Current Research (1999) Newfoundland Department of Mines and Energy
Geological Survey, Report 99-1, pages 125-137

STRATIGRAPHY AND AGE OF QUATERNARY SEDIMENTS EXPOSED ALONG THE COAST OF SOUTHERN ST. GEORGE'S BAY

T. Bell, K. Sheppard and D.G.E. Liverman[1]
Department of Geography, Memorial University of Newfoundland,
St. John's, Newfoundland, Canada A1B 3X9

ABSTRACT

Almost sixty years after the initial mapping of extensive Quaternary sediments along the coast of St. George's Bay, a revised stratigraphic section is presented that identifies five main sediment types and their stratigraphical position along 39 km of coastline from Highlands to Flat Bay. The section displays varied sequences of glacial, glaciomarine, glaciofluvial and fluvial sediments, deposited during the late Wisconsinan glaciation and deglaciation of the coastal lowlands. These sequences are more complex than initially mapped, especially those associated with hummocky ridges at the coast. Evidence supporting a basal till (St. George's River Drift) overlain by a deltaic sequence (Bay St. George's Delta) could not be substantiated, whereas an upper till and ice-contact gravels (Robinson's Head Drift) related to a late glacial readvance were generally only associated with the ridge topography.

Most of the exposed sediments have been deposited in an ice-proximal to ice-distal glaciomarine environment by debris flow, underflow, current flow or suspension settling. The complexity of the sedimentary sequences and the variability in depositional style associated with hummocky ridges are typical of grounding-line fans at a tidewater glacier margin. In contrast, sections remote from the ridges display a relatively simple deglacial sequence in a shallowing-marine to fluvial environment. Radiocarbon dates on marine shells suggest that both types of glaciomarine environment co-existed along the tidewater glacier margin between 14 000 and 13 500 BP.

INTRODUCTION

The objective of this paper is to report on detailed mapping of extensive coastal exposures of Quaternary sediments along southern St. George's Bay, southwest Newfoundland. Preliminary descriptions of the coastal exposures by Liverman and Bell (1996) highlighted the lateral and vertical complexity in sediment sequences and demonstrated the need for more detailed sedimentological description of critical sections. Furthermore, the chronology of glacial, glaciomarine and marine events preserved in the sedimentary record may contribute to the ongoing debate on the deglacial history of the coastal lowlands (Brookes, 1974; Liverman and Bell, 1996; Batterson and Janes, 1997). The field work formed part of a broader project to map the surficial geology and geomorphology of the coastal lowlands between St. George's Bay and the Long Range Mountains (Figure 1; NTS map areas 12B/2, 3 and 7; Liverman, 1998; Liverman *et al., this volume;* Liverman *et al.*, 1998; Sheppard, 1998).

Field work conducted during July and August of 1998 consisted of stratigraphic section descriptions at irregular intervals along the 39 km of coastal cliff exposure between Highlands and Flat Bay (Figure 1). Individual beds were traced between representative sections to document lateral variability. Clast-fabric analysis and pebble lithology were used to characterize diamicton units. Matrix samples were collected for grain-size and geochemical analyses, and organic material was recovered for radiocarbon dating.

PREVIOUS WORK

Previous work on the coastal exposures in southern St. George's Bay consisted of reconnaissance logging from the Port au Port Peninsula to the Anguille Mountains by MacClintock and Twenhofel (1940). Their three-fold stratigraphy, interpreted as showing three temporally distinct major depositional events, was later formalized and dated by Brookes (1969, 1972, 1974, 1977). In summary, from oldest to youngest are:

[1] Geochemistry, Geophysics and Terrain Sciences Section

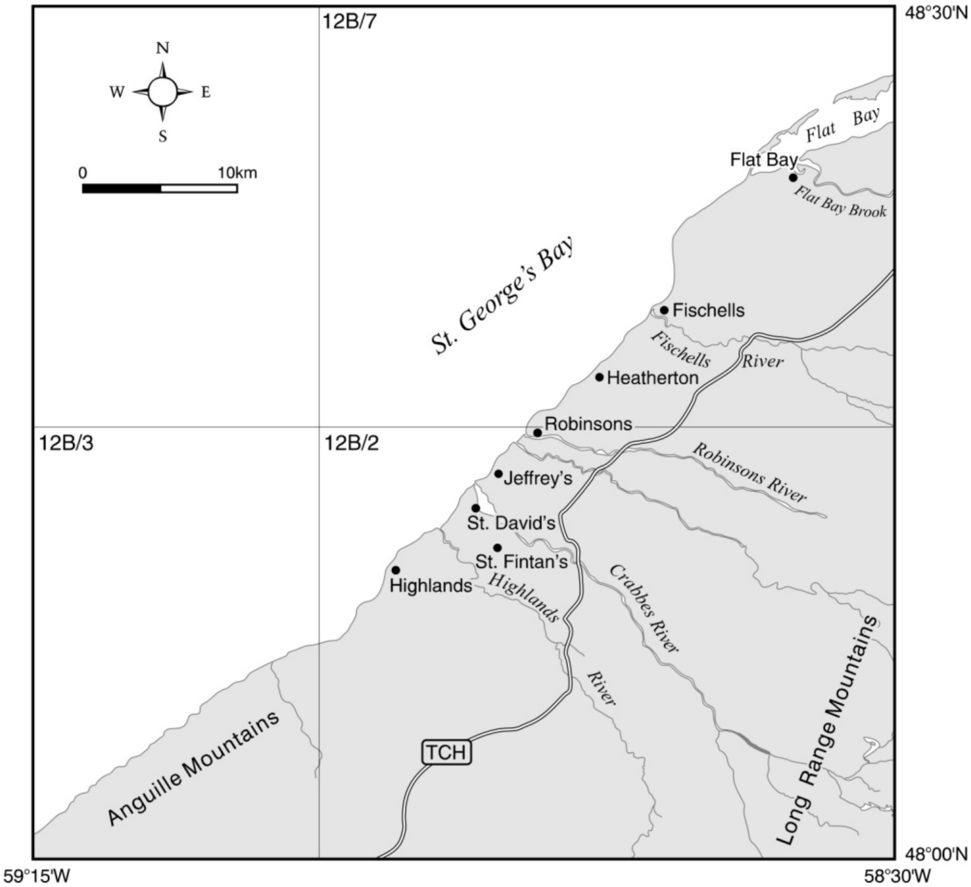

Figure 1. *Location map of study area.*

St. George's River Drift – a lower till lying on bedrock deposited during deglaciation of the coast approximately 14 000 BP.

Bay St. George's Delta – a deltaic sequence including fossiliferous silt and clay (bottomsets), sand (foresets), and gravel (topsets) deposited into a deglacial sea up to 44 m above sea level (asl) between 14 000 and 13 500 BP.

Robinson's Head Drift – a discontinuous upper coarse unit comprising till and ice-contact gravels deposited during a lobate readvance of ice (Robinson's Head readvance) across the present coastline by 12 600 BP.

According to Grant (1987, 1991), the geomorphic record of the Robinson's Head readvance is preserved as interlobate hummocky moraine ridges at Highlands, Robinsons Head, and Bank Head (Figure 2; cf., Liverman *et al., this volume*). The complex stratigraphy exposed in coastal sections through these "ridge" areas, however, prompted Liverman and Bell (1996) to re-examine the established three-fold stratigraphy and to present an alternative depositional model, one that does not require a late glacial readvance. In summary, they suggested that the basal till of the St. George's River Drift was likely deposited during initial deglaciation of the coast, as previously suggested by MacClintock and Twenhofel (1940) and Brookes (1974), but that the overlying sediments (well sorted sand, silt and clay, commonly with load structures and interbeds of gravel and diamicton) were more consistent with rapid deposition on grounding-line fans ("ridge" areas) or near the grounding line ("non-ridge" areas) in a tidewater glacier environment, not on deltas (Bay St. George's Delta), as implied by Brookes (1974). The small age range (13 900 to 13 500 BP) on marine shells from various stratigraphic positions in the "ridge" sediments was used by Liverman and Bell (1996) to support the idea of rapid and simultaneous deposition by various processes on a grounding-line fan, rather than a simple glaciomarine regressive sequence.

Occurrences of diamicton and/or ice proximal marine outwash capping "ridge" areas were interpreted by Liverman and Bell (1996) to represent marginal fluctuations of a quasi-stable tidewater glacier, and not a distinct readvance of ice from its inland position, as argued by Brookes (1974). Chronological control on the age of these marginal fluctuations, however, was lacking, as was detailed sedimentological analysis of the upper diamicton in "ridge" areas. Fieldwork in 1998 was intended to address these issues.

TOPOGRAPHIC SETTING AND GEOMORPHOLOGY

The coast along the southern part of St. George's Bay consists of a gently sloping lowland, backed by the Long Range Mountains to the east and the Anguille Mountains to the south. The Anguille Mountains and the coastal lowlands are composed of Carboniferous (Mississippian) sandstone, shale, siltstone and minor limestone and dolomite (Knight, 1982), whereas the Long Range Mountains consist mainly of Ordovician gabbro, diorite and granodiorite, and biotite granite and leucogranite (Van Berkel and Currie, 1986).

The lowland is covered by a thick wedge of surficial sediments, dominated by gravel, sand and mud at the coast, and a thin till cover inland (Liverman *et al., this volume*).

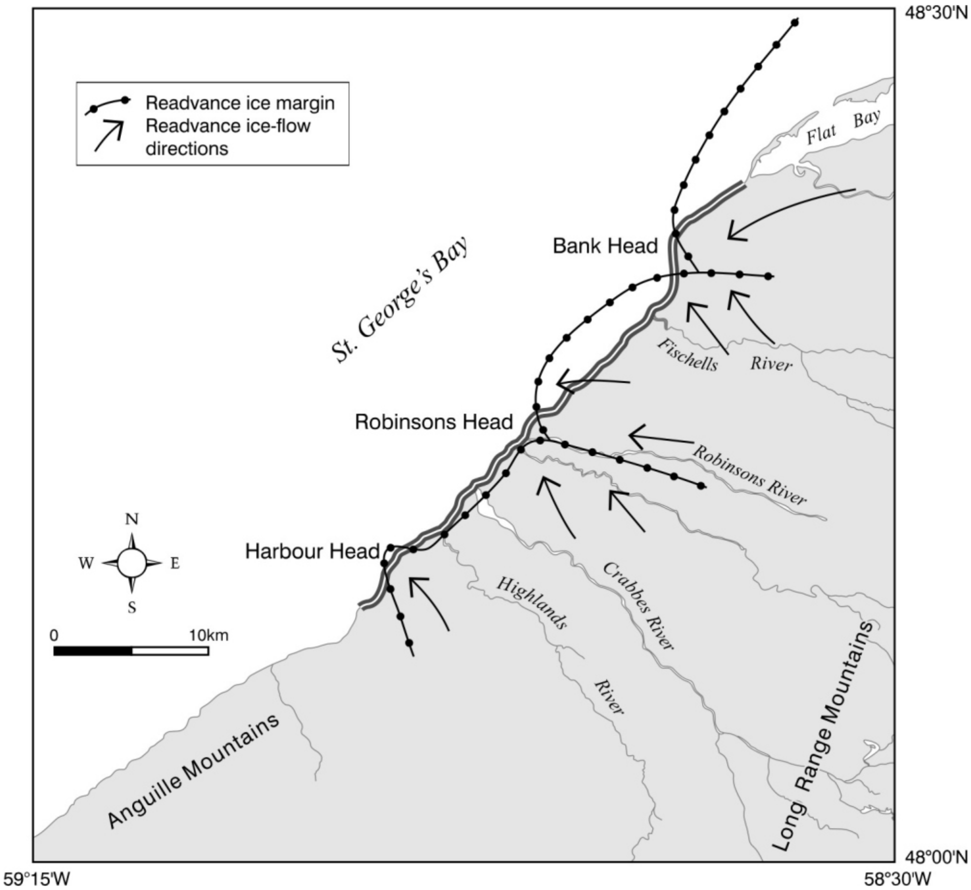

Figure 2. *Reconstructed ice limit for the Robinson's Head readvance in southern St. George's Bay (after Grant, 1987). Hummocky ridges perpendicular to the coastline occupy interlobate positions along the former ice margin (cf., Liverman* et al., this volume*). The bold portion of the coastline marks the location of the continuous stratigraphic log in Figure 3.*

Most of the sediment was deposited during, and immediately after, the late Wisconsinan glaciation, which covered the lowlands and extended offshore an unknown distance (Shaw and Forbes, 1990). Ice-flow history, reconstructed from striations and till fabrics, consists of a coast-parallel flow from farther north, possibly buffered by ice offshore, during the glacial maximum, and a dominantly westerly flow from a source in the Long Range Mountains during deglacial conditions (Liverman *et al., this volume*).

The dominant features of the coastal plain are the large elongate ridges (30 to 100 m asl), perpendicular to the coast, composed of hummocky glaciofluvial sand and gravel (Plate 1; Liverman *et al., this volume*). Some ridges are associated with meltwater channels and eskers inland. Between the ridges, a series of planar surfaces at 40 to 45 m, 24 to 26 m, and 18 to 20 m asl were interpreted by Liverman and Bell (1996) as outwash plains graded to successively lower base (marine) levels. Isolated patches of ribbed moraine occur north of Bank Head, and karst features (e.g., sinkholes) are common in areas underlain by gypsum (Liverman *et al., this volume*). Modern river valleys traverse the lowlands, dissecting surficial sediments down to bedrock.

SEDIMENTOLOGY AND STRATIGRAPHY

In total, 113 sections were logged along 39 km of coastline from French Brook to Flat Bay (Figure 3). Five recurring sediment types were observed: diamicton, mud, sand, gravelly sand, and gravel. Diamicton is subdivided based on its structural appearance, either stratified or structureless, whereas gravel is classified according to texture, either coarse (10 to 15 percent boulders) or fine (<1 percent boulders). A simplified, continuous stratigraphic section is reproduced here to: i) permit direct comparison with the three-fold stratigraphy of MacClintock and Twenhofel (1940) and Brookes (1974); ii) illustrate the stratigraphic relationships of the main sediment types; and iii) emphasize the lateral and vertical variability in "ridge" areas, as distinct from "non-ridge" areas. Specific parts of the logged coastline are

Plate 1. *View south across the hummocky "ridge" topography immediately inland of Robinson's Head. The St. George's Bay lowlands are in the background.*

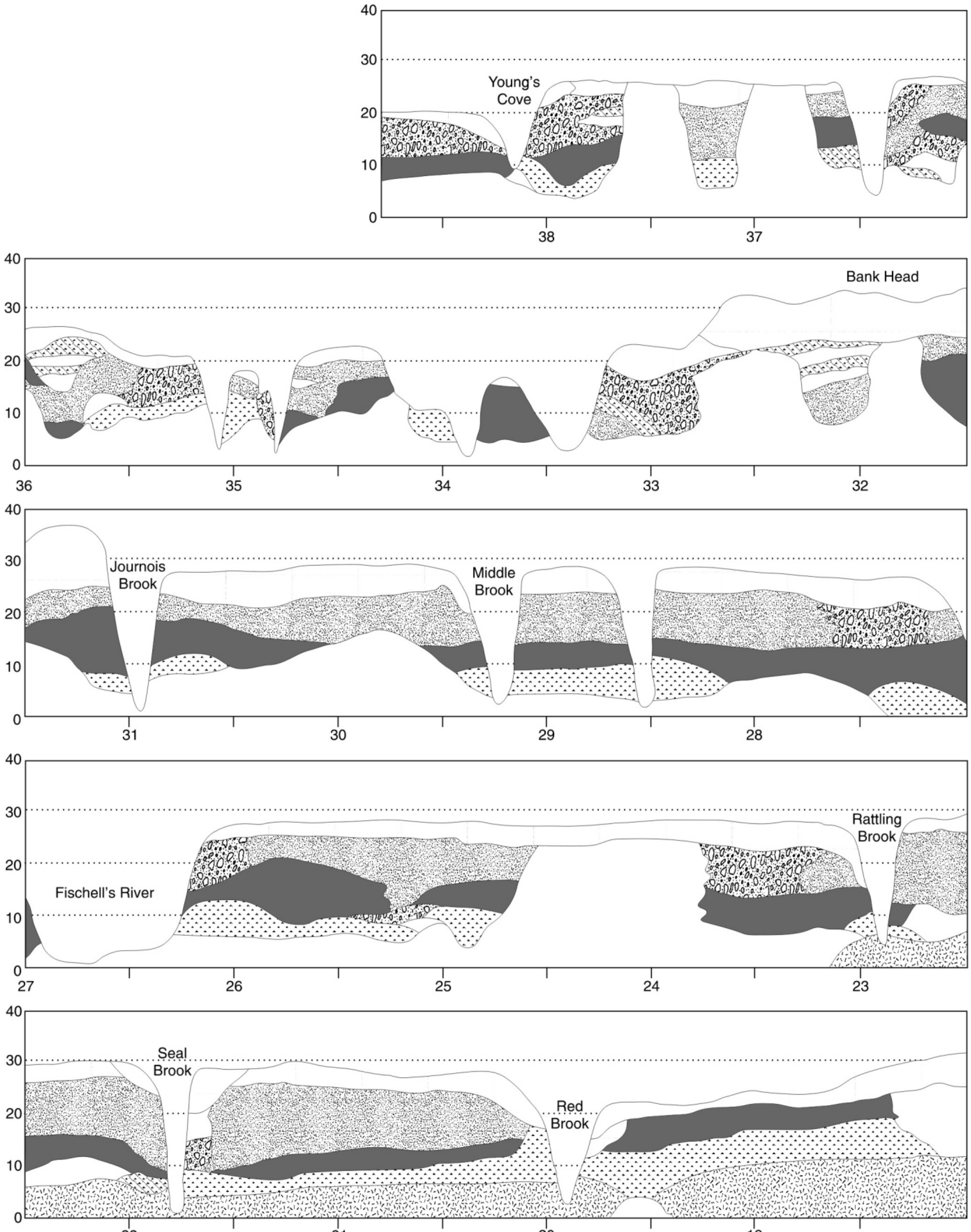

Figure 3. *Continuous stratigraphic log of the coastal exposures along southern St. George's Bay.*

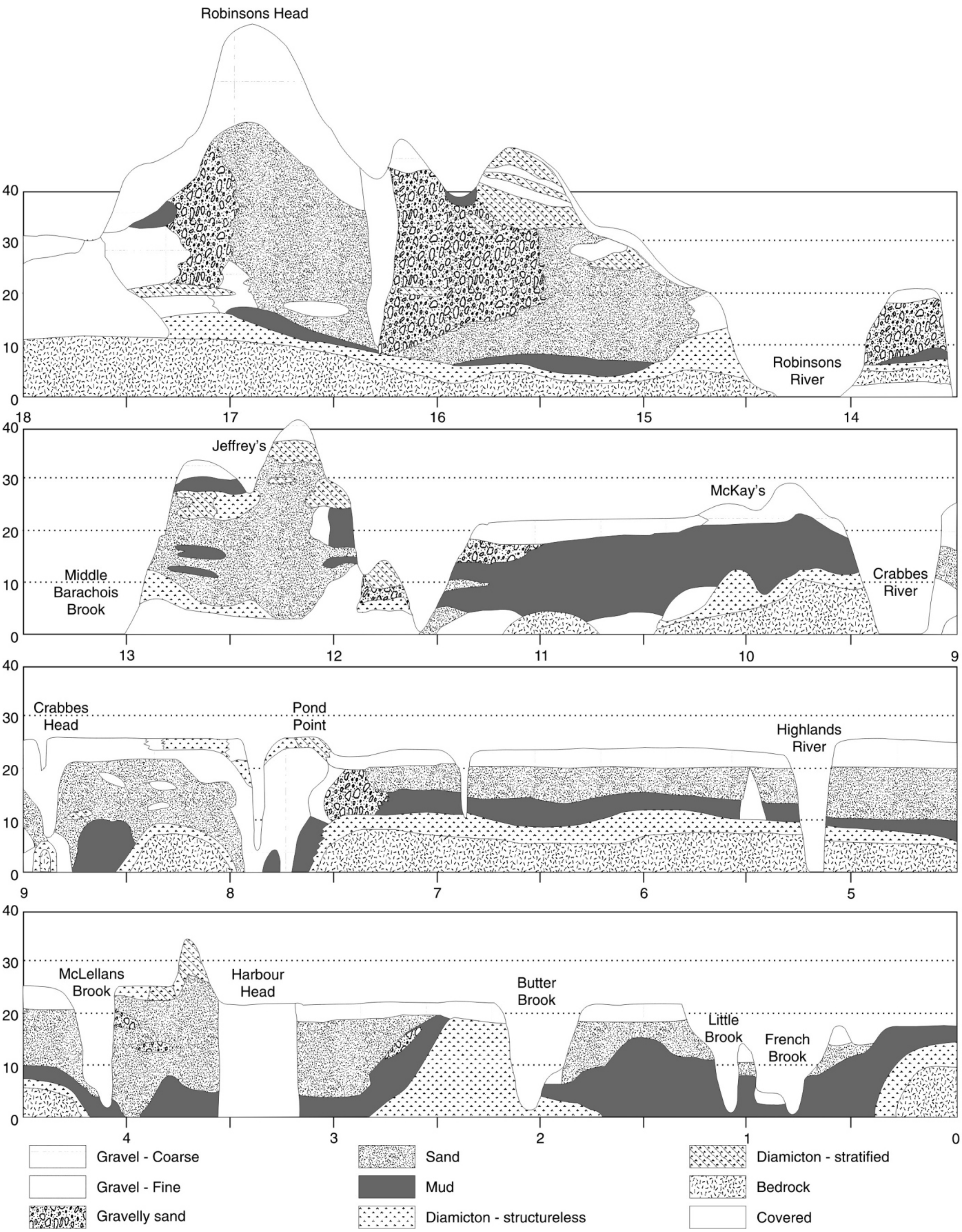

Figure 3. *Continued.*

identified in the text by place name or kilometre distance from its southern end. Detailed section-log descriptions are also presented for "ridge" and "non- ridge" areas to provide some appreciation of the relative complexity of sediment sequences and to introduce the stratigraphic context for new radiocarbon dates from the area.

MAIN SEDIMENT TYPES

DIAMICTON

Both structureless and stratified diamictons are exposed in the coastal cliffs. Structureless diamicton makes up the basal sedimentary unit along 90 percent of the coastal section, where complete vertical exposure is available. It commonly occurs as a tabular unit of variable thickness (1 to 18 m), resting directly on bedrock. In places, the diamicton dips below present sea level, following the topography on the bedrock surface (e.g., kilometre 0 to 4; Figure 3). In general, the diamicton is matrix-supported (sandy-silt to silt), contains striated pebbles to boulders, and has consistently moderate to strong unimodal clast fabrics (S1 range: 0.45 to 0.84, n=39; Figure 4). Clast provenance was more or less equally divided between local Carboniferous siltstone and sandstone (52 percent) and granite and gabbro (47 percent) from the Long Range Mountains, indicating a westerly ice flow across the coastal lowlands.

Diamictons interbedded with sand and gravel are commonly exposed where sediment ridges intersect the coast (e.g., Jeffrey's, kilometre 12 to 13; Robinsons Head south, kilometre 15 to 16; Figure 3). These diamictons tend to be structureless to weakly stratified, matrix-supported (sand to silt), 1 to 5 m thick and laterally discontinuous, pinching out over at most 10 to 20 m. Clast fabrics range from moderately to weakly oriented girdles to spread unimodal distributions (S1 range: 0.47 to 0.76, n=7; Figure 4).

At several locations along the coast, diamicton occurs as the uppermost unit (1 to 6 m thick) in section (e.g., Harbour Head, kilometre 3.5 to 4; Crabbes Head, kilometre 7.5 to 8.5; Jeffrey's, kilometre 11.5 to 13; Robinsons Head south, kilometre 15 to 16; Figure 3) and grades laterally from structureless to weakly stratified over several kilometres. It is commonly matrix-supported, but in places grades laterally into poorly sorted gravelly sand and silt. Clast fabrics are weakly to moderately oriented girdles to spread unimodal distributions (S1 range: 0.48 to 0.74, n=22; Figure 4). Clast provenance is similar to the basal diamicton, except that there are slightly more far-travelled granites and gabbros (52 percent) compared to the locally derived sandstone and siltstone (47 percent).

Different modes of deposition are proposed for the observed diamictons. The basal tabular diamicton that shows unimodal clast fabrics is interpreted as subglacial till (cf., Ham and Mickelson, 1994; Hicock *et al.*, 1996), but where fabrics are not well oriented, the diamicton is likely resedimented through debris flow. Stratified diamictons are interpreted as debris flows because of their interbedded relationship with sorted sediment and poorly to moderately oriented girdle fabrics (Lawson, 1981; Benn, 1994). Their close association with sediments interpreted as marine suggests that these debris flows were subaqueous. The lateral facies changes observed in the upper diamicton, together with the wide range in clast fabric data, suggest a variable depositional style. Massive diamicton having well-oriented, unimodal clast fabrics is likely basal till, whereas stratified diamicton having girdle fabrics is likely resedimented through debris flow.

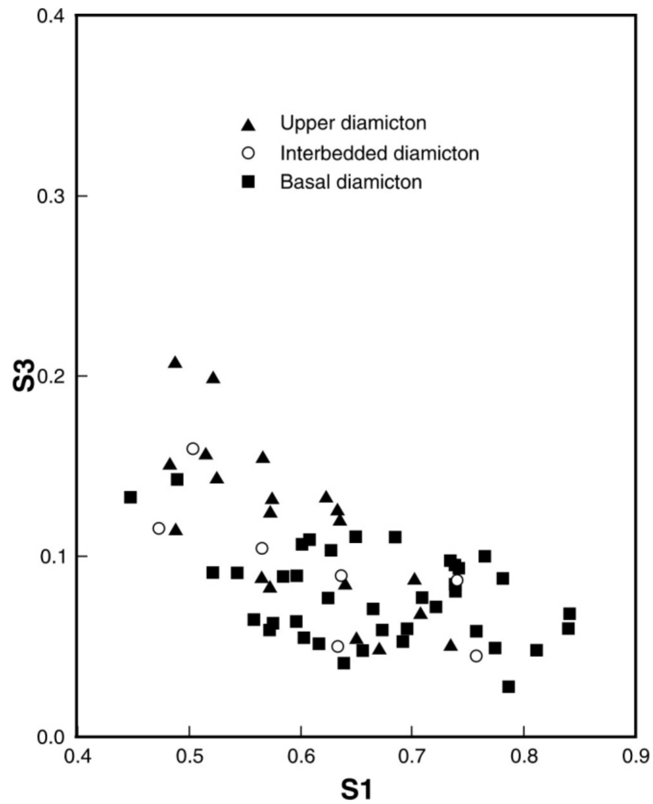

Figure 4. *Comparison of clast-fabric data for diamictons from different stratigraphic positions along the coast. S1 and S3 are summary statistics that measure the strength of clustering about the mean axis and the axis of minimum clustering, respectively (Dowdeswell and Sharp, 1986).*

MUD

Mud forms a more or less continuous unit, between 1 and 15 m thick, along the coastal exposure, directly overlying the basal diamicton along a sharp, conformable contact. It varies from structureless to rhythmically laminated silty clay and clayey silt, and in places, interlaminated with thin beds of very fine sand (Plate 2). Dropstones are very rare. The mud contains marine shells, radiocarbon dated between 14 000 and 13 400 BP (Liverman and Bell, 1996; Batterson *et al.,* 1992).

Plate 2. *Laminated mud near Highlands River.*

The abrupt contact between the basal till and the mud suggests an overlap relationship, where marine inundation and onset of deep-water conditions occurred immediately upon glacial retreat. Rare dropstones suggest limited iceberg rafting in the area. Laminated and massive muds result from suspension settling from overflow plumes generated by meltwater discharge from a nearby ice margin (Mackiewicz *et al.,* 1984; Powell, 1990).

SAND AND GRAVELLY SAND

Sand and gravelly sand form the highest proportion of sediment along the coast, although sand is most common. These sediments dominate the middle section of most exposures, enclosed by mud and gravel in "non-ridge" areas (e.g., kilometre 18 to 31; Figure 3), and interbedded with, or truncated by, coarse gravel and stratified diamictons in "ridge" areas (e.g., Robinsons Head, kilometre 14.5 to 17.5; Figure 3). These sediments are typically moderate- to well-sorted and planar-bedded (horizontal), although ripple bedding is also common. A gradational lower contact with underlying mud frequently occurs throughout the sections.

Sand was deposited by a combination of underflow traction currents and suspension settling from overflow plumes (cf., Benn, 1996; Powell, 1990), whereas gravelly sand was deposited by underflow. The gradational contact with mud supports deposition by suspension settling. Evidence of underflow is indicated by planar and ripple bedding.

GRAVEL

Gravel is differentiated into two units based on the main clast size. Fine gravel mostly consists of pebbles and cobbles, with only rare boulders (<1 percent). It occurs either as moderate- to well-sorted, commonly planar-bedded units (1 to 7 m thick) that are laterally continuous for several kilometres near the top of "non-ridge" sections, or as poor- to moderate-sorted lenses, interbedded with sand, gravelly sand and diamicton in "ridge" sections. Where laterally continuous, fine gravel beds represent a coarsening upward sequence from underlying sand and gravelly sand. The intervening contact is typically sharp and erosive, with loading structures evident in the underlying sand (Plate 3).

Plate 3. *Water-escape (flame) structure at the contact between sand and gravel beds near Butter Brook. These features form where relatively dense material (gravel) is deposited rapidly over liquefied sediments (sand).*

Coarse gravel consists of poorly sorted pebbles, cobbles and boulders (10 to 15 percent), and is mostly found in "ridge" sections (Plate 4). It is typically crudely to chaotically bedded (e.g., Robinsons Head, Bank Head), with variable dip angles (0-40°), though rarely at the angle of repose. Coarse gravel beds are between 5 and 25 m thick, and in some cases form the bulk of the exposure (e.g., Crabbes Head; Plate 5).

Plate 4. *Coarse, clast-supported, poorly sorted gravel at Crabbes Head.*

Plate 5. *Interbedded coarse gravel and planar-bedded sand make up most of the section through "ridge" topography at Crabbes River.*

Where fine gravel forms a continuous upper unit, it was likely deposited as fluvial outwash. The consistency of planar bedding indicates uniform flow and sediment supply, typical of proglacial outwash gravel (Maizels, 1995). Where inter-bedded with sand, gravelly sand, and diamicton, fine gravel was likely deposited as subaqueous outwash (Rust, 1977).

The interbedded relationship of coarse gravel with diamicton (debris flow) and sediments interpreted as marine (mud and gravelly sand) indicate an ice-contact, subaqueous depositional environment (Benn, 1996). Beds at or below the angle of repose (e.g., Crabbes Head) suggest deposition on a subaqueous ice-contact fan (Powell, 1990; Lønne, 1995).

LOESS

Well-sorted, fine to very fine sand and silt occur discontinuously as the uppermost unit along the coast. The sand and silt vary in thickness from 0.5 to 3 m, and normally overly gravel. This sediment was deposited as cliff-top loess.

STRATIGRAPHY

The stratigraphy along the coast of southern St. George's Bay has previously been divided into two general types – "non-ridge" and "ridge" – based on surface topography and sedimentary sequences (Liverman and Bell, 1996). "Non-ridge" areas are characterized by flat planar surfaces (e.g., kilometres 23 to 26, Figure 3) and display simple sedimentary sequences that are laterally continuous over many kilometres (e.g., kilometre 4.5 to 7, 27 to 30; Figure 3). They generally consist of structureless diamicton, overlain successively by marine mud, planar-bedded sand, planar-bedded gravel, and loess. In contrast, ridges that either dissect the coast (e.g., Robinsons Head) or terminate immediately inland (Crabbes Head) exhibit relatively complex stratigraphy because sedimentary units rapidly change vertically and laterally, pinching and swelling over short distances. They are composed of interbedded sand, gravel, and diamicton, overlain by gravel (commonly coarse) and/or structureless to stratified diamicton. The differences in sedimentology between "non-ridge" and "ridge" areas are illustrated using section logs from Butter Brook and Harbour Head, respectively.

BUTTER BROOK

The Butter Brook section shows a relatively simple sedimentary sequence having five distinct units that can be traced for several kilometres north and south of the site (Figures 3 and 5). At the base of the section is a brownish (7.5 YR 4/2, moist) diamicton (Unit A) approximately 6 m thick. It is compact, structureless, and contains pebble to boulder clasts of local (Carboniferous) and distal (Long Range Mountains) origins, many of which are striated. Clast fabric is strong (S1 range: 0.63 to 0.84, n=4), with a northeast–southwest orientation. The diamicton is overlain sharply and conformably by 4 to 5 m of massive to laminated mud (Unit B), containing abundant marine shells radiocarbon dated at 13 600 ±190 BP (GSC-4270). Rare pebbles are evident in the laminated sediments.

Approximately 5 m of planar (horizontal) and ripple-bedded, fine to medium sand (Unit C) overlies the mud along a gradational contact. Beds are commonly continuous across the exposure (~30 m), although individual beds are truncated at the upper contact. Rare clasts were noted in some beds. Two to 3 m of planar-bedded, pebble–cobble gravel (Unit D) overlies the sand across a sharp contact (Plate 6). The gravel is generally well sorted with subrounded to rounded clasts. Rare, discontinuous interbeds (up to 10 cm thick) of fine to medium sand are also present. The gravel is overlain conformably by 0.5 m of well-sorted fine sand (Unit E).

Unit A is interpreted as subglacial till, deposited by ice from the Long Range Mountains. Clast fabrics and local ice-flow indicators consistently show flow from the northeast. Laminated muds in Unit B were likely deposited by suspension settling from turbid overflow plumes (cf., Mackiewicz *et al.*, 1984). Massive muds were deposited in a similar fashion, but more rapidly. Pebbles in the mud are interpreted as dropstones from iceberg rafting (cf., Thomas and Connell, 1985). The abrupt contact between the till and overlying mud indicates that rapid marine inundation accompanied ice retreat. The sand of Unit C was deposited by suspension settling and underflow traction currents (cf., Powell, 1981; Benn, 1996). Suspension settling is supported by the gradational lower contact with Unit B, whereas underflow is rep-

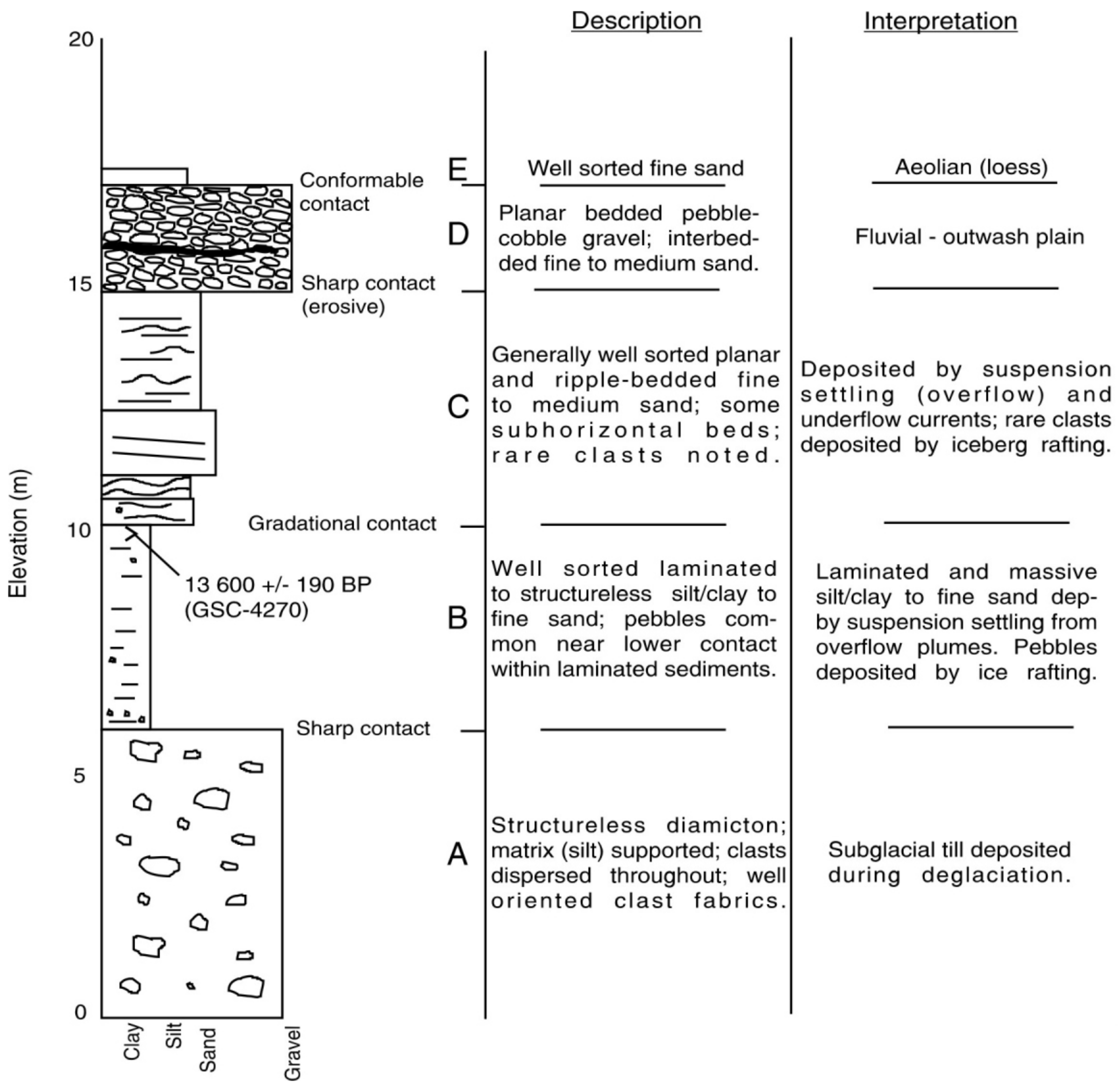

Figure 5. *Descriptive log and interpretation of sediments exposed at Butter Brook section.*

Plate 6. *Scour-and-fill, pebble–cobble gravel overlying planar-bedded sand north of Butter Brook.*

resented by ripple bedding throughout the unit. Rare clasts noted at the base of this unit may have been deposited by iceberg rafting. The planar-bedded gravel of Unit D is interpreted to represent fluvial deposition following emergence of the site above sea level. Unit E was deposited as aeolian sediment along the top of the cliff.

HARBOUR HEAD

The Harbour Head section exposes the internal composition of the "ridge" topography at Highlands, where it intersects the coast near McLellans Brook (Figures 3 and 6). Three distinct sedimentary units are recognized; however, some units are characterized by a variety of interbedded sediment types that are discontinuous across the section. Slumping obscures the lowermost 6 m of the 30-m-high

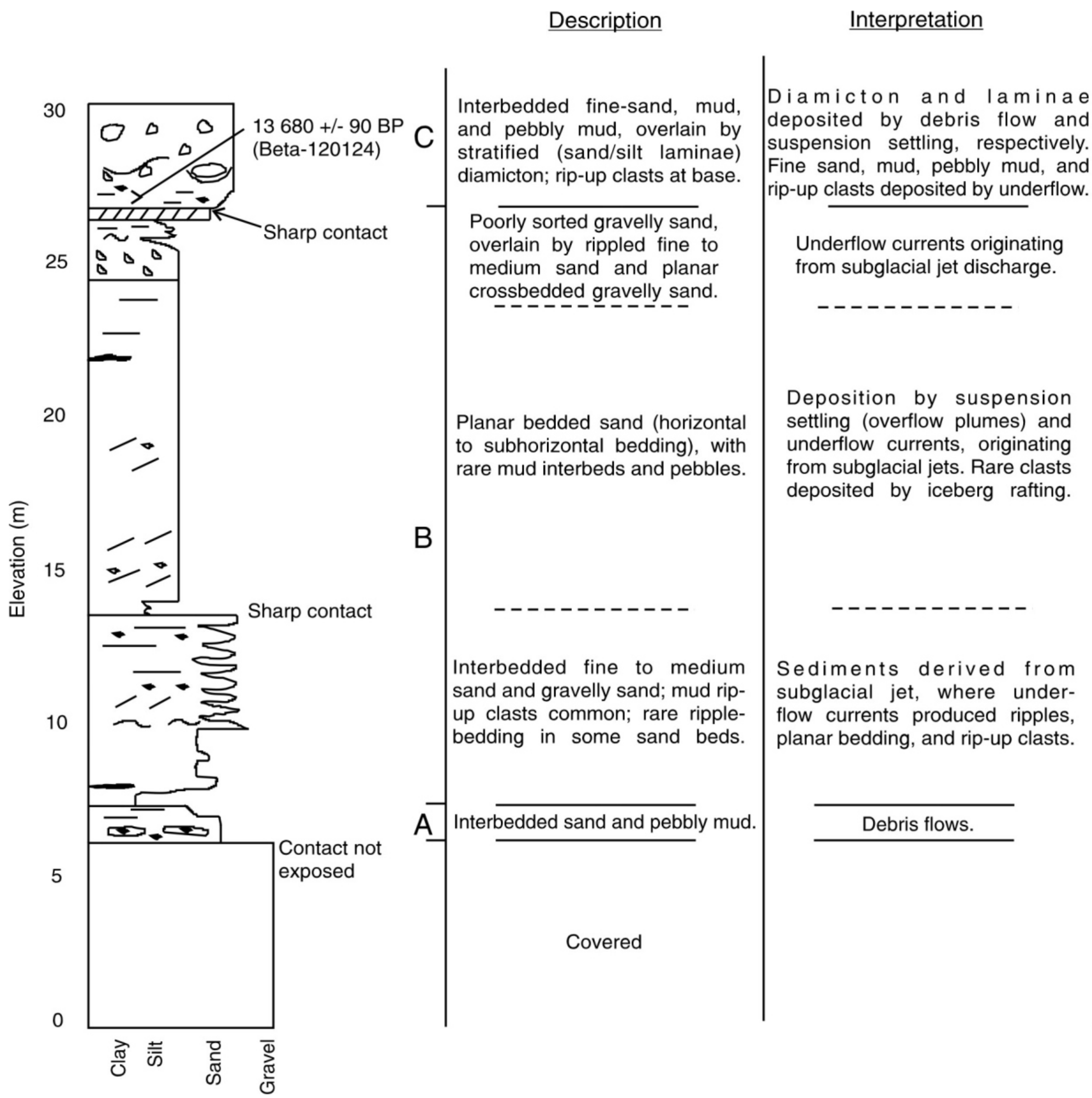

Figure 6. *Descriptive log and interpretation of sediments exposed at Harbour Head section.*

exposure. The lowest unit (A; 60 cm thick) consists of pebbly, fine to medium sand and interbedded diamicton, containing mud rip-up clasts. Unit B overlies Unit A across a gradational contact. Unit B is 19 m thick and consists of predominantly planar-bedded (commonly subhorizontal) sand, with interbedded pebbly mud, sand, and gravelly sand, coarsening up to planar-crossbedded gravelly sand. Generally, individual beds are laterally continuous and range from poorly sorted and ungraded to moderately well-sorted and graded. Bed contacts are typically gradational and mud rip-up clasts are common in sand and gravelly sand.

Unit B is abruptly overlain (erosive contact) by 1 m of interbedded fine sand, mud, and pebbly mud, grading into 4 m of stratified diamicton (Unit C). The sand beds contain rare mud rip-up clasts and are laterally discontinuous, pinching out over a few centimetres. The diamicton is generally compact, matrix (sandy–silt) supported, having a clast content of 5 to 10 percent (mostly pebbles with some boulders). Fine sand–silt laminae (1 to 2 mm thick) in the diamicton are discontinuous over a few tens of centimetres (Plate 7). Clast-fabric data display moderately well-oriented girdle distributions (S1 range: 0.57 to 0.62, n=2), oriented north-northeast–south-southwest. Paired shells of *Mya truncata* and *Hiatella arctica* collected from pebbly mud interbedded with diamicton, near the base of the stratified diamicton, provided a radiocarbon date of 13 680 ± 90 BP (Beta 120124).

Plate 7. *Deformed sand–silt lamination underlying a large cobble dropstone near the base of the upper diamicton at Harbour Head.*

Sediments exposed in the Harbour Head section have characteristics typical of subaqueous debris flow, underflow, current flow and overflow in an ice-proximal environment. Units A and B show evidence of rapid sedimentation, mostly by underflow and sediment gravity flow, as indicated by the consistent presence of mud rip-up clasts within generally poorly sorted sand and gravelly sand. Thin, discontinuous diamicton beds in Unit A were likely deposited by debris flow. Unit C shows a gradation from interbedded pebbly sand and mud to stratified diamicton, which is interpreted to represent deposition by sediment gravity flow, interspersed with suspension settling (mud and pebbly mud), in an ice-proximal environment. Discontinuity of individual beds, the presence of rip-up clasts, and the erosive nature of lower contacts indicate rapid deposition of sand and pebbly sand by underflow, whereas moderately oriented girdle fabrics and the presence of discontinuous laminae and mud rip-up clasts indicate a debris-flow origin for the diamicton (cf., Lawson, 1981; Dowdeswell and Sharp, 1986). The marine shells from Unit C are considered to be *in situ* because they are found in the pebbly mud, which was deposited from suspension settling and ice rafting. However, the shells date the onset of debris-flow deposition because the pebbly mud is interbedded with the lowest part of the stratified diamicton.

DISCUSSION

The three-fold stratigraphy of MacClintock and Twenhofel (1940) and its revised interpretation by Brookes (1974) conflict with the data and interpretations presented here. Nowhere along the coast has the classic three-fold stratigraphy of basal till, delta (bottomsets, foresets and rare topsets), and upper till or ice-contact gravels been observed. Instead, the typical section consists of till, glaciomarine mud and sand and glaciofluvial outwash. This sequence, representing a simple transition from deglacial marine to proglacial outwash, is characteristic of 80 percent of the coastal section along southern St. George's Bay, and has been observed from areas both inside and outside the proposed margins of the Robinsons Head readvance (Figures 2 and 3).

In contrast, sections through "ridge" topography at the coast generally show more complex sedimentary sequences, with discontinuous beds and rapid lateral and vertical facies transitions (Liverman and Bell, 1996). For example, sections at Robinsons Head and Crabbes Head are dominated by thick sequences of interbedded sand, gravel and diamicton, with rare fossiliferous muds. These complex sequences are characteristic of subaqueous fans deposited at the grounding-line of tidewater glaciers, where sediments are introduced mainly by subglacial meltwater jets (Powell, 1981; Lønne, 1995) and depositional processes such as debris flow, underflow, current flow and overflow operate simultaneously (cf., Pfirman and Solheim, 1989; Benn, 1996).

Liverman and Bell (1996) argued that the coarsening upward of these "ridge" sections and a return to ice-proximal conditions need not necessarily imply a climatically forced glacial readvance, as proposed by Brookes (1974), but that minor fluctuations of tidewater glacier termini may occur in response to changing water depth, either falling sea level or accumulation of grounding-line sediments (cf., Powell, 1991). The radiocarbon date of 13 680 ± 90 BP (Beta 120124) from the base of the upper diamicton (debris flow) at Harbour Head supports this argument, as it demonstrates that the re-establishment of ice-contact to ice-proximal conditions at the ridge (grounding-line fan) occurred more or less simultaneously with initial ice retreat and marine inundation at nearby Butter Brook.

The section descriptions presented here provide new information on the deglacial environments of southern St. George's Bay; however, many important questions remain unanswered. Some of these include:

1. What was the configuration of the deglacial ice margin during deposition of the extensive glaciomarine sequences along the present coastline?
2. Why are there so few dropstones, indicative of a nearby calving glacier margin, in the glaciomarine sediments along the coast?
3. What is the history of relative sea level change during the late-glacial and postglacial period?
4. How did changes in relative water depth at the grounding-line, either through sea level adjustments or sediment accumulation, influence the stability of the tidewater glacier margin?
5. Does the sedimentary record anywhere along St. George's Bay support a temporally distinct, late-glacial readvance of the retreating ice margin across the pres-

ent coastline at 12 600 BP (Robinson's Head readvance; Brookes, 1974)?

6. How does the coastal stratigraphy presented here correlate with the acoustic stratigraphic and sediment core records offshore in St. George's Bay (Shaw and Forbes, 1990; Shaw and Courtney, 1997)?

ACKNOWLEDGMENTS

Partial funding for this project was provided by Natural Sciences and Engineering Research Council of Canada (research grant to TB). KS acknowledges the support of an Atlantic Accord Career Development Award. The Memorial University of Newfoundland Cartographic Laboratory drafted Figure 3. Danny O'Dell and Mark Osmond provided excellent field assistance. Dr. Martin Batterson reviewed an earlier version of the manuscript.

REFERENCES

Batterson, M.J., Liverman, D.G.E. and St. Croix, L.
1992: Carbon-14 date list for Newfoundland and Labrador. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File NFLS/2190.

Batterson, M.J. and Janes, J.
1997: Stratigraphy of Late Quaternary sediments exposed in coastal cliffs, west of Stephenville. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 97-1, pages 151-165.

Benn, D.I.
1994: Fabric shape and the interpretation of sedimentary fabric data. Journal of Sedimentary Research, Volume 64A, pages 910-915.

1996: Subglacial and subaqueous processes near a glacier grounding line: sedimentological evidence from a former ice-dammed lake, Achnasheen Scotland. Boreas, Volume 25, pages 23- 36.

Brookes, I.A.
1969: Late-glacial marine overlap in western Newfoundland. Canadian Journal of Earth Sciences, Volume 6, pages 1397-1404.

1972: The glaciation of southwestern Newfoundland. Unpublished Ph.D. thesis, McGill University, 208 pages.

1974: Late-Wisconsin glaciation of southwestern Newfoundland (with special reference to the Stephenville map-area). Geological Survey of Canada, Paper 73-40.

1977: Radiocarbon age of Robinson's Head moraine, west Newfoundland, and its significance for postglacial sea level changes. Canadian Journal of Earth Sciences, Volume 14, pages 2121- 2126.

Dowdeswell, J.A. and Sharp, M.J.
1986: Characterization of pebble fabrics in modern terrestrial glacigenic sediments. Sedimentology, Volume 33, pages 699-710.

Grant, D.R.
1987: Quaternary geology of Nova Scotia and Newfoundland (including Magdelan Islands). International Union for Quaternary Research, XII INQUA Congress, Ottawa, Excursion Guidebook A-3/C-3, National Research Council of Canada, Publication 27525, 62 pages.

1991: Surfical geology, Stephenville-Port aux Basques, Newfoundland. Geological Survey of Canada, Map 1737A, scale 1:250 000.

Ham, N.R. and Mickelson, D.M.
1994: Basal till fabric and deposition at Burroughs Glacier, Glacier Bay, Alaska. Geological Society of America Bulletin, Volume 106, pages 1552-1559.

Hicock, S.R., Goff, J.R., Lian, O.B. and Lettle, E.C.
1996: On the interpretation of subglacial till fabric. Journal of Sedimentary Research, Volume 66(5), pages 928-934.

Knight, I.
1982: Geology of the Carboniferous Bay St. George Subbasin. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 82-1, scale 1:125,000.

Lawson, D.E.
1981: Distinguishing characteristics of diamictons at the margin of the Matanuska Glacier, Alaska. Annals of Glaciology, Volume 2, pages 78-84.

Liverman, D.G.E.
1998: Surficial geology and landform classification of the Flat Bay map Sheet (NTS 12B/7). Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 0412, Map 98-04.

Liverman, D.G.E. and Bell, T.
1996: Late Quaternary glacial and glaciomarine sediments in southern St. George's Bay. *In* Current

Research. Newfoundland Department of Natural Resources, Geological Survey Branch, Report 96-1, pages 29-40.

Liverman, D., Sheppard, K. and Taylor, D.
1998: Surficial geology and landform classification of the St. Fintan's map sheet (NTS 12B/2). Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 0413, Map 98-05.

Liverman, D.G.E., Sheppard, K. and Taylor, D.M.
This volume: Surficial geology of the St. Fintan's, Little Friars Cove, and Flat Bay map area (NTS 12B/2, 12B/3 and 12B/7).

Lønne, I.
1995: Sedimentary facies and depositional architecture of ice-contact glaciomarine systems. Sedimentary Geology, Volume 98, pages 13-43.

Mackiewicz, N.E., Powell, R.D., Carlson, P.R. and Molnia, B.F.
1984: Interlaminated ice-proximal glacimarine sediments at Muir Inlet, Alaska. Marine Geology, Volume 57, pages 113-147.

Maizels, J.
1995: Sediments and landforms of modern proglacial terrestrial environments. *In* Modern Glacial Environments: Processes, Dynamics, and Sediments. *Edited by* J. Menzies. Butterworth- Heinemann, Oxford, UK, pages 365-416.

MacClintock, P. and Twenhofel, W.H.
1940: Wisconsin glaciation of Newfoundland. Geological Society of America Bulletin, Volume 51, pages 1729-1756.

Pfirman, S.L. and Solheim, A.
1989: Subglacial meltwater discharge in the open-marine tidewater glacier environment: observations from Nordaustlandet, Svalbard Archipelago. Marine Geology, Volume 86, pages 265-281.

Powell, R.D.
1981: A model for sedimentation by tidewater glaciers. Annals of Glaciology, Volume 2, pages 129-134.

1990: Glacimarine processes at grounding-line fans and their growth to ice-contact deltas. *In* Glacimarine Environments: Processes and Sediments. *Edited by* J.A. Dowdeswell and J.D Scourse. Geological Society of London Special Publication, Number 53, pages 53-73.

1991: Grounding-line systems as second-order controls on fluctuations of tidewater termini of temperate glaciers. *In* Glacial Marine Sedimentation; Paleoclimatic Significance. *Edited by* J.B. Andrews and G.M. Ashley. Boulder, Colorado, Geological Society of America, Special Paper 261.

Rust, B.R.
1977: Mass flow deposits in a Quaternary succession near Ottawa, Canada: diagnostic criteria for subaqueous outwash. Canadian Journal of Earth Sciences, Volume14, pages 175-184.

Shaw, J. and Courtney, R.C.
1997: Multibeam bathymetry of glaciated terrain off southwest Newfoundland. Marine Geology, Volume 143, pages 125-135.

Shaw, J. and Forbes, D.L.
1990: Late Quaternary sedimentation in St. George's Bay, southwest Newfoundland: acoustic stratigraphy and seabed deposits. Canadian Journal of Earth Sciences, Volume 27, pages 964- 983.

Sheppard, K.
1998: Surficial geology and landform classification of the Little Friars Cove map sheet (NTS 12B/3). Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File 0414, Map 98-06.

Thomas, G.S.P. and Connell, R.J.
1985: Iceberg, drop, dump, and grounding structures from Pleistocene glaciolacustrine sediments, Scotland. Journal of Sedimentary Petrology, Volume 55, pages 243-249.

Van Berkel, J.T. and Currie, K.L.
1986: Geology of the southern Long Range Mountains, southwest Newfoundland (12 B/1, 12 B/8, 12 B/9, 12 A/5, 12 A/12). Geological Survey of Canada, Open File Report 1328 (1:100,000 map with marginal notes).