area in St. George's Bay that shows evidence of the Robinsons Head readvance, although the date of the readvance is derived from a section ~50 km to the north (Brookes, 1977b). Liverman and Bell (1996), on the basis of a reconnaissance-level survey in southern St. George's Bay, suggested that sediments in the coastal exposures could be explained without invoking a climatically induced readvance. This thesis addresses the conflicting issues by focusing on landforms and coastal exposures at Highlands, where strong evidence exists for renewed ice-contact conditions during deglaciation (Brookes, 1969; 1974; Liverman and Bell, 1996).

This work also has relevance in the understanding of the Quaternary history of northeastern North America because the Robinsons Head readvance is linked to a climatic deterioration that occurred much earlier than the Younger Dryas cooling event (Brookes, 1977b; Stea et al. 1996; Stea, 1999). A detailed stratigraphic and chronological analysis at Highlands will shed light on the contrasting interpretations of deglaciation in this area.

The specific objectives of this thesis as they relate to the overall objective are to:

1. describe and interpret the extensive exposures of sediments exposed along the coast.
2. establish a chronology of deposition.
3. map the surface sediments and geomorphological features.
4. determine the source location of glacigenic sediments in the study area.

5. interpret the ice-flow history in southern St. George's Bay.

6. present a pattern of late-glacial relative sea level changes for southern St. George's Bay.

Chapter 2 Methodology

2.1 Introduction

Data collection and analyses involved three separate stages: preliminary air-photo mapping, fieldwork, and lab analysis. A description of these is provided below.

2.2 Air photo mapping

Preliminary mapping, using black and white air photos (scale 1:40,000) was carried out during the spring of 1998. This was intended to provide a general overview of the surficial units that could subsequently be ground-checked during the summer field season. Interpretation was completed using the landform classification scheme of the Geological Survey, Newfoundland and Labrador Department of Mines and Energy (Figs. 2.1, 2.2; rear pocket). Surficial units were categorized as glacial, glaciofluvial, marine, fluvial, colluvial, organic, or bedrock. Generally, sediments are designated based on their thickness and/or geomorphological attributes (e.g. till veneer, till hummock, glaciofluvial terrace), whereas colluvium and bedrock units are classified as concealed, exposed, and/or eroded and dissected.

2.3 Fieldwork

2.3.1 Overview

Fieldwork involved ground coverage of the study area through a system of roadways via truck and all terrain vehicle and traverses along the coast. Some areas were not visited due to time constraints, especially remote upland areas of the Long Range and Anguille mountains, so classification of surficial units in those areas is based primarily on air photo mapping.

To complement and ground-check air photo mapping, sediment descriptions of natural (coastal cliffs and river valleys) and anthropogenic (road-cut and gravel pits) exposures were carried out at selected sites. Section logs were completed at several locations, although mainly along the coast where the most continuous exposures are located. Unit thickness and lateral extent, primary sedimentary structures, texture, and clast shape were described. Clast (pebble lithology), matrix (grain size distribution and geochemistry) and organic (radiocarbon dating) samples were collected, and clast fabrics from diamicton units were also measured. Elevations were determined with an altimeter at the coast and elsewhere using contours on 1:50,000 scale topographic maps.

2.3.2 Striations and fabrics

Ice flow was determined using striations on bedrock and clast fabrics from diamictons. Only six new striation measurements were recorded from the study area; however, other striation measurements (n=41) were obtained from the Newfoundland Striation Database (Taylor et al. 1994) (Appendix A). In the database, the direction of a striation has been identified and this direction is commonly based on micro-scale stoss-and-lee features found on the surface of the bedrock outcrop. However, some outcrop only provides a sense or orientation of the striation, not a direction.

Bedrock outcrop is rare in most of the study area due to continuous and relatively thick surficial sediment cover, especially in the lowlands and along the Codroy Valley. Striations are therefore mainly limited to areas on the Long Range and Anguille mountains where exposed bedrock is more abundant. In areas away from the Long Range Mountains relatively soft and easily weathered sandstone and siltstone dominate (Knight, 1982), and striations are rarely preserved. Thus, to more clearly identify ice flow in these and areas of thick sediment cover, clast fabrics were used.

Clast fabric analysis is used widely in Quaternary studies to characterize and identify the genesis of diamicton units, and also as an ice flow indicator (e.g. Domack and Lawson, 1985; Benn, 1994; Ham and Mickelson, 1994; Hicock et al. 1996). Clasts entrained at the base of actively moving ice are generally aligned parallel to the overall ice flow direction (Bennett and Glasser, 1995; Benn and Evans, 1998). When clasts are released through deposition by meltout or lodgement processes, they tend to maintain this orientation, although the dip may be up- or down-ice. Thus, the fabric orientation may parallel the former ice flow direction. Each fabric measurement involved determining the trend (direction/orientation) and plunge (angle) of twenty-five elongate clasts with a length:width ratio of at least 3:2 (Dowdeswell and Sharp, 1986). The results were plotted on a Schmidt equal-area projection using the GEOrient 7.2© (Stereographic Projection and Rose Diagram Plots for Windows95) software program. Several statistics were generated including normalized eigenvalues (S_1, S_2, and S_3; sum of values total 1) that summarize the strength or degree of clustering of the fabric, a k-value (shape parameter), which measures the distribution of the clast orientations, and a c-value (strength parameter). All of the above statistics are graphically illustrated using the method of Woodcock (1977) (Fig. 2.3), or alternatively S_1 is plotted versus S_3 (Mark, 1973).

Fabric statistics may be characterized as poorly to moderately oriented girdles to unimodal and bimodal clusters. Unimodal clusters have one dominant preferred orientation, whereas bimodal clusters have two distinct orientations. When S_1 values are

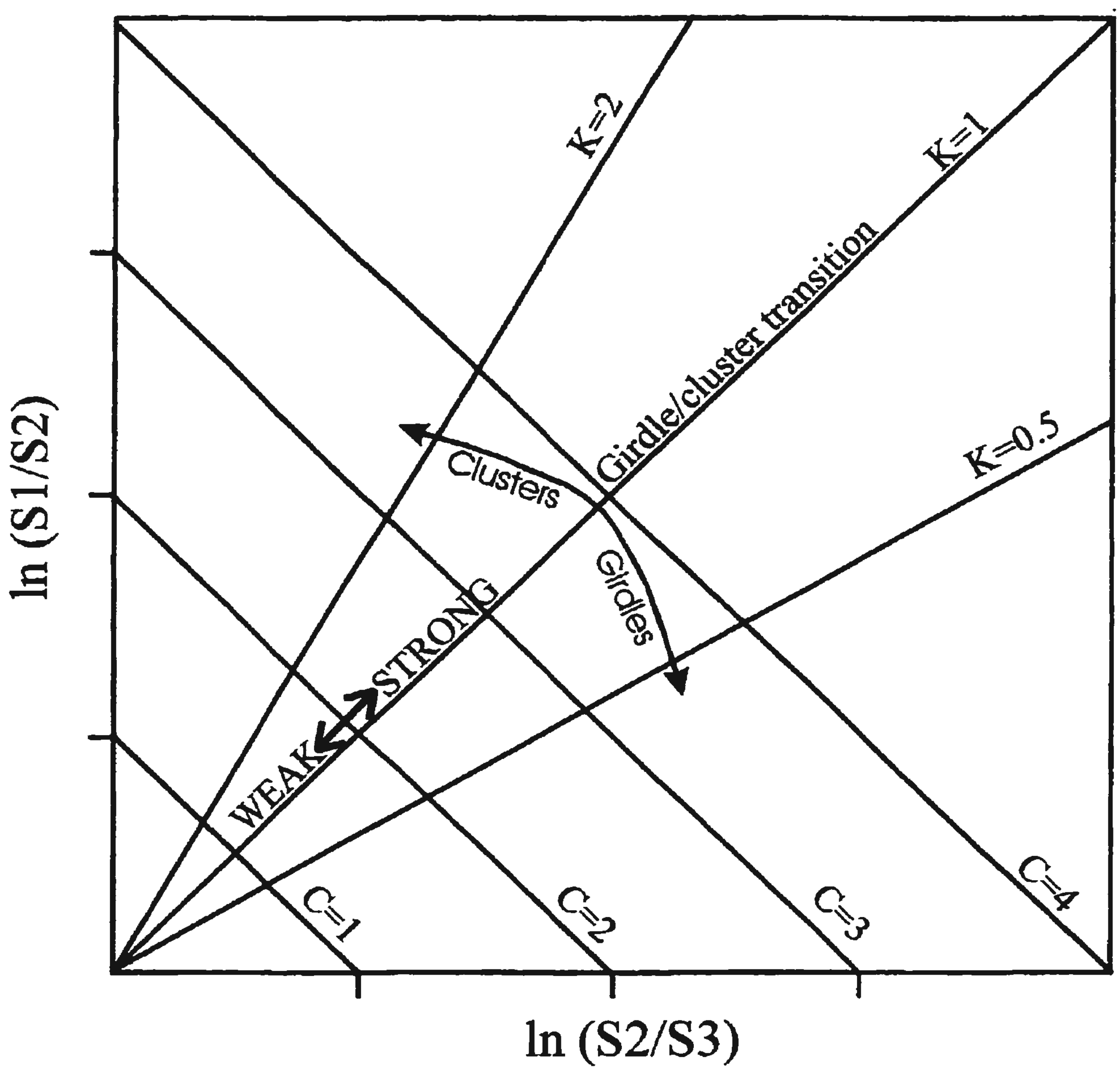

Figure 2.3 Eigenvalue method used to plot fabric data (after Woodcock, 1977; Rappol, 1985).

high (maximum of 1), fabrics have a strong cluster, whereas with $S_1 \approx S_2 > S_3$, the sample is described as a girdle (Rappol, 1985). Batterson (1998) used Mark's (1973) method to analyse fabric statistics, although Batterson (1998) defined envelopes around the plots to identify depositional mode (Fig. 2.4). Although there are some overlaps, generally $k<1$ and $S_1<0.6$ is characterized as a girdle, $k\geq1$ and $S_1<0.6$ is considered a weak cluster, and $k>1$ and $S_1>0.6$ is a strong (bimodal or unimodal) cluster (Liverman et al. 1999). The latter is typically associated with subglacial till and used to infer former ice flow direction.

2.3.3 Sampling

2.3.3.1 Pebble lithology

At 34 sites, ~100 pebbles were collected from diamicton exposures and later identified (Appendix B). Given the nature of the bedrock geology, collection of ~100 clasts per sample was considered a sufficient number for statistical purposes. Bedrock in the study area contrasts between igneous and metamorphic in the Long Range Mountains and sedimentary (Carboniferous) in the lowlands and Anguille Mountains (Ch. 1). For this reason, Long Range Mountains rock types are classified as "Long Range", whereas sedimentary clasts from the lowlands and Anguille Mountains are referred to as "Carboniferous". It was important to illustrate the spatial variability of the respective rock types to help clarify the ice-flow history in association with striations and clast fabrics.

Along the coast, diamicton occurs at different stratigraphic positions. Of importance are those that form the lowest unit overlying bedrock, and an upper unit,

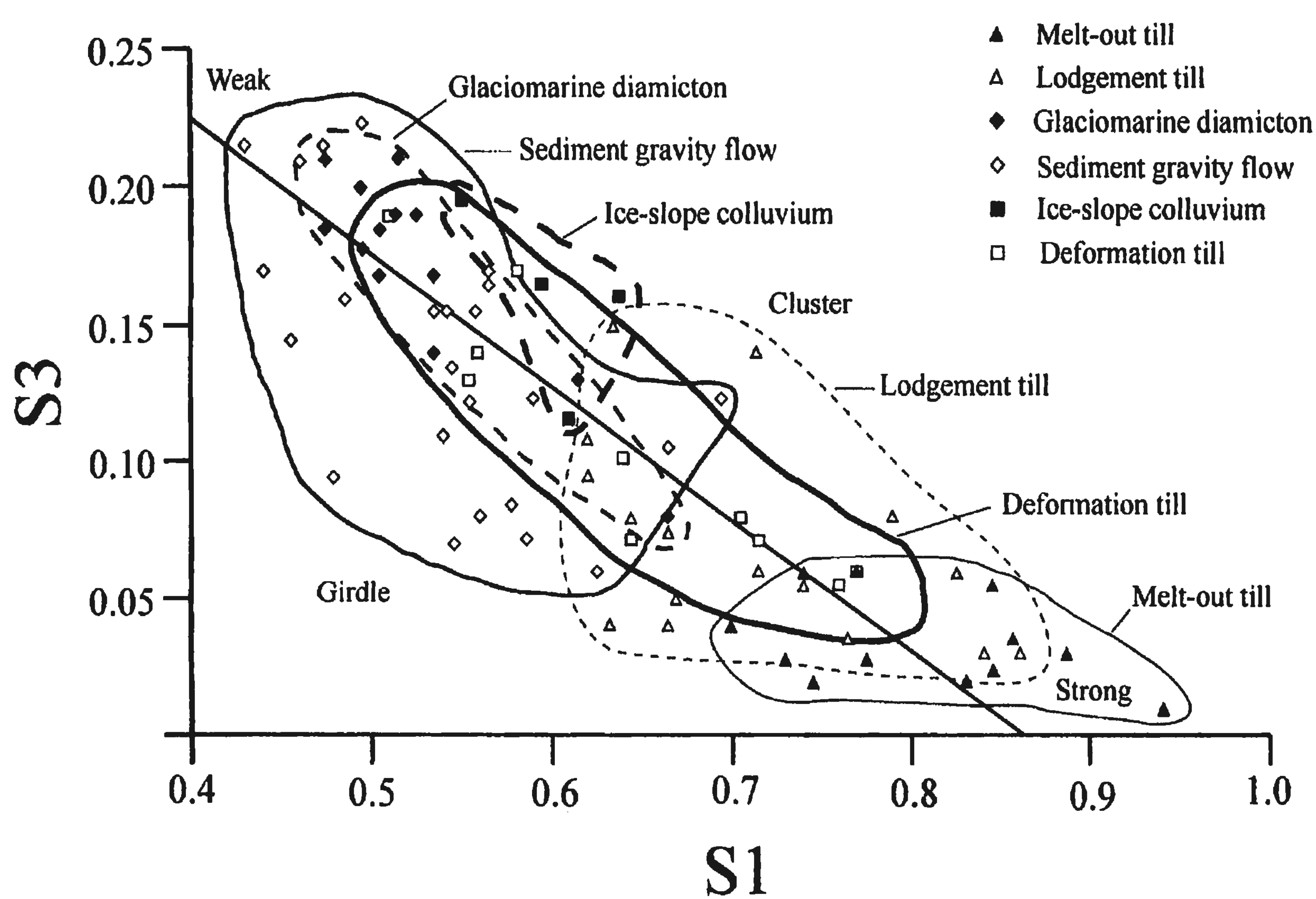

Figure 2.4 Plot of S1 versus S3 with envelopes to encompass values pertaining to depositional mode. Note that tills commonly plot in the area of S1>0.6 (from Batterson, 1998).

which is found between McLellans Brook and Harbour Head. To test whether these diamictons are derived from the same ice source, comparison of their pebble lithologies was undertaken by contrasting the within and between sample variations in the number of Long Range and Carboniferous rock types. This analysis was carried out using a parametric F-test, which allows individual elements (samples) in each population (basal and upper diamictons) to be compared: (1) Long Range vs. Carboniferous in the basal diamicton; (2) Long Range vs. Carboniferous in the upper diamicton; (3) Long Range vs. Long Range in the basal diamicton; (4) Carboniferous vs. Carboniferous in the upper diamicton.

2.3.3.2 Sediment matrix

Matrix samples (n=61; Appendix C) were collected and the grain size distribution analysed. The matrix of 24 diamicton samples were also examined for geochemical properties (Appendix D). To ensure that the results could be reproduced, field and lab duplicates were tested for every ten samples obtained. With the exception of diamicton, only grain size (see below) was analysed for the other sediments. Grain size distribution is important to more accurately describe the various sediment types and also compare the spatial variability that occurs within the study area. Geochemical analysis is used in a similar manner to pebble lithology in comparing the lower and upper diamicton units along the coast (see below).

2.4 Laboratory analysis

Laboratory analysis involved determining the grain size distribution of the sediment matrix samples (n=52), field duplicates (n=9), and lab duplicates (n=8). The processes for textural analysis are outlined in Appendix II of Ricketts (1987) and follow the procedures of the Newfoundland and Labrador Geological Survey. The method involved wet-sieving through a stack of six brass sieves (Appendix C), which range in size from –2ϕ (4 mm; pebble) to 4ϕ (0.063 mm; very fine sand), with a pan to retrieve the silt and clay fraction (>4ϕ) at the bottom. The material retained in each of the six sieves is expressed as a percent of the total mass of the sample after sieving. The initial sample mass is not used because a fraction of the sample is commonly lost during the sieving process; however, this amount is generally less than 1% and is considered negligible (H. Gillespie, personal communication, 1999).

The material collected in the pan was analysed by the Sedigraph 5100 using the methods outlined in Appendix C (see also Coakley and Syvitski, 1991). The Sedigraph method assumes that sediment particles dispersed in a fluid settle in accordance with Stoke's Law, similar to other techniques (e.g. pipette and hydrometer). However, the Sedigraph is totally automated once the sample is prepared and uses an x–ray beam to measure the changing concentration of the sediment settling in a suspension with time. This changing concentration provides the cumulative distribution throughout a specified range of grain sizes, which for this study consisted of 1ϕ intervals between 5ϕ (0.031 mm; coarse silt) and 11ϕ (0.00049 mm; clay), with a final boundary defined at >11ϕ. Only 1 to 3 g (<2-3% volume) of sediment were used in the Sedigraph, although commonly the sample retained in the sieve pan was >10 g. The results are expressed as a mass in the given interval, but are recalculated as a percent of the sample mass initially collected in the pan.

A complication that exists when using sieve and Sedigraph techniques is merging the two data sets. Often, the distributions from the two methods are not overlapped and smoothed, but abutted, and this generally causes a sharp break in the cumulative curve (Coakley and Syvitski, 1991). This complication may result because some of the coarser than 4ϕ fraction escapes through the 4ϕ sieve. Although the upper boundary for the Sedigraph is defined at 5ϕ, coarser fractions were still recognized. To resolve this, the percent coarser than 4ϕ generated by the Sedigraph output was recalculated as a percent of the initial sample mass (before sieving) and added to the mass already measured in the 4ϕ sieve; the remaining percentages calculated by the Sedigraph were then recalculated to total 100%. The mass in each interval then represents a continuous distribution throughout the entire grain size spectrum (-2ϕ to >11ϕ) that could subsequently be calculated as a "percent coarser than" and then plotted.

Two statistics relating to the grain size characteristics were also calculated. The mean grain size was determined using the following formula (Folk and Ward, 1957):

$$M_Z = (\phi_{16} + \phi_{50} + \phi_{84})/3$$

where: ϕ_{16} = 16th percentile on the cumulative curve

ϕ_{50} = 50th percentile on the cumulative curve

ϕ_{84} = 84th percentile on the cumulative curve

The degree of sorting, or deviation from the mean was also determined using the following (Folk and Ward, 1957):

$$s = -[(\phi_{16} - \phi_{84})/4] - [(\phi_5 - \phi_{95})]/6.6]$$

where: ϕ_5 = 5th percentile on the cumulative curve

ϕ_{95} = 95th percentile on the cumulative curve

This value has several ranges that relate to descriptive terms for the sorting parameter (Folk, 1966):

<0.35 ϕ	very well sorted
0.35 to 0.50 ϕ	well sorted
0.50 to 0.71 ϕ	moderately well sorted
0.71 to 1.00 ϕ	moderately sorted
1.00 to 2.00 ϕ	poorly sorted
2.00 to 4.00 ϕ	very poorly sorted
>4.00 ϕ	extremely poorly sorted

Other laboratory analysis involved determining the geochemical signatures of 36 diamicton matrix samples. The Newfoundland and Labrador Department of Mines and Energy laboratory carried out this analysis; the results are presented in Appendix D. Each sample was sieved as per the procedures described above, and the silt and clay (<4ϕ) fraction was analysed to determine the concentration of 28 elements: Mo, Cr, P, Zn, Pb, Co, Ni, Fe, Mg, Ti, V, Be, Ca, Nb, Cu, Na, Zr, Dy, Sc, Y, Al, Mn, Sr, La, Ce, Ba, Li, and K. The element Mo was omitted because it was below the level of detection in several samples. Elements were analysed using digestion methods (Wagenbauer et al. 1983). Duplicate samples and a reference standard of known composition were used to monitor accuracy and precision. The geochemical data were used specifically to contrast diamicton units, which occur at different stratigraphic positions along the coast. A non-parametric Mann-Whitney test was used to determine whether the two units are significantly different at the 99% confidence level (cf. Batterson, 1989). The element concentrations for each diamicton were arranged in ascending order and ranks assigned to the combined sample (Fig. 2.5). Rank 1 was assigned to the lowest-valued observation and rank $n_1 + n_2$ (n = number of samples in each population) assigned the highest (Chapter 3). The test statistic (S) is the sum of the ranks from the first sample and is compared to an estimated value (A). The Mann-Whitney test is based on the idea that if the two samples are drawn from the same population, then the average ranks of the two samples should be almost equal (Burt and Barber, 1996).

Hypothesis
H_O: δ = 0, the samples are drawn from the same population
H_A: δ ≠ 0, the samples are drawn from different populations

S_1 = test statistic = sum of the ranks from population X

If $S_1 < A = n_1(n_1 + n_2 + 1)/2 - z_{\alpha/2}\sqrt{n_1 n_2(n_1 + n_2 + 1)/12}$, reject H_O

Where A = estimate of S = **70.9**
$z_{\alpha/2}$ = prob-value associated with 99% confidence level

	Concentration (ppm)	Rank
Unit X	10	2
(n_1=10)	25	4
	35	6
	40	7
	55	10
	60	11
	75	14
	80	15
	85	16
	90	17
		S_1=102
Unit Y	5	1
(n_2=10)	15	3
	30	5
	45	8
	50	9
	65	12
	70	13
	95	18
	100	19
	105	20
		S=108

Do not reject H_O because $S_1 > A$. Therefore, the element concentration in both populations is similar.

Figure 2.5 Hypothetical example illustrating the Mann-Whitney test used to compare element concentrations.

Chapter 3 Results

3.1 Introduction

This chapter presents the results of air photo mapping; field data, and laboratory work. A regional overview of the surficial materials and landforms, including relevant details of the Highlands area is provided. The coastal sections at Highlands are described in detail. Clast fabrics and striations; pebble lithology, grain size distribution, radiocarbon dates, and geochemistry are also described.

3.2 Striations

A total of 47 striation measurements were obtained from southern St. George's Bay (Fig. 3.1; Appendix A; Taylor et al., 1993). Most (n=39) directional measurements range between 270° and 360° (mean=309°; st. dev.=24°), and four non-directional striations (140-320°, 177-357°, 168-348°; 174-354°) more or less parallel this trend. Striations in the southeast of the study area (upper Crabbes and Highlands rivers) indicate that ice flowed northwestward from the southern Long Range Mountains toward the lowlands. This flow appears to have crossed Bald Mountain (>530 m asl) because striations on its east, north, and west sides are roughly parallel, mimicking the northwestward flow. Southwest of Bald Mountain, the northwestward flow crossed the Codroy Valley, traversing the Anguille Mountains, where flow was approximately northward.

There is evidence to support a second ice flow in the area. Three directional measurements ranging between 205° and 252° indicate a southwestward flow, approximately perpendicular to the earlier flow. This is observed on the south side of

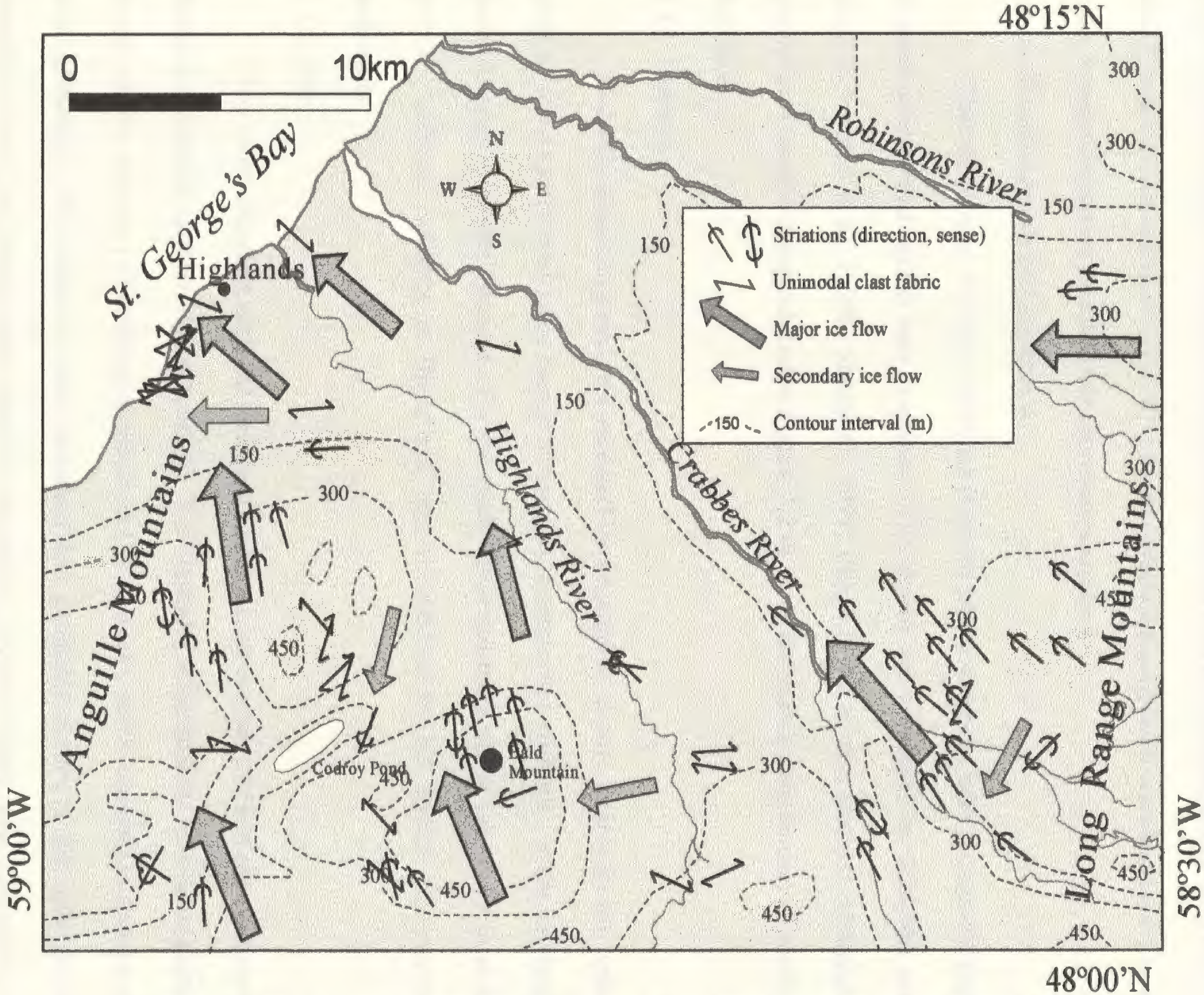

Figure 3.1 Ice-flow map of southern St. George's Bay based on striations and clast fabrics.

Bald Mountain (252°) and east of Codroy Pond (205°). Cross-cutting striae southwest of Codroy Pond indicate a northwestward flow followed by a southwestward flow (211°). A non-directional measurement (60-240°) from a northeast-southwest trending valley in the Long Range Mountains parallels the southwestward flow.

3.3 Surficial materials and landforms

Classification of surficial materials is by air photo mapping with ground checking in areas where road access was available. The results are presented on 1:50,000 scale maps (Liverman et al. 1999a; Sheppard, 1999; Fig. 2.1, 2.2 in rear pocket), although a generalized version is reproduced in Figure 3.2 to show the spatial distribution of surficial deposits.

3.3.1 Bedrock

Bedrock, either exposed or concealed by vegetation, occurs mainly in the upland areas of the Anguille and Long Range mountains, interspersed with till. In the lowlands, bedrock outcrop is rare because of a relatively thick sediment cover (up to 65 m at the coast). Bedrock outcrops at the coast, and is overlain by till and/or glaciomarine sediments.

3.3.2 Till

The most abundant surficial sediment is till, which covers ~50% of the study area, forming a regional unit overlying bedrock. It is typically structureless, matrix-supported, occurs as thin veneers (<2 m thick) or blankets (>2 m thick), and is variable in texture and clast lithology. Till veneer is most abundant and generally occurs in the uplands and foothills of the Long Range and Anguille mountains, Codroy Valley, and lowlands ~5-8 km inland from the coast. Thicker till was identified along the foothills of the Long

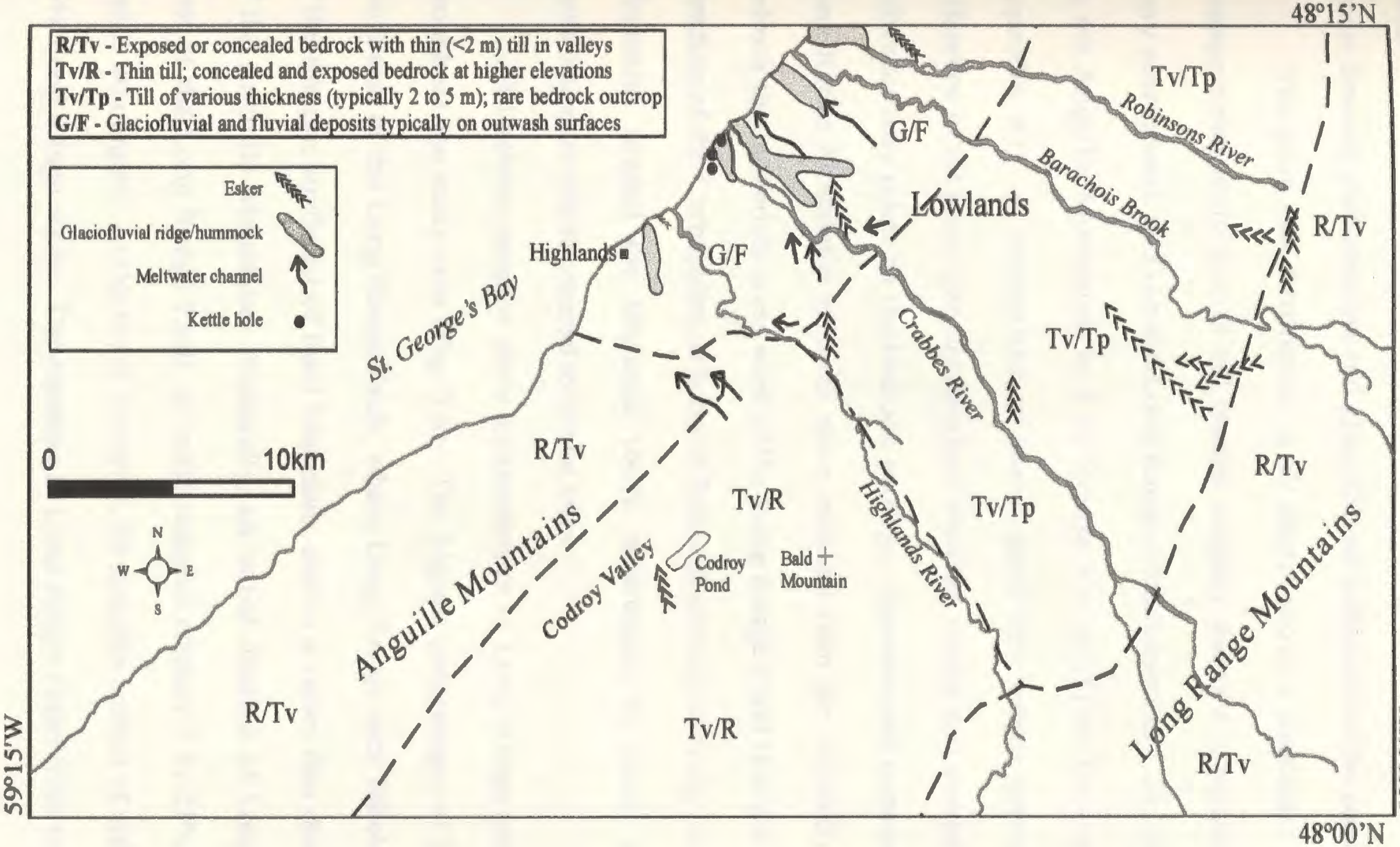

Figure 3.2 Generalized surficial geology map of southern St. George's Bay (see Figs. 2.1 and 2.2 for specific details). Also shown are landforms associated with these deposits.

Range Mountains, mainly in valleys, and the upper part of the Crabbes River valley. Till occurs beneath glaciomarine and glaciofluvial sediments at the coast.

The grain size distribution of till matrix shows a consistent pattern (Fig.3.3). The average mean grain size of till matrix samples shows a progressive fining from 1.5 ϕ (very coarse sand; n=5) on the Long Range Mountains and 1.7ϕ (very coarse sand; n=18) on the Anguille Mountains, to 4.8ϕ (coarse silt; n=11) on the lowlands/coast (Fig. 3.4; Appendix A). A comparison of mean grain size versus sorting also illustrates the difference in till grain size distributions between inland and coastal sites (Fig. 3.5). This difference may relate to the bedrock geology. Igneous and metamorphic bedrock on the Long Range Mountains is much more resistant than the relatively softer Carboniferous bedrock that underlies areas west of the Long Range Fault (Knight, 1982). Crushing and abrading of the Carboniferous bedrock beneath actively moving ice from the Long Range Mountains toward the lowlands likely contributed to much finer matrices in the lowlands/coast tills compared to inland sites.

Till pebble samples show an assortment of Long Range and Carboniferous clasts throughout the study area (Fig. 3.6). The highest percentages of Long Range clasts are found east of the Long Range Fault, where Long Range rock lithologies contribute 100% of the sample, southeast of Bald Mountain, and in a valley that dissects the northern part of the Anguille Mountains. Generally, an initial dilution of Long Range clasts occurs west of the Long Range Fault, as most samples contain 0 to 25% and 26 to 50% Long Range lithologies. At the coast, however, all samples consist of either 26 to 50% or 51 to 75% Long Range clasts. The increase in Long Range clasts from immediately west of the

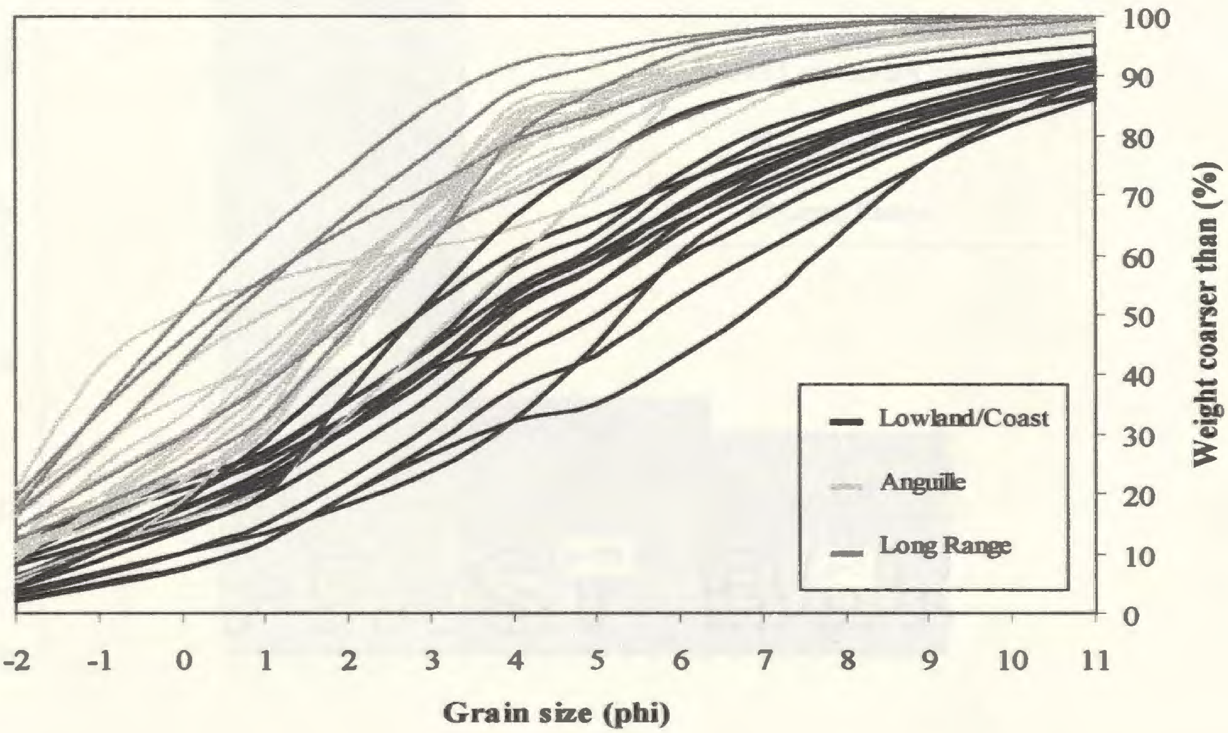

Figure 3.3 Grain size distribution of till matrix throughout the study area. Note the contrast between lowland/coast sites and those from the Anguille and Long Range Mountains.

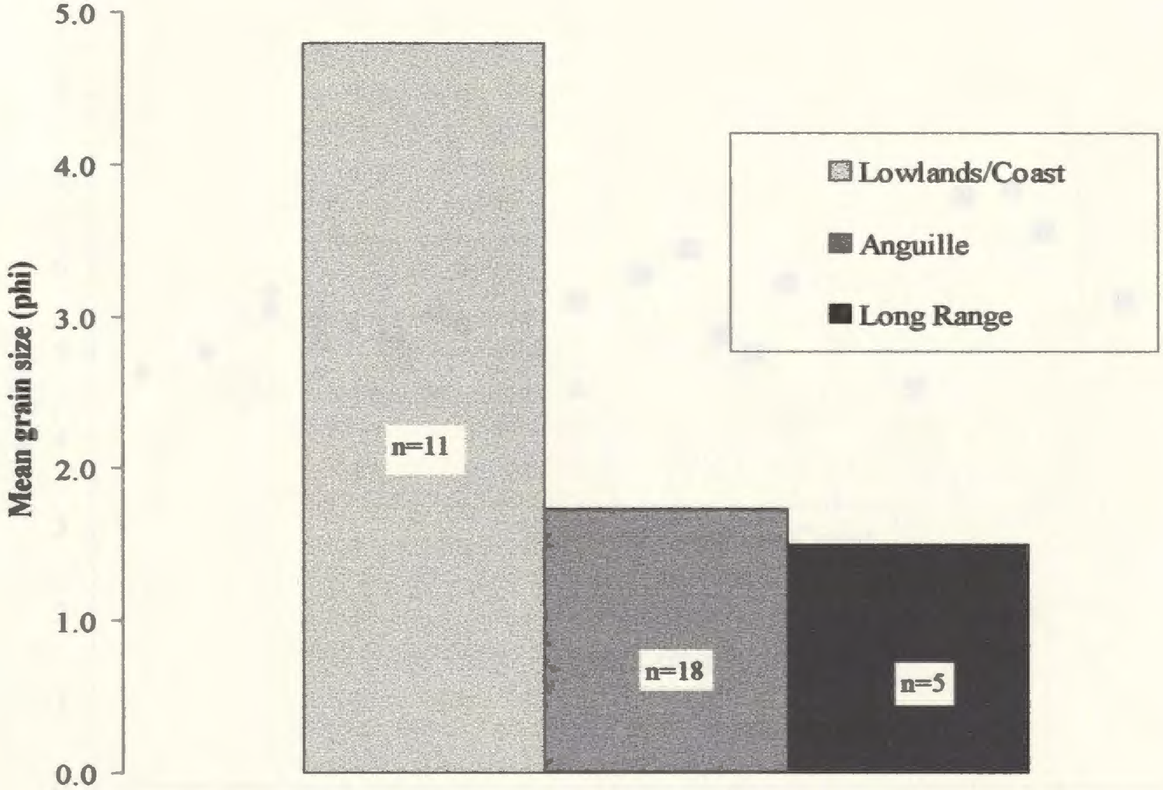

Figure 3.4 Average mean grain size of till matrix from different parts of the study areas. Note the contrast between lowlands and coastal sites versus Anguille and Long Range mountains sites.

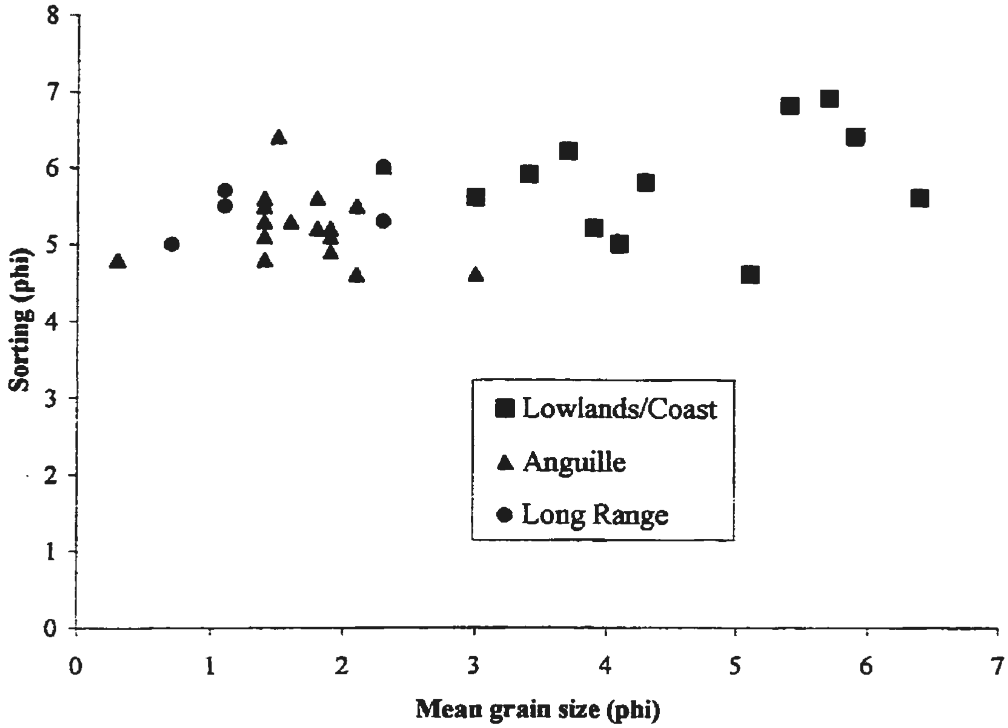

Figure 3.5 Mean grain size versus sorting parameters comparing till matrix samples. Note again the contrast between lowland and coastal sites and Anguille and Long Range Mountains sites. Overall, all of the diamictons are extremely poorly sorted, but inland sites have coarser mean grain sizes.

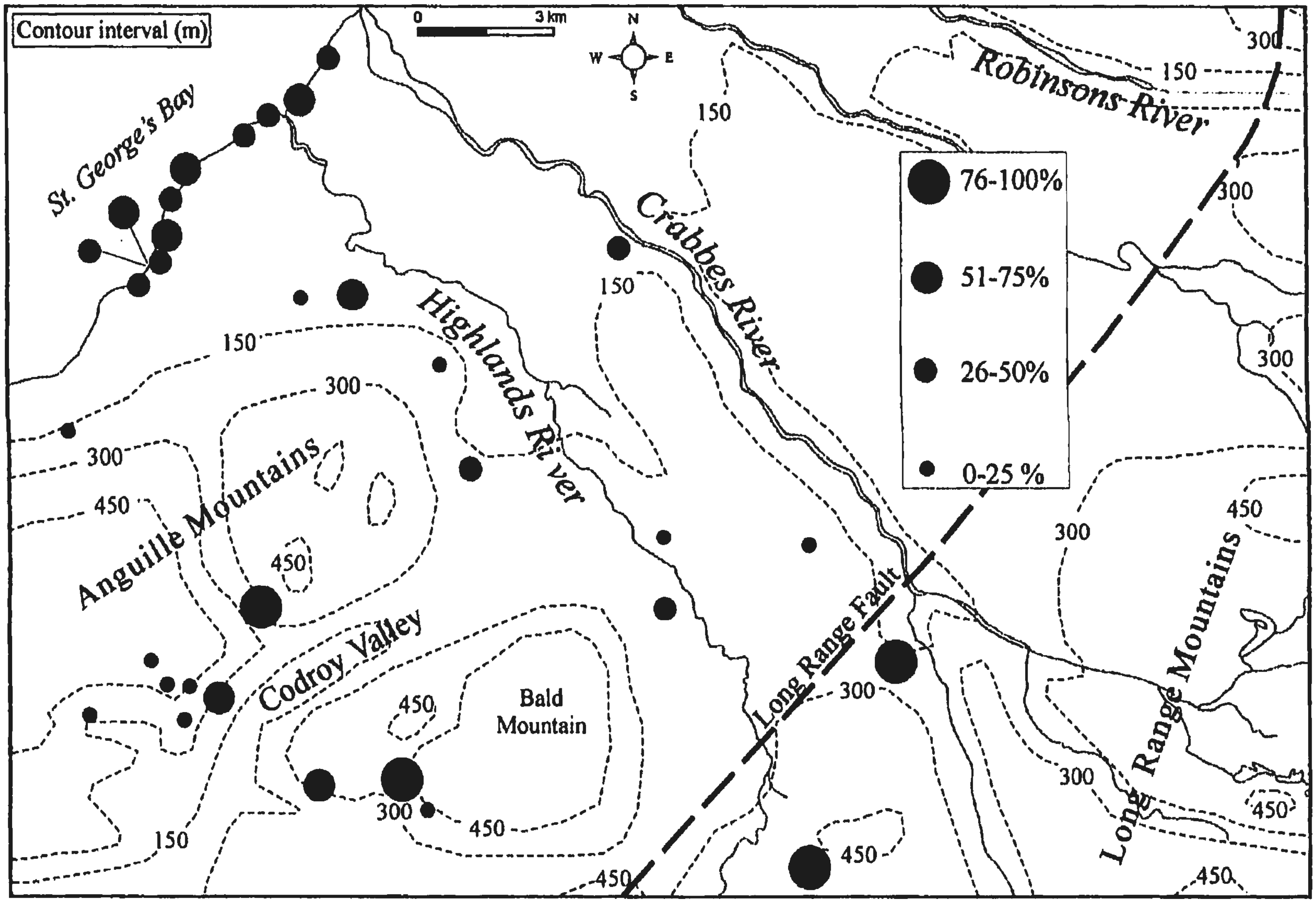

Figure 3.6 Percent Long Range clasts within tills throughout the study area. The two sites east of the Long Range Fault contain 100% Long Range clasts, whereas to the west, an initial dilution followed by increased percentages at the coast are evident. Southwest and west of Bald Mountain show relatively high Long Range percentages, although on the Anguille Mountain, typically <25% occur.

Long Range Fault toward the coast may be explained by considering the bedrock geology. Although bedrock to the west of the Long Range Fault is Carboniferous, some areas are underlain by conglomerates and pebbly sandstones that contain clasts of Long Range Mountains origin (Knight, 1982). Ice that overrode these areas on route to the coast may have entrained some of these clasts and deposited them at the coast. On the Anguille Mountains, Long Range lithologies generally make up 0 to 25%, although three sites contained >75% Long Range clasts. This increase may also be explained in a similar manner as the increase noted at the coast.

Clast fabrics from surficial tills have dominantly clustered to spread unimodal distributions (S1 range: 0.50 to 0.84; S1 mean: 0.74; n=20; Fig.3.7; Appendix A). Primary orientations vary from northeast-southwest, east-west, and southeast-northwest and appear to correspond with the striation record (Fig. 3.2). South of Bald Mountain, a west-southwestward striation roughly parallels three unimodal clast fabrics obtained southeast of the mountain. Two northwestward striae southwest of Bald Mountain coincide with two southeast-northwest oriented fabrics in that area. North of Codroy Pond, three south-southwest oriented fabrics align with a striation east and southwest of the pond. Striae on the Anguille Mountains are directed north-northwestward, and one unimodal fabric in a valley north of Codroy Pond parallels them. Two well-oriented fabrics west of Codroy Pond may relate to northwestward-directed striae in the southwest. At the coast, where striations are absent, fabrics south of Highlands parallel a west-southwest striation on the northern slopes of the Anguille Mountains. North of Highlands, fabrics indicate a northwestward flow across the coast.

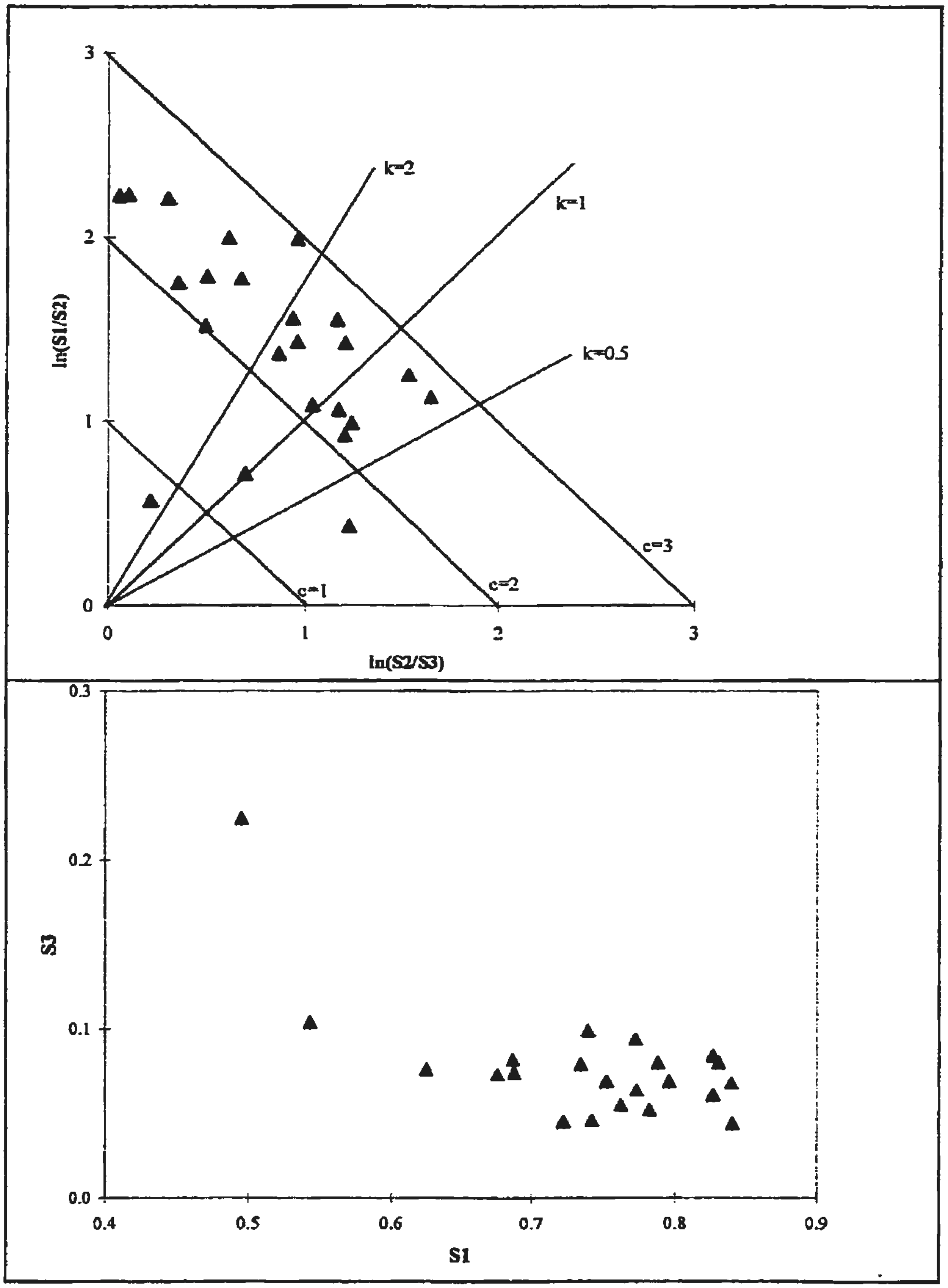

Figure 3.7 Clast fabric data from surficial tills throughout the study area. Most of these fabrics consist of unimodal clusters as they consistently plot above k=1 in the upper diagram and S1>0.6 in the lower.

3.3.3 Glaciofluvial

Glaciofluvial sediments, dominated by gravel, occur in the coastal lowlands and along modern river valleys. Exposures are limited inland, but at the coast, glaciofluvial deposits typically form the uppermost unit. The surface expression of these deposits is variable, and landforms include terraces, ridges/hummocks, eskers, meltwater channels, and kettle holes (Fig. 3.2; Liverman et al. 1999a).

In the Highlands area, south of Harbour Head, an 18 to 20 m asl terrace extends southward to French Brook (Plate 3.1), whereas north of Harbour Head, a 24 to 26 m asl surface continues to Crabbes River (Plate 3.2). Sediments beneath these terraces typically consist of planar-bedded pebble to cobble gravel overlying planar-bedded sand. The terrace surfaces at Highlands are interrupted at Harbour Head by the Highlands ridge, which rises steeply on its eastern and western flanks (Figs. 3.8, 3.9). This ridge is a 2 km long by 300 m wide linear feature that ranges in elevation from 34 m asl at the coast, to >60 m asl inland (Plate 3.3). Where the ridge intersects the coast at Harbour Head, sediments consist mainly of interbedded sand, gravel, and diamicton (see "Coastal Exposures" below). At Crabbes River, hummocks composed of sand and gravel rise to >45 m asl (Plate 3.4).

Eskers generally orientated northwest-southeast were mapped on the coastal lowlands, Long Range Mountains, and in the Codroy Valley (Fig. 3.2). On the lowlands, eskers are found immediately inland or adjacent to glaciofluvial ridges/hummocks. They range from 20 to 1500 m long, 50 to 150 m wide, and 2 to 30 m high. Exposures are rare, although south of Codroy Pond, a 25 m-high section crosscuts an esker at right angles, and shows a fining-upward sequence that consists of interbedded pebble to boulder

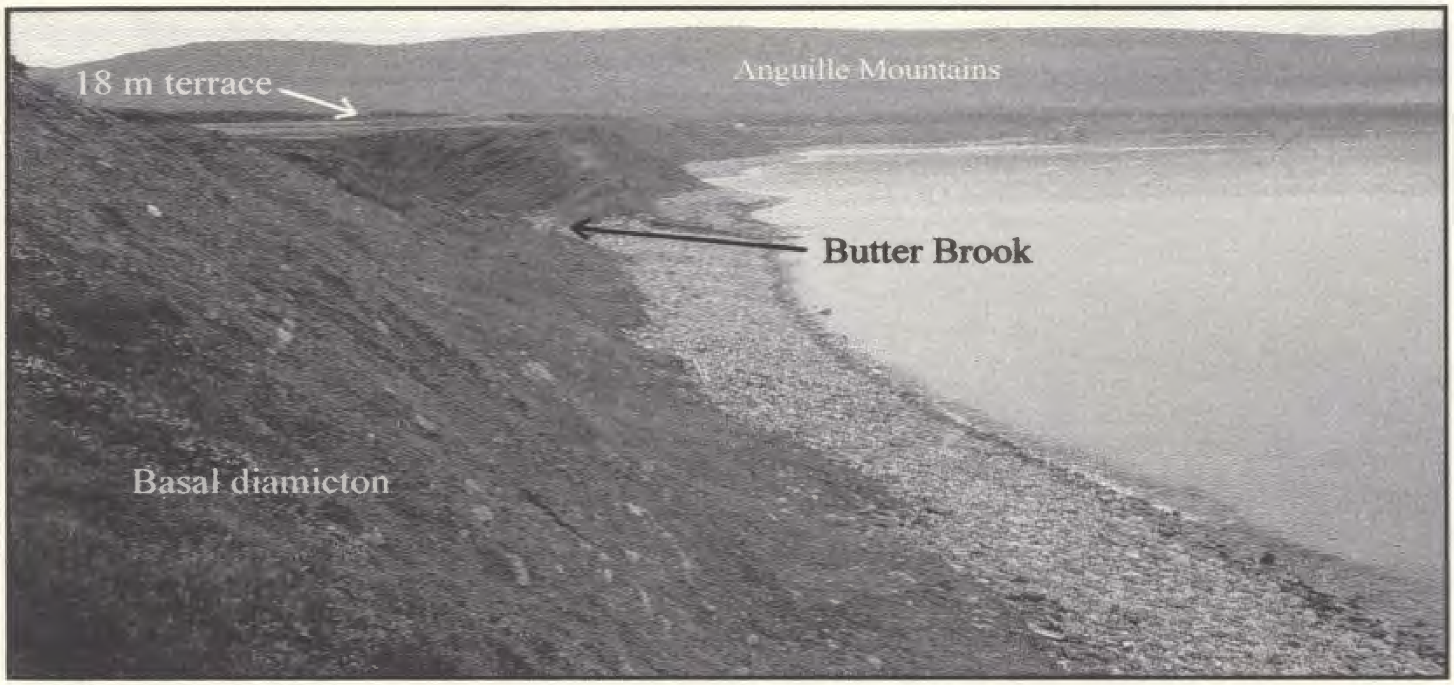

Plate 3.1 View looking south across 18 m terrace surface. The elevation of this feature ranges from 18 to 20 m asl between French Brook and Harbour Head.

Plate 3.2 View from south of McLellans Brook of terrace surface at 24 m asl. This surface continues northward to Crabbes River and ranges in elevation from 24 to 26 m asl.

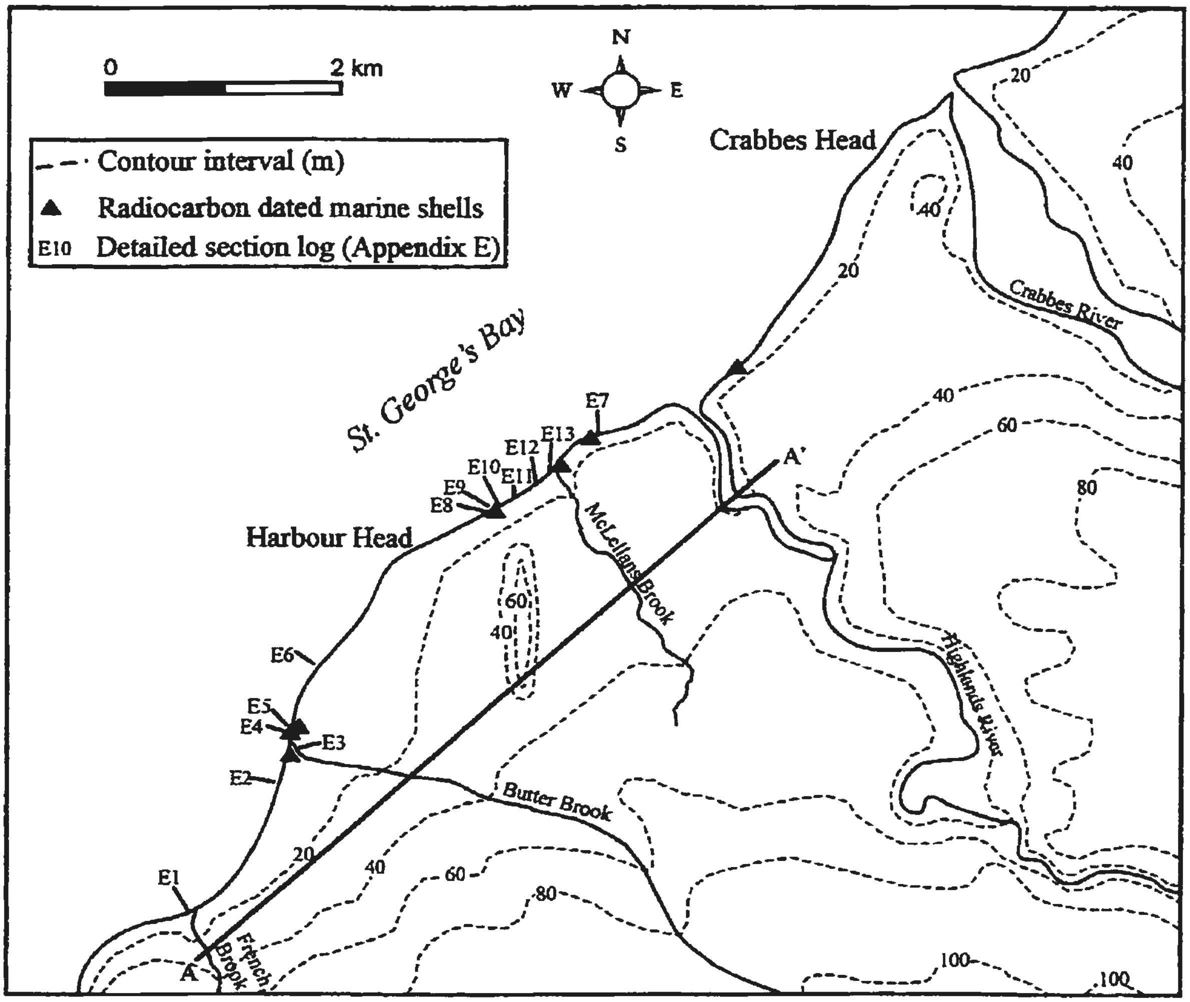

Figure 3.8 Map of the lowlands showing locations of detailed section logs and radiocarbon dates. The line denoted A-A' represents the location of the topographic profile in Figure 3.9.

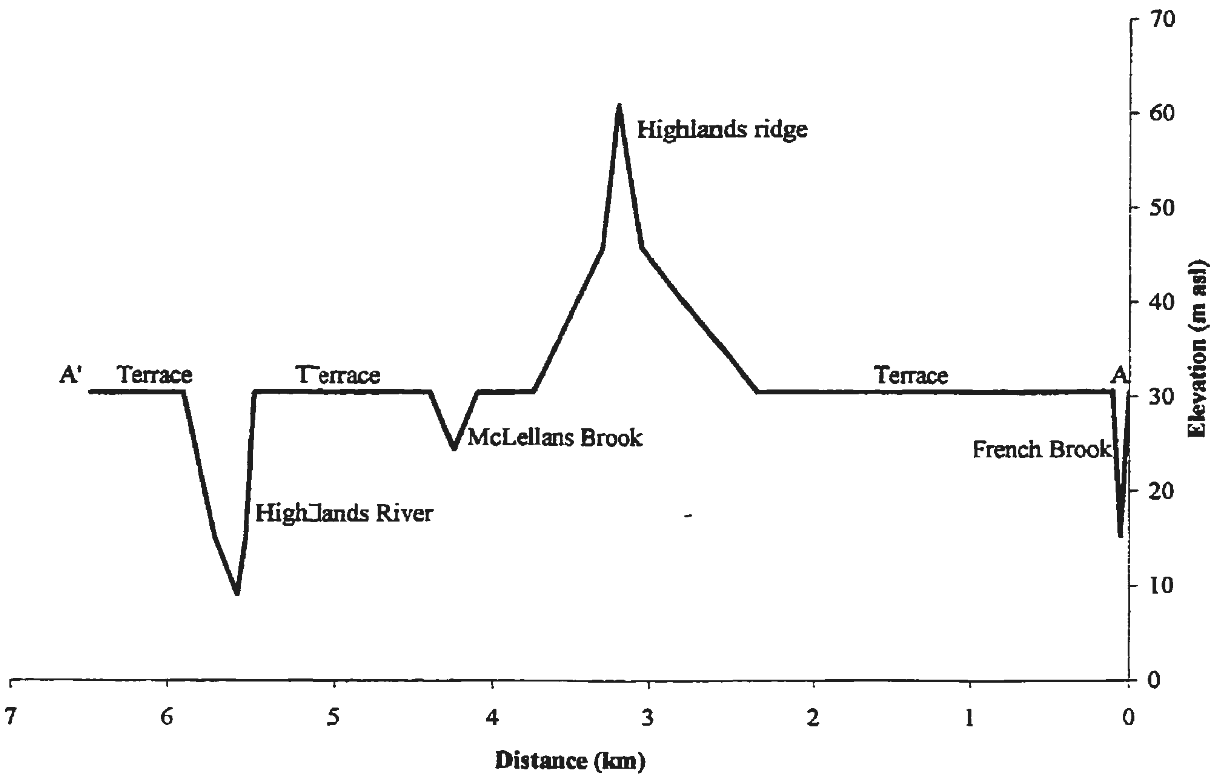

Figure 3.9 Topographic profile of coastal lowlands between French Brook and Highlands River. Location of profile shown in Figure 3.8. Vertical exaggeration = 64x.

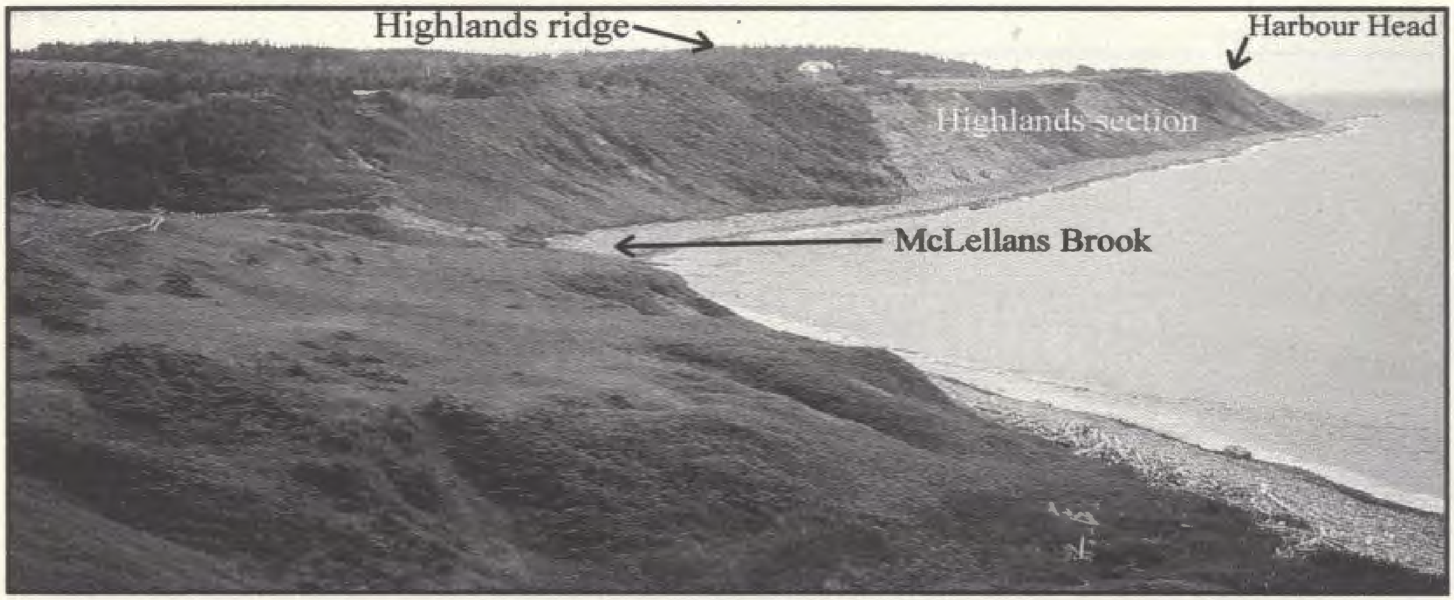

Plate 3.3 View of Highlands ridge in relation to the Highlands section. The ridge is >60 m asl and intersects the coast at Harbour Head.

Plate 3.4 Glaciofluvial hummocks near Crabbes River (note truck for scale). The terrace in the foreground is at 26 m asl and continues southward to McLellans Brook.

gravel, gravelly sand, and sand, with bedding that conforms to the sides of the ridge. The consistent orientation of eskers indicates subglacial drainage toward the coast.

Several meltwater channels occur on the lowlands and the northern slopes of the Anguille Mountains (Fig. 3.2). Air photo interpretation suggests that these channels consist of sub-glacial, pro-glacial, and lateral features. Subglacial channels occur north of Crabbes River adjacent to ridge deposits, range from 2 to 5 km long and 200 to 400 m wide, and are flat-bottomed. Proglacial channels occur ~5 km inland near Crabbes and Highlands rivers, and appear incised into glaciofluvial sediments. Lateral meltwater channels occur on the Anguille Mountains, are eroded into sediment and bedrock, and slope toward the northwest. These lateral channels appear to host ephemeral streams, one of which is a tributary of Butter Brook.

Landforms identified as kettle holes occur on a 26-m terrace surface near Crabbes River (Plate 3.5), where coastal erosion has exposed the sediments within two of these features. These features are interpreted as kettle holes because they occur in sediments interpreted as ice-proximal glaciofluvial outwash dipping steeply (up to 40°) into the depressions (cf. Maizels, 1992). They range from 8 to 10 m deep, 50 to 75 m wide, and are capped by up to 4 m of sand and silt, and peat.

3.3.4 Fluvial

Fluvial deposits consist of sand and gravel and occur near modern rivers at lower elevations compared to glaciofluvial terraces. At the coast, glaciofluvial terraces are dissected in several areas by modern river valleys, adjacent to which occur fluvial terraces at McLellans Brook (5 m asl), Butter Brook (3 to 12 m asl), and French Brook (5

Plate 3.5 Top: Kettle depression (outlined) near Crabbes River. Note 1.5 m high fence at the right of the photograph. Bottom: Cross-section through depression in coastal exposure. Note steeply dipping gravel beds, interpreted to represent collapse around melting ice. The kettle is now filled with peat. Note person for scale.

m asl; Plate 3.6). Sediments in these fluvial terraces consist mainly of planar-bedded pebble-cobble gravel, directly overlying glaciomarine mud.

3.3.5 Organic (bogs)

Organic deposits are dispersed throughout the study area. These deposits are generally <2 m thick and are most abundant on the lowlands, generally overlying glaciofluvial deposits. Exposures are limited to the coastal sections and consist mainly of well compacted woody peat.

3.3.6 Colluvium

Colluvial deposits commonly occur along the steep valley sides in the Anguille Mountains and Long Range Mountains and along modern river valleys. These deposits consist mainly of resedimented till and/or bedrock rubble. At the coast, colluvium is abundant because impermeable silt- and clay-rich tills and/or glaciomarine muds generally underlie the exposures. When overlying sediments become saturated, slope failures commonly occur. The bases of the coastal exposures often are obscured by slumped material, derived from higher up in the sections.

3.4 Coastal Exposures

The most extensive, diverse, and thickest (up to 34 m) sediment assemblages in the study area occur along the coast (Fig. 3.10). In these exposures, two distinct sediment sequences are evident. The typical sequence, which is found over ~90% (lateral distance of 5.5 km) of the coastline occurs between French Brook and Harbour Head and McLellans Brook and Highlands River. It is associated with glaciofluvial terraces at the surface. Exposures range from 20 to 26 m asl forming successions that mainly consist of diamicton (generally overlying bedrock), overlain sequentially by mud, sand, gravel, and

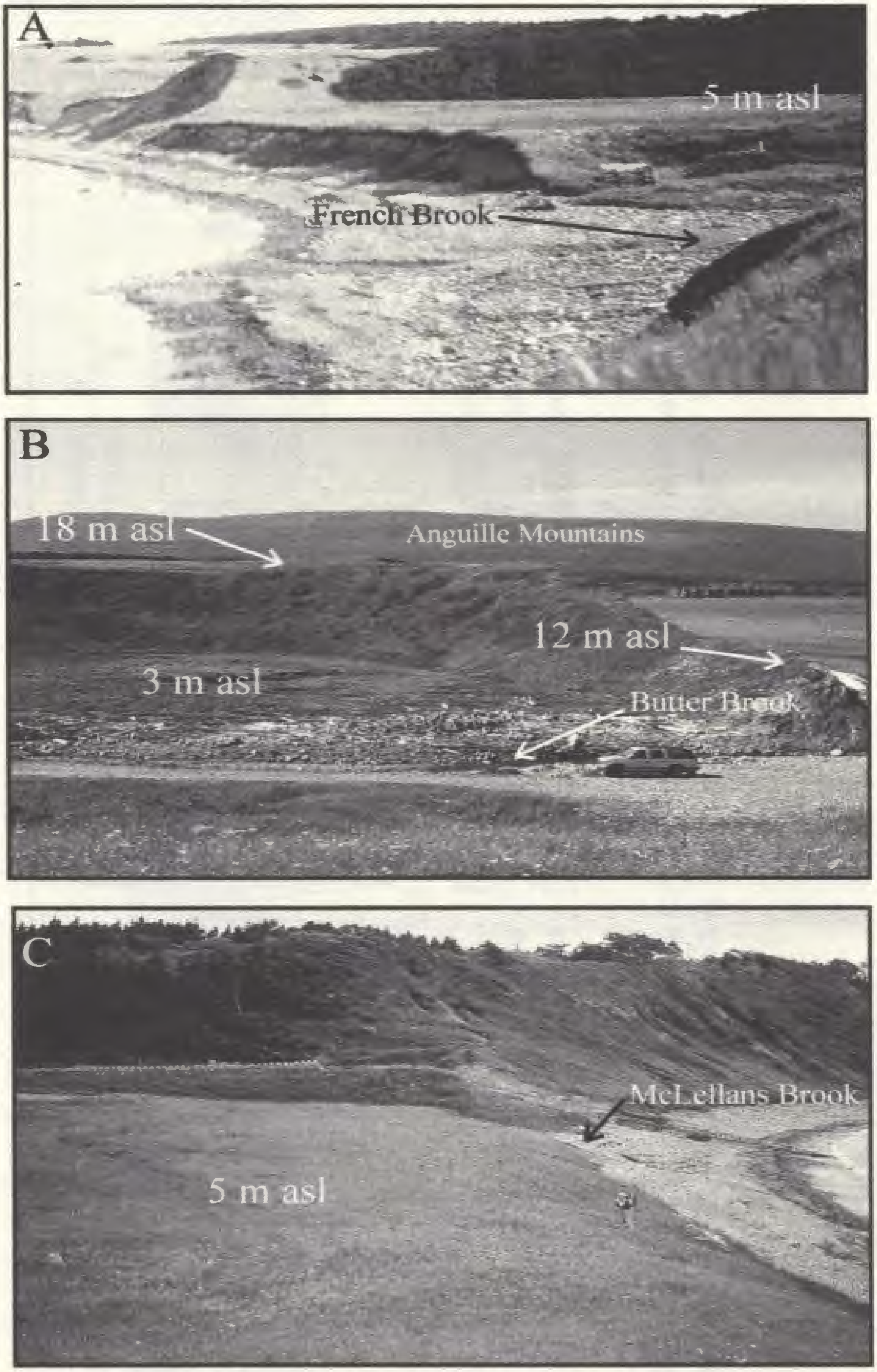

Plate 3.6 Fluvial terraces at French Brook (A), Butter Brook (B), and McLellans Brook (C). Sediments in these terraces mainly consist of planar-bedded gravel directly overlying mud.

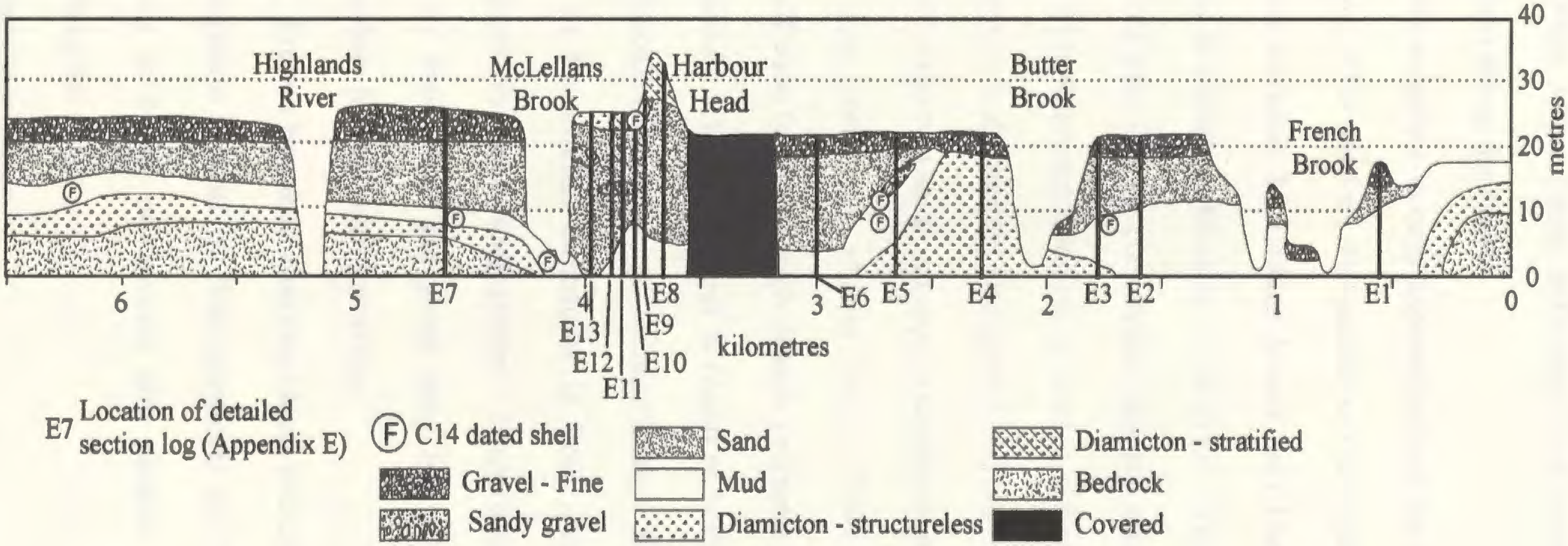

Figure 3.10 Generalized continuous section log representing coast from French Brook to north of Highlands River. Sand and silt unit is not included here because it is generally too thin for the scale of the diagram. Vertical exaggeration = 25x.

sand and silt (Plate 3.7). These sediments form continuous units that are traceable for several kilometres along the coast.

The other sequence is only exposed where the Highlands ridge intersects the coast at Harbour Head. This section, designated as the Highlands section, represents 0.6 km of coastal exposure between McLellans Brook and Harbour Head (Fig. 3.10; Plate 3.8). Exposures range in elevation from 26 to 34 m asl. The Highlands section consists of four sedimentary units that form a coarsening upward sequence and are traceable across the entire section. This sequence consists of mud; overlain successively by interbedded sand, gravel, and diamicton; diamicton; and gravel and gravelly sand.

To contrast the two section types, a description and interpretation of the sediments are provided using composite section logs. These illustrate the typical sedimentary characteristics of each type, although details pertaining to specific sites are also provided (Fig. 3.10; Appendix E). A mud unit is found in both section types overlying diamicton along the entire coast of southern St. George's Bay. Similarly, a silt and sand unit occurs along the top of the coastal exposures in both sections. Because of their consistent stratigraphic position and sedimentary characteristics, detailed descriptions and interpretations of these units are given only for the Type A sections, although these provide an overview for the entire coastline.

3.4.1 Type A: French Brook to Harbour Head, McLellans Brook to Highlands River

The composite section log that represents the Type A sections is shown in Figure 3.11. This log is based on several site section logs (Appendix E) and general observations along the coast.

3.4.1.1 Sediment Description

Plate 3.7 Photograph of a type A section north of McLellans Brook. This exposure consists of diamicton and mud at the base (obscured by slumping), overlain by sand, gravel, and sand and silt. Note the loading features in the sand, suggesting rapid deposition of the overlying gravel before the sand was dewatered.

Plate 3.8 Highlands section looking northward from Harbour Head. This section is ~0.6 km long and ranges in elevation from 26 m asl at the far left, where McLellans Brook enters the sea, to 34 m asl in the foreground. The sequence of sediments consists of mud, overlain successively by sand and gravel, diamicton, gravel and gravelly sand, and sand and silt.

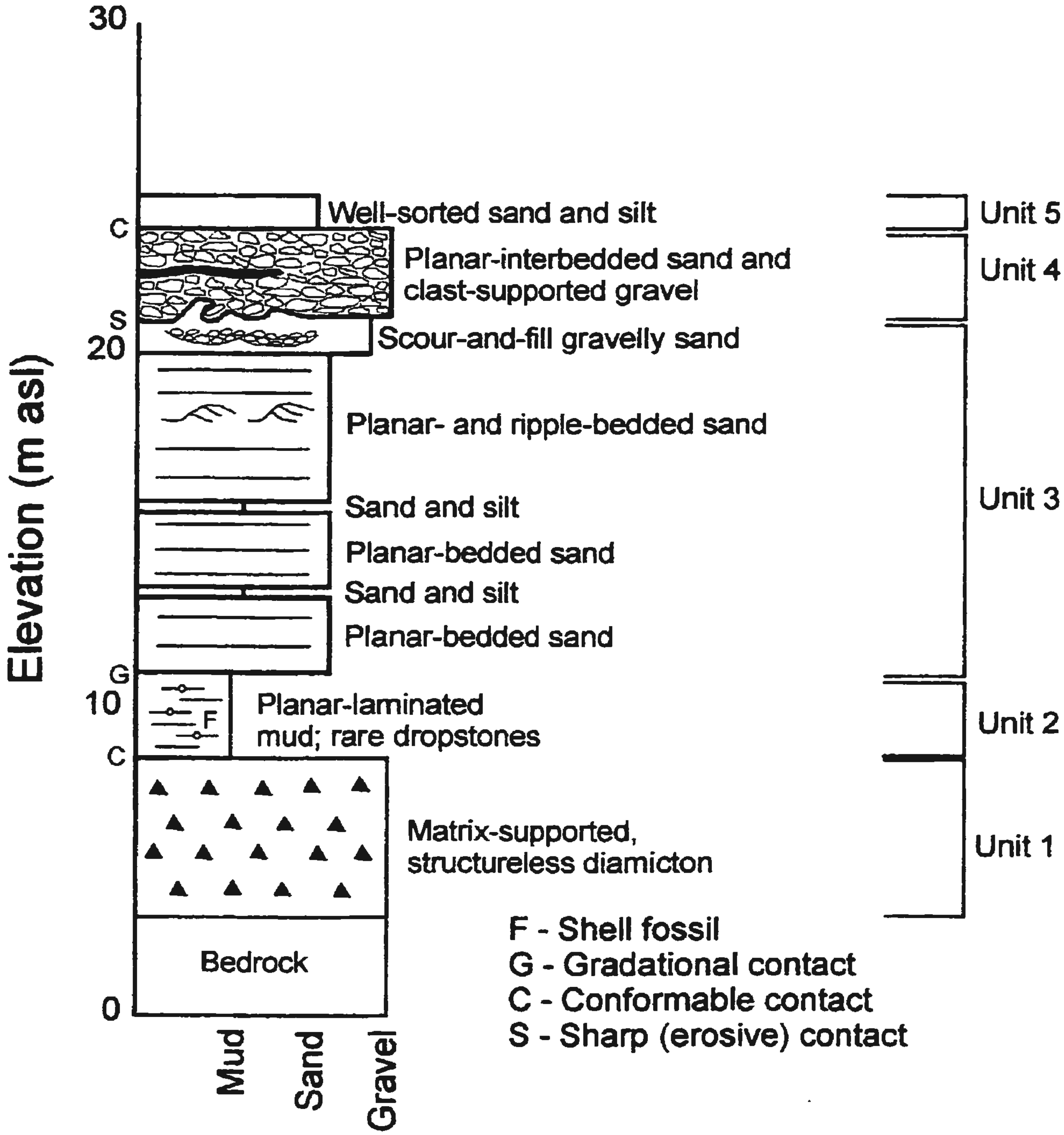

Figure 3.11 Composite section log of Type A sections.

3.4.1.1.1 Unit 1: Basal diamicton

Diamicton generally forms the basal sedimentary unit directly overlying bedrock. It is structureless, matrix supported (sandy-silt to silt), very compact and cohesive, and ranges from 1 to 17 m thick, although typically is 3 to 4 m thick. The upper contact is sharp and conformable (Plate 3.9). Moist colours include brown dark-brown (7.5YR 4/2), greyish brown (2.5Y 5/2), dark greyish brown (10YR 4/2), and dark reddish grey (5YR 4/2). Clast content ranges from 25 to 40%, consisting of abundant striated and faceted pebbles to boulders. Analysis of ten pebble samples from the diamicton revealed 27 to 60% (mean=47%) Long Range Mountains and 40 to 73% (mean=53%) local Carboniferous rock types.

The grain size distribution shows little variability along the coast (Fig. 3.12). Of 8 samples, the average percentages of mud (silt and clay), sand, and gravel are 48:39:13 (Fig. 3.13; Appendix C). Average mean grain size of the matrix ranges from 3.7 to 5.7ϕ (very fine sand to medium silt).

Clast fabrics show a range of unimodal and spread unimodal clusters, and girdles, although most have weak to strong unimodal distributions (S_1 range: 0.52 to 0.84; S_1 mean: 0.68; n=20; Fig. 3.14; Appendix A). Orientations include northeast-southwest, east-west, and southeast-northwest.

3.4.1.1.2 Unit 2: Mud

This unit is mostly composed of rhythmically planar laminated silt, clay, and fine to very fine sand (Plate 3.10). Moist colours include dark grey (2.5Y 3/0, 2.5YR 4/0, 2.5 YR 5/2, 10YR 4/1), very dark grey (2.5YR 3/0), dark greyish brown (10YR 4/2, 10 YR

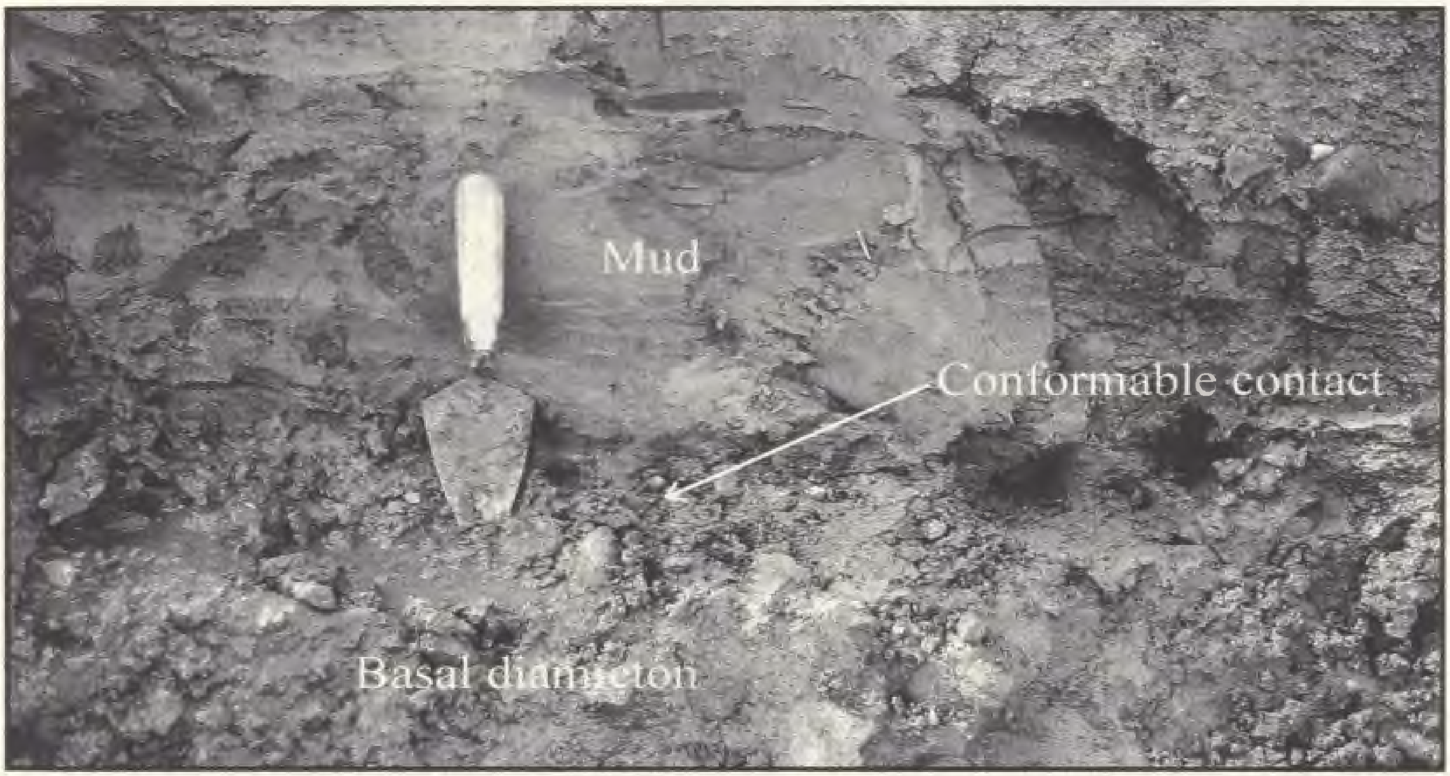

Plate 3.9 Planar-laminated mud overlying basal diamicton near Highlands River. Note sharp, conformable contact.

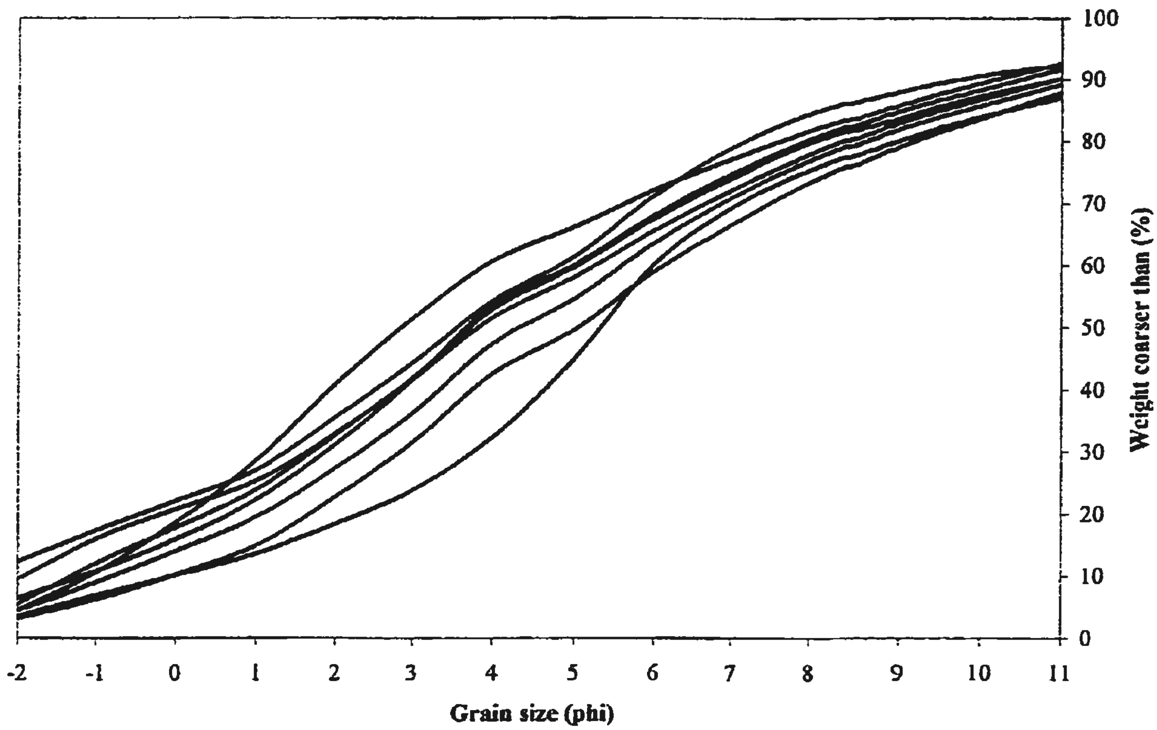

Figure 3.12 Grain size distribution of the matrix of basal diamicton in Type A sections.

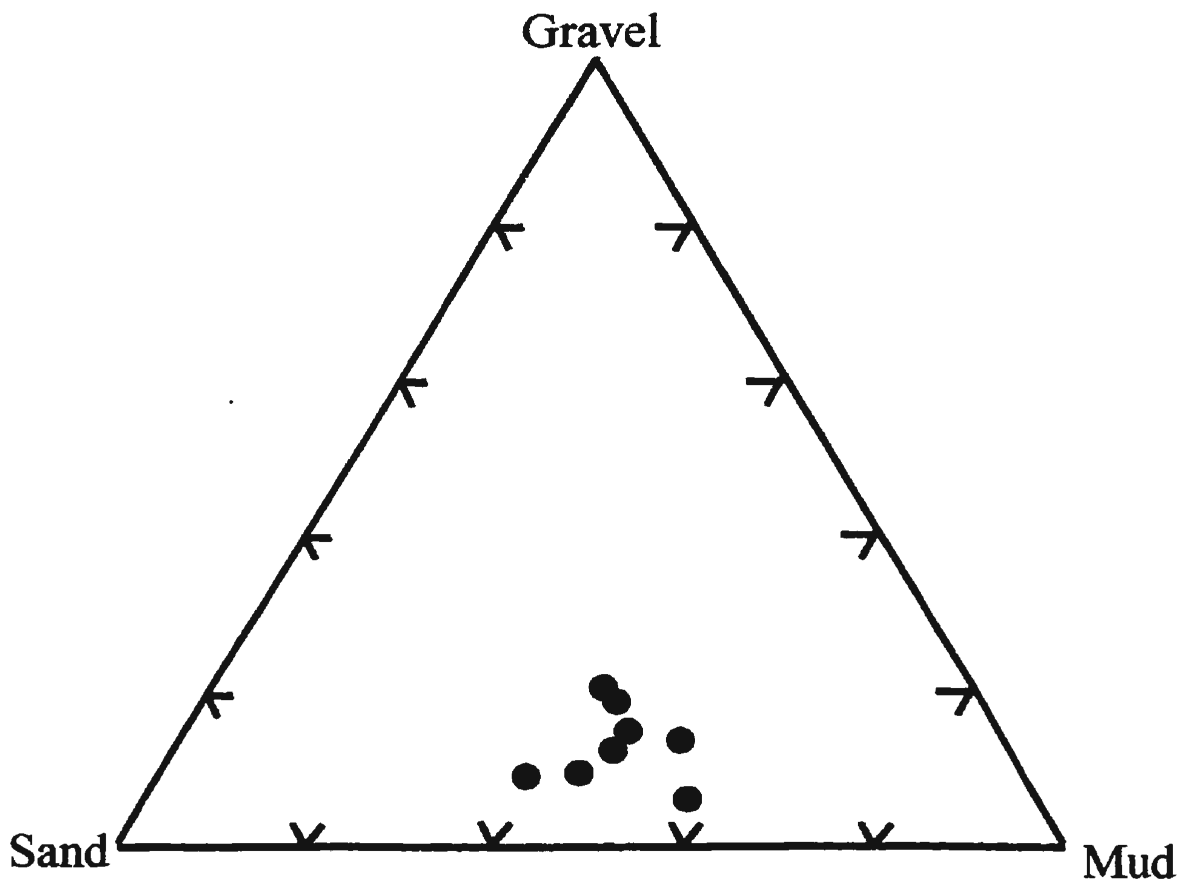

Figure 3.13 Ternary plot of matrix grain size from basal diamicton in Type A sections.

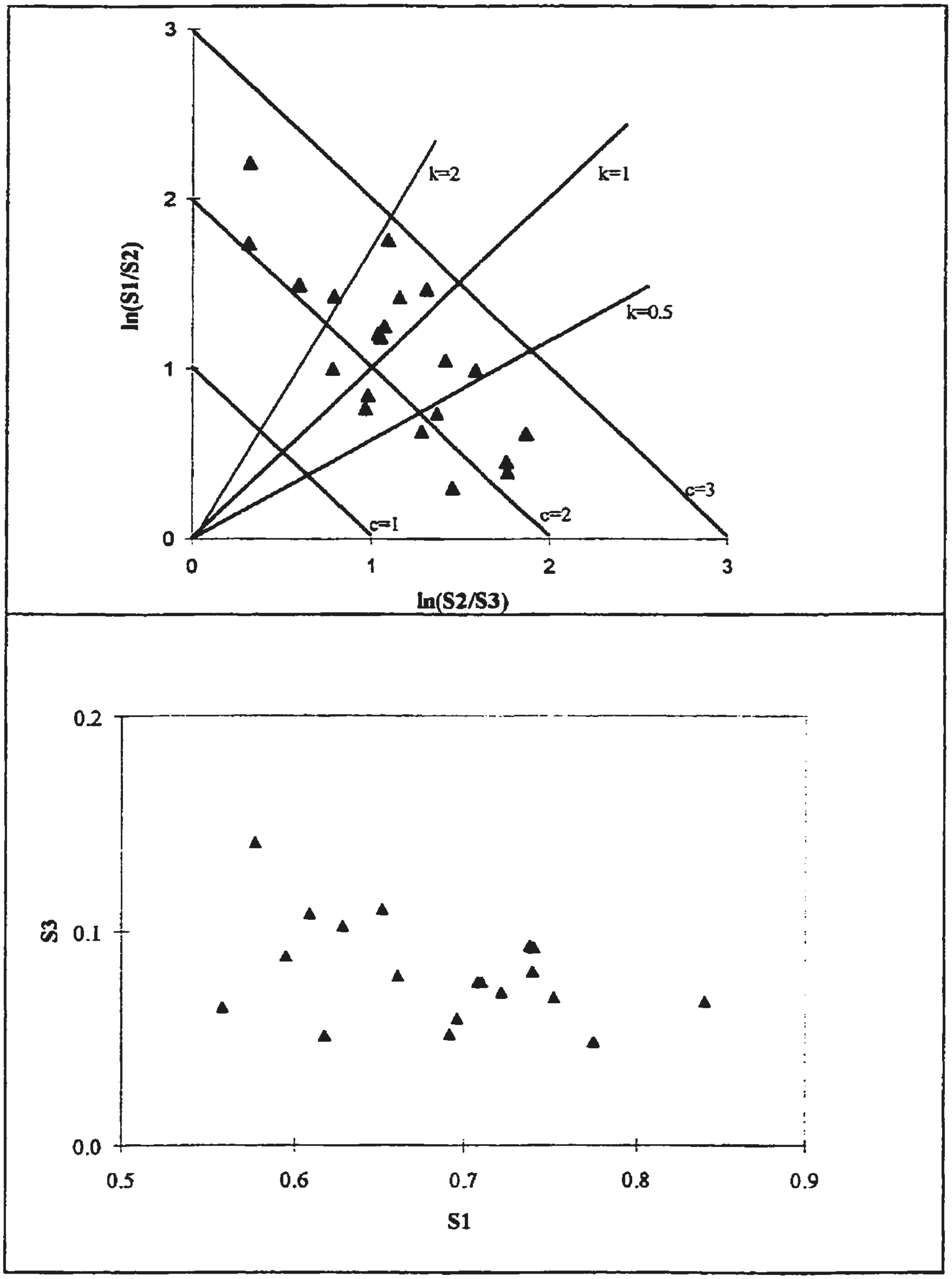

Figure 3.14 Clast fabric data from basal diamicton in Type A sections, indicating girdles to weak and strong clusters.

Plate 3.10 Planar-interlaminated silt and clay (mud) and sand north of Highlands River. This mud forms a regional unit, typically overlying basal diamicton along most of the coast.

5/2), brown (7.5YR 4/2), brown dark-brown (10YR 4/3), and reddish brown (5YR 4/3, 5YR 4/4, 5YR 5/4). Silt and clay compose most of this unit (analysis of 4 samples), ranging from 49 to 60% and 36 to 45%, respectively, whereas sand and gravel contribute 2 to 7% and 0 to 0.3%, respectively (Fig. 3.15). These samples represent the unit as a whole because each was extracted from a channel spanning a number of beds. Individual laminae are normally graded to structureless, typically 0.5 to 2 cm thick, and have sharp upper and lower contacts. Rare granule to pebble-sized clasts are also present (Plate 3.11). Marine shells are common in mud and radiocarbon dates (n=3) range from ~13.4 to 13.5 ka BP (Table 1.1, 3.1; Fig. 3.8).

3.4.1.1.3 Unit 3: Sand

Overlying a gradational contact with the mud of Unit 2 is 5 to 12 m of dominantly planar, horizontally bedded, moderate- to well-sorted fine to coarse sand. It has continuous beds, typically 5 to 100 cm thick (Plate 3.12). Ripple-bedding and interlaminated silt are common. Textural analysis of three samples shows 84 to 98% sand, and 2 to 16% mud (silt and clay) (Appendix C). Individual beds range from structureless to normal and inverse graded, with bed contacts either sharp (erosional) or gradational. The unit generally coarsens toward the top, where pebble-size clasts in minor scour-and-fill features occur, and in these areas, underlying beds are generally loaded and disturbed; evidence of more extensive, although localized loading and deformation occur north of McLellans Brook. The contact between Units 3 and 4 (Gravel) is sharp (erosional) and ranges from planar to contorted, although in some areas, scour-and-fill structures occur (Plate 3.13).

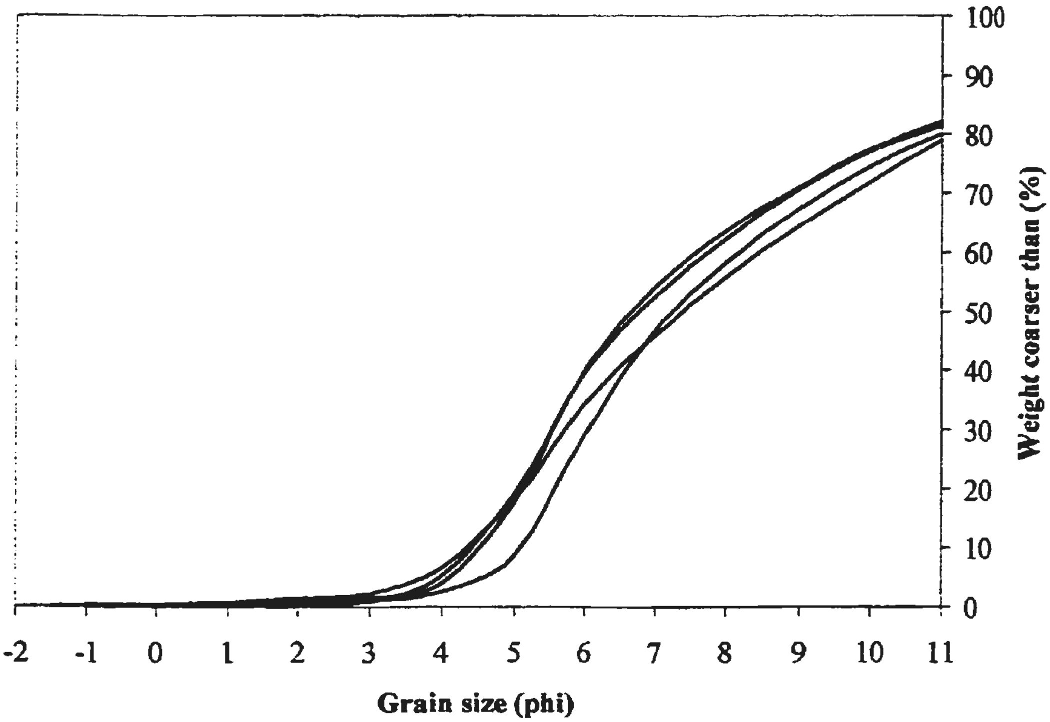

Figure 3.15 Grain size distribution of muds from coastal sections between French Brook and Highlands River.

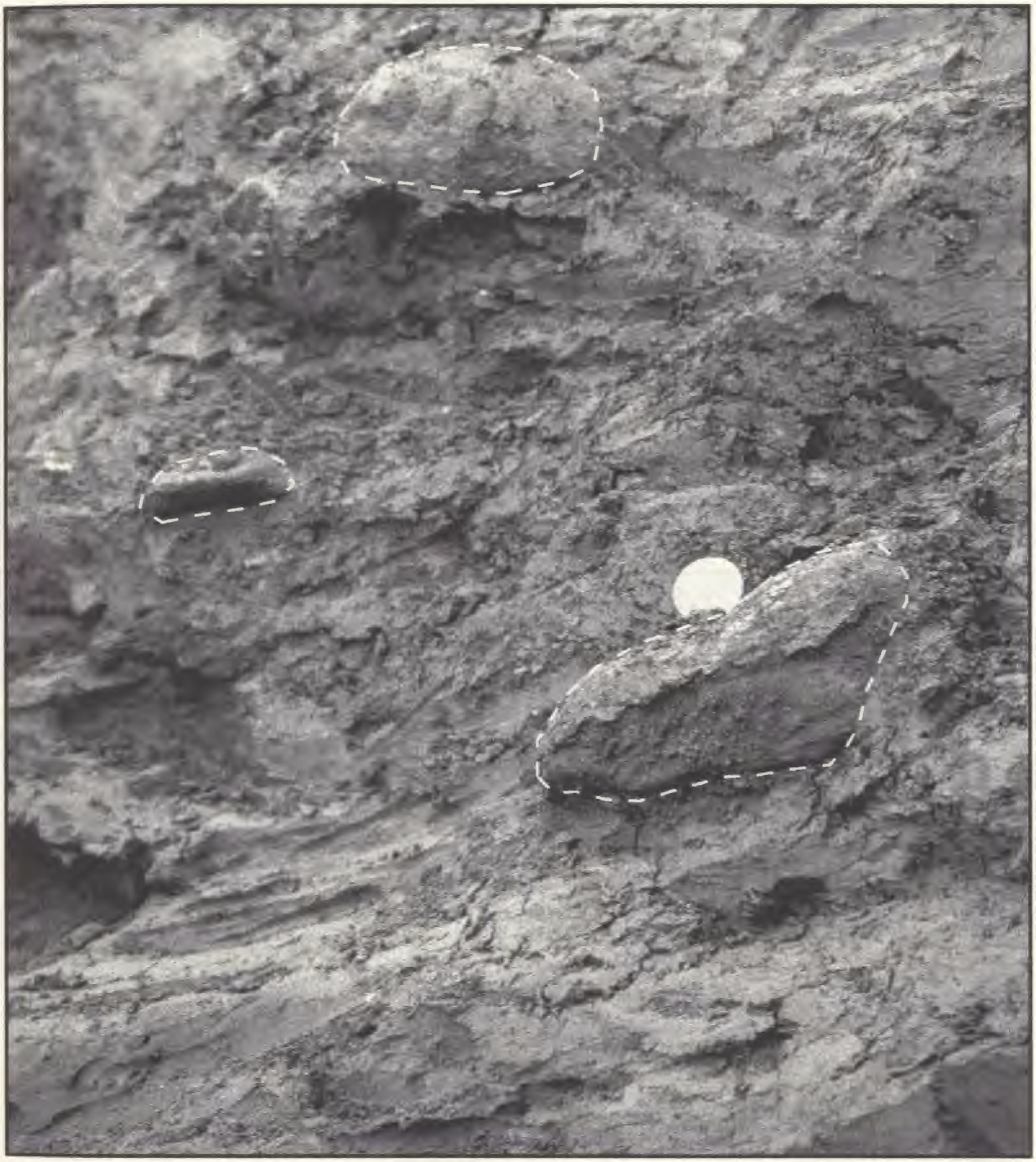

Plate 3.11 Scattered cobbles (outlined) in planar-laminated mud near Butter Brook. Coin for scale.

Table 3.1. New radiocarbon dates on marine shells from study area. Locations are shown in Figure 3.9 and Figure 3.10.

Age	Lab number	Location	Elev. (m asl)	Enclosing sediment
13 520 ± 110	TO-7453	Maidstone	10	Mud
13 470 ± 120	Beta-120125	Butter Brook North	10	Laminated diamicton
13 360 ± 70	Beta-120126	Butter Brook North	12	Sandy gravel
13 680 ± 90	Beta-120124	Harbour Head	26	Stratified diamicton

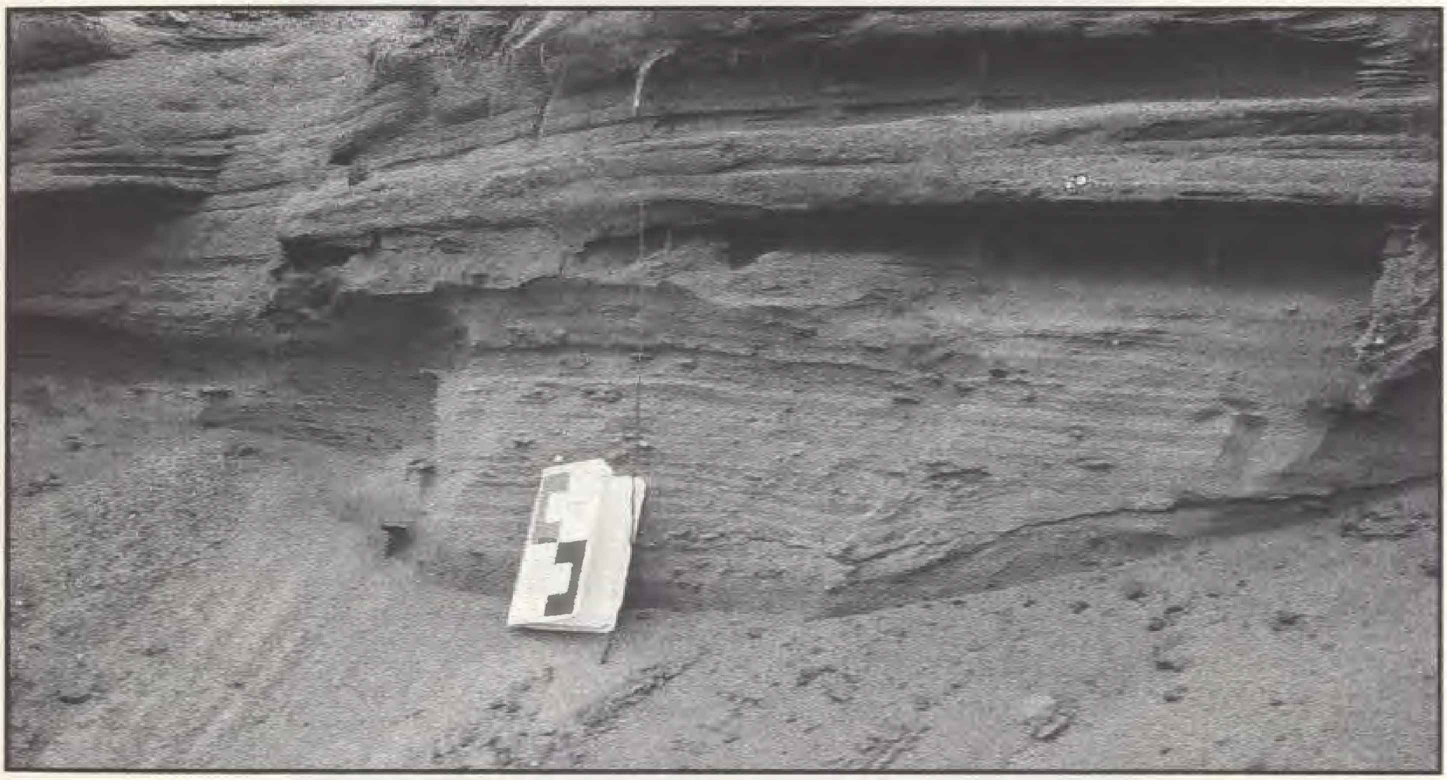

Plate 3.12 Planar-bedded sand forms the bulk of the exposure of Unit 3 in Type A sections and the Highlands section.

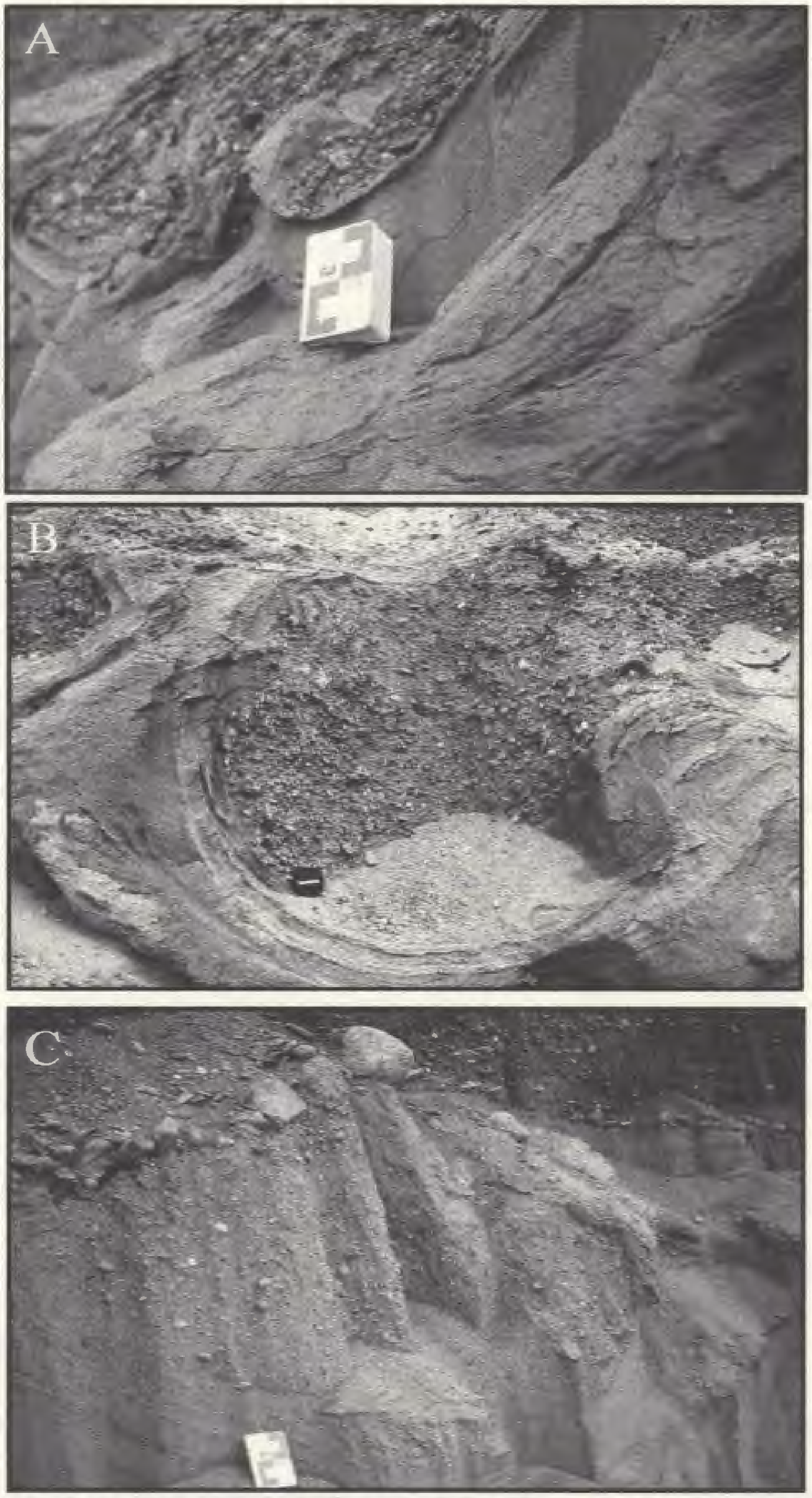

Plate 3.13 Contacts between sand and gravel in Type A sections are mainly sharp and erosional, although vary in sedimentary characteristics. A: convoluted; B: Flame structure; C: scour-and-fill feature. A and B indicate rapid loading of saturated sediments, whereas C suggests erosion into the sediment, likely by processes that deposited the overlying gravel.

3.4.1.1.4 Unit 4: Gravel

Gravel forms a continuous unit near the top of the coastal exposures, typically overlying sand, although adjacent to French Brook, Butter Brook, and McLellans Brook, gravel sharply overlies mud (Unit 2). Gravel is generally planar-bedded, clast-supported (medium sand matrix), moderately to well sorted, and ranges from 1 to 5 m thick (Plate 3.14). Trough-cross-bedding and rare interbeds of sand and gravelly sand occur in some areas. Interbeds are generally less than 20 cm thick and pinch out laterally over a few metres. Gravel consists mainly of subangular to rounded pebbles to cobbles, with a mixture of Long Range Mountains and Carboniferous rock types. Boulder-size clasts generally make up <1% of the unit.

There are several areas along the coast where features indicative of ice wedge casts occur in the gravel (Plate 3.15). The most distinct of these exists near Butter Brook. The cast is ~200 cm high, ~150 cm wide at the top, narrows to <10 cm at the base, and extends obliquely into the underlying sand unit. Clasts are pebble to cobble and dip gradually toward the centre of the feature.

3.4.1.1.5 Unit 5: Sand and silt

Very well to moderately well-sorted (s range: 0.2 to 0.7ϕ; mean=0.4ϕ; n=3) sand and silt form a continuous unit 1-2 m thick along the cliff-top of the coastal exposures, conformably overlying Unit 4 in both section types. There is little variability in the textural characteristics of this unit along the coast (Fig. 3.16). Analysis of three samples showed 86 to 94% sand, 4 to 12% silt, and 2% clay. Average mean grain size is 2.6ϕ (fine sand).

Plate 3.14 Two metre-thick exposure of planar-interbedded pebble-cobble clast-supported gravel (parallel lines) near Butter Brook. Note scour feature now filled with sand.

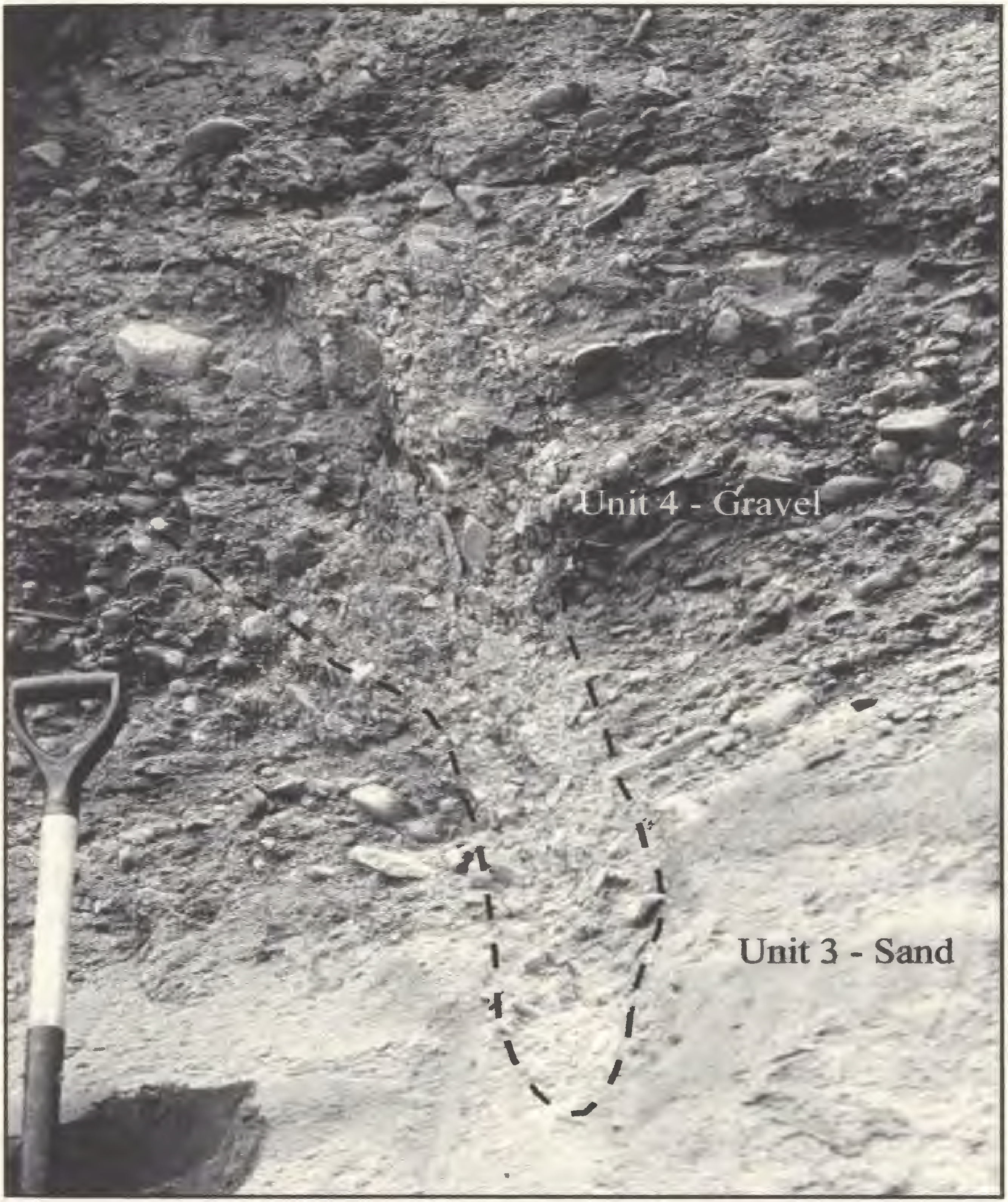

Plate 3.15 Ice-wedge cast developed in planar-bedded gravel north of Butter Brook. Note the orientation of clasts dipping into the feature.

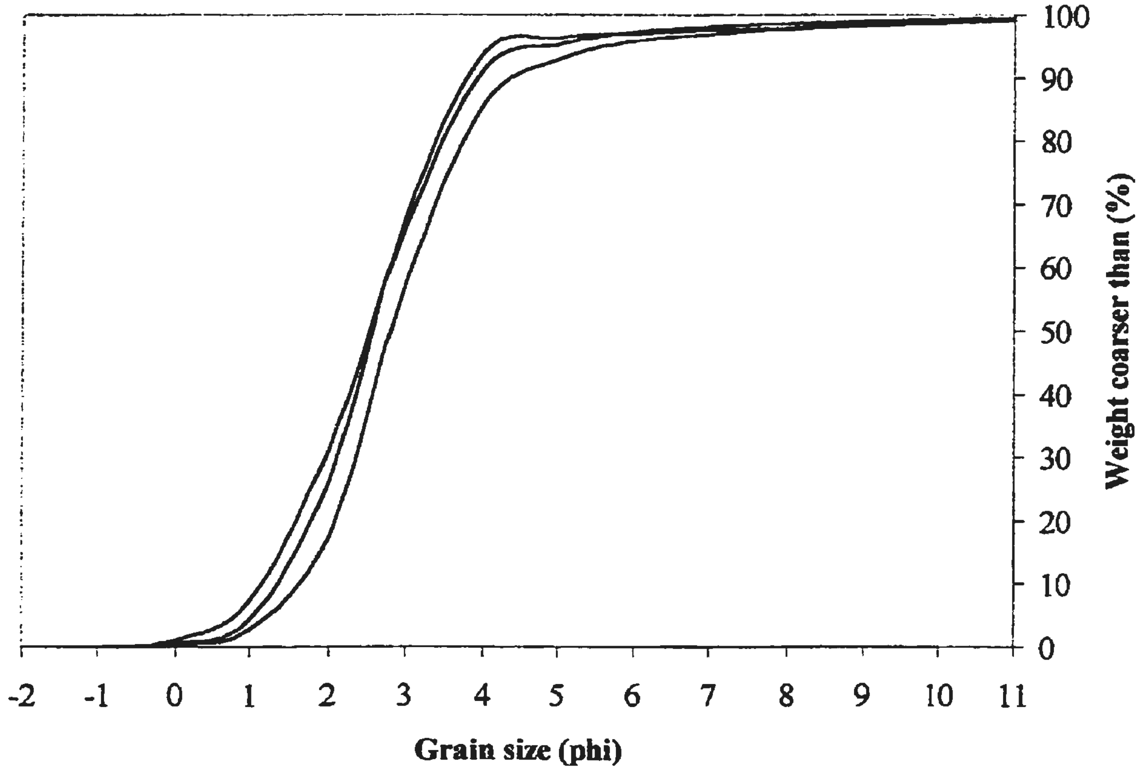

Figure 3.16 Grain size distribution of sand and silt from coastal sections between French Brook and Highlands River.

3.4.1.2 Interpretation

3.4.1.2.1 Unit 1: Basal diamicton

The basal diamicton unit is interpreted as subglacial till (cf. Krüger, 1979; Sharp, 1982; Dowdeswell and Sharp, 1986; Hicock et al. 1996) deposited by ice originating from the east in the Long Range Mountains. This interpretation is supported by its stratigraphic position directly overlying bedrock, the structureless nature of the sediment, weak to strong unimodal clast fabrics with orientations ranging from northeast-southwest to southeast-northwest, and striated and faceted clasts including those derived from the Long Range Mountains. Girdle fabrics suggest that in many areas, it may have been resedimented through debris flow (cf. Benn, 1994). Based on the close association with fossiliferous muds overlying the basal diamicton, resedimentation of the diamicton may have occurred in a glaciomarine environment. The basal diamicton unit forms a regional unit along most of the coast of southern St. George's Bay and relates to initial ice retreat across the lowlands prior to marine overlap (Brookes, 1974; Liverman and Bell, 1996; Bell et al. 1999; Liverman et al. 1999; Bell et al. submitted; Sheppard et al. in press).

3.4.1.2.2 Unit 2: Mud

This unit is interpreted to represent deposition in a distal glaciomarine environment by suspension settling from sediment-rich meltwater plumes that originated at the former ice margin (cf. Mackiewicz et al. 1984; Powell, 1984; Syvitski, 1989). Sediment supply was moderate to high, and the rhythmic bedding records variations in the sediment flux. Individual sand laminae suggest an increase in meltwater supply from the glacier margin, where relatively coarser sediment was carried in suspension. The absence of both current flow structures and interbedded sorted coarse sediments suggests a distal origin, away from the direct input of meltwater discharge. Intraclasts are interpreted to be deposited by rafting from floating ice (cf. Thomas and Connell, 1985; Gilbert, 1990). The radiocarbon dates from this mud unit are minimum estimates on deglaciation of the present coastline in southern St. George's Bay (Brookes, 1974; Liverman and Bell, 1996; Bell et al. 1999; Bell et al. submitted).

3.4.1.2.3 Unit 3: Sand

This unit is interpreted to be deposited in a subaqueous environment by a combination of current flow, underflow, and overflow. Planar-bedded sand is interpreted as underflow deposits, and ripple bedding indicates active current flow on the subaqueous surface (cf. Rust, 1977; Powell, 1990). The clasts toward the top of the unit may have been deposited as outrunners carried by momentum on the subaqueous surface (cf. Benn, 1996) or the distal areas of glaciofluvial deposition as relative sea level was falling (see below). Loaded and disturbed beds indicate rapid deposition of overlying sediments before dewatering occurred. Deposition by overflow is indicated by the gradational lower contact with mud and interlaminated fine-grained sediments throughout the unit.

3.4.1.2.4 Unit 4: Gravel

Gravel is interpreted to represent deposition as glaciofluvial outwash and fluvial sedimentation. This interpretation is supported by its stratigraphic position sharply overlying subaqueous outwash (mud and sand), lateral continuity along the coast, and the presence of horizontal (planar) and trough-cross-bedding. Miall (1977) described outwash gravels as massive or horizontally bedded, commonly clast-supported, and exhibiting bimodal or polymodal grain size distributions (i.e. good to moderate sorting).

A glaciofluvial interpretation for the gravel is also consistent with the idea that the overlying terraces are glaciofluvial in origin.

3.4.1.2.5 Unit 5: Sand and silt

This well sorted sediment is interpreted as cliff-top loess deposited when the terrace surfaces were abandoned. The texture of the sediment being dominated by fine to very fine sand and silt is characteristic of wind-blown deposits (Pye and Tsoar, 1990). Its spatial distribution, being limited to a narrow strip (<10 m) along the coast, suggests it was likely resedimented from material derived from the eroding coastal cliffs, which contain an abundant source of sand (cf. Hétu, 1992).

3.4.1.3 Type A oddity

One area within the Type A sections has sedimentary characteristics atypical of others in this section type.

3.4.1.3.1 Sediment description

Approximately 100 m north of Butter Brook, typical Unit 2 mud and Unit 3 sand are absent. In this particular area, the basal diamicton (Unit 1; 17 m thick) dips down toward sea level, and is conformably overlain by 4 m of fossiliferous stratified diamicton (Fig. E.4, E.5). This diamicton is laminated, similar to mud, although contains interspersed pockets of coarse sand and granules. Some of the laminae are truncated by pebble to boulder clasts. The grain size distribution is atypical of mud elsewhere along the coast (Fig. 3.17). One clast fabric measurement yielded a moderately oriented girdle distribution (S_1=0.67) with a relatively high mean plunge angle (21°). Shells obtained

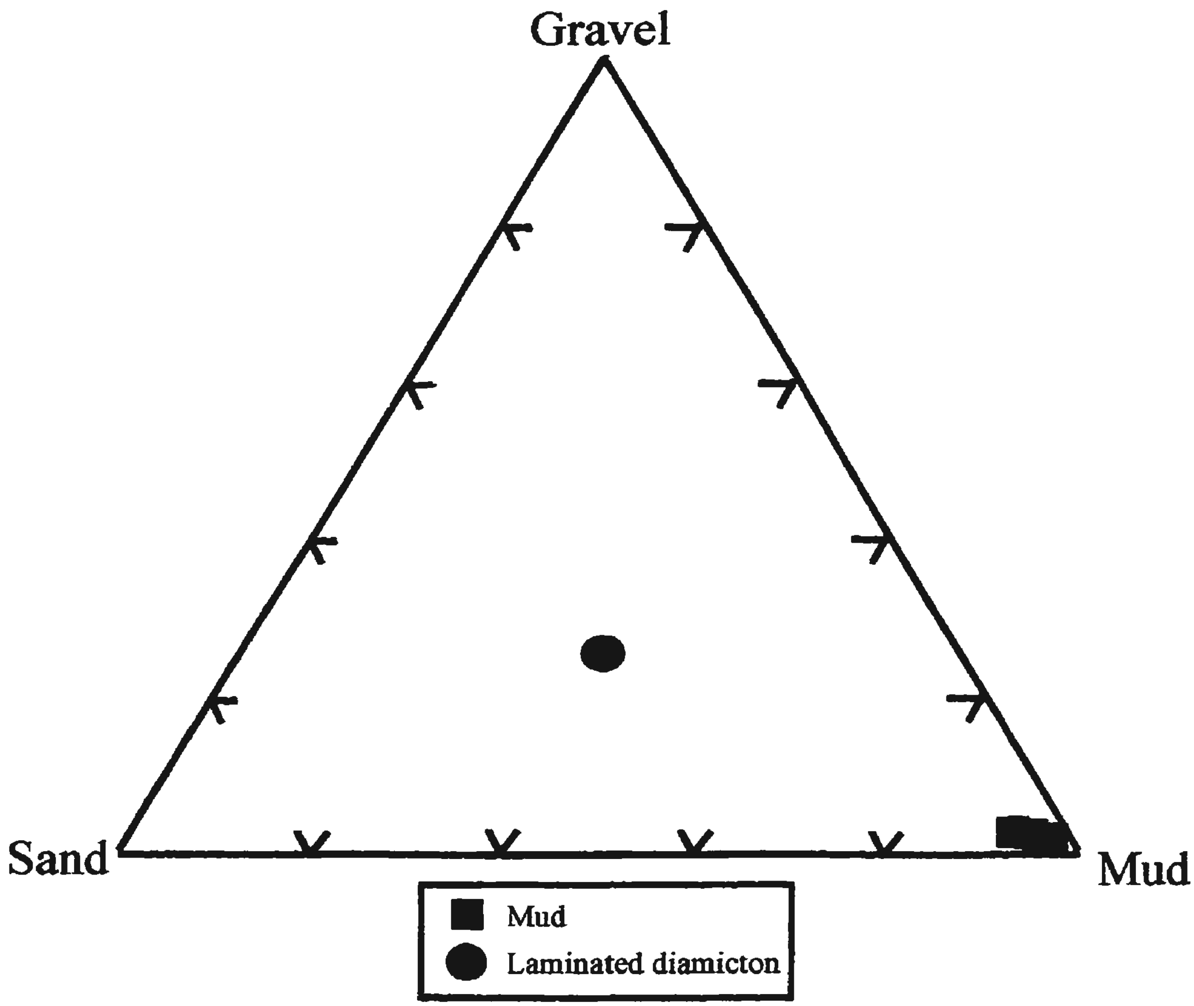

Figure 3.17 Ternary plot comparing matrix grain size of mud with laminated diamicton, which overlies the basal diamicton north of Butter Brook. The laminated diamicton plots in a similar position to that of the basal diamicton (Fig. 3.13).

from the stratified diamicton provided a radiocarbon date of 13 470 ± 120 (Beta 120125; Table 3.1; Fig. 3.8).

Overlying the stratified diamicton is a 1.5-m thick, laterally discontinuous (25 m), poorly sorted sandy gravel containing robust marine shells, radiocarbon-dated at 13 360 ±70 (Beta 120126; Table 3.1; Fig. 3.8). The sandy gravel is overlain sharply by a discontinuous 1-m bed of fossiliferous interbedded sand and diamicton, grading vertically into 2 m of planar- and ripple-interbedded sand and silt. This is capped by 1 m of planar- and trough-crossbedded pebble to cobble gravel (Unit 4).

3.4.1.3.2 Interpretation

The stratified diamicton overlying Unit 1 is interpreted to be an ice-rafted deposit. The unusual thickness of the basal diamicton may have contributed to enhanced rafting as floating ice grounded on the 17-m high obstruction. Laminae indicate continuous rainout from suspension and clasts truncating the laminae are interpreted as dropstones (cf. Mackiewicz et al. 1984; Ó Cofaigh, 1998). The grain size distribution is consistent with diamicton at other stratigraphic positions, including the basal diamicton. The relatively high mean plunge angle of the clast fabric suggests that clasts were imbedded in the sediment with minimal toppling following descent through the water column (cf. Domack and Lawson, 1985).

The fossiliferous sandy gravel is interpreted as a debris flow deposit from remobilized sediment originating on the slope of the basal diamicton. This is supported by a sharp lower contact, lateral discontinuity, and inclusion of shells that were likely incorporated from the surface during the flow. The interbedded sand and diamicton are interpreted as underflow and debris flow deposits (cf. Benn, 1996), respectively, also possibly by remobilized sediment from the slope of the 17-m thick diamicton. The gradational upper contact with planar- and ripple-bedded sand indicates reversion back to deposition by underflow and current flow.

3.4.2 Type B: Harbour Head to McLellans Brook (Highlands Section)

The sedimentary sequence in the Highlands section is represented in Figure 3.18. Site specific logs from this section are provided in Appendix E.

3.4.2.1 Sediment Description

3.4.1.1.1 Unit 1: Mud

In the Highlands section, mud is generally poorly exposed due to modern slumping at the base of the section. Where exposed, it has similar sedimentary characteristics to the mud in Type A sections, ranging in thickness from 5 to 8 m.

3.4.2.1.2 Unit 2: Sand and gravel

Unit 2 is a 16 to 20 m coarsening upward unit of interbedded sand and gravel and rare diamicton. It has a gradational lower contact with the underlying mud. Individual bed contacts typically are sharp and erosional. Sand beds generally are laterally continuous, horizontally bedded, and moderately to well sorted, whereas gravel is more variable with beds rarely traceable over a few metres. Individual bed thicknesses vary, but are generally less than one metre. Planar bedding is common, while ripple and planar- to trough-cross-bedding occur sporadically throughout the unit. Individual beds range from normal to inverse graded to structureless, and commonly contain pebbles to cobbles and mud intra-clasts. Flame and dewatering structures are observed in some

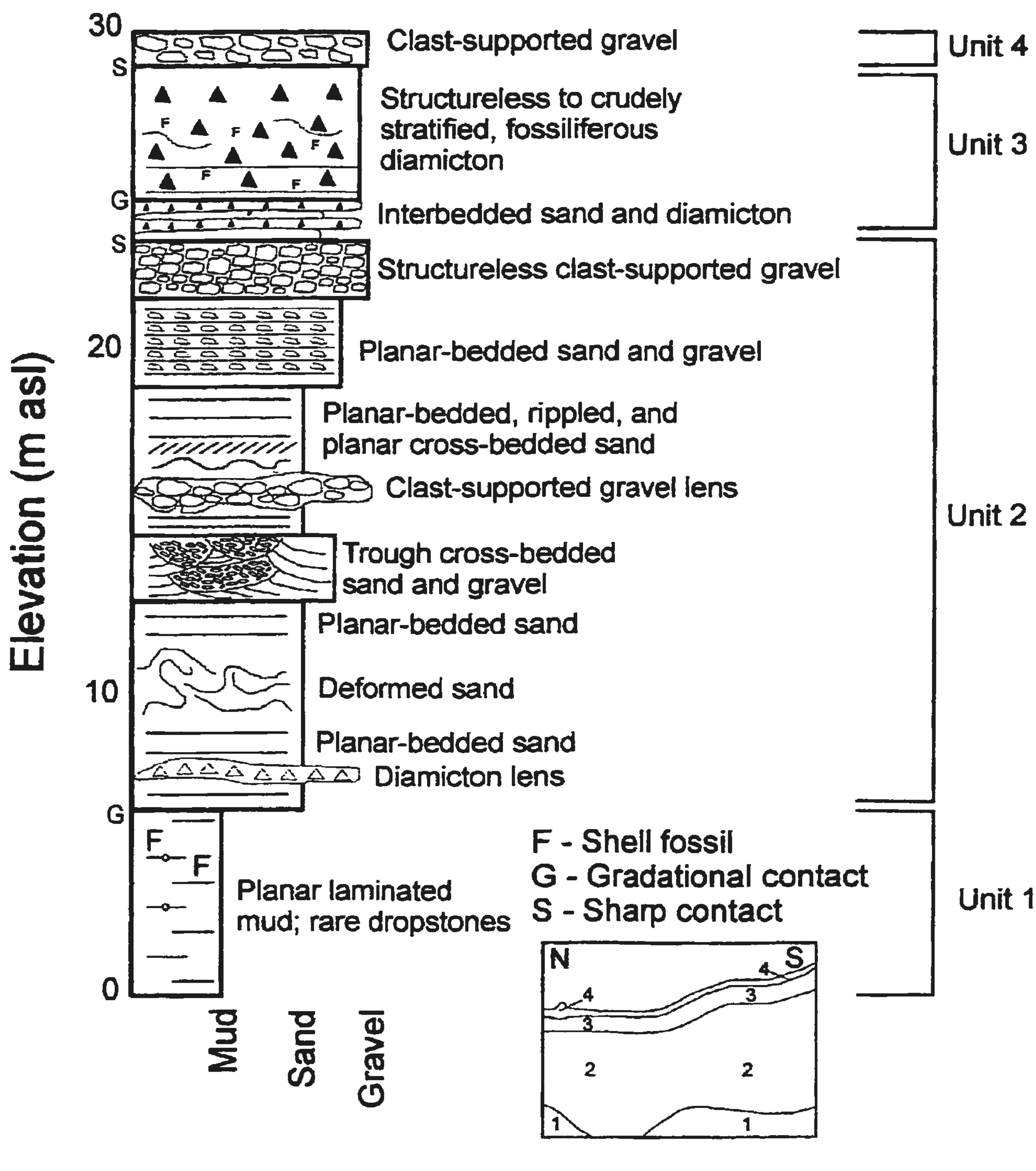

Figure 3.18 Composite section log of the Highlands section. This section represents an overall coarsening sequence that typifies this segment of coastline. Inset shows a generalized stratigraphy for the entire section, with individual units discussed in text.

areas. Textural analysis of two samples from representative sandy beds shows 1 to 20% gravel, 79 to 96% sand, and 1 to 4% mud.

Planar- and trough-cross-bedded gravel (pebble to cobble) and gravelly sand in scour-and-fill structures are seen, whereas clast supported gravel (pebble to boulder) lenses are found intermittently throughout (Plate 3.16). The top of Unit 2 generally shows beds of poorly to moderately sorted (commonly clast supported) pebble to cobble gravel and gravelly sand. Diamicton interbeds are rare and occur as discontinuous lenses from <30 to 100 cm thick and pinch out laterally over 1 to 2 m. The diamicton is matrix supported with a sandy-silt to silt matrix and clast content ranging from 10 to 40%. Basal contacts are typically sharp and erosional.

3.4.2.1.3 Unit 3: Diamicton

Diamicton is laterally continuous over 0.6 km near the top of the section. It is 0.5 to 6 m thick, loose to very compact, matrix-supported (silty-sand to clayey-silt), and structureless to weakly stratified. Moist colours include reddish brown (5YR 4/3), brown-dark-brown (7.5YR 4/2, 10YR 4/3), light grey (5YR 7/2), and dark greyish brown (2.5YR 4/2, 10YR 4/2). Clast content ranges from 15 to 40%, consisting of subangular to subrounded pebbles to boulders (a-axis up to 1.5 m long), some of which are striated and faceted. Clast provenance (7 samples) ranged between 36 to 79% (mean=49%) Long Range Mountains and 21 to 64% (mean=51%) local Carboniferous rock types (Appendix B). The sedimentary characteristics of Unit 3 vary laterally across the section.

Lower and upper contacts typically are sharp and erosional, although lower contacts may be interbedded/gradational. Approximately 75 m north of Harbour Head, where the base of Unit 3 consists of 75 cm of subhorizontal, interbedded fossiliferous

Plate 3.16 Clast-supported pebble-cobble gravel lens overlying planar-bedded sand in Unit 2 of the Highlands section. This lens pinches out over ~6 m laterally and the lower contact shows evidence of loading with irregular and dislocated beds in the sand.

sand and diamicton, irregular and convoluted bed contacts occur (Plate 3.17). Mud intraclasts occur in the sand beds. These sediments grade upward into a matrix-supported (clayey-silt) diamicton with discontinuous sand laminae/streaks and abundant paired and fragmented shells radiocarbon-dated at 13 680 ± 90 BP (Beta-120124) (Plate 3.18; Fig. 3.8; Table 3.1). Stratified diamicton is found throughout the entire unit, grading laterally into structureless diamicton. Structureless diamicton is found beneath the 2 m high ridge at McLellans Brook, between ~200 and 250 m south of McLellans Brook, and ~50 m north of Harbour Head, whereas other areas show some degree of stratification. Stratification generally consists of sand lenses, laminae, and streaks, that are irregularly shaped, discontinuous, and range from 0.1 to 15 cm thick. In places, they are deformed downward beneath clasts (Plate 3.19).

Clast fabrics along the section show variable patterns including poorly to moderately oriented girdle distributions (S1 range: 0.49 to 0.64; S1 mean: 0.54; n=9) and spread unimodal distributions (S1 range: 0.62 to 0.74; S1 mean: 0.67; n=5; Appendix A). Girdle fabrics were mostly obtained from stratified diamicton, whereas spread unimodal fabrics tend to be from structureless diamicton (Fig. 3.19).

The diamicton has a consistent matrix texture along the section, although two sites (E8 and E9; Fig. 3.8) have comparatively high silt and clay contents (Fig. 3.20). Analysis of the matrix (7 samples) shows 26 to 50% silt, 18 to 33% clay, 17 to 47%, sand, and 1 to 11% gravel (Appendix C). Average mean grain size ranges from 4 to 5.6ϕ (medium to coarse silt).

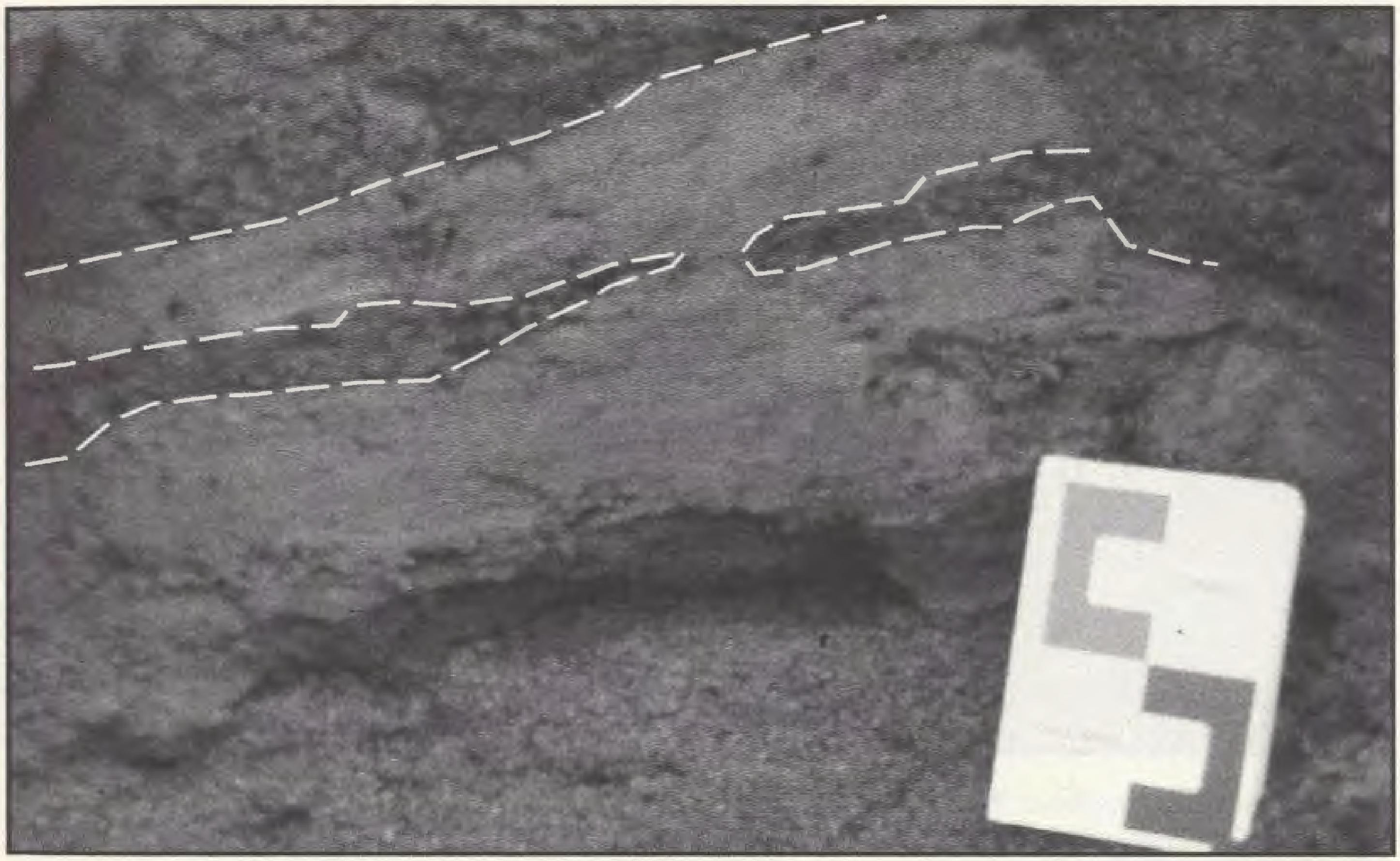

Plate 3.17 Subhorizontal, interbedded sand (light grey) and diamicton at the base of Unit 3 near Harbour Head in the Highlands section. Bed contacts are erosional and dislocated. The sand beds contain rare paired and fragmented shells and mud intraclasts. These beds grade up into 4 m of stratified diamicton (see Plate 3.18).

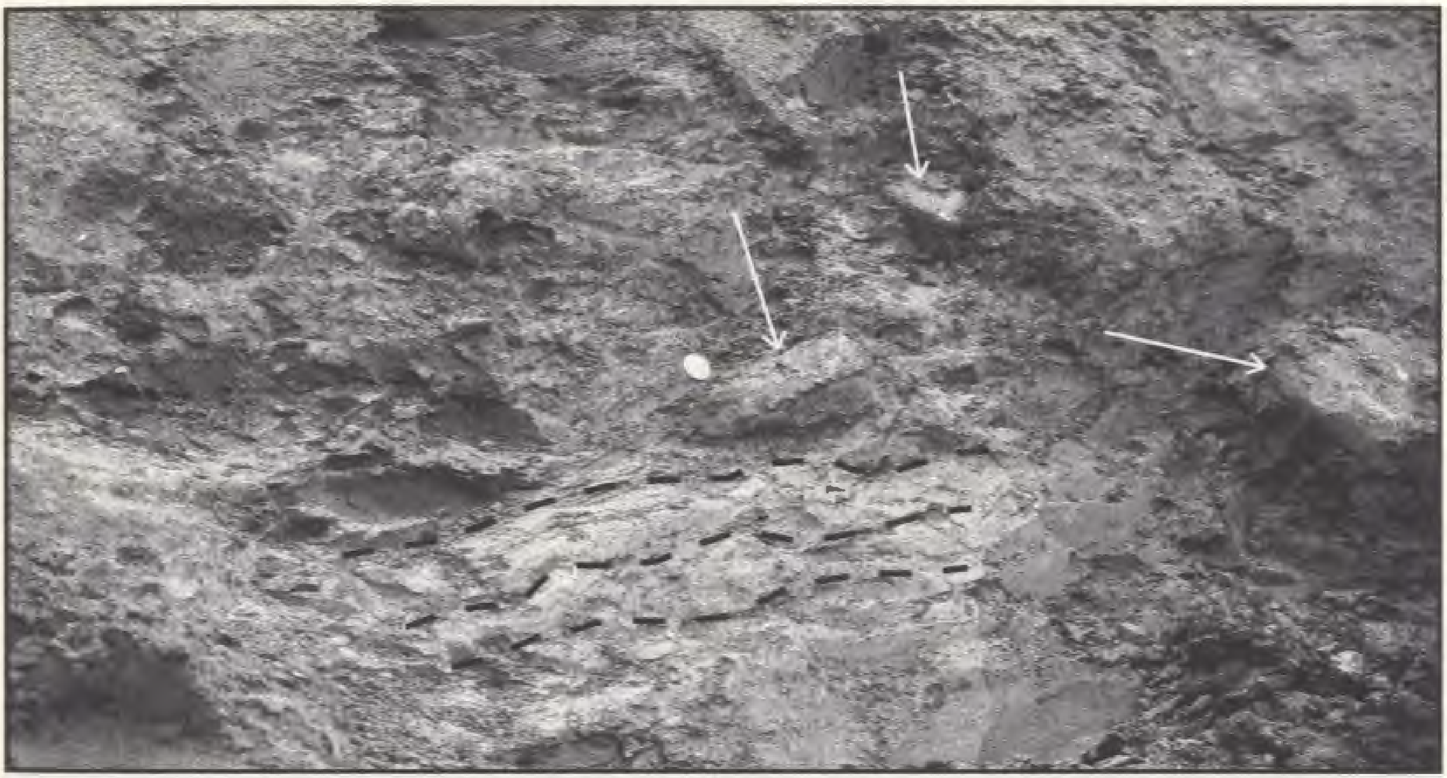

Plate 3.18 Stratified diamicton overlying interbedded sand and diamicton near Harbour Head (coin for scale). This diamicton contains abundant paired and fragmented shells of *Mya truncata* and *Hiatella arctica,* which provided a radiocarbon date of 13 680 +/- 90 BP (Beta 120124). Note crude stratification at base. Arrows point to clasts.

Plate 3.19 Deformed fine sand laminae beneath cobble clast in the fossiliferous diamicton north of Harbour Head.

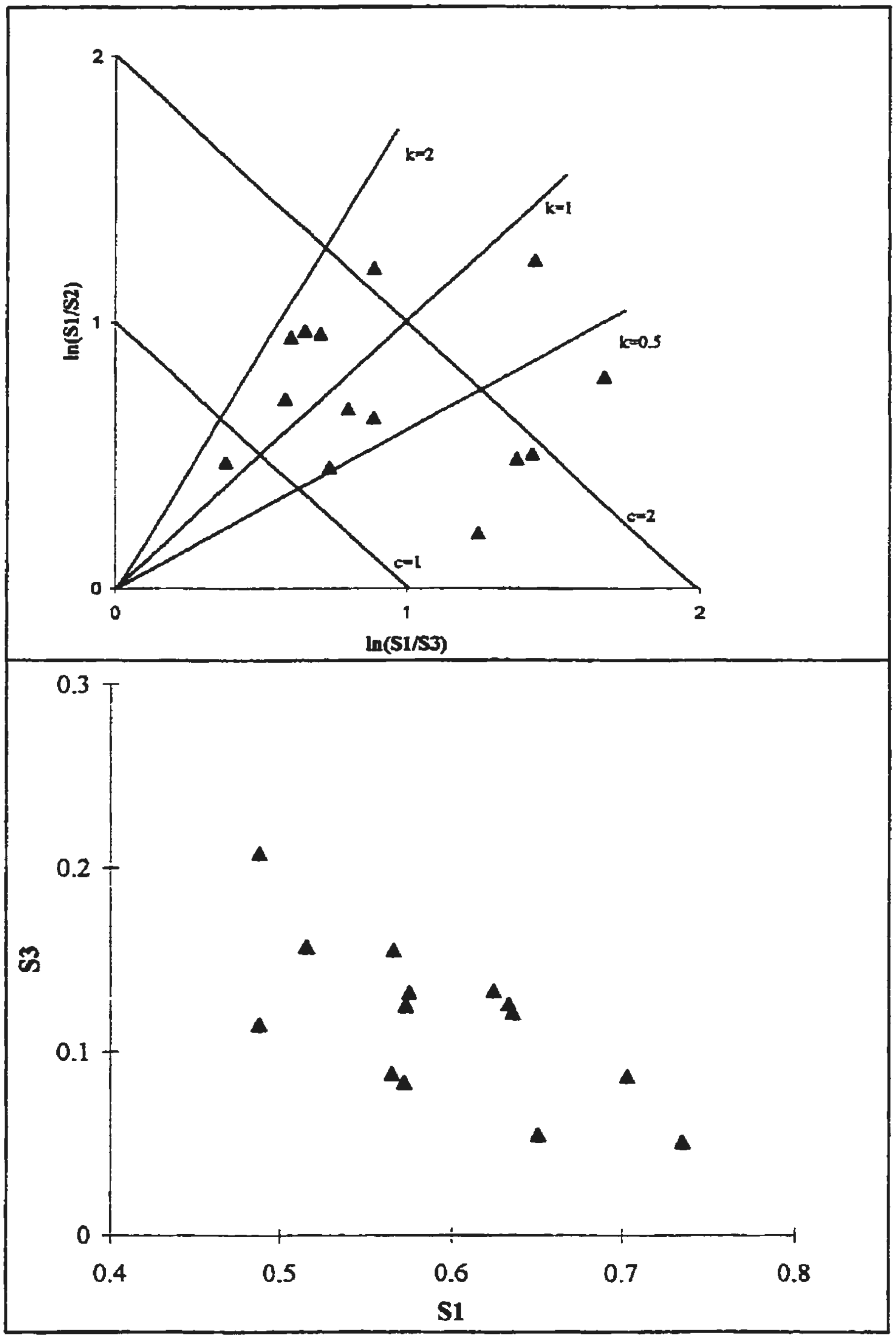

Figure 3.19 Clast fabric data from diamicton (Unit 3) in Highlands section. These data show a wide range of values, although S1 is commonly less than 0.6 and k below or marginally above 1.

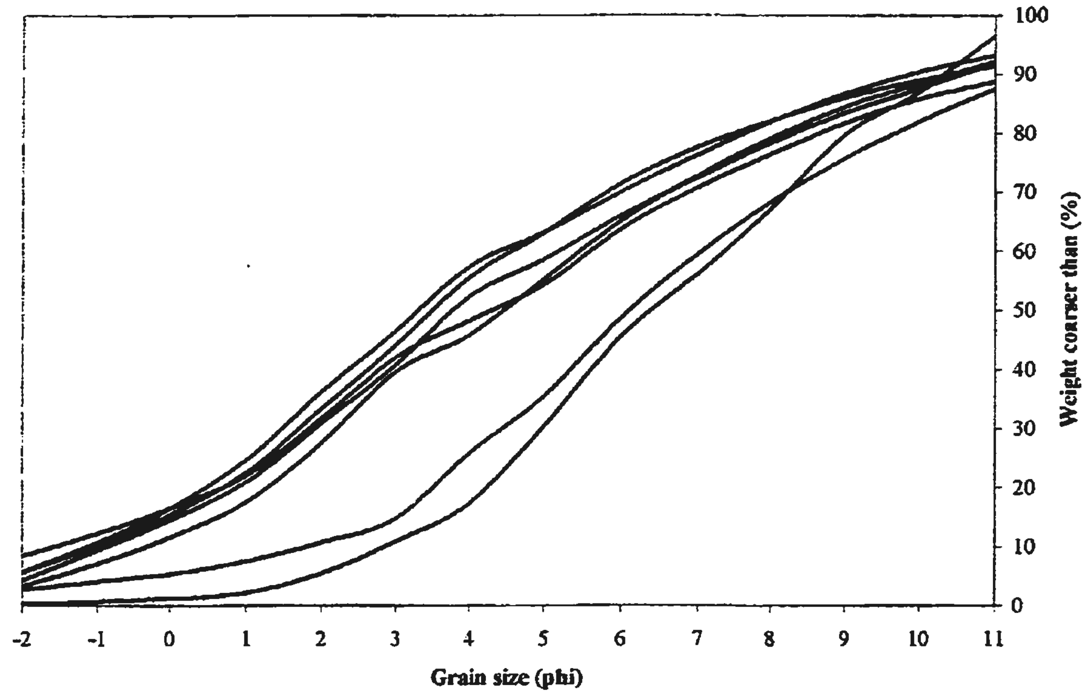

Figure 3.20 Grain size distribution of Unit 3 diamicton matrix in the Highlands section. Most samples show a consistent pattern, although the lowest two in the diagram have a higher percentage of mud (>4ϕ).

3.4.2.1.4 Unit 4: Gravel and gravelly sand

The diamicton is intermittently overlain sharply by 0.4 to 3 m of interbedded gravel, gravelly sand, and sand. At Harbour Head, Unit 4 consists of 50 cm of structureless gravelly sand, whereas ~75 m north, it includes 40 cm of open-work, clast-supported, cobble-boulder gravel, that fills a minor depression underlying peat (Plate 3.20).

3.4.2.1.5 Unit 5: Sand and silt

Well-sorted sand and silt is continuous along the top of the Highlands section, overlying gravel and gravelly sand, diamicton, and peat. This sediment occurs at similar stratigraphic positions in the Type A sections and has identical sedimentary characteristics.

3.4.2.2 Interpretation

3.4.2.2.1 Unit 1: Mud

Mud is interpreted to be deposited in a glaciomarine environment by suspension settling from sediment-rich meltwater plumes (cf. Mackiewicz et al. 1984; Powell, 1984; Syvitski, 1989). The similarity in sedimentary characteristics and stratigraphic position to mud in Type A sections suggest that the ice margin was distal from the coast when the mud was deposited. The presence of intraclasts interpreted as dropstones indicate a calving tidewater ice margin.

3.4.2.2.2 Unit 2: Sand and gravel

The sediments in Unit 2 indicate deposition in a subaqueous environment, where current flow, underflow, debris flow, and overflow operated simultaneously. Planar-bedded sand and gravelly sand, and ripple- and cross-bedded sand and gravel are

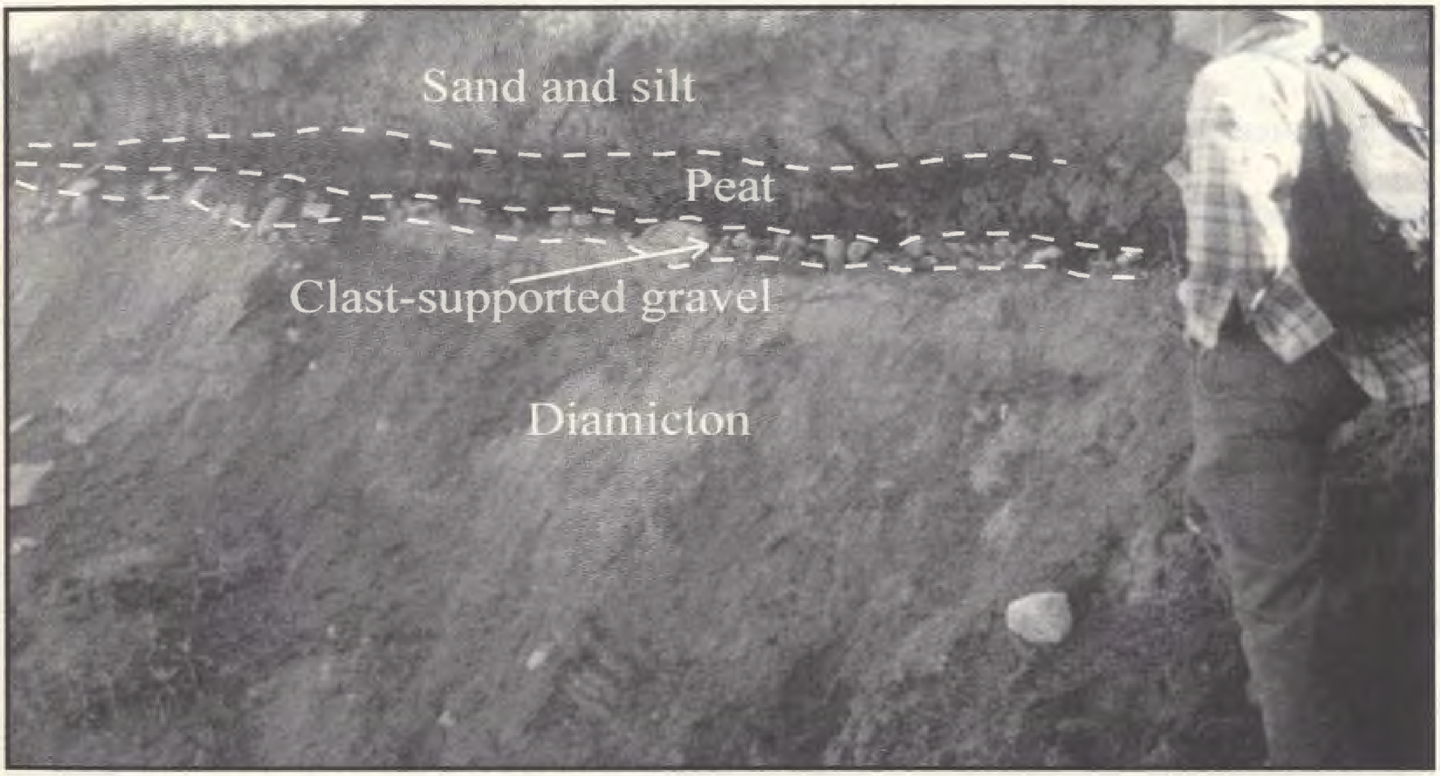

Plate 3.20 Open-work clast-supported gravel overlying diamicton 50 m north of Harbour Head. This gravel occurs in a minor depression underlying peat and sand and silt.

interpreted as underflow deposits (cf. Powell and Molnia, 1989; Powell, 1990; Benn, 1996). Features such as sharp bed contacts and mud intraclasts are evidence of erosion, and deformed sand beds suggest rapid loading by overlying sediments before dewatering occurred. Scour-and-fill structures indicate spatially focused flow when underflow currents migrated across the surface (cf. Rust, 1977), whereas clasts within individual sand beds suggest deposition as outrunners carried by momentum along the subaqueous surface (cf. Benn, 1996). Some of these clasts, especially near the base of the unit may have been deposited by ice rafting (cf. Thomas and Connell, 1985). The clast-supported gravel lenses and diamicton are interpreted to be deposited as debris flows based on sharp bed contacts and their interbedded relationship with sediments interpreted as subaqueous.

The gradational contact with Unit 1 suggests that deposition via suspension settling from overflow plumes initially deposited much sand at the base of the unit. This indicates a more proximal ice margin relative to where mud was deposited because sand particles cannot be carried a significant distance in suspension (cf. Cowan and Powell, 1990). Suspension settling likely contributed much sediment throughout Unit 2 when underflows were focused in other directions. The preservation potential of overflow deposits, however, is minimal because other processes such as underflow and debris flow would have reincorporated and redeposited them (cf. Powell, 1984; Lønne, 1995).

3.4.2.2.3 Unit 3: Diamicton

Based on its lateral continuity and inclusion of marine shells and striated clasts, Unit 3 is interpreted to be deposited in an ice-proximal, glaciomarine environment. Three depositional processes are evident: subglacial lodgement, sediment gravity flow, and rainout. This variability may be explained by considering the position along the ice front where the diamicton was deposited, as sediments in an ice-proximal zone may interfinger with other deposits (cf. Powell, 1984). The lateral transition from diamicton interpreted as subglacial till, to that deposited by sediment gravity flow and rainout illustrates this relationship (cf. McCabe, 1986).

Structureless diamicton with spread unimodal clast fabrics is interpreted as till (cf. King, 1993; Benn, 1994; Ham and Mickelson, 1994), although where girdle fabrics are found, structureless diamicton may have been resedimented through sediment gravity flow (cf. Lawson, 1979, 1981).

Stratified diamictons with poorly to moderately oriented girdle fabrics are interpreted as sediment gravity flow deposits. Lenses of fine sand and laminae/streaks suggest deposition by traction currents with variable flow strengths occurring between sediment gravity flow events. The fossiliferous diamicton has abundant laminae/streaks, some of which are deformed downward by clasts, and these clasts are interpreted as dropstones from ice rafting (Bell et al. 1999; cf. Thomas and Connell, 1985). The fossiliferous diamicton, thus, may have been deposited by rainout through a combination of suspension settling from meltwater plumes and ice rafting (cf. Domack and Lawson, 1985; Ó Cofaigh, 1998), sediment gravity flow, and traction current activity.

Domack and Lawson (1985) indicated that clast fabrics of debris flow (sediment gravity flow) and rainout (ice-rafted) diamictons are very similar, which suggests that either of the processes could have deposited the stratified fossiliferous diamicton. However, the grain size distribution of the fossiliferous diamicton is similar to mud, as opposed to the typical distribution of Unit 3 (excluding the fossiliferous diamicton; Fig. 3.21). This suggests that much of the sediment in the fossiliferous diamicton may have

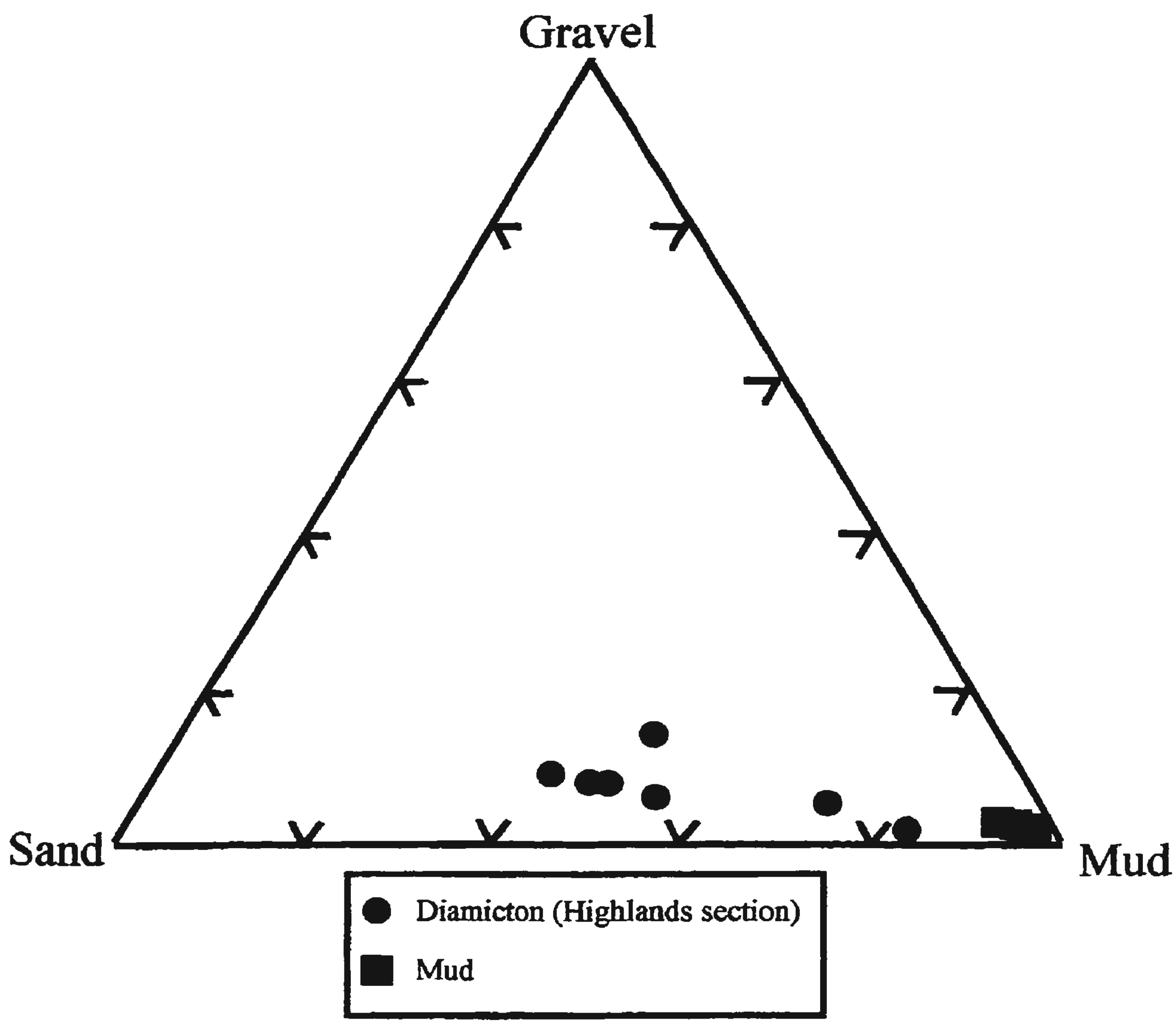

Figure 3.21 Ternary plot comparing matrix grain size of diamicton in the Highlands section with mud. Most of the diamicton plots in a similar position as the basal diamicton (Fig. 3.13), although two outliers (also in Fig. 3.20) plot closer to the mud.

been contributed from overflow plumes, with the coarser component introduced through ice rafting (cf. Stravers et al. 1991). Clast fabrics from this particular site consist of weakly to moderately oriented girdles (S1 range: 0.57 to 0.62; n=2), oriented north-northeast–south-southwest with an average dip of 8.5°. Paired and fragmented shells are found in the diamicton interpreted to be deposited by rainout, sediment gravity flow, and traction currents, and also in the interbedded sand and diamicton that underlie it. The interbedded sand and diamicton are interpreted as underflow and debris flow deposits, respectively, and paired shells in the sand are interpreted to have been living on the surface and subsequently buried during deposition. Paired shells in the diamicton are considered *in situ*, although shell fragments indicate reworking into the unit during sediment gravity flow. This suggests that the diamicton may have been subject to post-depositional sediment gravity flow, which incorporated shells living on the adjacent surface (cf. Lønne, 1997). This movement would have been minor and/or gradual (creep?) because the primary sedimentary structures (lenses and deformed laminae) are still preserved in the unit. The orientation (north-northeast–south-southwest) of the clast fabrics in this diamicton in addition to the low dip angle (mean=8.5°) suggest that the clasts may have been realigned during movement down a shallow slope. The gradational lower contact with the fossiliferous sand and diamicton indicates a continuous depositional sequence.

3.4.2.2.4 Unit 4: Gravel and gravelly sand

The gravelly sand and clast supported gravel in Unit 4 are interpreted to represent winnowing of the diamicton by glaciofluvial processes. The generally flat upper surface of the Highlands section relative to the terraces in adjacent areas to the north and south suggests subaerial exposure. At this time, proglacial streams progressively adjusted their grade to gradually dropping marine base levels (cf. Liverman and Bell, 1996; Bell et al. 1999).

3.4.2.2.5 Unit 5: Sand and silt

The sand and silt is interpreted as cliff-top aeolian sediment, equivalent to that in Type A sections.

3.4.3 Comparison of diamicton units

The sedimentary and lithological characteristics of two diamicton units have been presented from the coastal exposures between French Brook and Highlands River. The basal diamicton (Unit 1 in Type A sections) and the diamicton (Unit 3) that occurs in the upper part of the Highlands section relate to distinct phases in deposition. It is important to compare the provenance of these diamictons in order to assess whether they were derived from a similar source. In order to do this, pebble lithology and matrix geochemistry were compared.

3.4.3.1 Pebble lithology

A total of ten and seven samples were obtained from the basal and upper diamicton units, respectively (Appendix B). Long Range lithologies compose 27 to 60% of the basal diamicton samples (n=10), and contribute 36 to 79% in the upper diamicton (n=7). Local Carboniferous rock types made up the remainder. The within and between sample variations were compared for the respective pebble lithologies.

Comparison of the within sample variance between Long Range and Carboniferous rock types in the basal diamicton showed that at the 99% confidence level, there is no significant difference between the proportion of the two rock types (Fig. 3.22).

Hypotheses

H_O: $\sigma_1 = \sigma_2$
H_A: $\sigma_1 \neq \sigma_2$

$F = S_1^2 / S_2^2$ with degrees of freedom $n_1 - 1$ (i.e. r_1) and $n_2 - 1$ (i.e. r_2)

Where F = F statistic
S_1^2 = sample variance of number of Long Range clasts in basal diamicton samples
S_2^2 = sample variance of number of Carboniferous clasts in basal diamicton samples
σ_1 = variance (Long Range)
$n_1 = 10$
$r_1 = 9$
σ_2 = variance (Carboniferous)
$n_2 = 10$
$r_2 = 9$

Long Range

$S_i^2 = 206$

Carboniferous

$S_j^2 = 157$

F = 1.31

Prob-value of 0.01 (i.e. 99% confidence level) lies between 6.54 and 12.08. The measured F of 1.31 has a prob-value of >0.2, occurring outside this range; thus, the variances between the number of Long Range and Carboniferous clasts in the basal diamicton are similar.

Figure 3.22 Test for equality of variances between Long Range and Carboniferous clasts in basal diamicton.

Similarly, there is no significant difference between the rock types in the upper diamicton (Fig. 3.23).

The analysis of between sample variations yielded comparable results. There is no significant difference at the 99% confidence level in the variation of Long Range and Carboniferous rock types in the basal and upper diamictons (Figs. 24, 25).

3.4.3.2 Geochemistry

Twelve samples from the basal diamicton and ten from the upper diamicton (Highlands section) were collected for geochemical analyses. Three field duplicates from the basal diamicton and two from the upper diamicton were also analysed. These duplicates are compared to the original field samples and no significant differences were recognized (Appendix D). The results from the Mann-Whitney test showed that only Mg and Ca (2 of 27 elements) are statistically different at the 99% confidence level between the basal and upper diamicton units (Appendix D). Other elements, including Cr (Chromium), have similar concentrations in both diamicton units (Fig. 3.26).

3.4.4 Summary of sedimentary sequences

Two distinct sedimentary sequences occur along the coast between French Brook and Highlands River. Type A sections occur where terrace surfaces at 18 to 20 m asl and 24 to 26 m asl form ~90% of the coastline between French Brook and Harbour Head and McLellans Brook and Highlands River. These sections consist mainly of bedrock, or where bedrock dips below sea level, diamicton (till and resedimented till), overlain successively by glaciomarine mud, subaqueous planar-bedded sand, glaciofluvial planar-bedded gravel, and aeolian deposits. These sections represent a deglacial, regressive sequence from subglacial, to marine, to glaciofluvial deposition on outwash terraces.

Hypotheses

H_O: $\sigma_1 = \sigma_2$
H_A: $\sigma_1 \neq \sigma_2$

$F = S_1^2 / S_2^2$ with degrees of freedom $n_1 - 1$ (i.e. r_1) and $n_2 - 1$ (i.e. r_2)

Where F = F statistic
S_1^2 = sample variance of number of Long Range clasts in upper diamicton samples
S_2^2 = sample variance of number of Carboniferous clasts in upper diamicton samples
σ_1 = variance (Long Range)
$n_1 = 7$
$r_1 = 6$
σ_2 = variance (Carboniferous)
$n_2 = 7$
$r_2 = 6$

Long Range

$S_i^2 = 239$

Carboniferous

$S_j^2 = 87$

F = 2.75

Prob-value of 0.01 (i.e. 99% confidence level) lies between 11.07 and 25.63. The measured F of 2.75 has a prob-value of >0.2, occurring outside this range; thus, the variances between the number of Long Range and Carboniferous clasts in the upper diamicton are similar.

Figure 3.23 Test for equality of variances between Long Range and Carboniferous clasts in upper diamicton.

Hypotheses

H_O: $\sigma_1 = \sigma_2$
H_A: $\sigma_1 \neq \sigma_2$

$F = S_1^2/ S_2^2$ with degrees of freedom $n_1 - 1$ (i.e. r_1) and $n_2 - 1$ (i.e. r_2)

Where F = F statistic
S_1^2 = sample variance of number of Long Range clasts in basal diamicton samples
S_2^2 = sample variance of number of Long Range clasts in upper diamicton samples
σ_1 = variance (Basal diamicton)
$n_1 = 10$
$r_1 = 9$
σ_2 = variance (Upper diamicton)
$n_2 = 7$
$r_2 = 6$

Basal diamicton

$S_i^2 = 157$

Upper diamicton

$S_j^2 = 87$

F = 1.80

Prob-value of 0.01 (i.e. 99% confidence level) lies between 10.39 and 23.88. The measured F of 1.80 has a prob-value of >0.2, occurring outside this range; thus, the variances between the number of Long Range clasts in the basal and upper diamictons are similar.

Figure 3.24 Test for equality of variances comparing Long Range clasts between basal and upper diamictons.

Hypotheses

H_O: $\sigma_1 = \sigma_2$
H_A: $\sigma_1 \neq \sigma_2$

$F = S_1^2 / S_2^2$ with degrees of freedom $n_1 - 1$ (i.e. r_1) and $n_2 - 1$ (i.e. r_2)

Where F = F statistic
S_1^2 = sample variance of number of Carboniferous clasts in basal diamicton samples
S_2^2 = sample variance of number of Carboniferous clasts in upper diamicton samples
σ_1 = variance (Carboniferous)
$n_1 = 10$
$r_1 = 9$
σ_2 = variance (Carboniferous)
$n_2 = 7$
$r_2 = 6$

Basal diamicton

$S_i^2 = 206$

Upper diamicton

$S_j^2 = 239$

F = 0.86

Prob-value of 0.01 (i.e. 99% confidence level) lies between 10.39 and 23.88. The measured F of 0.86 has a prob-value of >0.2, occurring outside this range; thus, the variances between the number of Long Range clasts in the basal and upper diamictons are similar.

Figure 3.25 Test for equality of variances comparing Carboniferous clasts between basal diamicton and upper diamicton.

Hypothesis
H_O: $\delta = 0$, the samples are drawn from the same population
H_A: $\delta \neq 0$, the samples are drawn from different populations

S_1 = test statistic = sum of the ranks from the upper diamicton

If $S_1 < A = n_1(n_1 + n_2 + 1)/2 - z_{\alpha/2}\sqrt{n_1 n_2(n_1 + n_2 + 1)/12}$, reject H_O

Where A = estimate of S = 70.9
$z_{\alpha/2}$ = prob-value associated with 99% confidence level

	Concentration (ppm)	Rank
Upper diamicton	107.0	3.0
(n_1=10)	107.1	4.0
	107.6	5.0
	110.3	8.0
	110.9	9.0
	113.6	12.0
	114.5	13.0
	116.8	15.5
	117.4	17.0
	119.1	19.0
		S_1=105.5
Basal diamicton	103.8	1.0
(n_2=10)	104.0	2.0
	108.7	6.0
	109.3	7.0
	111.5	10.0
	112.0	11.0
	114.6	14.0
	116.8	15.5
	118.8	18.0
	120.3	20.0
		S=104.5

Do not reject H_O because $S_1 > A$. Therefore, the concentration of Cr in both diamictons is similar.

Figure 3.26 Example of Mann-Whitney test comparing Cr (Chromium) concentrations in basal and upper diamicton units. The sample concentrations from each of the respective units are arranged in ascending order and subsequently ranked.

The Type B section (Highlands section) occurs along ~0.6 km of coastline between Harbour Head and McLellans Brook. This section is associated with the Highlands ridge, which intersects the coast in this area. The sedimentary sequence in the Highlands section consists of glaciomarine mud, overlain sequentially by subaqueous interbedded sand, gravel, and diamicton; glaciomarine diamicton; glaciofluvial gravel and gravelly sand; and aeolian deposits. This represents a deglacial sequence from glaciomarine, interrupted by deposition of the upper diamicton, indicating a return to ice-proximal conditions during retreat, to glaciofluvial deposition correlative with the terraces in Type A sections.

Chapter 4 Discussion

4.1 Ice-flow history

Westward to northwestward flowing ice from the Long Range Mountains during the Late Wisconsinan glacial maximum crossed the present coastline of southern St. George's Bay. This flow extended several kilometres seaward (Shaw and Forbes, 1990; Forbes et al. 1993; Shaw and Forbes, 1995; Shaw and Courtney, 1997). Clast rock types from surficial till units between the Long Range Mountains and the coast (basal diamicton) show a decrease in proportion of Long Range Mountains clasts from 100% east of the Long Range Fault to mainly <50% at the coast. This clearly illustrates an eastern ice source in the Long Range Mountains.

Ice-flow from the Long Range Mountains appears to have been unconfined by topography because striations, especially those adjacent to upland areas (e.g. Bald Mountain; >530 m asl) show no evidence of diversion. Striations on the Anguille Mountains suggest that ice crossed them on route to the coast, although the striations were measured in valleys running through the mountains. Well-oriented clast fabrics from tills directly overlying bedrock in all parts of the study area generally correspond with the striation record, although northeast-southwest oriented fabrics occur in some areas. These fabrics, in addition to striations that cross-cut the dominant flow, suggest a secondary flow that may have been topographically controlled (see below).

At the coast, clast fabric orientations from the basal diamicton indicate a variable ice flow. North of Butter Brook, unimodal fabrics have southeast-northwest orientations, whereas at Butter Brook and south, northeast-southwest orientations dominate, with some oriented transverse to this trend. Clasts being transported at the base of actively moving ice have two modes of transportation (i.e. parallel or transverse to ice flow), although Rappol (1985) noted that transverse patterns are rare. Considering that transverse fabrics are obtained from sites that illustrate a northeast-southwest trend, this rare mode of deposition may have occurred. Conversely, the northeast-southwest oriented fabrics may relate to southwestward ice flow around the northern part of the Anguille Mountains following retreat of north–northwestward flowing ice that crossed the mountains. In combination with apparent southwestward ice flow at and south of Butter Brook, a unimodal fabric and striation measured on the northern slopes of the Anguille Mountains also parallel this trend.

Liverman et al. (1999) indicated that a southward ice flow affected southern St. George's Bay based on consistent coast-parallel unimodal fabrics north of Robinsons River. They suggested that northwestward flow from the Long Range Mountains was diverted southward by ice offshore or that ice from a source north flowed southward across the lowlands during the last glacial maximum. Evidence to support this southward flow in the study area was not found.

There is evidence to support a second, more variable flow that may relate to topographic control as ice retreated inland and thinned. This is best observed in the Codroy Valley, where clast fabrics and striations parallel the valley's orientation, suggesting a southwestward flow. South and west of Bald Mountain, a west-southwest flow occurred, as evidenced by well-oriented fabrics, and based on indications of the regional northwest flow in areas encompassing this, the west-southwest flow may have been diverted to the south by Bald Mountain. On the Long Range Mountains, a confined flow is illustrated by a northeast-southwest oriented non-directional striation perpendicular to the regional flow pattern.

4.2 Stratigraphy

Two contrasting sedimentary sequences occur along the coast of southern St. George's Bay between French Brook and Highlands River, and are associated with the surface topography. Type A sections, typically capped by glaciofluvial terrace surfaces at 18 to 20 m asl and 24 to 26 m asl form ~4.5 km of coastline between French Brook and Harbour Head and McLellans Brook and Highlands River. The 0.6-km wide Highlands section is sandwiched between these and intersects the Highlands ridge.

Although sediments in both section types are described and interpreted in isolation, there are links between them. The basal diamicton forms a regional unit, although it is absent in the Highlands section likely because it dips below sea level in that area. Laminated mud is also considered part of a regional unit that typically conformably overlies the basal diamicton. Unit 3 (sand) in Type A sections and Unit 2 (sand and gravel) in the Highlands section occur at the same stratigraphic position, and are considered a continuum of the same unit, although there are distinct differences in sedimentological characteristics. Glaciofluvial deposits (Unit 4) in both areas are regarded as similar based on stratigraphic position, but are better defined in Type A sections. Aeolian sediments form the uppermost unit in both section types.

The basal diamicton occurring along the coast relates to the most recent ice-coverage (Late Wisconsinan) that extended across the lowlands into St. George's Bay. This diamicton was defined initially by MacClintock and Twenhofel (1940) and Brookes

(1969, 1974) as the lowest unit (St. George's River Drift) in the three-fold stratigraphic sequence. At Robinsons Head, Liverman and Bell (1996) and Bell et al. (1999) interpreted a stratigraphically equivalent unit as a glaciomarine diamicton deposited at the margin of a retreating tidewater glacier. Sedimentological data including well-oriented fabrics from the basal diamicton suggest it was deposited mainly as subglacial till as ice retreated across the present coastline; however, girdle fabrics also indicate that resedimentation occurred in several areas. The stratigraphic position of glaciomarine muds conformably overlying the basal diamicton suggests that the ice margin was in direct contact with the sea during retreat. Resedimentation of the basal diamicton may have occurred because the diamicton was immediately exposed to the sea following retreat of ice. Alternatively, King (1993) suggested that till in the marine environment can be both subglacial and proglacial in origin. Girdle fabrics from the basal diamicton, thus, may represent proglacial till that was resedimented through sediment gravity flow on the sea floor.

Mud occurs in both section types, forming a continuous unit. This mud was interpreted by MacClintock and Twenhofel (1940) and Brookes (1969, 1974) to represent bottomsets of the Bay St. George Delta. Lønne (1995) examined a grounding-line fan complex in Norway, and identified a distal retreat facies that was deposited primarily by suspension settling from a buoyant plume, and tended to drape pre-existing deposits. The mud units studied here resemble this facies, a conclusion supported by the rhythmic nature of the bedding, the lack of sorted coarse grained material, and its conformable lower contact overlying a basal diamicton unit along most of the coast. Although features indicative of ice rafting (e.g. dropstones) are generally rare in the muds, the section north of Butter Brook, where laminated diamicton overlies the basal diamicton, indicates an abundance of rafting. The overall lack of dropstones in the muds may relate to the interpretation that they were deposited distally from the ice margin. Ice-rafted sediment is commonly deposited in the proximal zone, close to the area of calving (cf. Stevens, 1990). The paleo ocean-current and wind directions may also have caused much of the calved ice to drift adjacent to the ice margin, rather than seaward, because the tidewater setting in St. George's Bay was an open embayment, not a constricted fiord (cf. Powell, 1984).

Sand and gravel (Unit 2) in the Highlands section and sand (Unit 3) in Type A sections were interpreted by Brookes (1974) to consist of seaward-dipping gravel foresets of the Bay St. George Delta. However, sedimentary characteristics of delta foresets (Gilbert-type) including dipping beds that show repeating fining-upward sequences (cf. Bornhold and Prior, 1990; Corner et al. 1990; Nemec, 1990) are absent. Unit 2 in the Highlands section mainly consists of horizontal, planar-interbedded sand, gravel, gravelly sand, and diamicton, interpreted to represent subaqueous sedimentation via underflow, current flow, debris flow, and overflow processes (cf. Lønne, 1997). In contrast, Unit 3 in Type A sections consists of planar-interbedded fine to coarse sand and interlaminated sand and silt, and likely represents a more distal component of the system, where deposition by relatively weaker underflow, current flow, and overflow processes operated.

Unit 3 (diamicton) in the Highlands section forms a continuous unit along ~0.6 km of coastline between Harbour Head and McLellans Brook. MacClintock and Twenhofel (1940) and Brookes (1969, 1974) interpreted this diamicton as lodgement till deposited during the Robinsons Head readvance. The diamicton in the Highlands section indicates a spatial variability in depositional processes, including primary (subglacial) and secondary (debris flow and rainout) in an ice-proximal, glaciomarine environment. The similarity in geochemistry and clast lithology between the basal diamicton and the diamicton unit in the Highlands section indicates both diamictons were likely derived from the same ice source. Evidence for deposition by lodgement is rare in the Highlands section, as the absence of glaciotectonic features (e.g. thrusting, shearing) indicate the ice margin generally did not override Unit 2 (sand and gravel). This can be explained by using King's (1993) suggestion that till can be deposited pro-glacially (i.e. secondary till), and perhaps as till-tongues (Powell and Domack, 1995), not requiring an advance across the site. This would also justify the interfingering of till with rainout and sediment gravity flow diamictons (cf. Powell, 1984). The dominant mode of deposition of the diamicton unit in the Highlands section was through sediment gravity flow, with contribution from rainout and traction currents. The depositional environment suggests glaciomarine conditions, based on the inclusion of striated clasts (glacigenic sediment) and marine shells in the diamicton.

Brookes (1969, 1974) indicated that outside the limit (i.e. Highlands section) of the Robinsons Head readvance, gravel at the top of the coastal sections represented the topset component of the Bay St. George Delta. Gravel terraces at Highlands overlie subaqueous outwash, and in this context cannot be interpreted as topsets. However, the coastline along southern St. George's Bay has been eroding during the last ~10 ka (cf. Forbes et al. 1993) due to marine submergence, and previously deposited sediments have been removed. The terraces identified here may represent the topset component of a prograding delta with its foresets initially farther out in St. George's Bay (cf. Powell, 1981), but subsequently removed by coastal erosion (Bell et al. submitted). Shaw and Forbes (1995) identified submerged deltas at –25m asl, indicating that deltas graded down to that level, although these are associated with a relative sea level lowstand between 8.5 and 10.5 ka BP, later than when terraces formed along the present coastline. Terraces on the lowlands grade gently toward the coast, and their presence support the conclusion that gravel (Unit 4) was deposited in response to lowering marine base levels (Liverman and Bell, 1996; Bell et al., 1999).

The terrace in the Highlands section at 24 to 26 m asl was interpreted by Brookes (1969, 1974) to be marine in origin, forming contemporaneous with the Robinsons Head readvance. Observations here suggest that this feature is not marine, but is more consistent with glaciofluvial deposition corresponding with formation of the terrace surfaces to the north and south (Type A sections). Considering the terrace in the Highlands section has the same elevation as that between McLellans Brook and Crabbes River, correlation between them must be considered. Meltwater channels, interpreted as proglacial in origin, dissect glaciofluvial deposits near Highlands and Crabbes rivers, suggesting that meltwater and sediment became channelized (following the modern river valleys) as ice retreated across the lowlands and base level fell.

Sand and silt that everywhere cap the coastal exposures relate to modern aeolian deposition of sediment reworked from the eroding coastal cliffs. Erosion continues in the present due to relative sea level rise and submergence of the coastline (Forbes et al. 1995).

4.2.1 Depositional model

The stratigraphic sequence presented for the coastline between French Brook and Highlands River is consistent with deposition in a tidewater, glaciomarine environment (Fig. 4.1). Most of the sediments (and meltwater) entered the sea via a subglacial tunnel and spread out and migrated laterally along the sea floor as a meltwater jet (cf. Powell, 1990; Lønne, 1995). Different aspects of this environment are represented: subglacial and proglacial deposition of the basal diamicton; muds deposited distally from meltwater plumes; distal to proximal subaqueous deposition of sand and gravel and sand on a grounding-line fan; and proglacial/ice-proximal sedimentation of diamicton overlying the fan (represented in the Highlands section).

Unit 2 in the Highlands section shows evidence of rapid sedimentation through sharp bed contacts, lateral discontinuity of individual beds, and deformation resulting from loading of saturated sediments. The coarsening upward from mud to interbedded sand, gravel, and diamicton may indicate a more proximal glacier margin, although the lower parts may have been dominated by suspension settling. Unit 3 in adjacent sections to the north and south have similar characteristics, although the coarse-grained component (interbedded gravel and diamicton) is generally absent. This suggests that Unit 3 of Type A sections was deposited more distally relative to Unit 2 of the Highlands section.

In addition to the coarsening upward from mud to sand and gravel, diamicton in the upper part of the Highlands section indicates that the ice margin, after retreating back from the coast, reestablished a position close to the present coastline. This coarsening is

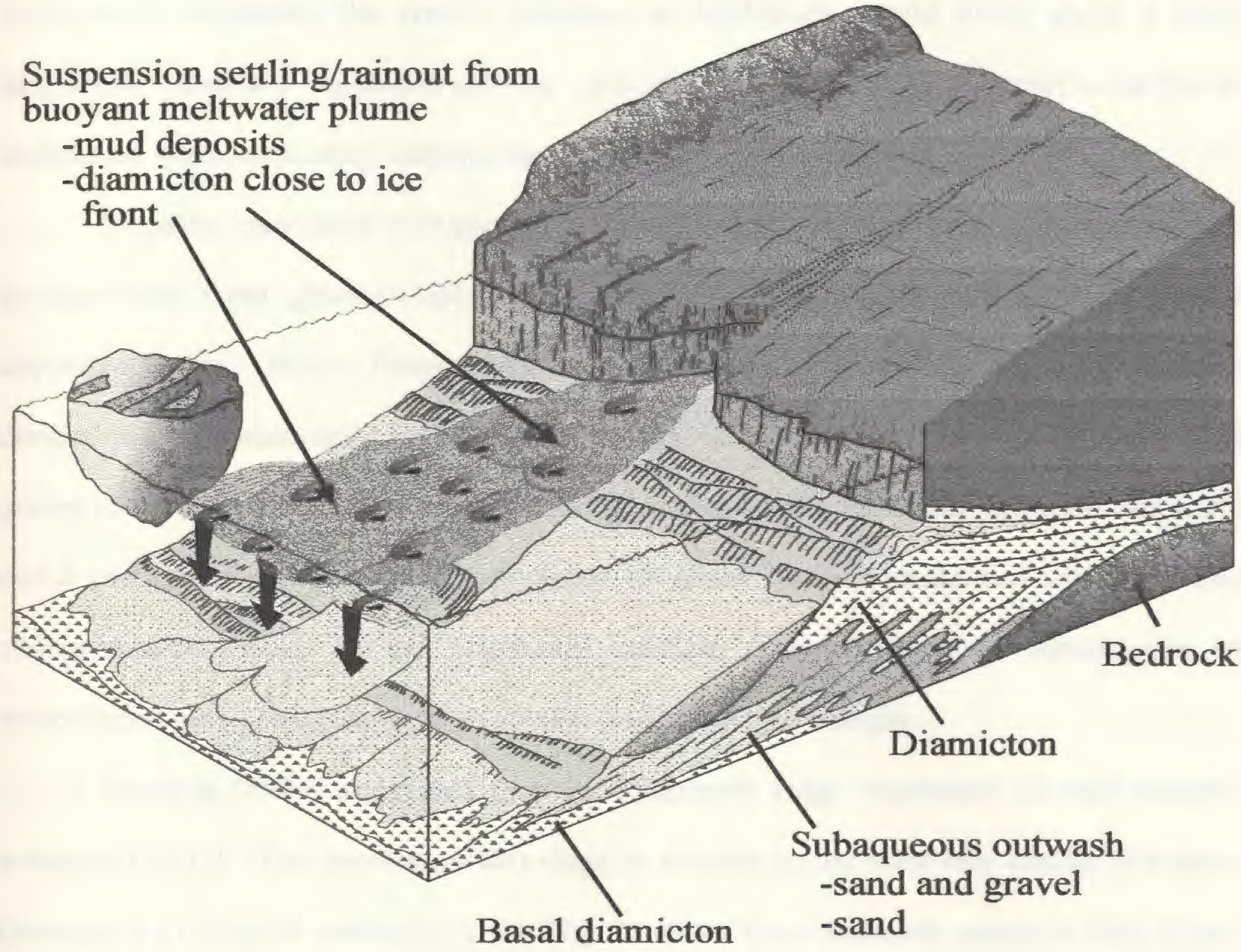

Figure 4.1 Depositional environment of grounding-line fan sedimentation along the coast of southern St. George's Bay prior to ~13.1 ka BP. Sediment and meltwater entered the sea via a jet efflux and spread out along the subaqueous surface. Basal diamicton was deposited during deglaciaion, with mud deposited distally from meltwater input. Sand and gravel represent more proximal parts of the fan, and diamicton may have been deposited by resedimentation of glacigenic material (after Batterson and Janes, 1997).

also represented in Type A sections, as muds grade upward to sand. With part of the ice margin located adjacent to the Highlands section, areas to the north and south remained ice-free, building up as the distal component of the fan. If the ice margin had continuously retreated, the typical sequence at Highlands would likely show a basal diamicton, overlain successively by glaciomarine mud and glaciofluvial/fluvial sediments, with interceding subaqueous deposits being absent.

Deposits associated with grounding-line fans may contain foreset bedding, but are distinguished from glaciofluvial sediments by the presence of resedimented glacial deposits (Lønne, 1995). Foreset beds are absent along the coast, as sections consist dominantly of horizontally bedded sand in Type A sections; and interbedded sand and gravel in the Highlands section. Sand and gravel overlying mud may represent the more distal part (toe?) of the fan. The presence of debris flows (interbedded diamicton and coarse gravel lenses) in the Highlands section, however, suggest introduction of remobilized glacigenic sediment relatively close to the ice margin.

Brookes (1974) suggested that the Highlands ridge represents an end moraine composed of till. The position of this ridge in relation to the relatively coarse sediments (compared to Type A sections) in the Highlands section, however, suggests that it may represent the subglacial component of the grounding-line fan that supplied sediment and meltwater to the open sea. Several eskers have been identified on the coastal lowlands and attest to subglacial drainage toward the coast. In this respect, the Highlands ridge may represent an esker (glaciofluvial ridge; Liverman et al., 1999a,b), although with a submarine terminus, that was deposited when ice retreated and grounded near the present coastline. The thick unit of subaqueous sand, gravelly sand, and gravel exposed in the

Highlands section thus represents the bulk of sediments in the Highlands ridge, although sections through the ridge inland were not available. Ridges similar to the Highlands ridge occur at Crabbes Head, Jeffrey's, Robinsons Head, and Bank Head (Liverman and Bell, 1996; Bell et al. 1999; Bell et al. submitted). Liverman et al. (1999) suggested that large channels (100s of metres wide and up to 5 km long), which occur perpendicular to the coast at Jeffrey's, Robinsons Head, and Bank Head may be related to the ridges. These channels could be associated with subglacial meltwater erosion (N-channels).

Ice retreated landward following formation of the grounding-line fan and deposition of the diamicton in the Highlands section. This retreat initiated construction of the glaciofluvial terraces as the ice margin became terrestrial and proglacial meltwater issued from the ice front (cf. Powell, 1981). Gravel in Type A sections; and gravel and gravelly sand in the Highlands section were deposited as this proglacial system graded into a shallowing sea coincident with ice retreat (Liverman and Bell, 1996). This shallowing resulted because of isostatic rebound as the forebulge migrated northward along the coast (Liverman, 1994).

4.2.2 Links to offshore

Sediments exposed in the coastal sections may be correlated with seismic units on the sea floor of St. George's Bay. Shaw and Forbes (1990) identified a mostly unstratified, undulating or hummocky deposit unconformably overlying bedrock. They interpreted this unit as till, equivalent to the St. George's River Drift (basal diamicton in this study). Some areas revealed that this unit also contained pockets of stratified sediment, also similar to the St. George's River Drift (Shaw and Forbes, 1990). Brookes (1974) interpreted the stratified sediment in the drift along the coast as representing ice-contact deposition, but in the context of the depositional model suggested for the coastline, this unit is consistent with a glaciomarine diamicton (Liverman and Bell, 1996; Bell et al. 1999).

Shaw and Forbes (1990) described interbedded sand, mud, ice-rafted debris, and ice-contact sediments overlying the basal ice-contact unit, interpreting them as subaqueous outwash. This unit resembles Unit 2 (sand and gravel) in the Highlands section, where interbedded sand, gravel, and diamicton are interpreted to be deposited by underflow, current flow, debris flow, and overflow in an ice-distal to ice-proximal glaciomarine environment. Unit 3 (sand) in Type A sections has similar characteristics, although the coarse-grained component is generally absent.

The mud unit in the coastal exposures has an offshore seismic equivalent. This unit was defined by Shaw and Forbes (1990) as draped glaciomarine sediments containing dropstones. This draped unit overlies subaqueous outwash along a conformable contact, although in places, the contact is interfingered. Shaw and Forbes (1990) interpreted this unit to be deposited by suspension fallout close to an ice front in a turbid, sediment-laden environment. This interpretation is consistent with deposition from meltwater plumes from a rapidly retreating tidewater ice margin. The reversal in stratigraphic position of subaqueous outwash and glaciomarine mud between offshore records and land-based sequences can be explained by considering the position of the ice front during deglaciation. The offshore data appear to represent a rapidly retreating ice margin back to the present coastline as glaciomarine mud conformably overlies subaqueous outwash (Shaw and Forbes, 1990). Muds directly overlying the basal diamicton in the coastal exposures also illustrate rapid ice retreat because there are no interceding deposits between the basal diamicton and mud. Subaqueous outwash at Highlands above the glaciomarine mud suggests that the ice margin, after retreating back from the coast, reestablished a position close to the present coastline and subsequently deposited the upper diamicton in the Highlands section.

4.3 Chronology and sea level implications

Sedimentological evidence indicates diamicton in the upper part of the Highlands section was deposited in a glaciomarine environment following a return to ice-proximal conditions from distal deposition of the muds. This diamicton was interpreted by Brookes (1974) as representing a distinct surge of ice from its inland position during the Robinsons Head readvance at ~12.6 ka BP. This date is derived from sediments interpreted as ice-contact from a coastal section at Kippens in northern St. George's Bay (Brookes, 1977b). The date on shells from the diamicton at Highlands, however, demonstrates that reactivation of the ice margin occurred at 13 680 ± 90 years BP (Beta-120124), approximately 1 ka earlier than the proposed culmination of the Robinsons Head readvance. Grounding-line fluctuations of tidewater termini may occur in response to changing relative water depths and accumulation of grounding-line sediments (cf. Fyfe, 1990; Powell, 1990; Hunter et al. 1996b), which overall may have caused a shift in the position of the grounding-line (Liverman and Bell, 1996).

The relative sea level history of southern St. George's Bay indicates that relative sea level fell continuously between 14 and 13 ka BP (Forbes et al. 1993). This may have contributed to an ice-marginal fluctuation during overall retreat (Liverman and Bell, 1996), not requiring a climatic reversal and return to full glacial conditions, as suggested by Brookes (1969, 1974, 1977b). The date used to constrain the Robinsons Head readvance has been suggested by Batterson and Janes (1997) to be unrelated to a climatic shift, bringing to question the validity of the overall existence of a large-scale readvance.

The dates on marine organisms from southern St. George's Bay range between ~13.1 and 14 ka BP (Bell et al. submitted). This further supports the idea that sediments exposed along the coast at Highlands were deposited rapidly with no significant delay in retreat across the coast and deposition of the diamicton in the Highlands section. These dates support a rapidly falling sea level from the marine limit (~45 m asl (?); Fig. 4.2), and considering the position of marine isobases in southern St. George's Bay (Grant, 1989), it suggests that southern and northern (north of Bank Head) areas may have been influenced by different relative sea level histories. The date from the diamicton in the Highlands section is thus important for two reasons:

1. Deposition of the diamicton in the Highlands section occurred at ~13.7 ka BP when relative sea level was at least 26 m asl (elevation of dated material). Brookes (1974, 1977b) suggested that during the Robinsons Head readvance at ~12.6 ka BP, relative sea level stood at ~28 m asl. This cannot be substantiated because a relative sea level curve based on dates from southern St. George's Bay indicates that a relative sea level position at 28 m asl occurred at ~13.2 ka BP (Fig. 4.2). The terrace in the Highlands section that Brookes suggested was marine, has been reinterpreted here to represent mainly glaciofluvial winnowing of the diamicton, and this is also considered to have occurred simultaneous with formation of glaciofluvial terraces in Type A sections. This indicates that the

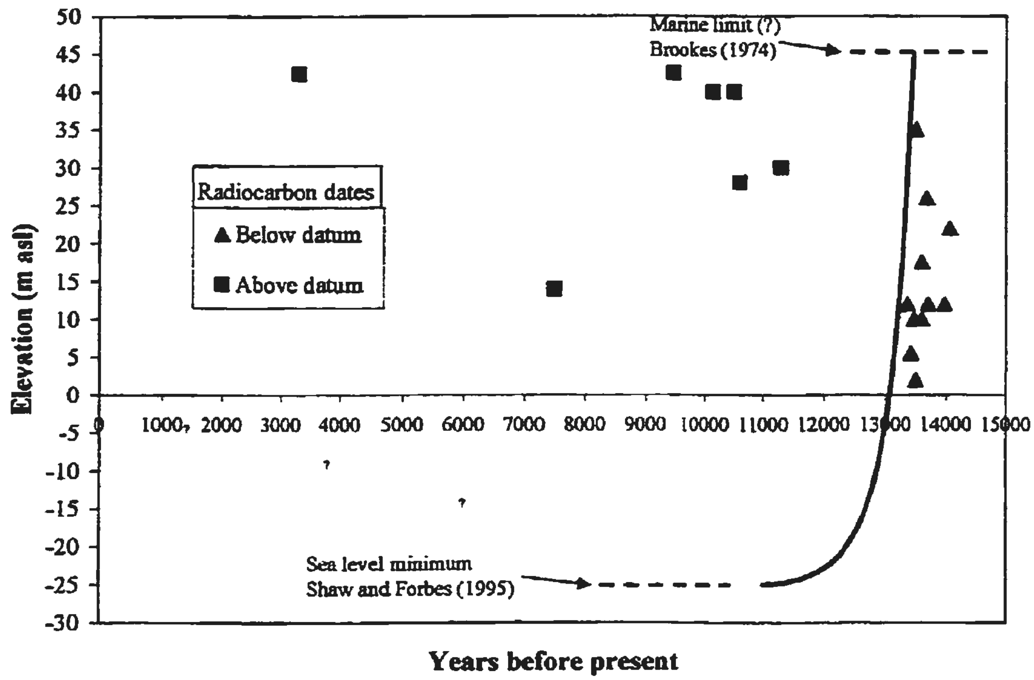

Figure 4.2 Proposed relative sea level curve for southern St. George's Bay (south of Bank Head). Note the rapid drop from the marine limit to below present by ~13 ka BP. Based on this curve, the Robinsons Head readvance at 12.6 ka BP into a relative sea level of 28 m asl could not have occurred because at 12.6 ka BP, relative sea level was approximately −15 m asl.

relative sea level to which these terraces graded, was significantly lower than 28 m asl, and older than 12.6 ka BP.

2. The date of ~13.7 ka BP falls within the range of all other dates (~13.1 to 14 ka BP) from various locations and stratigraphic positions along the coast of southern St. George's Bay, indicating that the bulk of sediments were deposited prior to ~13.1 ka BP. This suggests the ice margin existed near the coast during the entire period of deglaciation and subsequent deposition of all the sediments along the coast.

4.4 Implications for western Newfoundland, the Province, and Atlantic Canada

New evidence from the coastal exposures at Highlands provides insight regarding the deglacial history of southwest Newfoundland. The date from the diamicton in the Highlands section indicates that sediments associated with the Robinsons Head readvance were deposited at ~13.7 ka BP, with no evidence to support a return to ice-contact conditions at ~12.6 ka BP.

The pattern of sediments exposed along the coast at Highlands is similar to that to the north between Highlands River and Flat Bay (Liverman and Bell, 1996; Bell et al. 1999; submitted). This area also contains ridges occurring between terrace surfaces at Crabbes Head, Robinsons Head, and Bank Head. These ridges are located where ice-frontal surges occurred during the Robinsons Head readvance (Brookes, 1974; Grant, 1987), although Liverman and Bell (1996) interpreted the ridges to represent former positions of grounding-line fan sedimentation. The revised stratigraphy at Highlands in this study reconfirms the interpretation by Liverman and Bell (1996). In this respect, the coastline of southern St. George's Bay was characterized by a tidewater margin in an open embayment, where sediments were introduced mainly via four subglacial conduits into the open sea. Ice-proximal and ice-contact sediments that typically form sections through the ridges along the coast (Bell et al. 1999; submitted) could also be related to minor grounding-line fluctuations during overall retreat, and not a distinct surge of an inland ice source (Liverman and Bell, 1996).

Batterson and Janes (1997) and Batterson and Sheppard (2000) also suggest that sediments in coastal exposures in northern St. George's Bay indicate initial ice-proximal subaqueous fan sedimentation. In southern St. George's Bay, subaqueous deposition was followed by glaciofluvial deposition on deltas that existed farther out in the bay. In northern St. George's Bay, Batterson and Janes (1997) identified deltas along the coast that cap subaqueous sediments. This indicates that deglaciation and registration of marine limit was locally non-synchronous creating the differences in stratigraphic sequences between southern and northern St. George's Bay (Bell et al. submitted).

Sediments and landforms in the Highlands area indicate that a climatic deterioration likely did not occur during the proposed date of the Robinsons Head readvance; therefore, other areas on the west coast of Newfoundland need to be re-evaluated. Most of the coastline of Newfoundland was being deglaciated between 14 and 12 ka BP, resulting in raised relative sea levels (Liverman, 1994). This, in addition to glaciers with tidewater termini could have produced unstable glaciodynamic conditions. Brookes (1975) and Grant (1992) noted the close association of glacial margins with marine overlap, but because the Robinsons Head readvance had been established at 12.6 ka BP, they made efforts to constrain geological history to this data point. The date of ~13.8 ka BP on shells from sediments at Codroy that Brookes (1975) attributed to a readvance may merely represent the date at which retreat occurred and the glacier margin grounded in the sea, subsequently depositing a glaciomarine diamicton over till.

Readvances at ~13 ka BP documented in other areas of Atlantic Canada (e.g. Nova Scotia; Stea et al. 1996; Stea, 1999) cannot be discounted based on the data from Highlands. However, the existence of the Robinsons Head readvance has been questioned in St. George's Bay in this and other studies, suggesting that a regional scale climatic deterioration did not occur at ~12.6 ka BP. As other areas of Atlantic Canada were likely influenced by local factors, an isolated cooling and readvance may have occurred in those areas (Kiegwin and Jones, 1995).

There is evidence from the coastal exposures at Highlands to suggest a period of atmospheric cooling. The Younger Dryas cooling event has been bracketed between ~11 and 10 ka BP and features interpreted as ice-wedge casts in gravel from Type A sections may have formed during this interval. This gravel was deposited prior to 13 ka BP as relative sea level from the marine limit, and would therefore have been exposed subaerially during the Younger Dryas as relative sea level was approaching a minimum level (Shaw and Forbes, 1995). The timing of formation of ice wedges is consistent with observations and conclusions by Brookes (1971) in other locations around St. George's Bay; on the northeast coast of Newfoundland (Eyles, 1977); and near Grand Falls in central Newfoundland (Batterson and Taylor, 1998).

4.4.1 Economic and land-use issues

The data presented in this study has relevance to issues including mineral exploration, aggregate resources, and geotechnical hazards. Understanding ice-flow history in an area of drift cover is important for tracing elements (e.g. gold, silver) of economic value (Batterson, 1989). Ice-flow mapping indicates that the Long Range Mountains were the ice-dispersal centre for southern St. George's Bay during the last glaciation. The source area for anomalies encountered in till geochemistry data from southern St. George's Bay could possibly be determined using the ice-flow indicators presented in this study. Active prospecting occurs on the Long Range Mountains, and data from this thesis would aid in this process.

The coastal lowlands and river valleys of southern St. George's Bay contain an abundant supply of glaciomarine, glaciofluvial, and fluvial deposits. Detailed mapping in this area has helped delimit the extent and character of these deposits. Sand and gravel is an important commodity for road and infrastructure development in the Province and possibly for export, especially with shipment facilities located to the north at Flat Bay and Stephenville (Liverman et al. 1999; Batterson and Sheppard, 2000). Muds exposed along the coast may also have economic value for use in pottery, brick making, and as liners in waste disposal and landfill sites (Liverman et al. 1999b). Extracting sediments from the coastal exposures, however, presents other problems.

The presence of glaciomarine and marine sediments along the coast poses a hazard to future development. Impermeable silt- and clay-rich diamicton and mud form a high proportion of the exposures along the coast of southern St. George's Bay. These sediments are susceptible to slumping and mass movement when saturated (Liverman et al. 1999). There is also a threat of coastal erosion due to sea level rise and perhaps increase in wave activity at the base of the exposures (Forbes et al. 1995). Any development close to the coast must consider the implications of such factors.

4.5 Conclusions

This thesis has resolved many issues regarding the deglacial history of southern St. George's Bay. Ice-flow indicators suggest that during the last (Late Wisconsinan) glaciation, the study area was covered by ice that originated on the southern Long Range Mountains. Ice flowed generally westward and extended across the present coastline to a terminal position offshore.

Ice retreat to and across the modern coastline was in a tidewater setting, which existed for a significant period during overall deglaciation. Radiocarbon-dated marine shells obtained from sediments in the coastal exposures indicate that deglaciation of the coastline commenced between ~14 to 13.1 ka BP, during which time, distinct units of glacial and glaciomarine sediments were deposited.

The existence of ice proximal sediments overlying deglacial deposits need not be a response to climatic forcing, causing regrowth of an ice sheet and subsequent advance. In a glaciomarine environment, secondary controls including changing relative water depth and sedimentation rate may affect the overall glaciodynamics of the ice margin (Powell, 1990). Reevaluation of the sediments along the coast at Highlands shows that return to ice proximal conditions was likely not related to a climatic shift. Deposition of the diamicton in the Highlands section occurred at ~13.7 ka BP during overall climatic amelioration as the Newfoundland Ice Sheet retreated landward to local ice centres.

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Appendix A: Ice-flow data

Table A1. Striation information (Source: Taylor et al. 1993).

UTM			
Easting	Northing	Elevation (m asl)	Direction/Sense
362550	5319700	365	300
362200	5319900	350	333
354300	5320450	243	305
354300	5320450	243	211
361550	5324400	381	205
370100	5326100	167	275
370100	5326100	167	315
355750	5319300	152	357
360500	5333100	198	268
387300	5335300	304	280
386800	5335200	304	270
379400	5327500	388	330
384900	5320200	365	300
380600	5318750	335	330
380600	5319300	337	140-320
382700	5321400	365	320
383200	5321700	365	330
383200	5322200	320	310
365100	5324200	426	345
364900	5324600	434	177-357
365000	5325400	305	340
365600	5325800	426	340
380200	5326700	365	320
378900	5326600	381	315
378300	5327000	365	330
379850	5325850	350	321
383200	5324100	411	310
381400	5324650	381	305
380500	5325400	342	303
385500	5323000	350	060-240
380900	5326650	381	316
384100	5325950	373	296
385500	5325800	403	304
386400	5328000	388	307
356400	5327600	312	2
355700	5328000	281	350
357400	5329500	396	2
355100	5329000	320	168-348

Table A1. Cont'd.

UTM			
Easting	Northing	Elevation (m asl)	Direction/Sense
365500	5325900	439	174-354
367000	5323000	258	252
365500	5325900	439	276
375800	5326200	318	311
358600	5329750	350	345
358750	5329150	374	340
367500	5325400	318	336
367200	5323850	364	336
359000	5329900	381	320

Table A2. Diamicton clast fabric statistics.

Site	UTM					
	Easting	Northing	S1	S2	S3	k
Basal diamicton	355300	5335200	0.740	0.178	0.081	1.81
Basal diamicton	355800	5336300	0.711	0.213	0.076	1.17
Basal diamicton	356400	5337600	0.739	0.167	0.093	2.54
Basal diamicton	358300	5339000	0.696	0.244	0.059	0.74
Basal diamicton	359000	5339400	0.617	0.332	0.051	0.33
Basal diamicton	359700	5339650	0.775	0.178	0.048	1.12
Basal diamicton	360000	5340300	0.692	0.256	0.052	0.62
Basal diamicton	360400	5340800	0.608	0.283	0.108	0.79
Basal diamicton	360500	5341100	0.574	0.364	0.062	0.26
Basal diamicton	360500	5341200	0.625	0.299	0.076	0.54
Basal diamicton	355700	5336400	0.841	0.092	0.067	6.98
Basal diamicton	355700	5336400	0.722	0.207	0.071	1.17
Basal diamicton	355700	5336400	0.628	0.270	0.102	0.87
Basal diamicton	354900	5334900	0.651	0.239	0.110	1.29
Basal diamicton	354900	5334900	0.595	0.317	0.088	0.49
Basal diamicton	354900	5334900	0.708	0.216	0.076	1.14
Basal diamicton	363900	5334200	0.577	0.282	0.141	1.03
Basal diamicton	363900	5334200	0.660	0.262	0.079	0.77
Basal diamicton	355400	5335500	0.558	0.377	0.064	0.22
Basal diamicton	355400	5335500	0.741	0.167	0.092	2.50
Basal diamicton	355700	5336500	0.766	0.135	0.099	5.60
Basal diamicton	355700	5336500	0.758	0.184	0.058	1.23
Basal diamicton	355700	5336500	0.522	0.388	0.090	0.20
Basal diamicton	355700	5336500	0.812	0.140	0.047	1.61
Ice-rafted diamicton (Butter Brook)	355700	5336700	0.666	0.264	0.070	0.70
Diamicton (H. section)	357200	5338300	0.515	0.327	0.157	0.62

Table A2. Cont'd.

Site	UTM Easting	UTM Northing	S1	S2	S3	k
Diamicton (H. section)	357200	5338300	0.488	0.397	0.115	0.17
Diamicton (H. section)	357400	5338350	0.703	0.211	0.087	1.36
Diamicton (H. section)	357400	5338350	0.566	0.278	0.155	1.22
Diamicton (H. section)	357400	5338350	0.572	0.345	0.083	0.35
Diamicton (H. section)	357450	5338400	0.573	0.302	0.125	0.73
Diamicton (H. section)	357450	5338400	0.624	0.243	0.133	1.56
Diamicton (H. section)	357600	5338500	0.635	0.244	0.121	1.36
Diamicton (H. section)	357600	5338500	0.565	0.347	0.088	0.36
Diamicton (H. section)	357600	5338500	0.633	0.241	0.126	1.49
Diamicton (H. section)	357700	5338550	0.575	0.293	0.132	0.85
Diamicton (H. section)	357700	5338550	0.735	0.214	0.051	0.86
Diamicton (H. section)	357700	5338550	0.650	0.294	0.055	0.47
Diamicton (H. section)	357700	5338550	0.488	0.304	0.208	1.25
Inland	366250	5336000	0.752	0.180	0.069	1.49
Inland	373000	5324250	0.840	0.092	0.068	7.32
Inland	373250	5319700	0.773	0.163	0.064	1.66
Inland	361800	5320850	0.831	0.089	0.080	20.95
Inland	361900	5319850	0.796	0.135	0.069	2.64
Inland	371500	5319500	0.772	0.134	0.094	4.94
Inland	360850	5326200	0.734	0.187	0.079	1.59
Inland	360150	5326400	0.687	0.231	0.082	1.05
Inland	360300	5327400	0.762	0.183	0.055	1.19
Inland	359950	5328000	0.782	0.166	0.052	1.34
Inland	358600	5325550	0.688	0.238	0.074	0.91
Inland	358000	5324700	0.676	0.251	0.073	0.80
Inland	354900	5329000	0.495	0.280	0.225	2.61
Inland	356200	5324250	0.827	0.089	0.084	38.55
Inland	357400	5324050	0.739	0.162	0.099	3.08
Inland	357200	5324000	0.543	0.353	0.104	0.35
Inland	354250	5325050	0.742	0.212	0.046	0.82
Inland	356700	5324200	0.788	0.132	0.080	3.57

Appendix B: Grain size data

Grain size analysis procedures

Sieving

Before sieving, the sample was divided with the use of a splitter and weighed after drying between 70 and 140 g. Samples were air dried and/or placed in an oven for a sufficient amount of time. A set of seven sieves with screen sizes of 4 mm (-2ϕ), 2 mm (−1ϕ), 1 mm (0ϕ), 0.5 mm (1ϕ), 0.25 mm (2ϕ), 0.125 mm (3ϕ), and 0.0625 mm (4ϕ) were used. The sieves were placed on automatic shakers for 12 minutes. A pan to retrieve the silt and clay fraction (<0.0625 mm) was placed at the bottom and a cover placed on the upper sieve. The silt and clay fraction was analysed using the Sedigraph 5100 (see below).

Dry-sieved samples (sand and gravel) contained generally <2% silt and clay. Samples with a relatively low silt/clay content readily separated into individual grains, whereas higher amounts required the use of mortar and pestle to break down silt/clay clumps. Excessive churning with mortar and pestle was avoided so that individual grains were not disintegrated into smaller grains (this will lead to a misrepresentation of the grain size distribution).

To ensure that an accurate analysis was carried out, any sample that contained a significant amount of silt and clay was wet-sieved. Wet-sieved samples (e.g. diamicton, mud) generally contained a high percentage (often greater than 20%) of silt and clay. Prior to wet-sieving, the portion of the sample was soaked in distilled water and stirred. This allowed individual grains to separate prior to sieving.

Dry Sieving

When the sample was prepared for sieving, each sieve was weighed and recorded (this was carried out before every sample was sieved). After 12 minutes on the automatic shaker, each sieve, including the retained sediment, was weighed. The difference between the initial weight of the sieve and that of the sieve + sediment represented the weight of the sediment in that size fraction.

Wet Sieving

When the sample was prepared, it was wet-sieved through the 0.0625 mm sieve using distilled water and a high pressure nozzle. The <0.0625 fraction was retained in a 1 gallon plastic bucket or equivalent container. The sample was thoroughly rinsed so as to wash through all of the silt and clay. The material retained in the 0.0625 sieve was then dried and sieved using the dry-sieve procedure discussed above. A small amount of magnesium chloride (1N $MgCl2$) was added to the water and silt and clay mixture to flocculate it, causing the sediment to settle out faster. The water was then decanted or siphoned off.

Sedigraph 5100 analysis

The Sedigraph 5100 allows an analysis of the silt and clay fraction within 15 minutes once the sample is prepared, compared to 24 hours with other methods (e.g. hydrometer). Below is a description of the procedures used to prepare the sample for the Sedigraph once the sieving was completed. The Sedigraph analysed size fractions including 0.031 mm (5ϕ), 0.0156 mm (6ϕ), 0.0078 mm (7ϕ), 0.0039 mm (8ϕ), 0.002 mm (9ϕ), 0.00098 mm (10ϕ), 0.00049 mm (11ϕ), and <0.00049 mm (>11ϕ).

Sedigraph sample

Not all of the silt and clay collected in the sieves was analysed by the Sedigraph. Rather, a representative amount was used, generally 2 to 3 grams (dry). Where samples are dry-sieved, the specified amount can be weighed straight away. When wet sieving, most of the water is siphoned or decanted off. The sample is placed in a beaker with a sufficient amount of distilled water and mixed using a magnetic stirrer. The stirrer not only removes magnetic minerals from the sample, but places all of the sample in suspension. While the sample was stirring, a representative amount was pipetted off. Generally, 15 to 20 ml (based on the concentration) provided an adequate amount to be used in the Sedigraph.

Whether wet- or dry-sieved, the sample was then mixed with 10 to 15 ml of hydrogen peroxide (30%) to remove any organic material. If the sample was dry, it was wetted with distilled water before adding the peroxide. The sample was stirred every few hours to stimulate reaction. A minimum of 24 hours is required for peroxide to react.

Centrifuge

Some samples will react for several days, so after 24 hours expired, the peroxide was removed from the sample. If the sample settled in the container, the standing water was decanted or pipetted off. If reaction was still occurring, it meant that some of the sediment was likely still in suspension. In this case, the sample was split and mixed with distilled water in two 50 ml tubes. The tubes containing the sample were then balanced on a scale before being put in the centrifuge. The centrifugal forces cause the sediment to settle at the bottom of the tube, leaving only water and peroxide, which was decanted off. This procedure was repeated to ensure that all of the peroxide was removed. Before repeating, however, each tube was placed on the vortex mixer. After completing the centrifuge procedure, sediment in both tubes was reunited.

Calgon

Calgon is a dispersing agent that prevents the sediment from clumping. Sodium hexametaphosphate is mixed with distilled water to create a 0.1% concentration (i.e. 1 g/L). The sample was removed from the tube and placed in a 80 ml beaker by rinsing with distilled water; the vortex mixer aided in removing sediment stuck to the side of the tube.

Ultrasonic disaggregation

An ultrasonic pulse helps to further separate individual grains. Using ear protection, the sample was insonified for 15 - 25 seconds.

Magnetic stirrer

Prior to the sample being analysed on the Sedigraph, it was placed on a magnetic stirrer for at least 30 minutes.

Table B1. Textural sample information. Sample numbers ending in "D" are duplicates.

Location	Material	UTM Easting	UTM Northing	Sample #
Coast	Basal diamicton	355300	5335200	8500
Coast	Basal diamicton	355300	5335200	8500D
Coast	Basal diamicton	355700	5336500	8502
Coast	Basal diamicton	355700	5336500	8502D
Coast	Basal diamicton	356400	5337600	8515
Coast	Basal diamicton	359000	5339400	8528B
Coast	Basal diamicton	359700	5339650	8536
Coast	Basal diamicton	360400	5340800	8538
Coast	Basal diamicton	360400	5340800	8538D
Coast	Basal diamicton	360900	5341700	8577
Coast	Basal diamicton	358300	5339000	8527
Coast	Basal diamicton	358300	5339000	8527D
Coast	Basal diamicton	355700	5336400	8502
Coast	Basal diamicton	354900	5334900	8504
Coast	Basal diamicton	363900	5334200	8503
Coast	Basal diamicton	355400	5335500	8505
Coast	Mud	358300	5339000	8567
Coast	Mud	355300	5335200	8559
Coast	Mud	355300	5335200	8559D
Coast	Mud	355800	5336300	8566
Coast	Mud	359850	5340050	8568
Coast	Mud	361050	5341750	8573
Coast	Mud	361050	5341750	8573D
Coast	Mud	355700	5336700	8528
Coast	Sand	355900	5337000	8562
Coast	Sand	355900	5337000	8561
Coast	Sand and gravel	357450	5338400	8565
Coast	Sand and gravel	357450	5338400	8564
Coast	Sand and gravel	360900	5341700	8575
Coast	Sand and gravel	360900	5341700	8576
Coast	Diamicton (H. section)	357200	5338300	8516
Coast	Diamicton (H. section)	357400	5338350	8517
Coast	Diamicton (H. section)	357450	5338400	8518
Coast	Diamicton (H. section)	357450	5338400	8518D
Coast	Diamicton (H. section)	357600	5338500	8523
Coast	Diamicton (H. section)	357600	5338500	8523D
Coast	Diamicton (H. section)	357600	5338500	8524
Coast	Diamicton (H. section)	357700	5338550	8525
Coast	Diamicton (H. section)	357700	5338550	8526
Coast	Diamicton (H. section)	357700	5338550	8526D

Table B1. Cont'd.

Location	Material	UTM Easting	UTM Northing	Field #
Coast	Sand and silt	355900	5337000	8563
Coast	Sand and silt	360900	5341700	8574
Coast	Sand and silt	359900	5340150	8569
Inland	Diamicton	361300	5334500	8508
Inland	Diamicton	360000	5334200	8510
Inland	Diamicton	353300	5332500	8513
Inland	Diamicton	364100	5328800	8543
Inland	Diamicton	373250	5319700	8529
Inland	Diamicton	369100	5335350	8535A
Inland	Diamicton	358700	5320500	8530
Inland	Diamicton	361800	5320850	8531
Inland	Diamicton	361900	5319850	8532
Inland	Diamicton	377050	5323900	8535
Inland	Diamicton	373500	5326450	8534
Inland	Diamicton	373500	5326450	8534D
Inland	Diamicton	368700	5322550	8539
Inland	Diamicton	370700	5320400	8540
Inland	Diamicton	370700	5320400	8540D
Inland	Diamicton	364550	5330600	8542
Inland	Diamicton	364600	5327450	8544
Inland	Diamicton	360300	5327400	8545
Inland	Diamicton	358000	5324700	8549A
Inland	Diamicton	355150	5328250	8546
Inland	Diamicton	354900	5329000	8547
Inland	Diamicton	356200	5324250	8548
Inland	Diamicton	357400	5324050	8549
Inland	Diamicton	357400	5324050	8549D
Inland	Diamicton	357200	5324000	8550
Inland	Diamicton	354250	5325050	8551
Inland	Diamicton	351950	5323350	8553
Inland	Diamicton	351950	5323350	8553D
Inland	Diamicton	355850	5324200	8554
Inland	Diamicton	356700	5324200	8555
Inland	Diamicton	356700	5324200	8555D

Table B2. Grain size analysis. Sample numbers ending in "D" represent duplicates.

	Sieve							**Sedigraph**							
Wentworth	Peb. +	Gran	V.c.sa	C.sa	M.sa	F.sa	V.f.sa	C. si	M. si	F.si.	V.f. si.	Clay			
mm	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002	0.0001	0.0005	<0.0005
phi (ϕ)	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	>11
Sample #	**Weight coarser than (%)**														
8500	12.3	17.3	22.1	27.1	35.6	44.4	54.3	61.4	71.2	78.9	84.5	88.0	90.6	92.3	100.0
8500D	8.1	11.8	16.0	21.3	30.7	40.7	46.8	55.8	66.5	75.0	81.5	86.1	89.6	92.2	100.0
8502	6.4	10.8	15.8	22.4	31.2	41.7	53.6	60.1	68.1	74.7	80.3	84.8	88.3	91.7	100.0
8502D	4.4	9.0	14.0	19.5	27.4	36.3	47.5	54.7	63.7	70.9	77.0	81.9	85.7	89.2	100.0
8515	3.2	6.2	10.2	14.9	22.7	31.6	42.6	49.6	59.1	66.6	73.4	79.1	83.6	87.9	100.0
8528B	3.5	6.9	10.1	13.6	18.4	23.9	32.4	45.0	60.3	69.3	75.4	80.1	84.0	87.0	100.0
8536	8.2	11.9	16.1	21.4	30.9	41.0	45.5	54.6	65.2	73.6	80.1	84.6	88.1	90.7	100.0
8538	6.0	11.8	17.4	22.9	30.7	39.5	50.7	58.0	68.5	75.8	80.9	84.6	87.9	90.2	100.0
8538D	6.1	10.6	15.3	20.5	28.2	36.9	49.8	57.6	66.0	73.0	78.6	83.2	87.2	90.5	100.0
8577	8.9	13.6	19.3	26.3	35.5	45.2	57.5	63.8	73.7	80.8	85.2	88.7	91.2	93.2	100.0
8527	5.4	12.0	17.8	24.0	32.8	41.7	51.7	58.1	65.7	72.1	78.0	83.0	86.7	90.1	100.0
8527D	10.4	15.9	21.1	27.1	36.2	45.7	55.7	62.3	69.2	74.9	80.3	84.7	88.5	91.8	100.0
8502	4.4	9.0	14.0	19.5	27.4	36.3	47.5	54.6	63.7	70.8	77.0	81.9	85.7	89.2	100.0
8504	9.4	16.0	20.8	25.4	33.0	41.9	53.0	59.7	67.5	74.0	79.8	83.7	87.3	90.0	100.0
8503	4.4	10.6	18.6	28.6	40.9	51.5	60.8	66.2	72.2	77.1	81.8	85.8	89.3	92.6	100.0
8567	0.0	0.0	0.0	0.1	0.3	0.8	5.3	19.1	39.5	52.5	62.3	70.6	77.2	81.5	100.0
8559	0.0	0.3	0.3	0.4	0.7	1.1	2.6	8.6	29.2	46.7	58.2	67.5	74.5	80.1	100.0
8559D	0.2	0.2	0.4	0.4	0.8	1.1	4.4	10.2	25.5	42.4	54.8	65.3	73.2	81.4	100.0
8566	0.0	0.1	0.4	0.7	1.4	2.2	6.6	18.0	34.3	46.0	55.7	64.5	71.9	79.0	100.0
8568	0.0	0.1	0.4	0.5	1.0	1.5	3.9	17.6	39.9	54.1	63.6	71.1	77.4	82.1	100.0

Table B2. Cont'd.

	Sieve							Sedigraph							
Wentworth	Peb. +	Gran	V.c.sa	C.sa	M.sa	F.sa	V.f.sa	C. si	M. si	F.si.	V.f. si	Clay			
mm	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002	0.0001	0.0005	<0.0005
phi (ϕ)	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	>11
Sample #	Weight coarser than (%)														
8573	0.3	0.4	0.5	0.5	0.5	1.0	8.8	33.7	56.2	66.6	74.2	80.3	85.2	89.8	100.0
8573D	0.0	0.1	0.3	0.4	0.4	1.0	14.9	38.8	59.1	68.9	76.3	81.8	86.0	90.6	100.0
8528	8.8	14.3	19.3	25.5	35.2	45.8	56.1	60.9	69.9	76.8	81.7	85.4	88.3	91.1	100.0
8562	0.0	0.0	0.0	13.9	71.8	90.7	98.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
8561	0.0	0.0	0.0	0.0	7.7	42.5	84.4	94.1	96.8	97.5	98.1	98.4	98.7	98.9	100.0
8565	0.1	0.6	1.2	2.4	16.3	68.8	96.2	98.6	99.3	99.5	99.7	99.8	99.8	99.9	100.0
8564	6.3	20.3	36.8	59.6	93.0	98.8	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
8575	0.0	0.0	0.4	5.4	39.0	74.7	96.2	98.4	99.0	99.2	99.4	99.5	99.6	99.7	100.0
8576	0.4	3.8	28.3	73.0	94.5	98.4	99.3	99.8	99.9	99.9	100.0	100.0	100.0	100.0	100.0
8516	3.2	7.0	11.6	17.6	27.6	39.7	45.9	55.3	65.2	72.8	79.2	84.5	88.5	92.1	100.0
8517	0.4	0.7	1.2	2.2	5.4	10.9	17.3	30.4	45.6	56.2	67.2	79.8	87.0	96.5	100.0
8518	2.7	4.0	5.4	7.5	10.7	14.8	25.8	35.5	48.8	59.5	68.3	75.8	82.0	87.5	100.0
8518D	4.9	6.5	8.1	10.1	13.2	17.3	27.4	38.5	52.4	62.4	70.8	77.6	83.1	87.9	100.0
8523	8.4	12.2	16.5	22.0	31.7	42.1	48.3	54.4	63.8	70.8	76.5	81.8	85.8	88.8	100.0
8523D	6.4	11.1	15.7	21.3	30.5	40.0	50.4	59.0	68.8	75.9	81.5	85.9	89.4	92.1	100.0
8524	5.6	10.2	15.4	22.5	33.4	44.2	55.6	63.2	71.5	77.6	82.1	86.1	88.9	91.4	100.0
8525	5.7	10.6	16.5	24.7	36.2	46.6	57.4	63.3	70.1	76.3	82.0	86.7	90.4	93.2	100.0
8526	4.2	9.4	14.6	20.9	31.0	40.8	52.4	58.8	66.1	72.5	78.4	83.5	87.6	92.0	100.0
8526D	1.8	5.2	9.6	15.8	26.3	36.8	49.1	56.5	63.9	70.9	77.5	82.7	87.3	91.6	100.0
8541	9.3	19.4	29.1	39.6	50.7	58.4	65.9	71.1	76.7	81.1	84.9	88.3	91.2	93.2	100.0
8556	5.6	12.4	19.7	28.4	39.2	48.8	57.2	63.0	71.1	78.0	83.7	88.0	91.4	94.1	100.0

Table B2. Cont'd.

	Sieve							Sedigraph							
Wentworth	Peb. +	Gran	V.c.sa	C.sa	M.sa	F.sa	V.f.sa	C. si	M. si	F.si.	V.f. si.	Clay			
mm	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002	0.0001	0.0005	<0.0005
phi (ϕ)	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	>11
Sample #	**Weight coarser than (%)**														
8557	5.2	8.0	11.5	16.2	22.3	28.7	35.9	41.6	50.9	60.8	70.1	77.0	83.0	87.4	100.0
8558	10.5	14.5	17.6	21.7	32.7	42.8	51.9	56.7	63.1	68.9	74.2	79.1	83.3	87.3	100.0
8563	0.0	0.0	0.5	4.3	26.1	67.7	93.9	96.3	97.1	97.6	98.0	98.6	99.0	99.2	100.0
8574	0.0	0.0	0.4	2.8	17.4	57.3	85.7	92.9	95.8	96.9	97.7	98.3	98.8	99.2	100.0
8569	0.0	0.0	1.0	7.2	31.0	66.1	91.3	95.3	97.3	98.0	98.6	98.9	99.2	99.4	100.0
8508	2.0	4.6	7.3	11.9	19.9	26.6	32.2	35.0	42.8	52.4	64.4	75.5	83.6	89.8	100.0
8510	2.3	5.0	7.7	11.8	19.8	28.2	37.5	43.0	52.9	60.7	68.3	75.6	81.7	86.3	100.0
8513	4.4	10.6	14.7	20.0	36.8	52.4	66.5	75.6	83.5	87.7	90.3	92.3	94.0	95.2	100.0
8543	13.2	19.2	26.1	34.7	50.1	66.5	73.3	76.8	82.8	87.7	91.6	94.4	96.5	97.8	100.0
8529	15.4	30.4	42.9	52.9	62.2	71.4	80.1	84.7	90.7	94.6	97.1	98.4	99.1	99.7	100.0
8535A	12.5	18.1	24.6	32.7	47.2	62.6	70.0	75.8	82.7	87.7	91.5	94.0	96.0	97.3	100.0
8530	17.3	34.6	50.1	63.4	74.4	85.1	91.9	94.2	96.5	97.9	98.9	99.5	99.9	99.9	100.0
8531	8.8	18.3	28.3	39.8	55.3	69.4	84.9	87.9	91.8	94.5	96.4	97.8	98.8	99.2	100.0
8532	5.4	10.5	19.1	31.7	45.8	62.4	82.5	86.0	90.0	92.6	94.5	95.9	97.0	97.7	100.0
8535	9.0	15.8	21.3	27.5	45.9	60.9	70.8	78.5	86.7	92.2	95.8	98.2	99.3	99.8	100.0
8534	19.4	33.7	46.0	56.2	64.6	71.4	79.2	83.4	88.4	92.2	95.3	97.3	98.4	99.4	100.0
8534D	26.7	40.5	52.6	60.7	67.1	72.1	78.0	82.0	87.0	90.9	94.1	96.4	98.1	98.8	100.0
8539	14.3	22.1	29.8	38.4	49.4	62.0	79.3	87.5	93.8	96.6	98.2	99.0	99.5	99.6	100.0
8540	16.9	28.1	42.1	54.7	66.7	77.2	87.5	91.6	95.4	97.6	98.8	99.5	99.8	99.8	100.0
8540D	6.2	15.6	27.4	39.3	52.3	65.8	79.6	84.9	91.3	95.5	97.9	99.0	99.7	100.0	100.0
8542	11.4	24.4	33.3	44.5	57.3	68.8	81.7	87.9	93.7	96.8	98.4	99.2	99.6	99.7	100.0
8544	11.1	17.5	28.7	41.8	53.7	65.4	78.7	83.8	89.0	92.8	95.4	97.1	98.3	99.0	100.0

Table B2. Cont'd.

	Sieve							Sedigraph							
Wentworth	Peb. +	Gran	V.c.sa	C.sa	M.sa	F.sa	V.f.sa	C. si	M. si	F.si.	V.f. si.	Clay			
mm	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002	0.0001	0.0005	<0.0005
phi (ϕ)	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	>11
8545	12.5	18.1	24.6	32.7	47.2	62.6	71.0	79.3	87.6	92.6	95.9	98.3	99.6	99.8	100.0
8549A	14.3	19.5	26.6	37.9	54.4	69.8	83.6	86.8	90.7	93.5	95.4	96.8	97.8	98.5	100.0
8546	20.9	41.1	50.5	55.3	58.8	61.5	64.6	69.7	78.6	86.0	91.3	94.4	96.4	97.5	100.0
8547	10.5	15.3	22.1	32.8	54.5	68.6	80.1	84.3	89.5	92.9	95.3	97.1	98.5	99.4	100.0
8548	18.5	28.8	36.2	41.9	55.5	68.6	78.2	85.3	91.9	95.1	97.0	98.2	99.1	99.5	100.0
8549	11.4	19.7	29.5	38.8	50.8	62.6	74.6	80.0	87.1	92.3	96.0	98.0	99.0	99.2	100.0
8549D	5.4	13.2	24.6	37.0	50.6	54.6	69.4	76.6	85.3	91.6	95.5	97.8	99.0	99.3	100.0
8550	10.9	16.9	24.7	35.5	51.1	65.4	81.1	84.6	89.0	92.3	94.5	96.1	97.3	98.4	100.0
8551	14.1	22.5	30.3	38.3	53.6	64.8	72.5	79.6	86.9	91.8	95.4	97.6	99.0	99.5	100.0
8553	6.2	11.3	15.7	20.2	33.1	46.1	58.7	72.1	87.6	93.9	96.8	98.4	99.4	100.0	100.0
8553D	15.1	22.4	27.0	31.3	42.3	53.2	62.7	75.2	88.9	95.0	97.5	99.0	99.8	100.0	100.0
8554	9.6	16.4	23.1	30.2	48.2	62.9	75.8	85.5	93.6	96.7	98.2	99.0	99.6	99.9	100.0
8555	16.2	27.5	41.4	50.1	57.4	67.9	77.4	82.8	89.7	93.9	96.3	97.8	98.7	99.3	100.0
8555D	15.8	29.0	39.4	47.2	57.1	66.2	75.1	80.6	88.2	93.5	96.4	98.1	99.2	100.0	100.0

Appendix C: Pebble lithology

Table C1. Pebble sample information.

Location	UTM Easting	UTM Northing	Sample #	Clast origin L.Range	Clast origin Carb.
Basal diamicton	355300	5335200	8500	31	81
Basal diamicton	355700	5336400	8502	58	39
Basal diamicton	354900	5334900	8504	26	69
Basal diamicton	363900	5334200	8503	8	111
Basal diamicton	355400	5335500	8505	48	59
Basal diamicton	359700	5339650	8536	62	25
Basal diamicton	355800	5336300	8566	57	57
Basal diamicton	355700	5336500	8520	58	40
Basal diamicton	356400	5337600	8515	52	48
Basal diamicton	358300	5339000	8527	33	65
Diamicton (H. section)	357200	5338300	8516	53	57
Diamicton (H. section)	357400	5338350	8517	63	17
Diamicton (H. section)	357450	5338400	8518	51	56
Diamicton (H. section)	357600	5338500	8523	37	59
Diamicton (H. section)	357600	5338500	8524	48	52
Diamicton (H. section)	357700	5338550	8525	48	48
Diamicton (H. section)	357700	5338550	8526	36	63
Inland	361300	5334500	8508	85	50
Inland	360000	5334200	8510	31	74
Inland	353300	5332500	8513	17	80
Inland	364100	5328800	8543	28	65
Inland	358700	5320500	8530	65	32
Inland	373250	5319700	8529	94	0
Inland	369100	5335350	8535A	31	69
Inland	361800	5320850	8531	78	22
Inland	361900	5319850	8532	20	9
Inland	377050	5323900	8535	93	0
Inland	373500	5326450	8534	6	94
Inland	368700	5322550	8539	24	72
Inland	364550	5330600	8542	4	101
Inland	360300	5327400	8545	109	1
Inland	356200	5324250	8548	3	96
Inland	357400	5324050	8549	53	48
Inland	357200	5324000	8550	17	79
Inland	356700	5324200	8555	0	99
Inland	354250	5325050	8551	0	100
Inland	351950	5323350	8553	1	99

Table C2a. Proportion of Long Range and Carboniferous rock types in Highlands section diamicton.

	Long Range				Carboniferous			
Sample #	Granite/Granodiorite	Gabbro/Diorite	Gneiss	Total	Siltstone	Sandstone	Total	Total sample
8516	13	39	1	**53**	27	30	**57**	**110**
8517	20	43		**63**	13	4	**17**	**80**
8518	24	27		**51**	28	28	**56**	**107**
8523	10	26	1	**37**	16	43	**59**	**96**
8524	22	26		**48**	11	41	**52**	**100**
8525	23	24	1	**48**	9	39	**48**	**96**
8526	14	22		**36**	25	38	**63**	**99**
Total	126	207	3	336	129	223	352	**688**

Total Long Range	336
Prop. Long Range	0.49
Total Carboniferous.	352
Prop. Carboniferous	0.51

Table C2b. Proportion of Long Range and Carboniferous rock types in basal diamicton

	Long Range				Carboniferous			
Sample #	Granite/Granodiorite	Gabbro/Diorite	Gneiss	Total	Siltstone	Sandstone	Total	Total sample
8500	11	18	2	**31**	8	49	**81**	**112**
8502	27	31		**58**	9	17	**39**	**97**
8504	15	11		**26**	11	39	**69**	**95**
8503	9	39		**48**	6	28	**59**	**107**
8505	23	34		**57**	2	29	**57**	**114**
8536	20	38		**58**	5	17	**40**	**98**
8566	27	23		**50**	4	20	**46**	**96**
8520	18	34		**52**	4	25	**48**	**100**
8515	10	22	1	**33**	9	27	**65**	**98**
8527	23	35	1	**59**	4	12	**39**	**98**
Total	183	285	4	472	62	263	543	**1015**

Total Long Range	472
Prop. Long Range	0.47
Total Carboniferous.	543
Prop. Carboniferous.	0.53

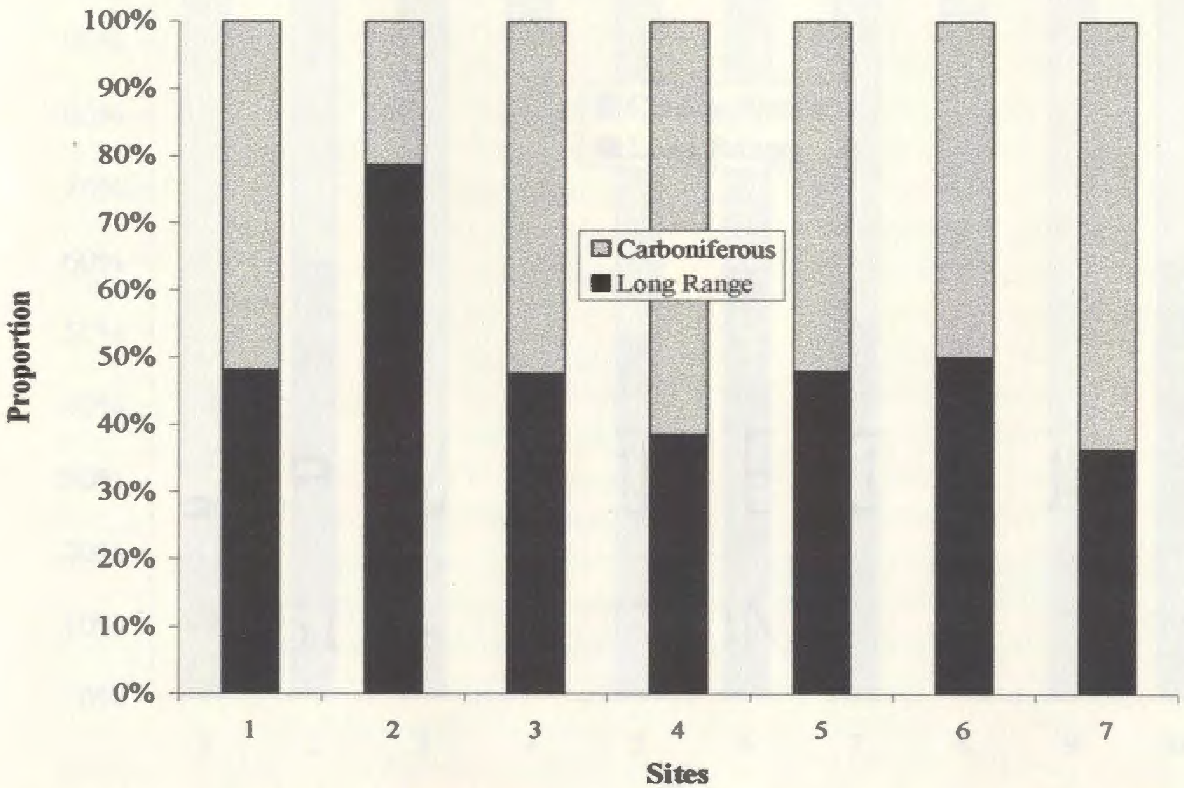


Figure C.1 Proportion of Long Range and Carboniferous rock types from upper diamicton in Highlands section (south to north).

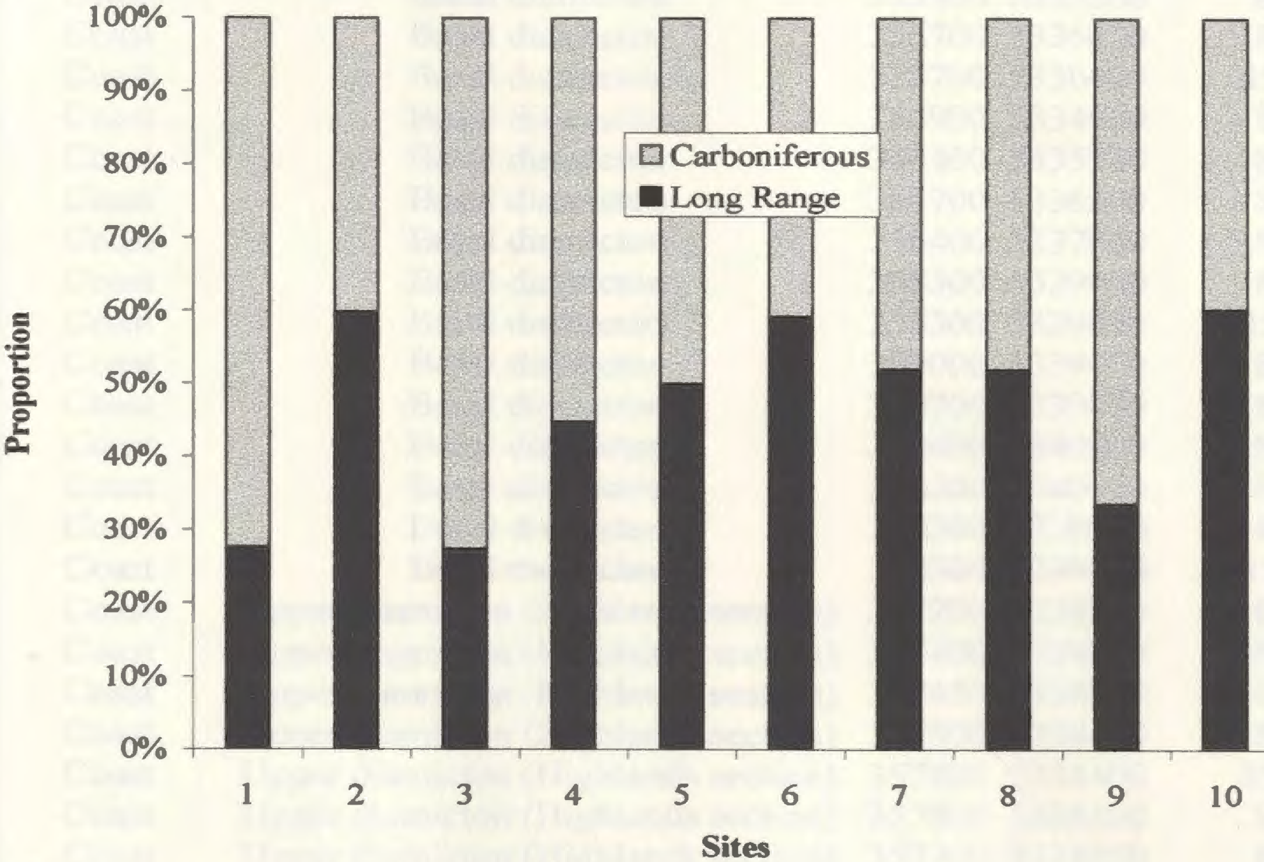


Figure C.2 Proportion of Long Range and Carboniferous rock types from basal diamicton (south to north).

Appendix D: Diamicton geochemistry data.

Table D1. Geochemistry sample data. Sample numbers ending in "D" are duplicates.

Location	Material	UTM		Sample #
		Easting	Northing	
Coast	Basal diamicton	355300	5335200	8500
Coast	Basal diamicton	355700	5336400	8502
Coast	Basal diamicton	355700	5336400	8502D
Coast	Basal diamicton	354900	5334900	8504
Coast	Basal diamicton	355400	5335500	8505
Coast	Basal diamicton	355700	5336500	8520
Coast	Basal diamicton	356400	5337600	8515
Coast	Basal diamicton	358300	5339000	8527
Coast	Basal diamicton	358300	5339000	8527D
Coast	Basal diamicton	359000	5339400	8528
Coast	Basal diamicton	359700	5339650	8536
Coast	Basal diamicton	360400	5340800	8538
Coast	Basal diamicton	360500	5340000	8541
Coast	Basal diamicton	358300	5339000	8527
Coast	Basal diamicton	358300	5339000	8527D
Coast	Upper diamicton (Highlands section)	357200	5338300	8516
Coast	Upper diamicton (Highlands section)	357400	5338350	8517
Coast	Upper diamicton (Highlands section)	357450	5338400	8518
Coast	Upper diamicton (Highlands section)	357800	5338400	8523
Coast	Upper diamicton (Highlands section)	357800	5338400	8523D
Coast	Upper diamicton (Highlands section)	357800	5338400	8524
Coast	Upper diamicton (Highlands section)	357700	5338550	8525
Coast	Upper diamicton (Highlands section)	357700	5338550	8526
Coast	Upper diamicton (Highlands section)	357700	5338550	8526D

Table D2a. Trace element concentration in Highlands section diamicton. Concentrations are in ppm, unless otherwise stated.

Sample #	8516	8517	8518	8523	8523D	8524	8525	8526	8526D
Elem./Conc.									
Mo	-1.00	1.19	-1.00	1.50	-1.00	1.01	-1.00	1.27	1.30
Cr	110.34	119.10	113.59	117.43	115.53	110.94	114.48	116.84	121.35
P	1113.00	974.58	934.85	1003.71	983.62	1013.62	946.94	935.84	913.59
Zn	84.56	89.63	77.21	93.02	85.44	86.16	103.27	87.58	86.98
Pb	12.12	12.25	9.90	10.65	10.12	10.53	11.19	10.72	12.18
Co	22.60	21.96	18.62	21.27	21.77	20.00	20.23	19.94	20.88
Ni	60.12	57.90	58.12	64.57	62.42	58.37	64.42	60.85	61.17
Fe/%	5.09	4.79	4.51	5.15	4.94	4.84	4.95	5.18	5.14
Mg/%	1.65	2.10	2.10	1.79	1.71	1.84	1.79	1.78	1.80
Ti	6638.53	6169.13	5636.06	6450.17	6359.53	6208.61	6029.76	6262.03	6246.31
V	137.97	155.24	127.42	143.92	138.07	136.65	135.03	143.38	140.39
Be	1.70	1.76	1.68	1.82	1.73	1.73	1.76	1.80	1.79
Ca/%	1.20	1.77	2.92	1.08	1.08	1.41	0.95	1.06	1.04
Nb	13.98	13.35	12.60	13.60	14.22	12.26	12.81	13.30	12.74
Cu	46.65	44.12	33.40	49.31	46.41	41.55	49.76	51.58	58.25
Na/%	1.18	0.90	0.95	1.05	1.01	1.05	1.00	1.01	1.02
Zr	114.50	98.05	100.75	100.92	103.00	104.54	96.14	97.81	97.25
Dy	6.97	6.41	5.07	6.66	6.62	6.15	6.14	6.65	6.98
Sc	18.93	19.47	16.34	18.98	18.58	18.04	18.34	19.18	19.76
Y	37.63	34.66	28.33	37.73	37.13	33.47	34.67	38.91	40.17
Al/%	7.09	7.15	6.79	7.57	7.22	7.19	7.20	7.40	7.47
Mn	1163.63	872.47	831.19	1054.55	1101.68	1020.43	969.46	933.86	945.10
Sr	175.39	172.82	169.46	170.2[illegible]	167.99	176.83	161.43	155.79	158.21
La	70.80	64.30	52.00	61.45	62.61	59.40	56.85	64.99	67.63
Ce	113.53	109.62	88.29	97.66	100.94	98.29	89.04	99.07	103.78
Ba	689.32	633.78	611.93	723.82	670.91	616.14	655.73	688.23	668.19
Li	31.04	35.54	39.59	36.08	33.56	36.22	36.43	33.70	33.79
K/%	2.08	2.18	2.19	2.25	2.13	2.21	2.25	2.10	2.09

Table D2b. Trace element concentration in basal diamicton. Concentrations are in ppm, unless otherwise stated.

Sample # Elem./Conc.	8500	8502	8502D	8504	8505	8520	8515	8527	8527D	8528	8536	8538	8541	8577	8577D
Mo	1.50	1.24	1.27	1.47	1.32	1.14	1.73	1.68	1.61	1.60	1.60	1.88	1.17	1.62	1.40
Cr	104.03	112.04	109.34	118.75	108.74	120.25	111.54	105.43	103.79	114.58	113.40	116.84	105.10	94.42	91.17
P	898.50	934.20	1012.64	765.10	906.60	989.90	933.00	933.36	942.58	798.41	932.67	971.12	1020.88	1197.00	1298.51
Zn	68.83	85.65	77.76	68.07	73.42	95.73	83.09	86.77	82.56	77.04	84.60	85.47	90.01	70.52	66.61
Pb	8.30	10.08	11.30	9.35	9.16	10.41	11.07	9.38	10.35	11.04	9.70	9.57	16.40	11.30	9.78
Co	17.27	21.83	23.23	17.78	18.13	26.81	20.43	20.71	20.28	19.08	20.88	22.81	23.30	19.15	19.21
Ni	51.34	59.99	55.90	57.92	53.22	66.91	58.07	55.74	54.04	59.48	59.44	62.34	56.04	44.82	43.13
Fe/%	4.02	4.89	4.85	3.88	4.30	5.28	4.64	4.68	4.54	4.34	4.72	4.76	4.92	4.34	4.22
Mg/%	1.94	2.07	1.96	2.11	1.97	1.99	2.18	2.20	2.13	2.39	2.12	2.18	1.77	1.82	1.76
Ti	5343.09	5831.81	6162.04	4762.02	5544.19	6479.52	5771.01	5669.74	5601.43	5223.78	5569.87	5775.43	5977.80	5934.41	6002.87
V	109.61	136.47	131.30	103.72	119.96	147.02	134.34	131.39	128.48	124.39	136.24	139.14	149.42	133.69	136.89
Be	1.48	1.69	1.53	1.56	1.52	1.72	1.75	1.68	1.63	1.71	11.69	1.75	2.10	1.72	1.69
Ca/%	3.59	2.92	2.97	3.41	3.41	2.78	3.22	3.61	3.56	3.14	3.33	3.22	1.21	3.27	3.20
Nb	13.06	13.21	13.74	11.15	13.01	15.33	14.36	13.90	13.14	12.01	12.41	13.50	13.68	13.79	13.79
Cu	24.65	37.56	35.77	23.81	28.53	54.42	31.65	35.47	32.53	25.77	32.53	36.17	64.98	29.75	27.76
Na/%	1.16	1.11	1.06	0.90	1.12	1.05	1.02	1.05	1.02	0.91	0.91	1.14	1.11	1.35	1.41
Zr	95.68	88.09	93.18	100.22	89.19	88.03	92.93	91.80	87.45	94.21	91.24	90.62	102.73	101.99	98.71
Dy	5.26	5.65	5.53	4.73	5.31	5.96	5.45	5.48	5.14	4.66	4.98	5.28	6.43	5.17	5.21
Sc	15.15	17.51	29.32	14.55	15.77	18.72	16.92	16.91	16.55	15.68	16.88	17.33	19.81	16.91	17.31
Y	28.37	29.35	17.02	25.80	28.41	31.40	28.98	29.63	28.65	25.91	28.67	29.55	33.08	30.01	29.40
Al/%	6.24	6.97	29.32	6.28	6.55	7.29	6.98	7.02	6.93	6.90	7.07	7.01	7.85	6.66	6.65
Mn	964.48	1023.04	6.74	932.45	1024.41	1184.77	930.23	895.22	880.63	775.38	946.19	975.78	588.47	853.53	821.75
Sr	197.92	189.35	1124.93	150.01	188.36	182.21	191.22	200.59	198.89	166.53	179.55	184.75	209.49	252.02	259.38
La	52.02	59.75	184.15	42.70	55.04	67.33	54.60	54.15	52.79	45.01	52.31	50.70	69.05	50.81	49.32
Ce	87.55	102.09	52.50	72.12	91.69	113.93	91.84	90.03	89.34	76.31	88.44	86.19	117.28	87.03	87.10
Ba	617.53	631.04	89.88	750.76	650.73	694.61	594.35	692.22	664.36	623.13	594.41	627.79	698.66	596.87	586.84
Li	33.28	35.17	595.58	42.25	34.47	33.94	37.15	37.34	35.43	43.81	37.30	38.36	33.75	26.97	24.24
K/%	2.03	2.11	89.88	2.31	2.08	2.05	2.19	2.17	2.11	2.31	2.11	2.10	2.24	1.87	1.82

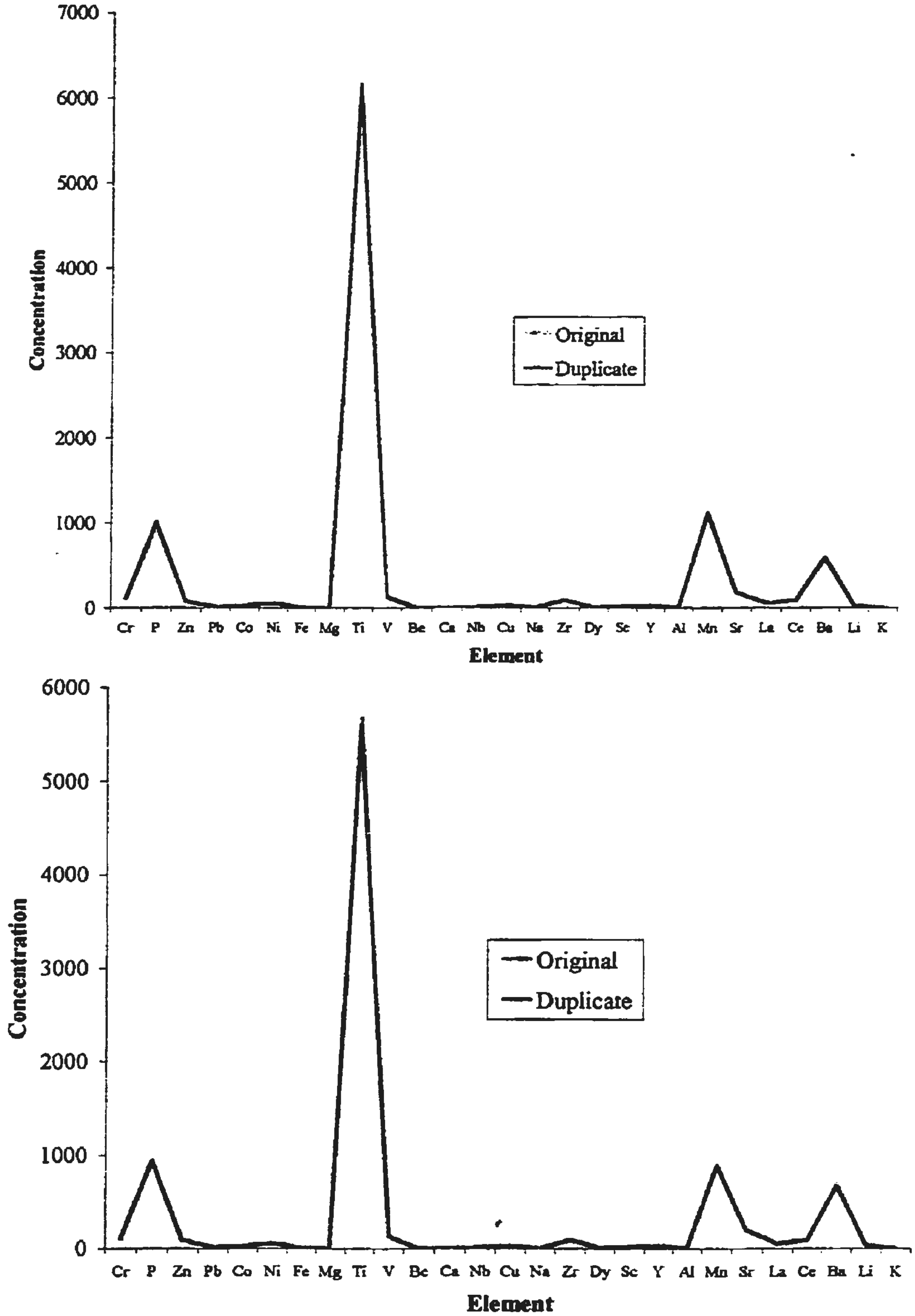


Figure D.1 Comparison of original and duplicate (separate) from two basal diamicton samples.

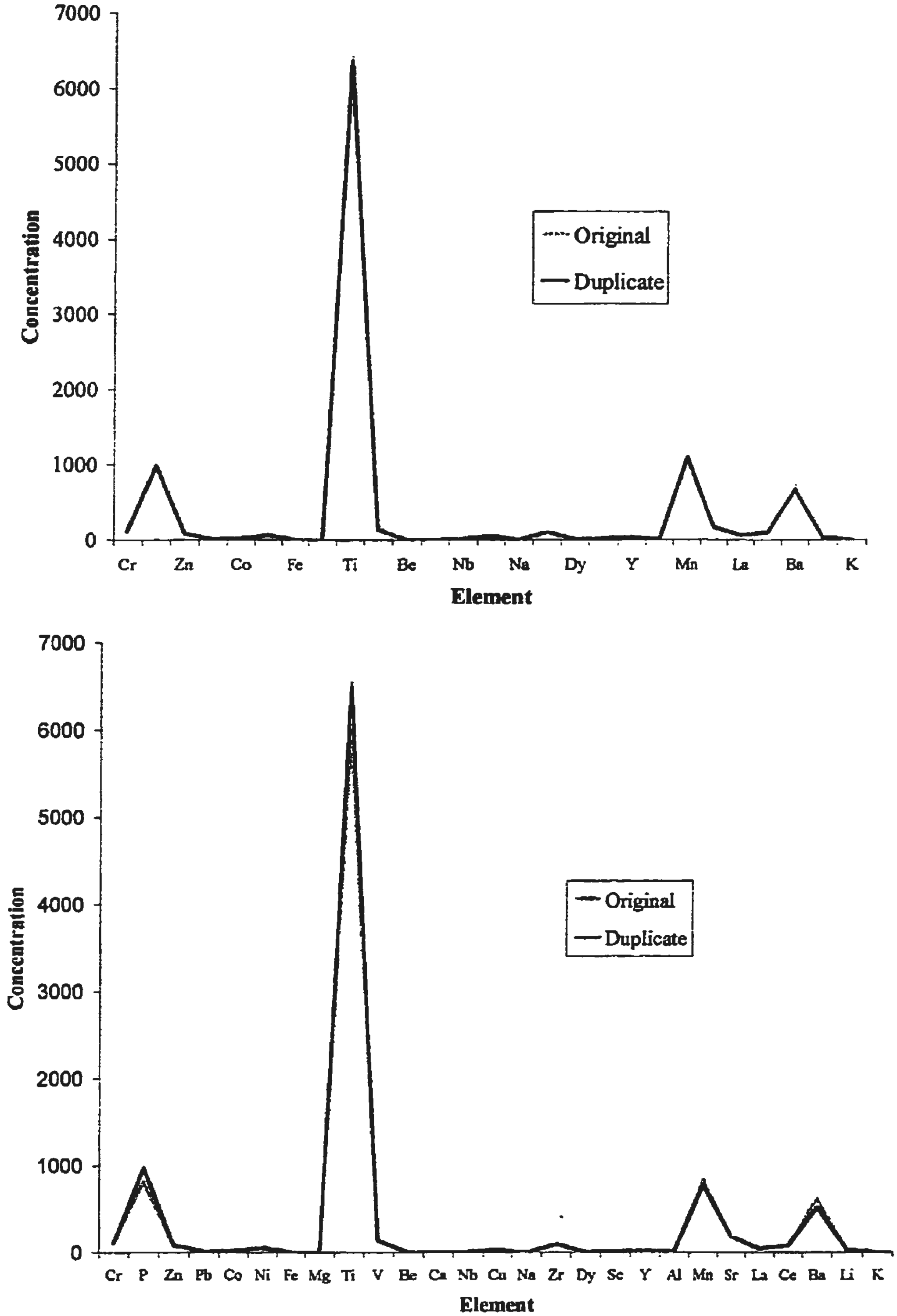


Figure D.2 Comparison of original and duplicate (separate) in upper diamicton samples.

Appendix E – Individual site section logs

Key

<u>Unit contacts</u>

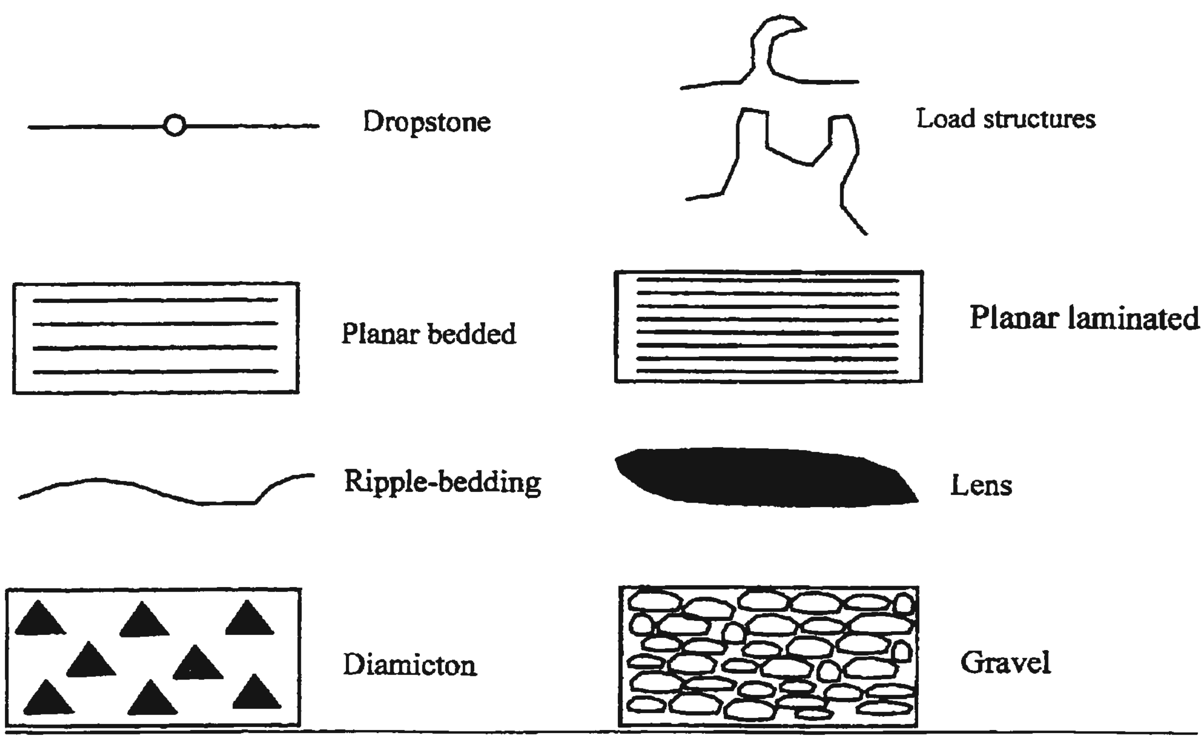
S – sharp

G – gradational

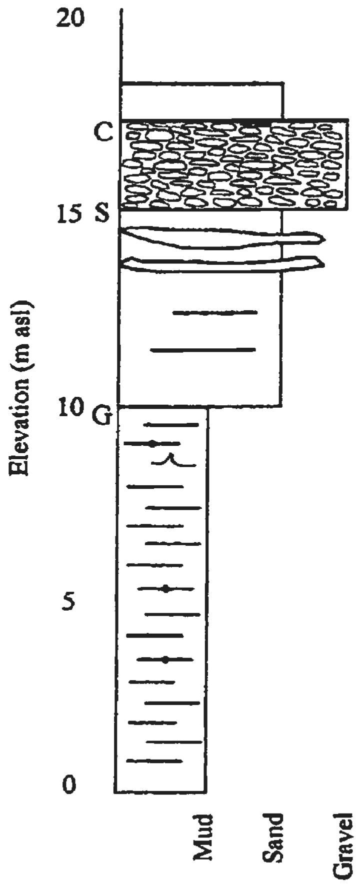
C – conformable

<u>Miscellaneous</u>

F – shell fossil

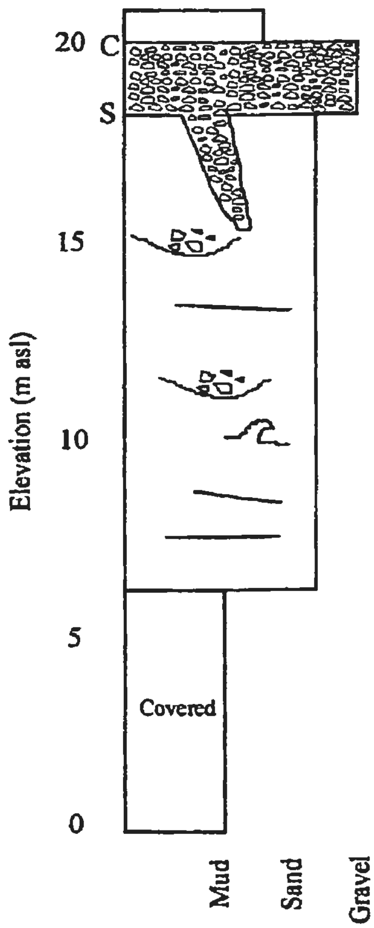


Type A sections



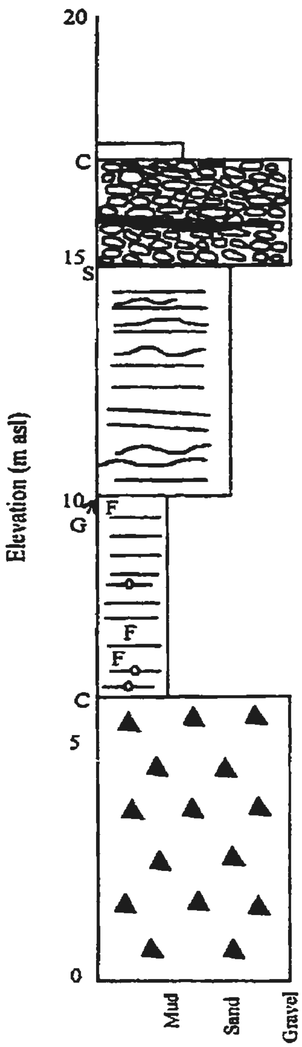
Unit	Description	Interpretation
5	Well sorted fine sand and silt	Aeolian - loess
4	Clast-supported, planar-bedded pebble-cobble gravel	Glaciofluvial/fluvial outwash
3	Planar-interbedded fine to medium sand, silt and gravelly sand	Underflow deposits in subaqueous environment; silt deposited by suspension settling; gravelly sand near top of unit may be fluvial in origin in shallowing marine environment
2	Structureless to planar laminated clay, silt, and sand; rare pebbles and localized disturbed bedding (fluid escape structures)	Suspension settling from meltwater plumes and ice-rafting; disturbed beds resulted from clasts protruding into saturated sediments and/or bioturbation

Figure E.1 French Brook South



Unit	Description	Interpretation
5	Well sorted fine sand and silt	Aeolian - loess
4	Clast-supported, planar-bedded pebble-cobble gravel; wedge dips ~2 m into underlying unit.	Glaciofluvial/fluvial outwash; wedge represents ice cast.
3	Planar-interbedded sand and gravelly sand. Minor scour-and-fill structures and fluid escape structures noted	Underflows in subaqueous environment; scour-and-fills indicate channelized flow; fluid escape structures indicate rapid deposition overlying saturated sedments

Figure E.2 Butter Brook South



Unit	Description	Interpretation
5	Well sorted fine sand and silt	Aeolian (loess)
4	Planar-interbedded pebble-cobble gravel and fine to medium sand	Glaciofluvial/fluvial outwash
3	Moderate to well sorted planar and ripple-bedded fine to medium sand; some subhorizontal beds; rare clasts in some beds	Deposited by suspension settling (overflow) and underflow currents; clasts deposited as outrunners
2	Planar-laminated to structureless silt, clay, and fine sand; pebbles common near lower contact within laminated sediments	Suspension settling from overflow plumes interspersed with ice-rafting (pebbles)
1	Structureless diamicton; matrix-supported; clasts dispersed throughout; well-oriented clast fabrics (n=4)	Subglacial till deposited during deglaciation of present coastline

Figure E.3 Butter Brook

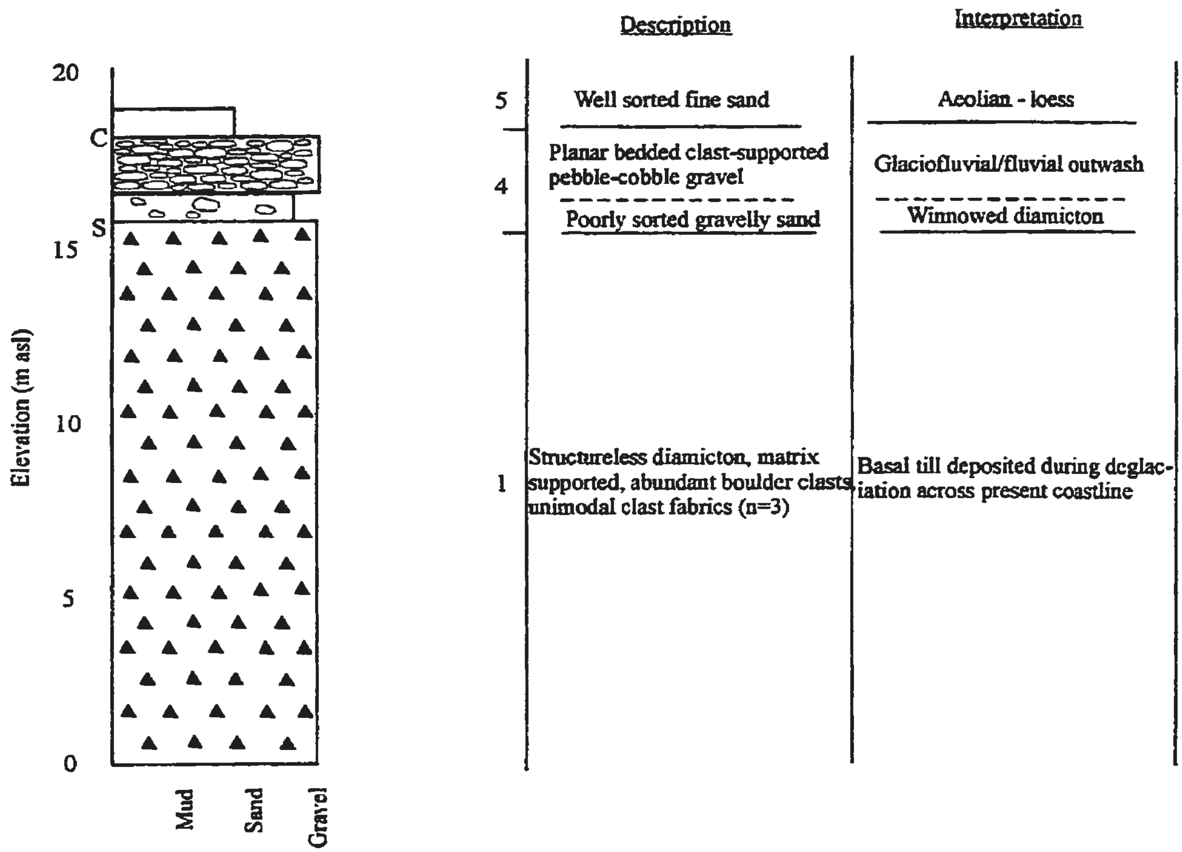


Figure E.4 Butter Brook 2

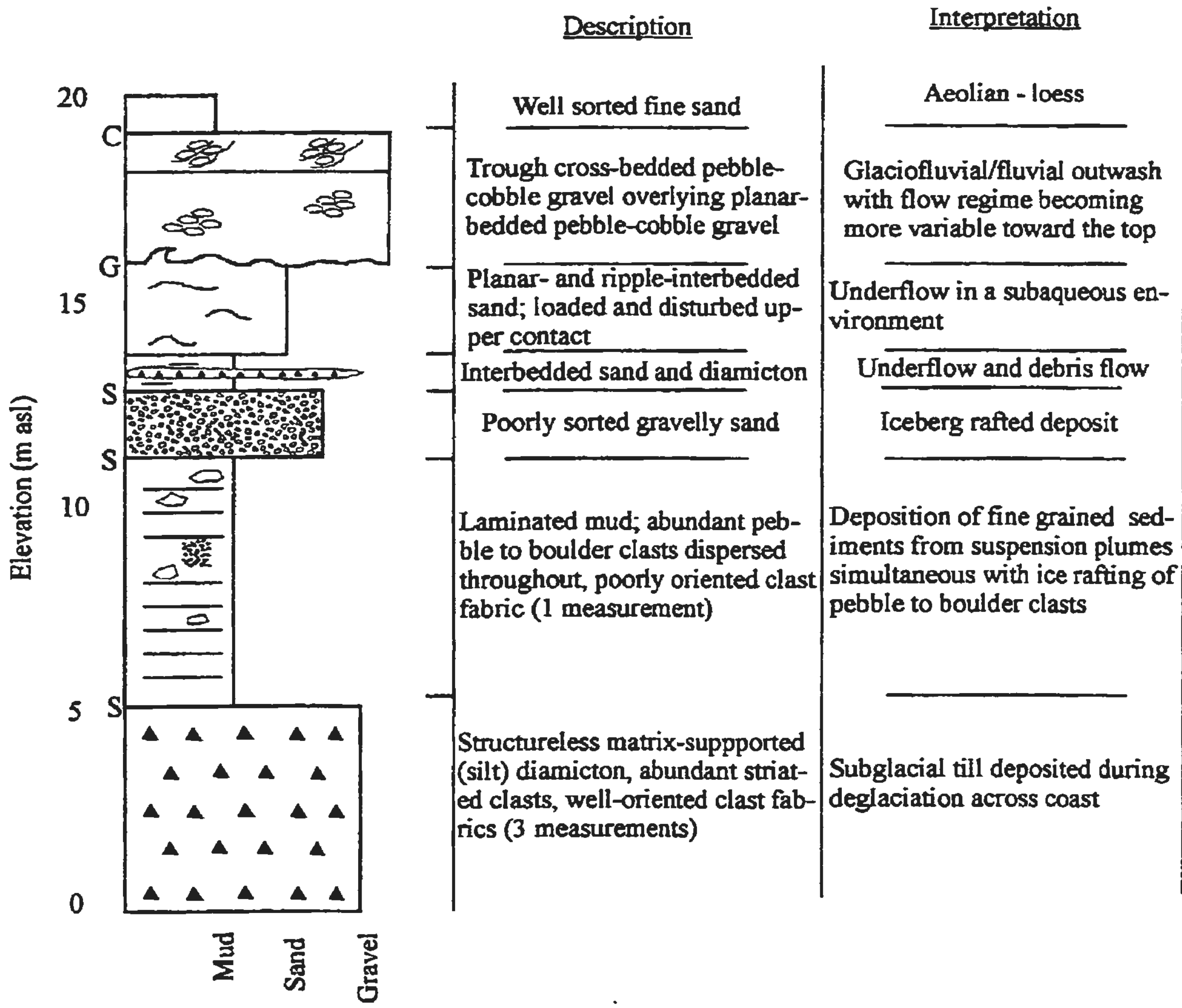


Figure E.5 Butter Brook North

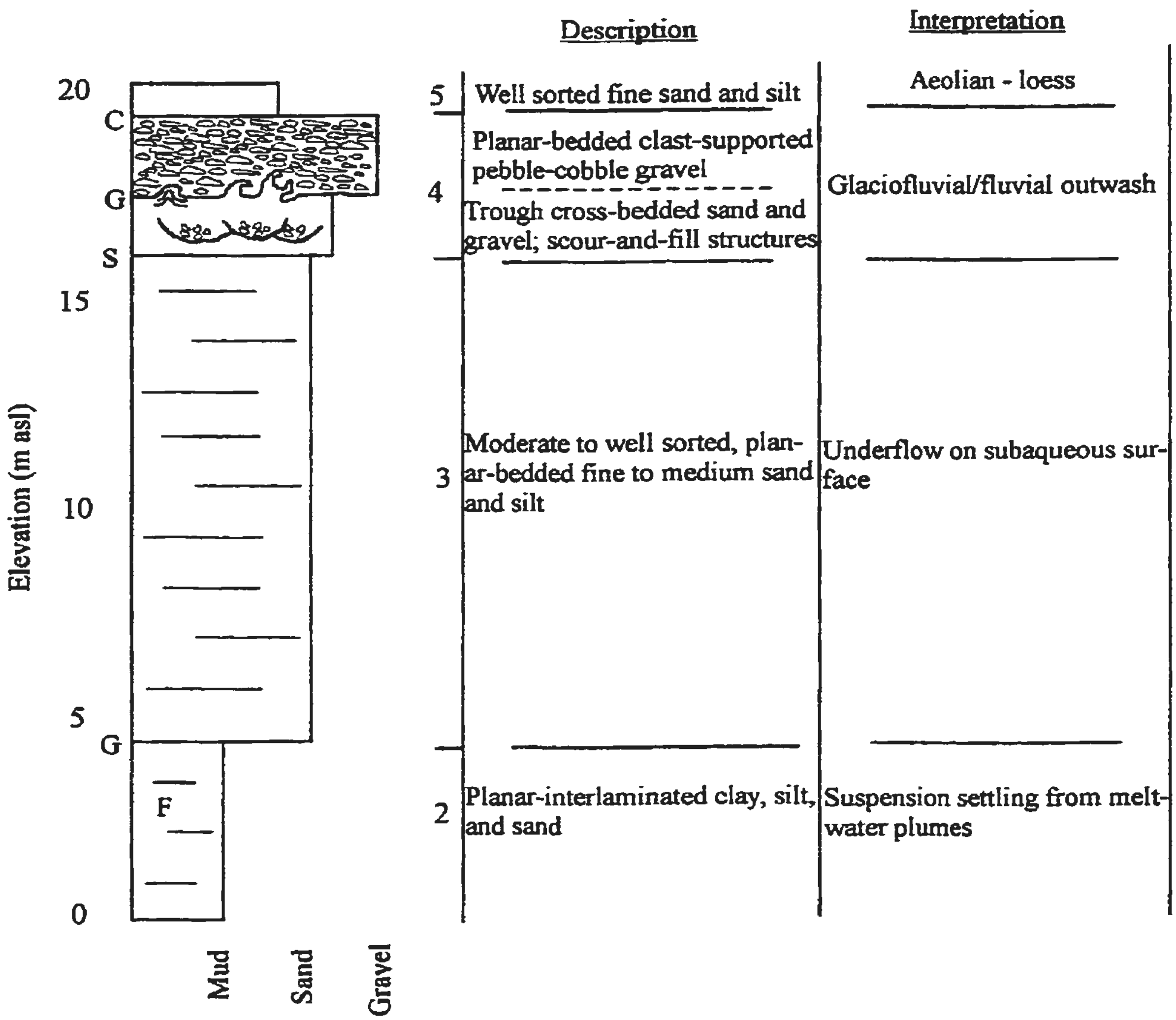
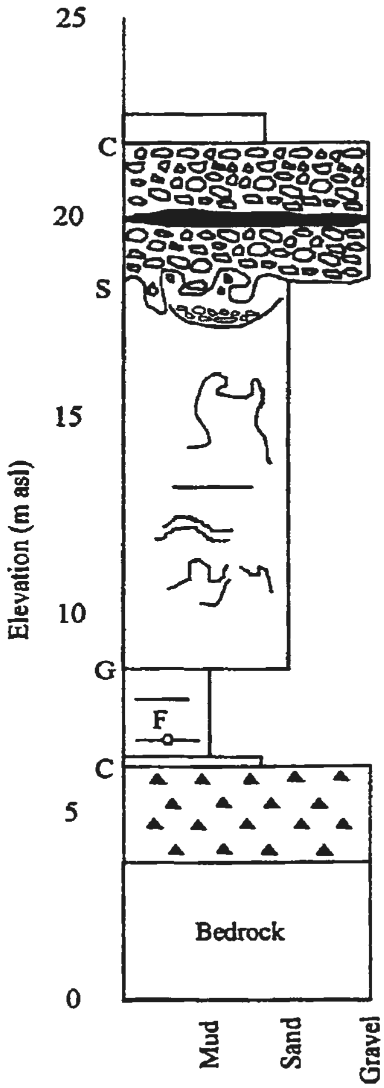


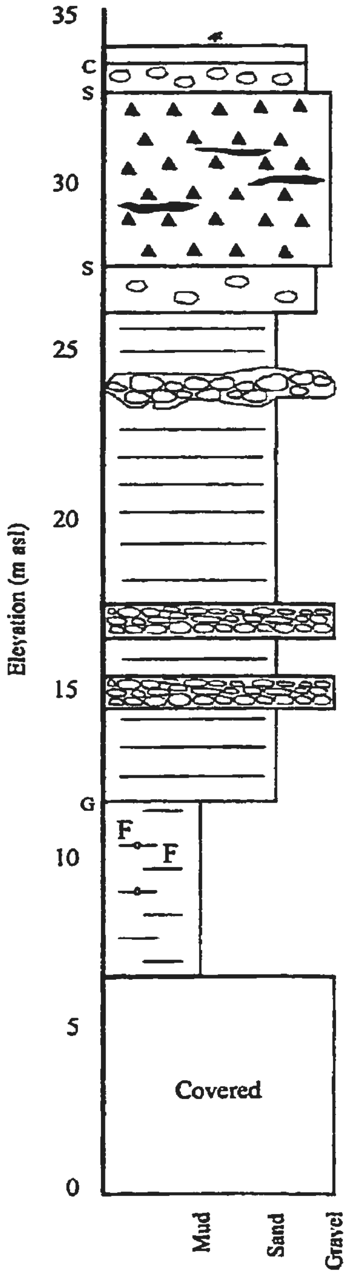
Figure E.6 Highlands



Unit	Description	Interpretation
5	Very fine sand and silt	Aeolian (loess)
4	Planar-interbedded pebble-cobble gravel, sand, and gravelly sand	Glaciofluvial/fluvial outwash
3	Planar and ripple bedded fine to medium sand with dislocated and disturbed bedding	Depostion by suspension settling and underflow currents. Disturbed bedding due to loading of saturated sediments during deposition of overlying sediments
2	Planar laminated mud overlying thin bed of fine sand and silt	Suspension settling from overflow plumes and ice-rafting
1	Structureless diamicton. Matrix supported (silty to silty-sand); Abundant striated clasts	Subglacial till deposited during deglaciation

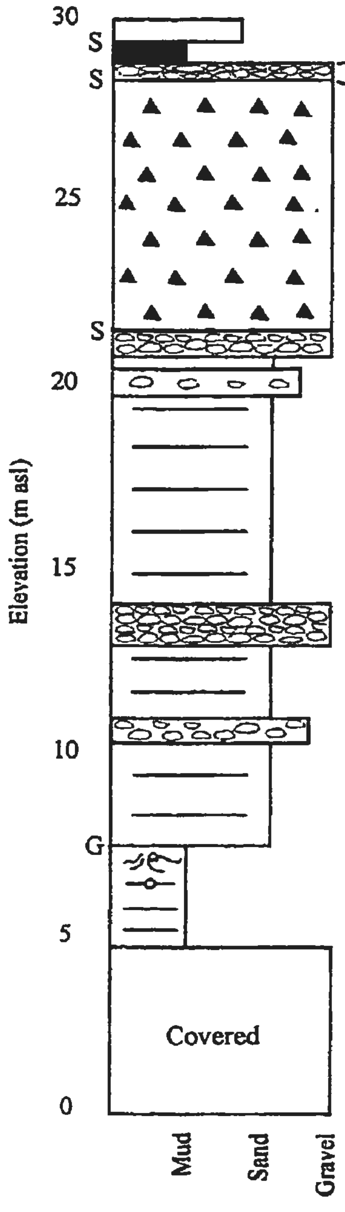
Figure E.7 McLellans Brook North

Type B sections (Highlands section)



Unit	Description	Interpretation
5	Well sorted fine sand	Aeolian - loess
4	Poorly sorted gravelly sand	Glaciofluvial outwash
3	Matrix-supported diamicton containing discontinuous fine sand lenses; sorting of coarse sand beneath clasts; poorly oriented clast fabrics (n=2)	Subaqueous debris flow of glacigenic sediment in ice-proximal environment; lenses and sorting by bottom traction currents
2	Planar-interbedded sand and gravelly sand; clast-supported gravel lens; some sand beds contain pebbles	Underflow currents in subaqueous environment; pebbles in sand beds deposited as outrunner on subaqueous surface; gravel lens deposited by debris flow
1	Planar-laminted silt, clay, and sand; loaded and disturbed in some places; rare pebbles within laminae	Suspension settling from meltwater plumes and ice-rafting; disturbed bedding resulted from rapid deposition of overlying sediments

Figure E.8 H arbour Head



Unit	Description	Interpretation
5	Well sorted fine sand and silt	Aeolian - loess
	Peat	
4	Open-work, clast-supported bouldery gravel	Glaciofluvial/fluvial winnowing of diamicton
3	Structureless, matrix-supported (silty) diamicton; spread unimodal clast fabrics (n=2)	Subglacial till; fabrics indicate some post-depositional modification by debris flow
	Planar-interbedded gravel, sand, and gravelly sand; pinches out over 4 m laterally	Underflow currents with variable flow strengths; migrating current on surface
2	Planar-interbedded sand and gravelly sand; some gravel lenses noted	Continuous deposition via underflow; clasts in some beds (gravelly sand) deposited as outrunners; gravel lenses deposited by debris flow
1	Planar-interlaminated clay, silt, and sand; clasts in some laminae; some disturbed bedding near top	Suspension settling from meltwater plumes; clasts deposited by ice-rafting; rapid sedimentation of Unit 2 caused disturbed bedding

Figure E.9 Harbour Head North 1

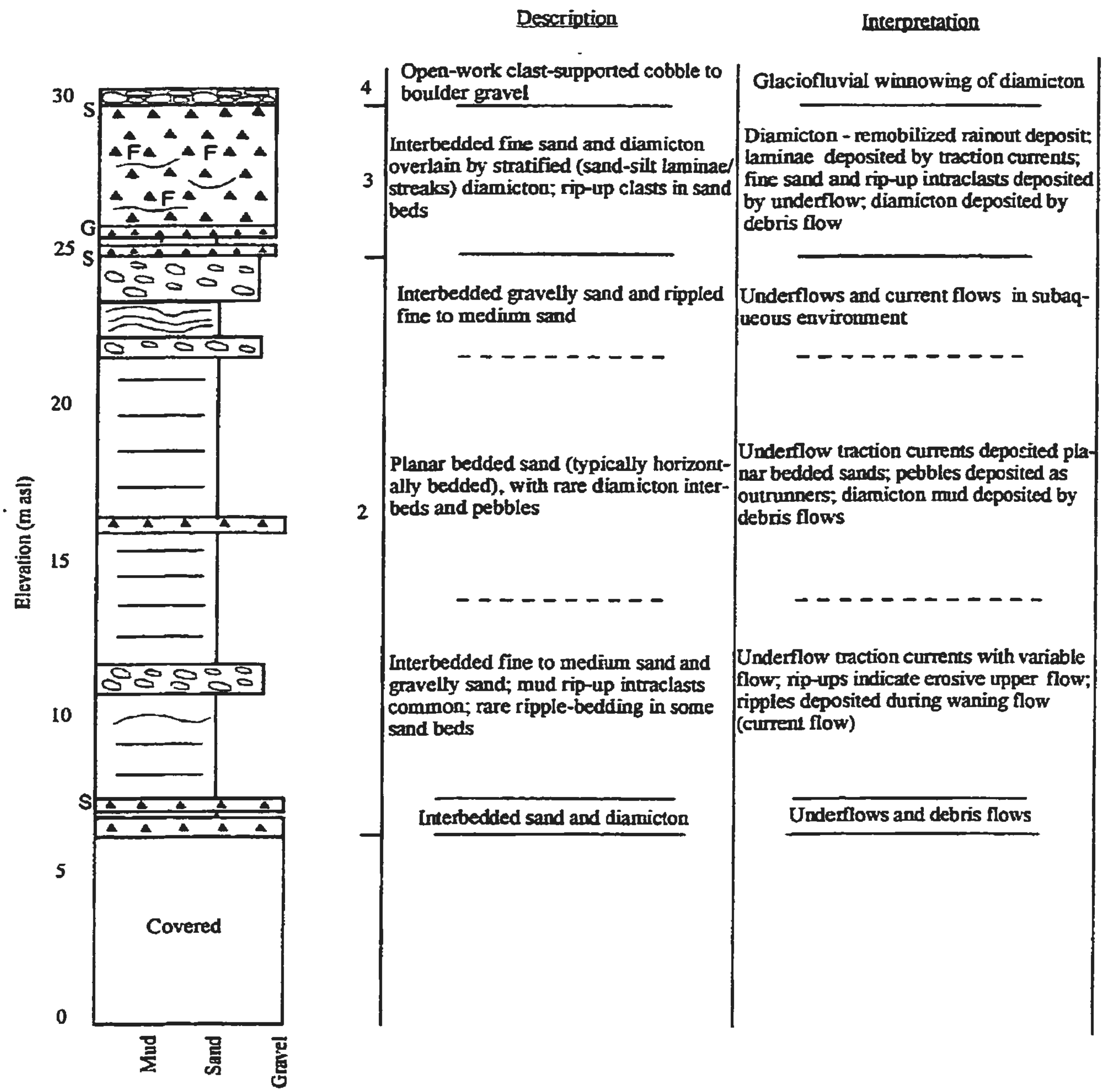


Figure E.10 Harbour Head North 2

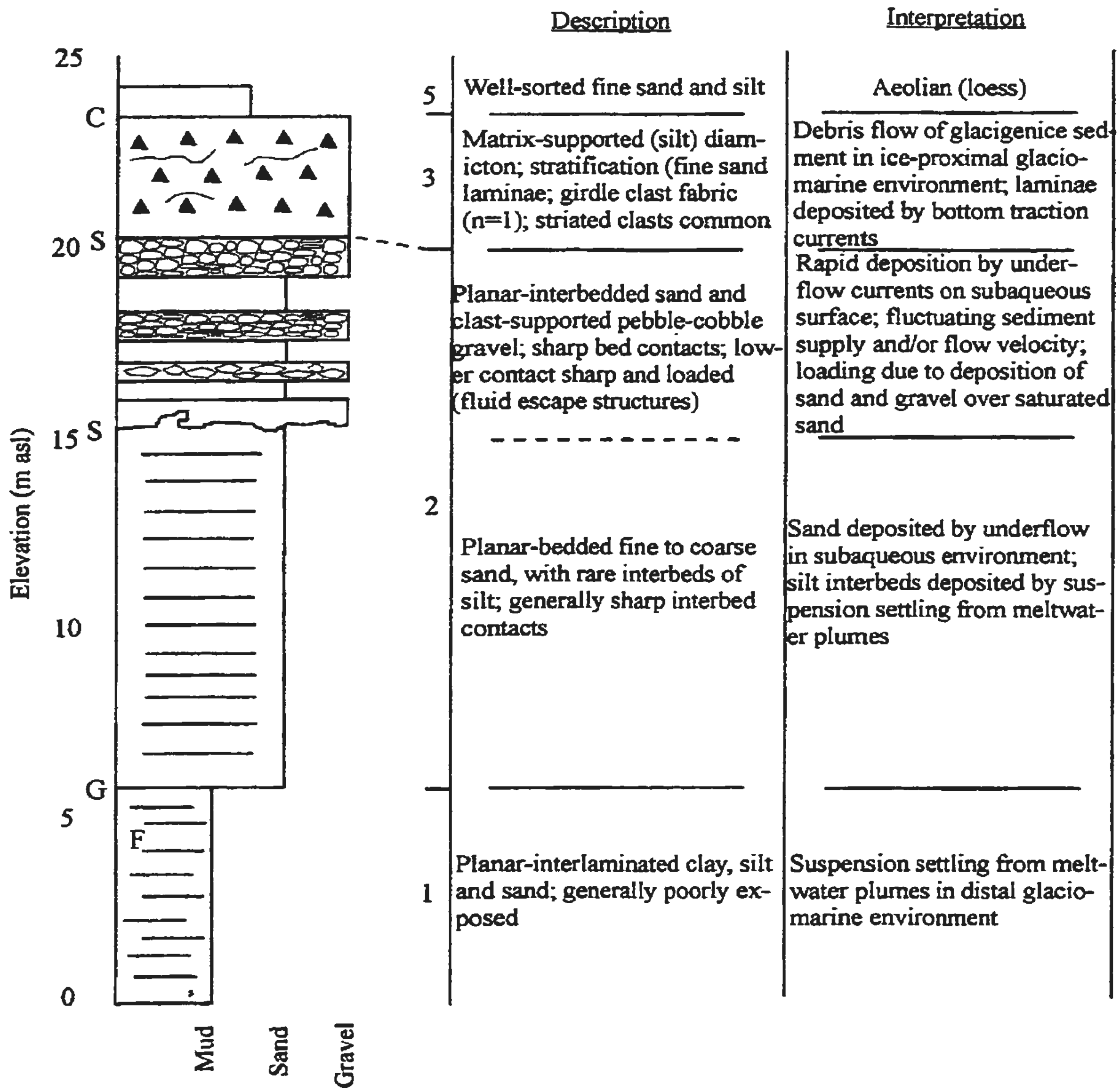


Figure E.11 McLellans Brook South 1

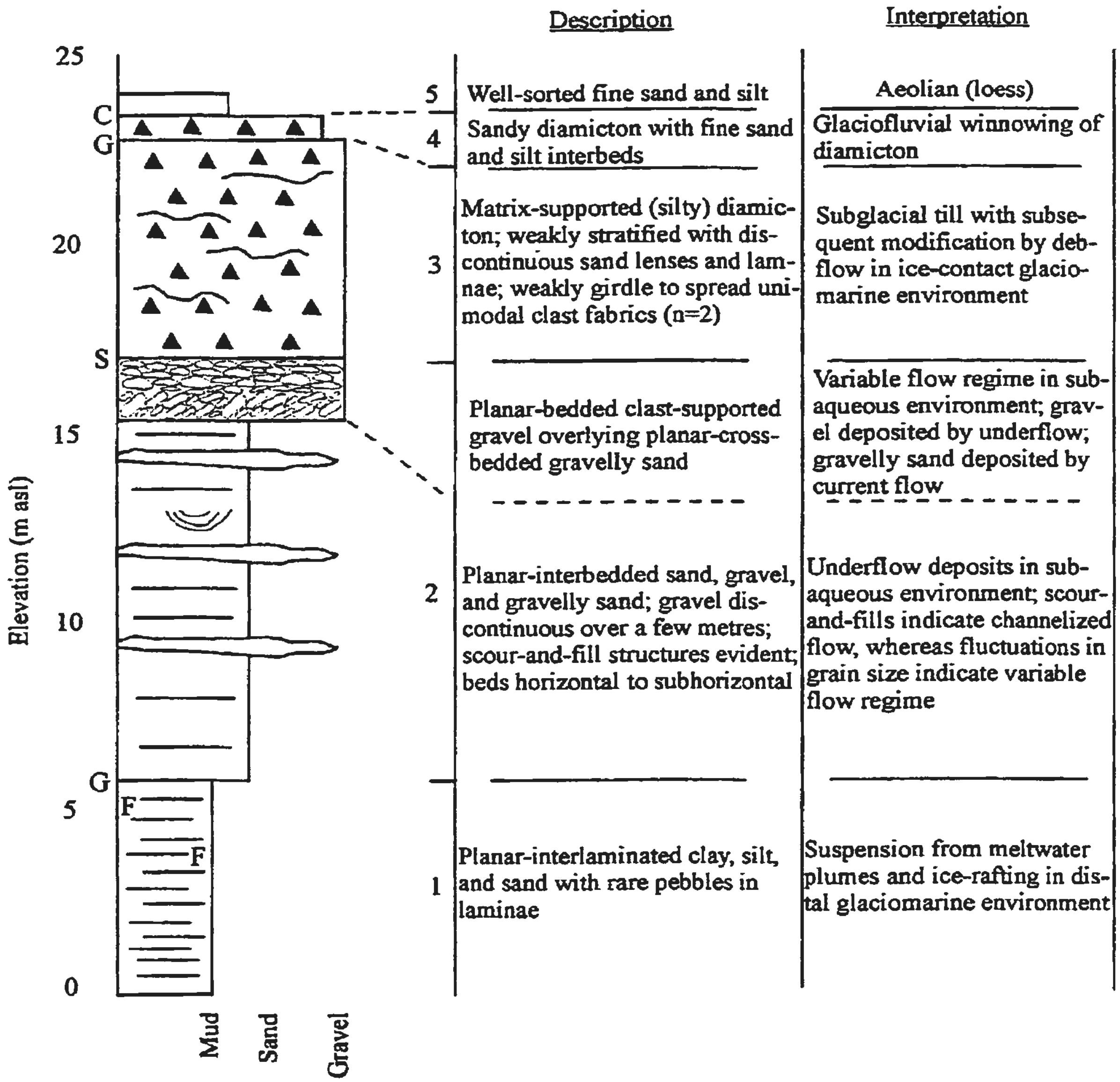


Figure E.12 McLellans Brook South 2

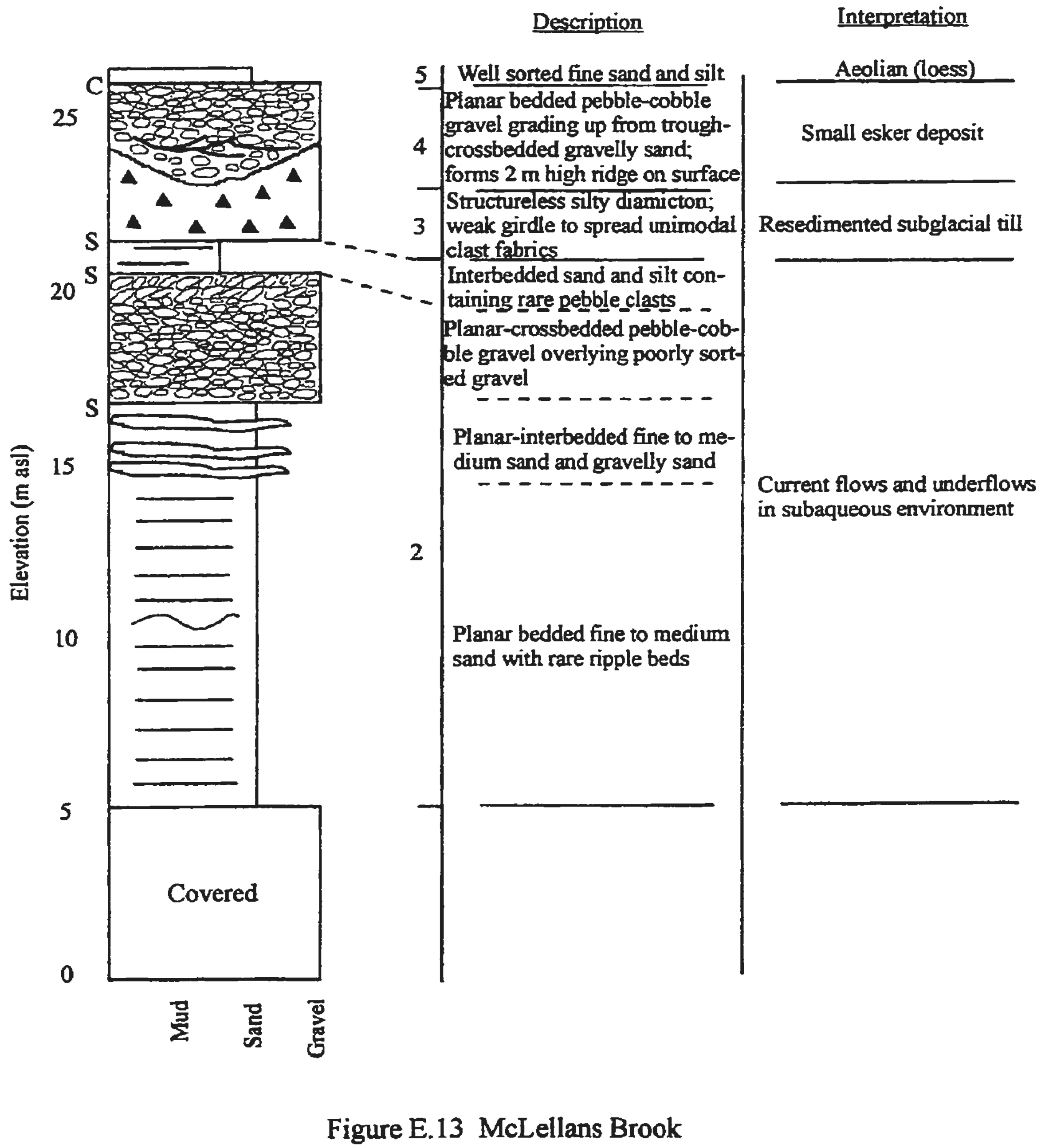
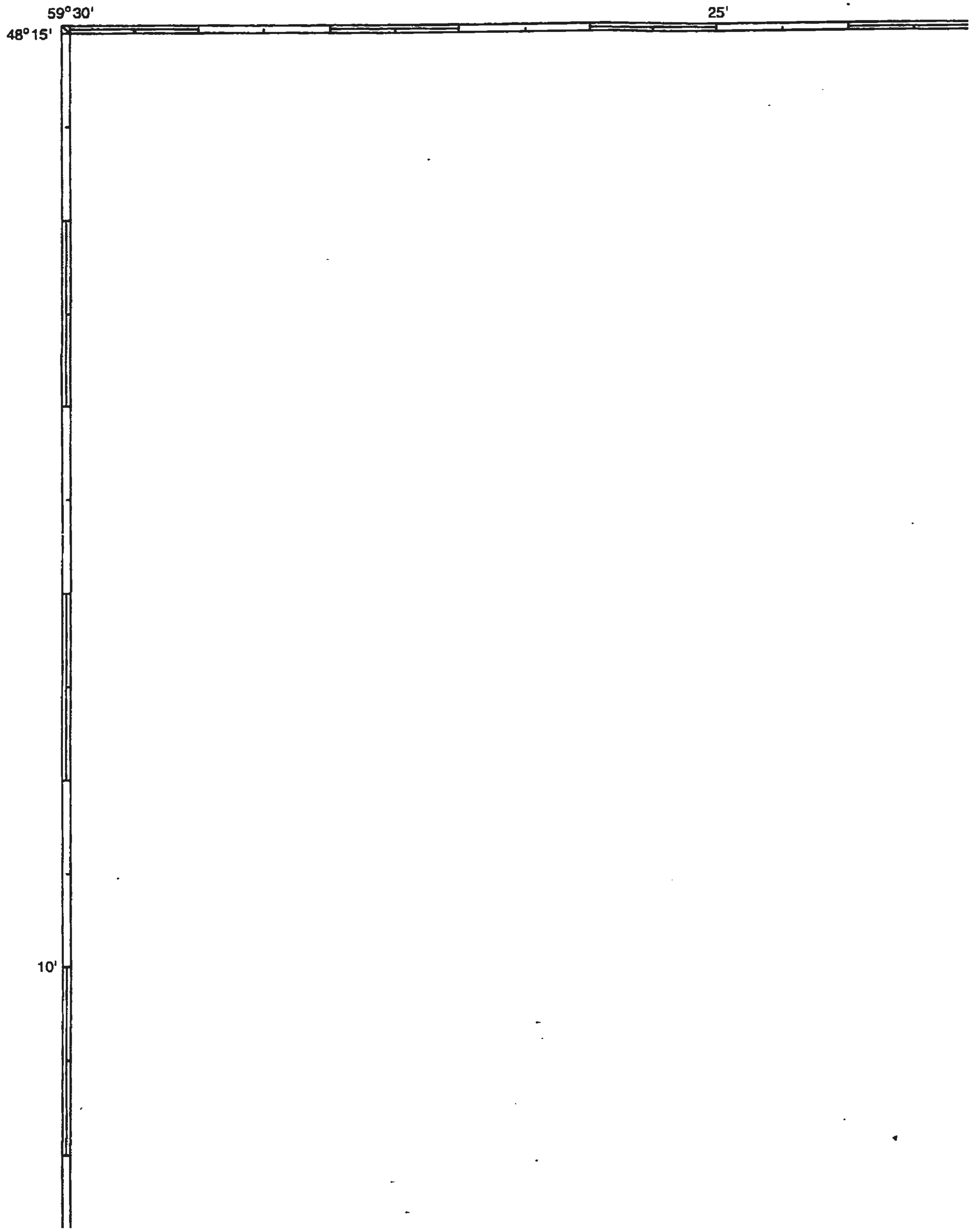


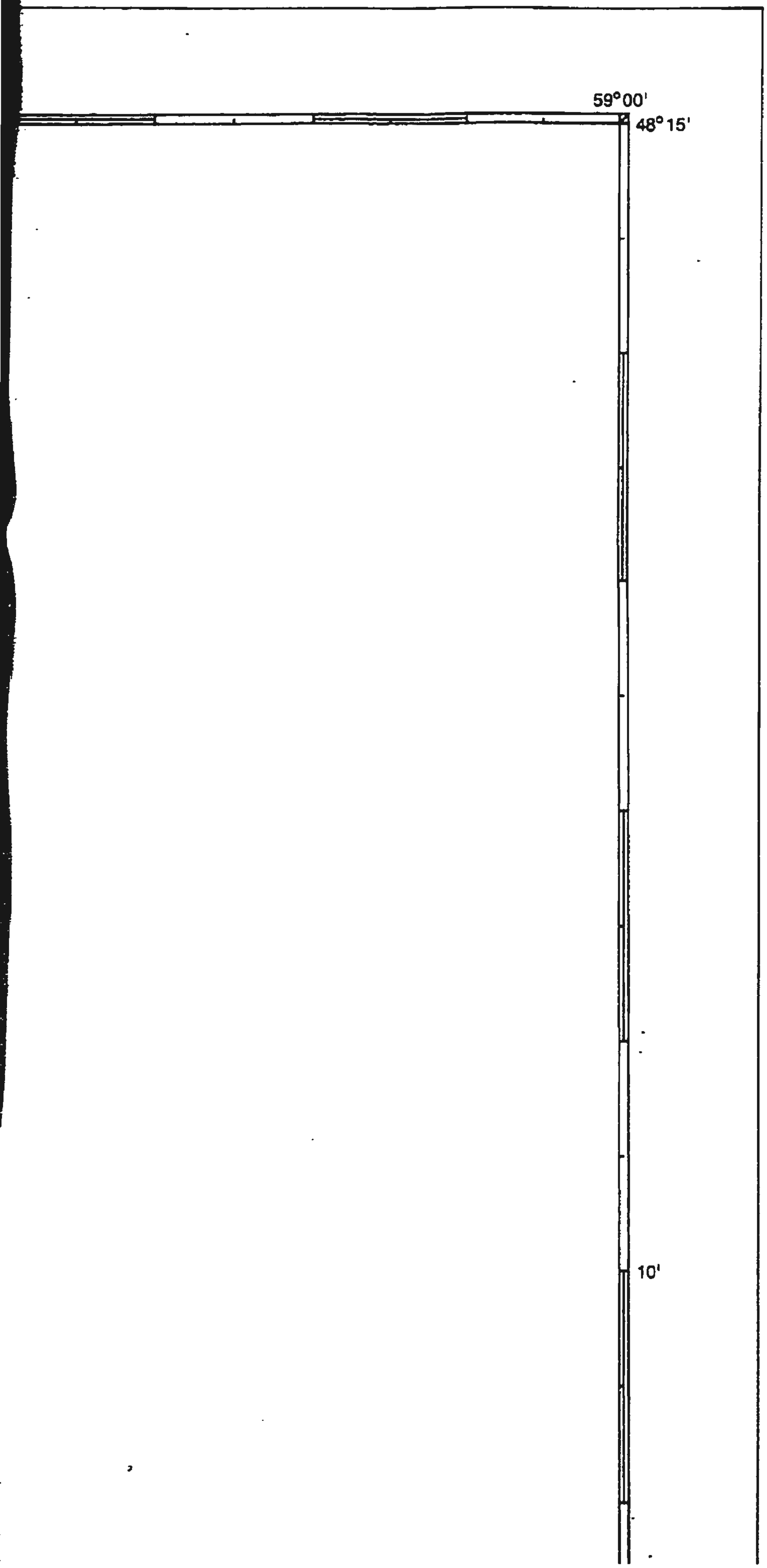
Figure E.13 McLellans Brook


59°30'
48°15'
25'
10'

20'


15'
10'


10'
5'



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LANDFOR

Each outlined area is assigned a classification consis
types of deposits within each area. Each category, wi
the other categories by a slash (e.g., Tv/R). Generally
identified within a given area. The classification syst
occurring within an outlined area, but those which co
Four variations of the landform system are as follows

1. Where three different landforms are included in
relative percentages are (60 - 85), (15 - 35), an
2. Where two landforms are included in a single m
and their relative percentages are (85 - 95) and
3. A hyphen between two landform types indicates
that till veneer and rock concealed by vegetatio
4. A composite symbol is used to show combinatio
percent of the area is covered by fluvial sedime

The striation data reported on this map has been ref

LANDFORM

Symbol	Depositional Environment	
F	Fluvial	Alluvium consis associated with than 1 m thick;
C	Colluvial	Colluvium cons include sand, si rock faces; tran
E	Aeolian	Medium to fine as dunes up to

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Department of Mines and Energy

Geological Survey

LANDFORM
OF THE LITT

LANDFORM CLASSIFICATION

gned a classification consisting of up to three genetic categories and modifiers that designate the ach area. Each category, within a classification, is listed in order of dominance and is separated from slash (e.g., Tv/R). Generally ,the areas are divided so that three landforms or deposit types are rea. The classification system is also used to denote the approximate percentage of landforms d area, but those which comprise less than 5 percent of the area are not included in the classification. lform system are as follows:

t landforms are included in a single map unit they are each separated by a single slash (/) and their s are (60 - 85), (15 - 35), and (5 - 15) .

s are included in a single map unit, a double slash (//) or single slash (/) is used to separate them, rcentages are (85 - 95) and (5 - 15) for double slash, or (60 - 85) and (15 - 40) for a single slash.

vo landform types indicates that they are approximately equal in area. For example, Tv-Rc indicates ck concealed by vegetation or a thin regolith are equal in area.

is used to show combinations of the above cases. For example, F/G(T) indicates that about 60 - 85 s covered by fluvial sediment, 15 - 40 percent by glaciofluvial sediments, and is underlain by till.

d on this map has been referenced from the Newfoundland Striation Database (Taylor et al., 1994)

LANDFORM CLASSIFICATION: GENETIC

l t	Origin and Characteristics of Materials
	Alluvium consisting of silt and clay to bouldery gravel, forms terraces and plains associated with modern stream channels, their floodplains and deltas; usually less than 1 m thick; deposited by fluvial action at or below maximum flood levels
	Colluvium consists of coarse-grained bedrock derived materials, but may include sand, silt or clay, accumulates on the lower parts, or at the base of steep rock faces; transported by gravity
	Medium to fine grained sand and silt, well sorted, poorly compacted; commonly occur as dunes up to 10 m high; transported and deposited by wind

MORPHOLOGY	Fluvial (F)	Colluvial (C)
apron (a)		Ca
blanket (b)	Fb	Cb
concealed by vegetation (c)		Cc
drumlinoid (d)		
eroded and dissected (e)	Fe	Ce
fan (f)	Ff	Cf
hummock (h)		
kettle (k)		
lineated (l)		
plain (p)	Fp	
ridge (r)	Fr	
terrace (t)	Ft	
veneer (v)	Fv	Cv
weathered (w)		
complex (x)		
undivided	F	C

Geological boundary (assumed)

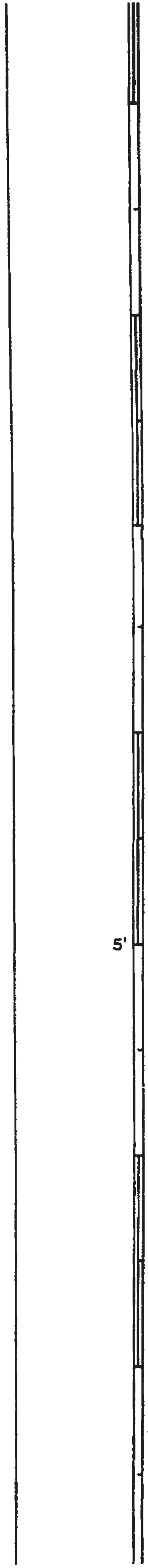
LANDFORMS AND SURFICIAL GEOLOGY OF THE LITTLE FRIAR'S COVE MAP SHEET (NTS 12B/3)

MAP 99 - 06

LANDFORM CLASSIFICATION

	GENETIC								
RPHOLOGY	Fluvial (F)	Colluvial (C)	Aeolian (E)	Glaciofluvial (G)	Lacustrine (L)	Marine (M)	Glacial (T)	Organic (O)	Rock (R)
on (a)		Ca							
nket (b)	Fb	Cb		Gb	Lb	Mb	Tb	Ob	
cealed by etation (c)		Cc							Rc
mlinoid (d)							Td		
ded and ected (e)	Fe	Ce	Ee	Ge	Le	Me	Te		Re
(f)	Ff	Cf		Gf					
nmock (h)			Eh	Gh			Th		
le (k)				Gk			Tk		
ated (l)			El				Tl	Ol	
n (p)	Fp			Gp	Lp	Mp	Tp	Op	
e (r)	Fr		Er	Gr	Lr	Mr	Tr	Or	Rr
ace (t)	Ft			Gt	Lt	Mt	Tt		Rt
eer (v)	Fv	Cv	Ev	Gv	Lv	Mv	Tv	Ov	
thered (w)									Rw
plex (x)				Gx	Lx	Mx	Tx		
vided	F	C	E	G	L	M	T	O	R

SYMBOLS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Gu
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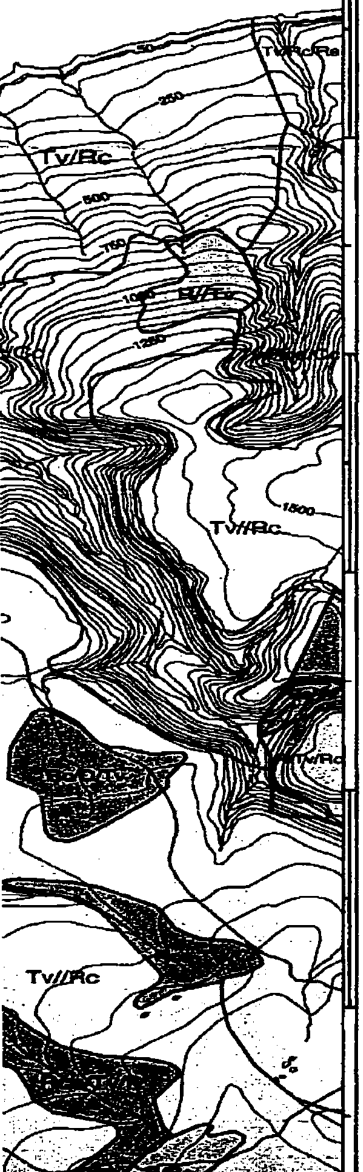
St. Lawrence



F	Fluvial	Alluvium co[...] associated [...] than 1 m thi[...]
C	Colluvial	Colluvium c[...] include san[...] rock faces; [...]
E	Aeolian	Medium to [...] as dunes u[...]
G	Glaciofluvial	Fine graine[...] hummocks, [...] outwash in [...]
L	Lacustrine	Silt, clay, gr[...] freshwater l[...] sand by sho[...]
M	Marine	Clay, silt, gr[...] to well sorte[...] deltas, terra[...] shoreline wa[...] and turbidity[...]
T	Glacial	Includes all [...] deposited b[...]
O	Bog	Poorly drain[...] developed i[...]
R	Rock	Bedrock

LANDFOR[...]

Symbol	Morphology	
a	apron	A relatively g[...] colluvium at [...] steeper uppe[...]
b	blanket	Any deposit [...] masked but [...]
c	concealed by vegetation	Vegetation m[...] shattered an[...] (less than 1 [...]
d	drumlinoid	Elongate rid[...] long; ridges [...] that taper in [...] steeper slop[...] streamlined [...] some may c[...]
e	eroded and dissected	Series of clo[...] may be a si[...] streams
f	fan	A gently slop[...] lowland; has[...] results from [...] lowland; fluv[...] glaciofluvial [...] environment[...] shaped)
h	hummock	An apparent[...] pronounced[...] stagnation a[...] materials

Colluvium consists of coarse-grained bedrock derived materials, but may include sand, silt or clay, accumulates on the lower parts, or at the base of steep rock faces; transported by gravity

Medium to fine grained sand and silt, well sorted, poorly compacted; commonly occur as dunes up to 10 m high; transported and deposited by wind

Fine grained sand to coarse grained cobbly gravel occur as plains, ridges (eskers), hummocks, terraces and deltas; generally greater than 1 m thick; deposited as outwash in an ice-contact position or proglacially

Silt, clay, gravel and sand occur as plains and blankets; silt and clay deposited in freshwater lakes from suspension, sand and silt by lake-floor currents, gravel and sand by shoreline wave action

Clay, silt, gravel and diamicton; sand is present in some places, generally moderately to well sorted and commonly stratified, but may be massive; occurs as beach ridges, deltas, terraces and bars deposited in a marine environment; gravel and sand by shoreline wave action; may include shells, clay and silt deposited from suspension and turbidity currents; gravel is generally a wavewashed lag

Includes all types of till; composed of diamicton; transported and subsequently deposited by/or from glacier ice with no significant sorting by water

Poorly drained accumulations of peat, peat moss and other organic matter; developed in areas of poor drainage

Bedrock

LANDFORM CLASSIFICATION: MORPHOLOGY

Description

A relatively gentle slope at the foot of a steeper slope, commonly used to describe colluvium at the base of a rock escarpment; consists of materials derived from the usually steeper upper slope

Any deposit greater than 1.5 m thick; minor irregularities of the underlying unit are masked but the major topographic form is still evident

Vegetation mat developed on either colluvium surfaces or a thin layer of angular frost-shattered and frost-heaved rock fragments overlying bedrock; includes areas of shallow (less than 1 m), discontinuous overburden

Elongate ridge(s) between 1.5 and 20 m high, 20 and 300 m wide, and 200 to 5000 m long; ridges have a rounded end pointing in the up-ice direction and gently curving sides that taper in the down-ice direction; exhibit a convex longitudinal profile, commonly with a steeper slope in the up-ice direction; consist of subglacially formed deposits shaped in a streamlined form parallel to the direction of glacial flow; commonly consists of till, although some may contain stratified drift; may have a rock core

Series of closely spaced gullies or deeply incised channels; can have a dendritic pattern or may be a single straight or arcuate channel; gullies and channels may contain underfit streams

A gently sloping accumulation of debris deposited by a stream issuing from a valley onto a lowland; has its apex at the mouth of the valley from which the stream issues; the fan shape results from the deposition of material as the stream swings back and forth across the lowland; fluvial fans are usually derived from eroded glacial and glaciofluvial deposits; glaciofluvial fans (deltas) are deposited in standing water rather than a terrestrial environment; colluvial fans are derived from bedrock and are usually steeper (i.e., cone shaped)

An apparently random assemblage of knobs, mounds, ridges and depressions without any pronounced parallelism, significant form or orientation; formed by glacial melting during ice stagnation and disintegration; includes subglacial, englacial, supraglacial and stratified materials

A basin or bowl-shaped closed depression or hollow in glacial drift; results from the melting

undivided F C

Geological boundary (assumed) . . . .

Scarp face at edge of fluvial terrace . . . . . .

Esker (flow direction known or assumed, unk

Meltwater channel (small, large) . . . .

Crestline of major moraine ridge . . . .

Trend of ribbed or minor moraine ridges . . . .

Beach ridges . . . .

Crevasse fill ridge . . . .

Sand dunes . . . .

Drumlin . . . .

Crag-and-tail hill . . . .

Fluting . . . .

Rôche Moutonnée . . . .

Striation (direction known, unknown) . . . . . .

Kettle hole (small, large) . . . .

Sinkhole (small, large) . . . .

Observation site . . . .

Elevation in feet above mean sea level. Conto

NOTE : All symbols and classifications may n

Geology by M.J. Batterson, Geological Surve

Digital Cartography by T. Paltanavage, Geolo
Labrador.

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of Mines and Energy, P.O. Box 8700, St. John

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PUBLISHED 1999

Reference

Taylor, D.M., St. Croix, L. and Vatcher, S.V., 1
Energy, Geological Survey Branch. 174 page

Recommended citation:

Batterson, M.J.
1999: Landforms and Surficial Geo
Department of Mines and Energy,

SYMBOLS

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vation in feet above mean sea level. Contour interval 50 feet.

TE : All symbols and classifications may not occur on this map.

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ies of this map may be obtained from the Geoscience Publications and Information Section, Geological Survey, Department lines and Energy, P.O. Box 8700, St. John's, Newfoundland, Canada, A1B 4J6.

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or, D.M., St. Croix, L. and Vatcher, S.V., 1994: Newfoundland striation data base. Newfoundland Department of Mines and rgy, Geological Survey Branch. 174 pages, Open file NFLD 2195 (version 3).

ommended citation:

terson, M.J.
1999: Landforms and Surficial Geology of the Grand Falls Map Sheet (NTS 2D/13), Newfoundland Department of Mines and Energy, Geological Survey, Map 99-02, Open File 002D/13/0340

MAP 99-06

LITTLE FRIAR'S COVE

NEWFOUNDLAND

Scale 1 : 50 000

GOVERNMENT OF
NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Geological Survey

LANDFORMS AND SURFICIAL GEOLOGY OF THE LITTLE FRIAR'S COVE MAP SHEET (NTS 12B/3)

MAP 99 - 06

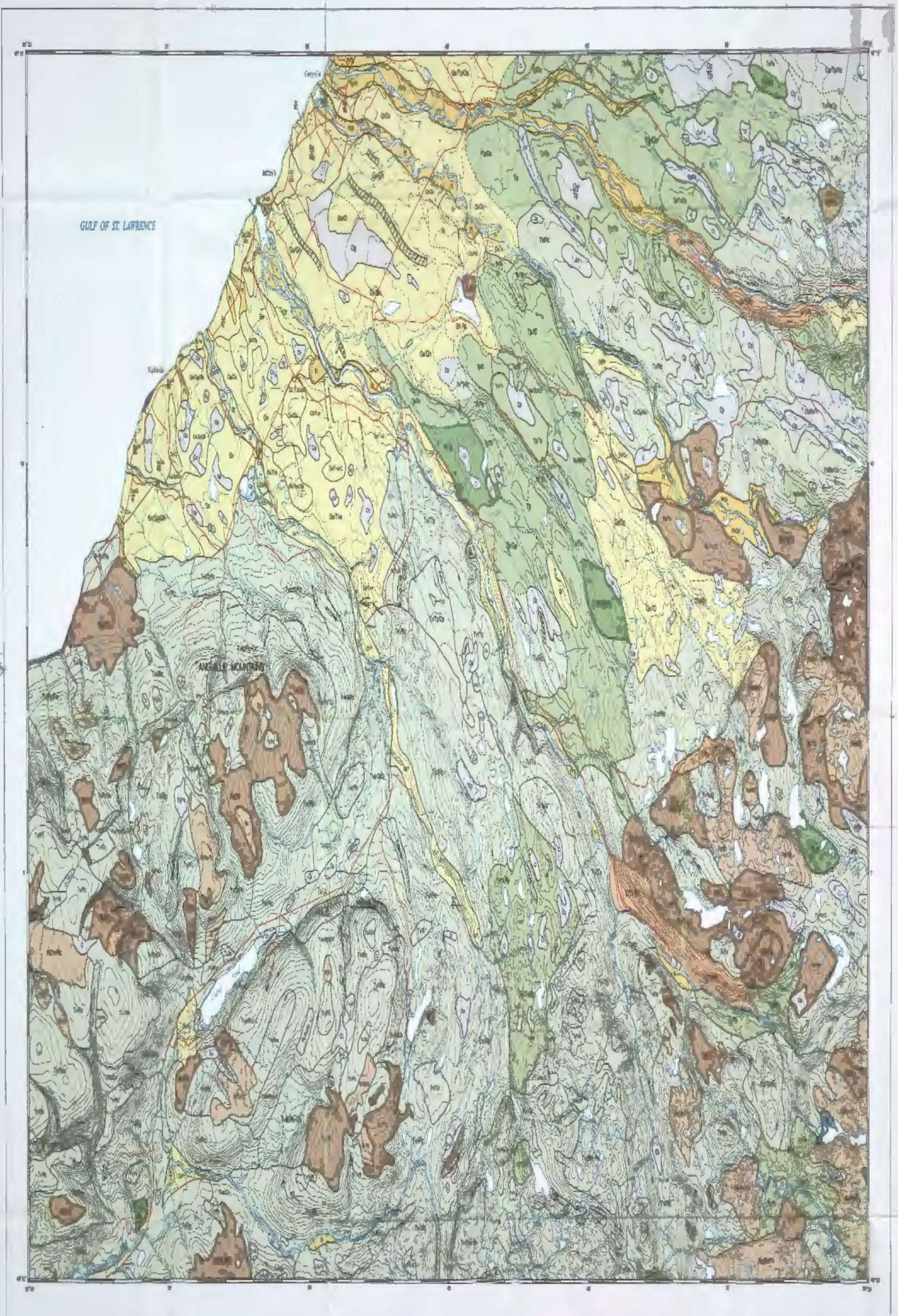
LANDFORM CLASSIFICATION

LANDFORM CLASSIFICATION: GENETIC

LANDFORM CLASSIFICATION: MORPHOLOGY

LANDFORM CLASSIFICATION

SYMBOLS



MAP 99-05

ST. FINTAN'S

NEWFOUNDLAND

Scale 1 : 50 000

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Geological Survey

LANDFORMS AND SURFICIAL GEOLOGY OF THE ST. FINTAN'S MAP SHEET (NTS 12B/2)

MAP 99 - 05

LANDFORM CLASSIFICATION

LANDFORM CLASSIFICATION: GENETIC

LANDFORM CLASSIFICATION: MORPHOLOGY

SYMBOLS

Geology by D.G.E. Liverman and K. Sheppard, Geological Survey, Department of Mines and Energy, Government of Newfoundland and Labrador.

Digital Cartography by T. Paltanavage, Geological Survey, Department of Mines and Energy, Government of Newfoundland and Labrador.

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