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STRATIGRAPHY OF LATE QUATERNARY SEDIMENTS EXPOSED IN COASTAL CLIFFS, WEST OF STEPHENVILLE

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ABSTRACT

Exposures of Quaternary sediment between Stephenville and Port au Port Peninsula were examined to develop a Quaternary stratigraphy for the northern part of St. George's Bay. This area contains the only dated exposure, at Kippens, related to the Robinsons Head readvance, a major component of the late glacial history of western Newfoundland. The western extent of this readvance is marked by exposures near Romaines Brook. Sediment sections were logged at 15 locations along the coast. Exposures, 7 to 35 m high, contained diamicton, mud, sand and silt, sand and gravel, marl, peat and loess. Detailed descriptions of exposures at Kippens and Romaines Brook are presented.

Preliminary interpretation suggests that sediment assemblages west of Romaines Brook, particularly between Berry Head and Romaines Brook, were deposited in an ice-proximal glaciomarine environment, along the grounding line of a tidewater glacier. Sediment east of Romaines Brook were deposited as glaciofluvial deltas built by a proglacial outwash system. The interpretation of the sediment at the Kippens section supports a history of initial ice-proximal glaciomarine sedimentation, followed by deltaic progradation produced by glacial retreat in a shallowing sea. Sediment in the Romaines Brook section show a complex depositional sequence of ice-proximal glaciomarine sediments, some of which have collapsed into a depression, and mud showing a transition from a marine to freshwater environment, deposited during postglacial relative sea level fall.

Surface geomorphology in the Kippens area that shows numerous near-coast depressions interpreted as kettle holes, supporting an ice-contact environment, may be explained through an origin as gypsum karst sinkholes.

INTRODUCTION

The field work program undertaken in 1996 was a continuation of the Quaternary geological mapping program of the west coast of Newfoundland. This program initially focused on the Humber River valley (Batterson and Vatcher, 1992; Batterson and McGrath, 1993; Batterson and Taylor, 1994), and was extended in 1996 to the northern part of St. George's Bay (NTS map sheets 12B/7 and 10), but excluding the Port au Port Peninsula (Figure 1). This region has some of the most extensive exposures of Quaternary sediment in the province. A section near Kippens contains marine mollusc fossils that have been radiometric dated (Brookes, 1977) to provide chronological control for the Robinsons Head glacial readvance, a major feature of the deglacial history of the west coast. However, detailed descriptions of the coastal exposures are lacking. The area of Port au Port East has been the site of recent coastal cliff failures, resulting in the loss of significant areas of cliff-top property (Forbes *et al.*, 1995). The area is the site of cliff-top residential development, small areas of market-gardening, and potential groundwater contamination problems.

During this survey, analytical work involved aerial photograph interpretation of the surface geology, ground checking and sampling, mapping ice-flow indicators from bedrock outcrops, and section description. Considerable time was devoted to describing the Quaternary stratigraphy exposed in coastal cliffs between Stephenville and the Port au Port Peninsula, in an attempt to provide a Quaternary stratigraphic framework for the northern part of St. George's Bay. Similar work in southern St. George's Bay was reported recently by Liverman and Bell (1996). An effort was made to be consistent in the terminology and subdivisions used by these authors to allow comparisons with this study.

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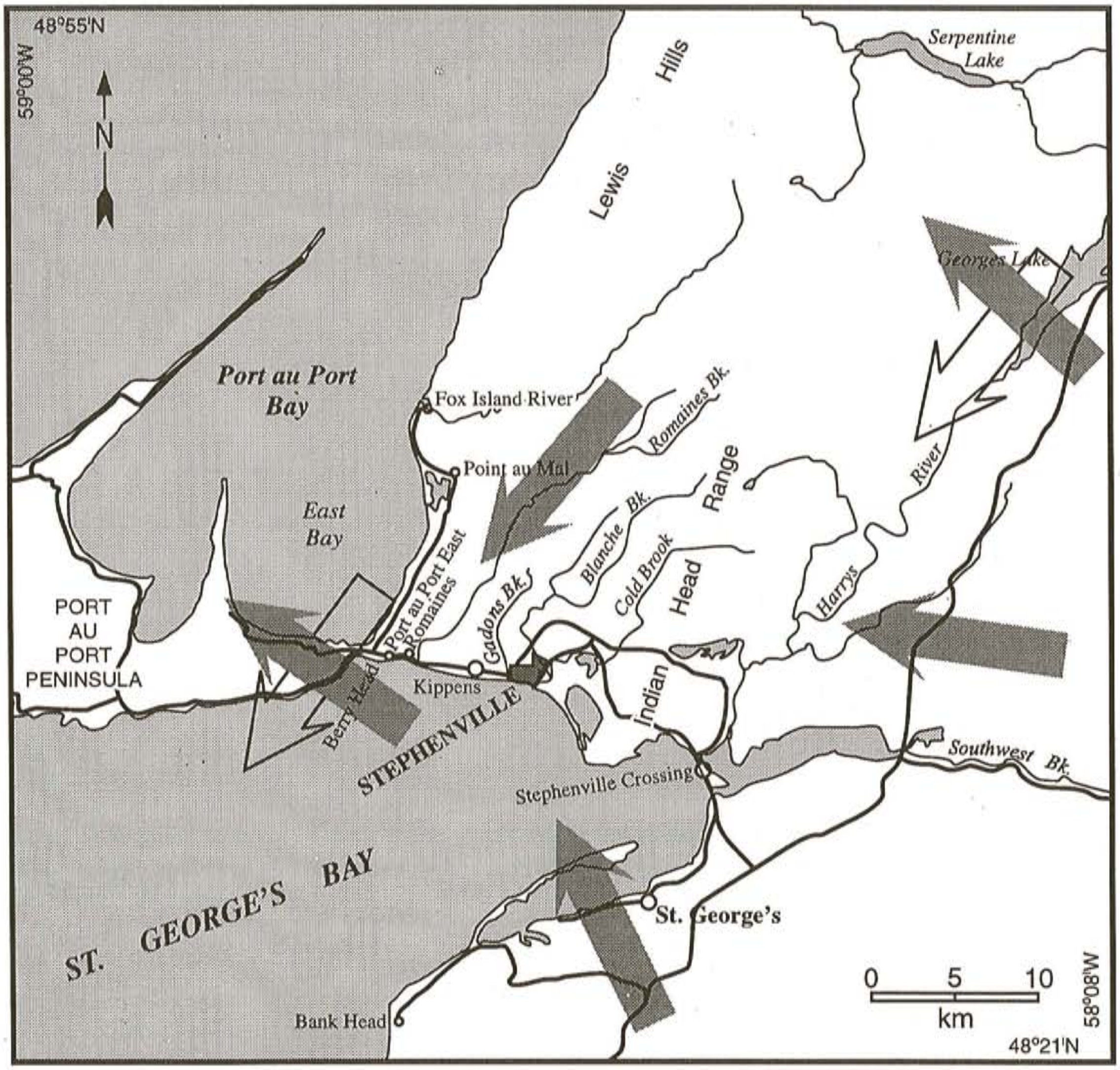

Figure 1. *Geography of the northern part of St. George's Bay showing paleo ice-flow directions.*

OBJECTIVES

The objectives of this Quaternary geological mapping program is the systematic identification, delineation and interpretation of unconsolidated deposits that overlie bedrock in the Humber River valley and northern St. George's Bay areas. It includes surficial geological mapping, mapping of ice-flow indicators, coastal change and sea-level history studies, modern processes (including geological hazards, such as landslide and avalanche), and their impact on the province.

LOCATION AND ACCESS

The study area is located from the Indian Head Range (between Stephenville and Stephenville Crossing), to the Port au Port Peninsula, and as far north as the Fox Island River valley (Figure 1). Paved highway crosses the southern and western parts of the field area, and logging roads extend inland from these. Access to the study area was by truck, all-terrain vehicles, or by foot. Remote areas were not visited.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Regressive cliffs of unconsolidated sediment dominate the northern St. George's Bay coast. A narrow coastal plain west of Romaines Brook has a generally flat surface, dipping westward with a slope of about 1:210. Cliffs are punctuated by numerous active gullies, and amphitheatrical depressions resulting from cliff failure. Cliff recession in this area is up to 1.25 m per year, based on digital photogrammetry (Forbes *et al.*, 1995), but is likely episodic. In 1994, a cliff failure about 1 km west of Romaines Brook resulted in about 60 m of headwall recession of a gully.

The coastal plain is wider east of Romaines Brook, and forms an undulating lowland, dissected by several north–south valleys, including Gadons Brook, Blanche Brook and

Cold Brook. This area also contains numerous large depressions, several of which back onto the coastal cliffs. Coastal erosion is less active in this area, generally less than 0.25 m per year (Forbes *et al.*, 1995).

The eastern part of the study area is flanked by Proterozoic gneiss of the Indian Head Complex that composes part of the Grenville basement. Bedrock exposures are common inland of the coastal plain, and are mostly Middle Cambrian to Middle Ordovician limestone, dolostone and shale (Table Head and Kippens formations). Overburden is commonly thin and discontinuous. Bedrock is rarely exposed on the coastal plain, but where found is Carboniferous floral-bearing sandstone (containing fossilized plants) of the Barachois or Codroy groups. Gypsum is exposed at Romaines, and strikes westward for several hundred metres.

PREVIOUS WORK

Coastal exposures around St. George's Bay were first examined by MacClintock and Twenhofel (1940), who distinguished a three-fold stratigraphy for the area consisting of a basal till (St. George's River Drift), a delta complex (St. George's Bay Delta), and surface ice contact sediments (Robinson's Head Drift). Brookes (1969, 1970, 1974) expanded this stratigraphy, and provided further details on the areal extent, character and relation to postglacial sea-level changes. The St. George's River Drift overlies bedrock, and outcrops in many places around St. George's Bay. It is described as a compact greyish pink to grey till, and is generally overlain by delta bottomsets and foresets of the St. George's Bay Delta that was deposited in the sea up to about 43 m asl. An exception was the area between Stephenville and just west of Romaines Brook, where there was a delay in raised marine sedimentation until the sea level had fallen to near 30 m. Farther west, the St. George's Bay Delta sediment extend to the surface. This delay was the result of a readvance or stillstand of the ice front termed the Robinsons Head readvance. Brookes (1970) mapped this readvance as extending from near Romaines Brook in the north of St. George's Bay, to near Highlands in the southern St. George's Bay, intersecting the coast as several lobes advancing from the Long Range Mountains and Table Mountain. The Robinsons Head readvance was dated at about 12 600 BP, based on a single date from marine shells found within a sand bed sandwiched between kame gravels at Kippens (Brookes, 1977). However, a section at Romaines, located at the western end of the Robinsons Head moraine, contains organic material that provides a conflicting view of the chronology (Grant, 1987; Proudfoot *et al.*, 1990; Liverman and Batterson, 1995).

Taylor (1994) recorded a complex ice-flow history in the Stephenville area. An early southwest (220°) flow is recorded on the Port au Port Peninsula, followed by a roughly westward flow from The Topsails ice centre, which became northwestward during the late stages.

Liverman and Bell (1996) described coastal cliff exposures in southern St. George's Bay, and suggested that sediment sequences could be explained by sedimentation along the grounding line of a tidewater glacier.

RESULTS

ICE-FLOW HISTORY

Striations on bedrock exposures along the coast, west of Berry Head, show an early southward (195°) ice flow crossed by a later northwestward flow (320°) (Figure 1). A similar relationship is recorded by clast fabrics from two diamictons at Kippens. The lower diamicton has a moderate fabric (S_1=0.68, S_3=0.06) having a preferred clast trend of 015°, overlain by a diamicton having a very strong fabric (S_1=0.91, S_3=0.02) and a preferred clast trend of 136°. Clast provenance data from the diamicton are consistent with these ice-flow directions.

Clast fabrics recorded inland commonly show strong preferred trends indicating southward ice flow. This is supported by striation data that shows a general southward trend to ice flow, mainly influenced by the southward orientation of slopes. This data suggests that the northwestward ice flow that crossed St. George's Bay from a source in the Long Range Mountains was likely restricted to coastal areas of northern St. George's Bay. The source of the southward ice flow is uncertain. It may have been from the Lewis Hills, or may have initially been westward-flowing ice from The Topsails, deflected southward along the Lewis Hills foothills.

QUATERNARY SEDIMENTS

Much of the coastline has good exposure of Quaternary sediment, particularly the area west of Romaines Brook, the area of most rapid cliff recession. Fifteen sections were examined in detail (Figure 2). Other areas were described briefly, or were covered by vegetation and therefore not examined. The following provides a brief description of the sediment found.

Diamicton

Diamicton was encountered as either thick (>2 m) beds at the base of sections, overlying bedrock (Plate 1), or as thin (<1 m) layers interbedded with mud, sand, or gravel, and was found also at the base of cliffs in 6 exposures along the coast. Generally, it is a compact, structureless, matrix-supported sediment having a very poorly sorted, fine sand to silt matrix. Moist colour ranges from dark reddish brown (5YR 3/2) to dark greyish brown (10YR 4/2). Clasts are of mixed rock types. Fine-grained clasts are commonly striated; clast fabric is variable. Some show strong (S_1=0.72 to 0.90; n=4) uni-

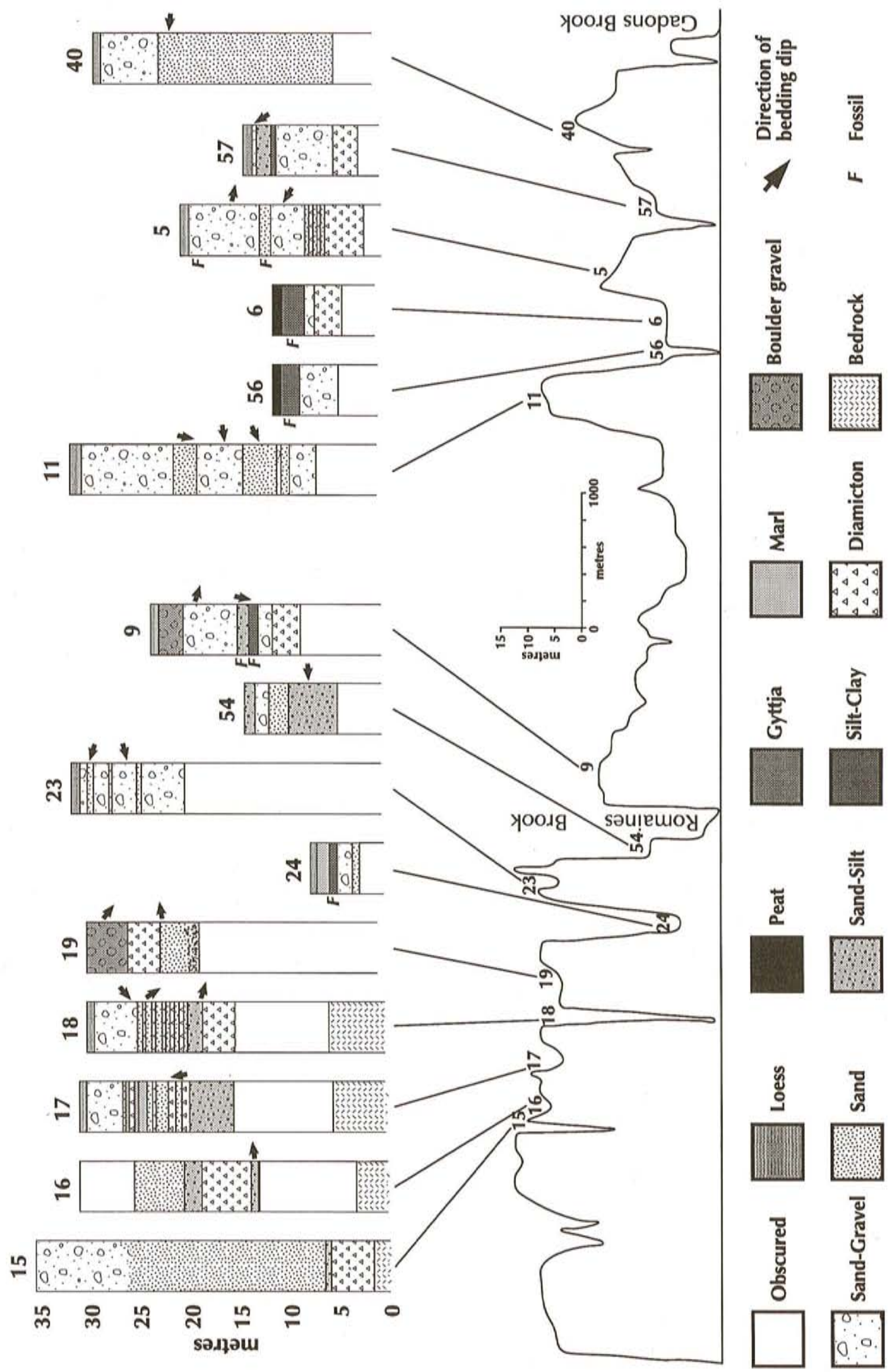

Figure 2. Summary of section logs of the coastal cliffs between Gadons Brook and Port au Port Peninsula.

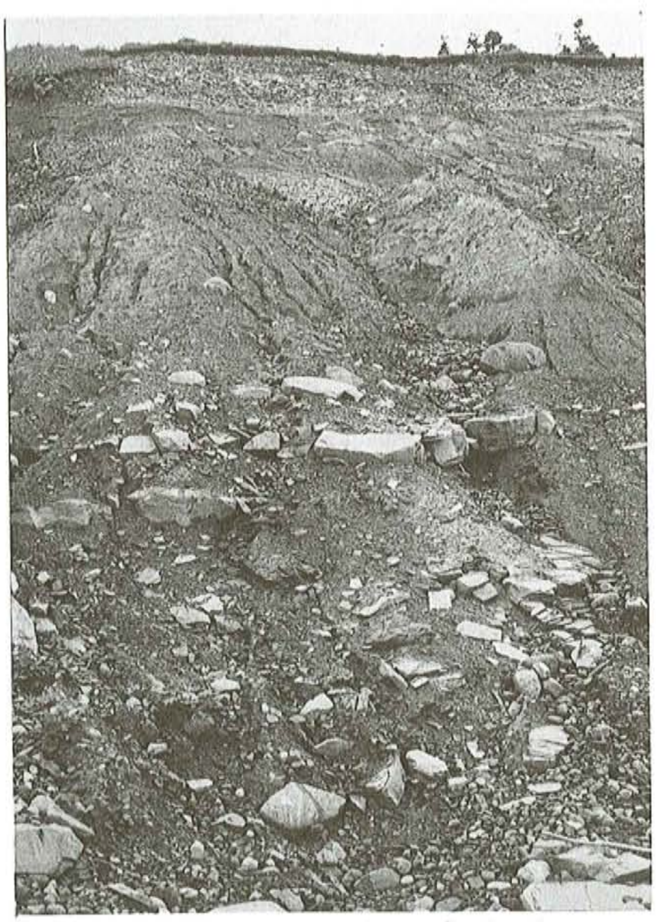

Plate 1. *Cliff face near Garbage Gully (Site 18). It shows bedrock at the base overlain by till, planar-bedded sand and silt, disturbed sands, and interbedded sand and gravel.*

directional trends, whereas others are weak (S_1=0.54 to 0.59; n=2) girdle fabrics. Diamictons are commonly overlain by mud, or interbedded mud, sand and gravel.

Diamicton found interbedded with sand, silt, or gravel have similar characteristics to that at the base, except that the beds are thinner (12 to 90 cm thick) and commonly inclined 12 to 20°. Some beds thicken downslope, and most are laterally discontinuous.

Thick, structureless diamictons located at the base of sections, commonly above bedrock are interpreted as subglacial tills. This is supported by the stratigraphic position above bedrock, strong unimodal fabrics having a preferred clast orientation similar to adjacent striae, and striated clasts (Dreimanis, 1988; Ashley *et al.*, 1985; Dowdeswell and Sharpe, 1986). Tills overlain by waterlain sediment suggests the glacier terminus was in standing water. Diamictons located on inclined surfaces above basal tills, and interbedded with sand, silt and/or gravel, are interpreted as sediment gravity-flow deposits, possibly formed in an ice-contact environment (Lønne, 1995; Lawson, 1988; Powell, 1981, 1984).

Mud

Fine-grained sediments (mud) are exposed rarely in the cliffs west of Stephenville. Generally, the mud is restricted to the lowlands, including Romaines (Site 24; Figure 2), and the lowlands west of the Kippens section (Sites 6 and 56; Figure 2). In these areas, the mud is generally structureless, although some small, planar- to irregular-shaped, normal-graded, fine sand lenses were noted. The mud is commonly fossiliferous, with cold, shallow-water fauna dominating (*Hiatella* and *Mya* species common). Fossiliferous mud commonly grades up into fossil-poor mud containing roots from freshwater flora. This gradation marks a transition from marine to freshwater conditions.

At two locations mud was found higher up the exposures. Just east of Romaines Brook (Site 9; Figure 2) a 60-cm-thick, well-sorted, weakly stratified, silty clay, containing rare granule to pebble clasts is found at 12 m asl. The mud is underlain by planar stratified, moderately sorted fine to medium sand to poorly sorted, medium to coarse sand and gravel, and are overlain across a gradational contact by 130 cm of stratified, moderately sorted, fine sand to silt containing rare clasts. The mud contains shells (mostly *Hiatella*), many of which were paired. East of the Kippens section (Site 57; Figure 2) is a thin (40 cm) bed of clay–silt rhythmites at 10 m asl; they are in sharp contact with the underlying, poorly exposed sand and gravel, and grade upward into interbedded sand–silt, with some sand beds containing silt–clay rip-up intraclasts. Individual clay–silt rhythmites are 0.3 to 1.0 cm thick, showing gradational within-rhythmite contacts and sharp between rhythmite contacts, and are commonly interlaminated with fine sand. Upper contacts are commonly loaded. Sand laminae contain oval- to irregular-shaped silt–clay rip-up intraclasts. In both sections beds are subhorizontal.

Mud found in lowland areas is interpreted as marine and freshwater and deposited by suspension settling from overflow currents (normal graded, subhorizontal bedding). The absence of clasts in these muds suggests that the ice was not in contact with water. Shells from marine mud have arctic affinities (Dyke *et al.*, 1996). Muds found higher in sections are interpreted as marine, confirmed by the inclusion of shells. Deposition was likely through a combination of suspension settling from overflow currents (suggested by the normal-graded rhythmites), or by underflow currents (shown by the sand laminae that loaded the underlying silts), and the inclusion of rip-up intraclasts (Mackiewicz *et al.*, 1984; Powell, 1981; Ashley *et al.*, 1985).

Sand and Silt

Interbedded sand and silt (up to 3 m thick) are common in exposures west of Romaines Brook, where they are found in 5 of 8 exposures, but are generally absent east of Romaines Brook. Beds are ungraded to normal graded, and commonly subhorizontal and disturbed. Silt laminae and beds are commonly loaded and show soft-sediment deformation structures, including drag folds and diapirs (Plate 2). Sand beds are commonly faulted and contain convexo-planar lenses of normal-graded fine sand to silt. Rare clasts were noted that disturbed bedding.

Plate 2. *Water escape structures in marine muds in exposure along shores of Port au Port Bay.*

These sediments are interpreted as subaqueous; they were deposited rapidly, dominantly by underflow, as suggested by normal grading, loading structures and faulting common throughout. Minor deposition by suspension settling from overflow currents, especially of finer grained sediments is possible. Rare clasts are interpreted as dropstones from floating ice (Thomas and Connell, 1985).

Sand and Gravel

Sand and gravel form the bulk of sediment found in the cliffs west of Stephenville. These deposits range from well-sorted sand, through various proportions of sand and gravel, to well-sorted gravel. Sand beds from 5 cm to 20 m thick were found. West of Romaines Brook, sand is interbedded with diamicton, sand and gravel, or gravel. Sand beds are commonly faulted and have water-escape structures. The amount of deformation was less east of Romaines Brook. Current-flow structures (ripples and crossbeds) were only noted west of the Kippens section (Site 11), and showed southwestward flow.

Well-sorted gravels are generally found as normal-graded to ungraded beds of open-work pebble to cobble gravel, interbedded with sand and gravel beds. Thicker (120 cm) clast-supported gravel beds were found in the cliffs between Romaines Brook and the marl exposure (Site 24).

Matrix-supported sand and gravel was found in every exposure examined. The matrix proportion varied between 15 and 60 percent, and was generally a poorly sorted fine to coarse sand. Sand and gravel beds show little internal structure, and are generally ungraded, although some normal-graded beds were noted. Sand and gravel beds are commonly crudely stratified, with individual beds inclined at 16 to 24°. The dip direction is shown on Figure 2, and it varied between east, west and south. The long axes of clasts showed little imbrication, but were commonly aligned parallel to the dip of the bed in which they were found. The exception was sand and gravel beds found close to the top of sections. These were 2.0 to 3.5 m thick, and were commonly crudely horizontally stratified, showing laterally discontinuous beds of sand and gravel, and sand. Rare trough crossbedding was noted (e.g., Site 9). Clasts were mixed rock types, and commonly imbricated. Near-surface sand and gravel beds have a sharp, horizontal basal contact, truncating underlying bedding.

Sand and gravel found within coastal exposures, commonly in inclined beds, and interbedded with sands and diamictons are interpreted as subaqueous deposits. Beds are commonly shallow dipping, below the angle of repose, and thus are unlikely to represent true deltaic deposits (Lønne, 1995). Individual beds were likely deposited by sediment gravity flow (grain flow?), rather than current flow. Hence, this is probably a subaqueous fan. The association with diamicton beds, particularly in sections west of Romaines Brook, suggests deposition in an ice-proximal environment, whereas the lack of diamicton beds and the finer grained sediment found east of Romaines Brook suggest the glacier was more distal.

Sand and gravel beds, showing imbricate clasts in crudely horizontally stratified beds found at the top of most exposures, are interpreted as fluvial gravels. No evidence, e.g., interbedded diamictons, high-angle crossbeds, or collapse structures, were found within these beds to suggest an ice-proximal environment. Many cliff-top areas are flat, inclined surfaces, rising generally northward, supporting the concept that the sediment consists of graded fluvial sand and gravel.

Marl

Rare exposures of marl are found along the coast. A large area west of Romaines Brook (Site 24) has been described and sampled by Grant (1987). The marl here is underlain by freshwater organic detritus. These sediments have been dated at 12 700 ± 110 BP (GSC-4017) from 2 m asl, and 11 500 ± 100 BP (GSC-4291) from 2.5 m asl. The freshwater sediment is underlain by fossiliferous marine mud. The sequence shows a marine to freshwater transition in a period of rapidly falling relative sea level (Grant, 1987; Proudfoot *et al.*, 1990; Liverman and Batterson, 1995). A similar stratigraphy is found in the lowland west of Kippens (Site 56), where a small area of marl is found.

Peat

Areas of peat, formed within small infilled freshwater ponds that occupied depressions along the coast during the Holocene, are restricted to lowland areas along the coast. Up to 120 cm of strongly humified peat are exposed in the lowland west of the Kippens section. Other areas of peat were noted in the lowland area east of Romaines Brook, although much of this area is obscured by vegetation.

Loess

Thin (< 75 cm) accumulations of fine sand and silt that cap much of the cliff top west of Stephenville are interpreted as aeolian deposits. They are found beneath, and within, the soil mat and are still actively accumulating in some areas.

MAJOR EXPOSURES

Although thirteen other exposures have been described in detail during field work, it is appropriate to review the Kippens and Romaines sections in detail because they are critical to the ongoing debate on the stratigraphy of Quaternary sediment, and the late-glacial history of the west coast.

Kippens Section

Review

The Kippens section is the chronostratigraphic section that dates the Robinsons Head readvance. It was first described by Brookes (1977), who interpreted the sequence as a basal diamicton (St. George's River Drift) overlain by kame sand and gravel that included a thin sand layer containing marine shell fragments dated at 12 600 ± 140 BP (GSC-2295). This date was used to constrain the age of the Robinsons Head readvance. The section was briefly examined by Liverman and Batterson (1995) who suggested the section may represent a prograding deltaic sequence into a shallowing postglacial sea.

Description

The Kippens section is a 20-m-high coastal exposure (Plate 3; Figure 3). The base is a dark reddish brown (5YR 3/2, moist) diamicton more than a metre thick. The unit is compact, structureless, and dominated by angular to subangular grey to brown micaceous sandstone clasts. Clast

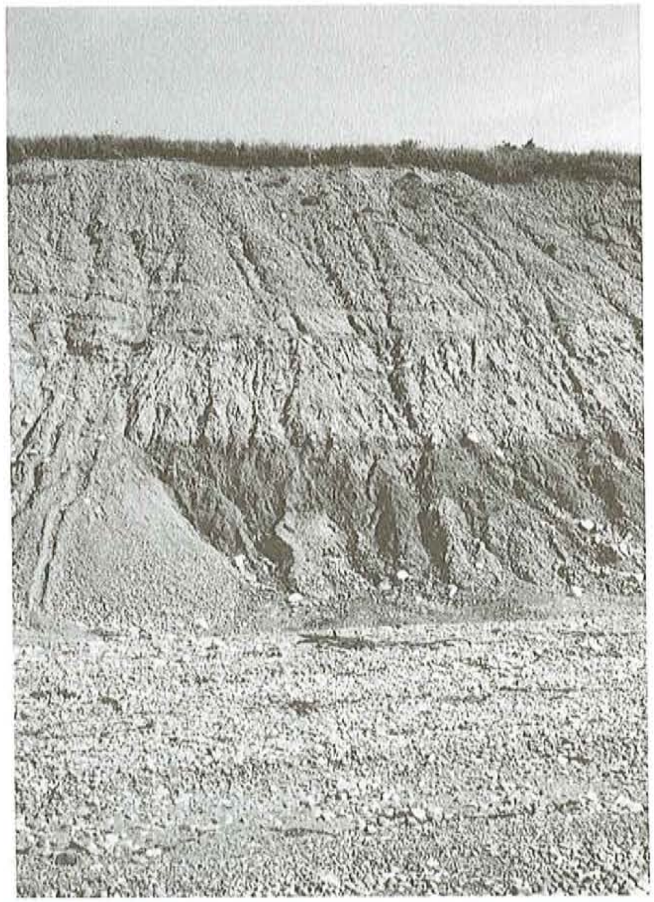

Plate 3. *Kippens section (Site 5). The four main stratigraphic units are shown – basal tills; coarse unit of interbedded sand, gravel and diamicton; thin sand bed; dipping unit of interbedded sand and gravel. The sand bed and the upper sand and gravel bed both contain marine shells dated at 12.6 ka.*

fabric is strong (S_1=0.68, S_3=0.06) showing a preferred trend toward the north (015°). It is overlain across a sharp, horizontal contact by 60-cm-thick, structureless, dark greyish brown (10YR 4/2, moist) diamicton. Clast rock types are mixed and include granites from the Long Range Mountains. Fine-grained clasts are striated. Clast fabric is very strong (S_1=0.91, S_3=0.02) having a preferred clast trend toward the southeast (130°).

The diamicton is overlain by 400 cm of interbedded silt, crudely stratified gravelly sand, open-worked granule to pebble gravel, and diamicton. Beds are commonly laterally discontinuous. Fine-grained beds include silt–clay rip-ups and also exhibit water-escape structures. Beds dip 15° toward 330°.

Overlying a sharp, undulating contact is a 70-cm-thick, poorly sorted gravelly sand to crudely planar stratified, fine to medium sand. Some boulders along the contact had

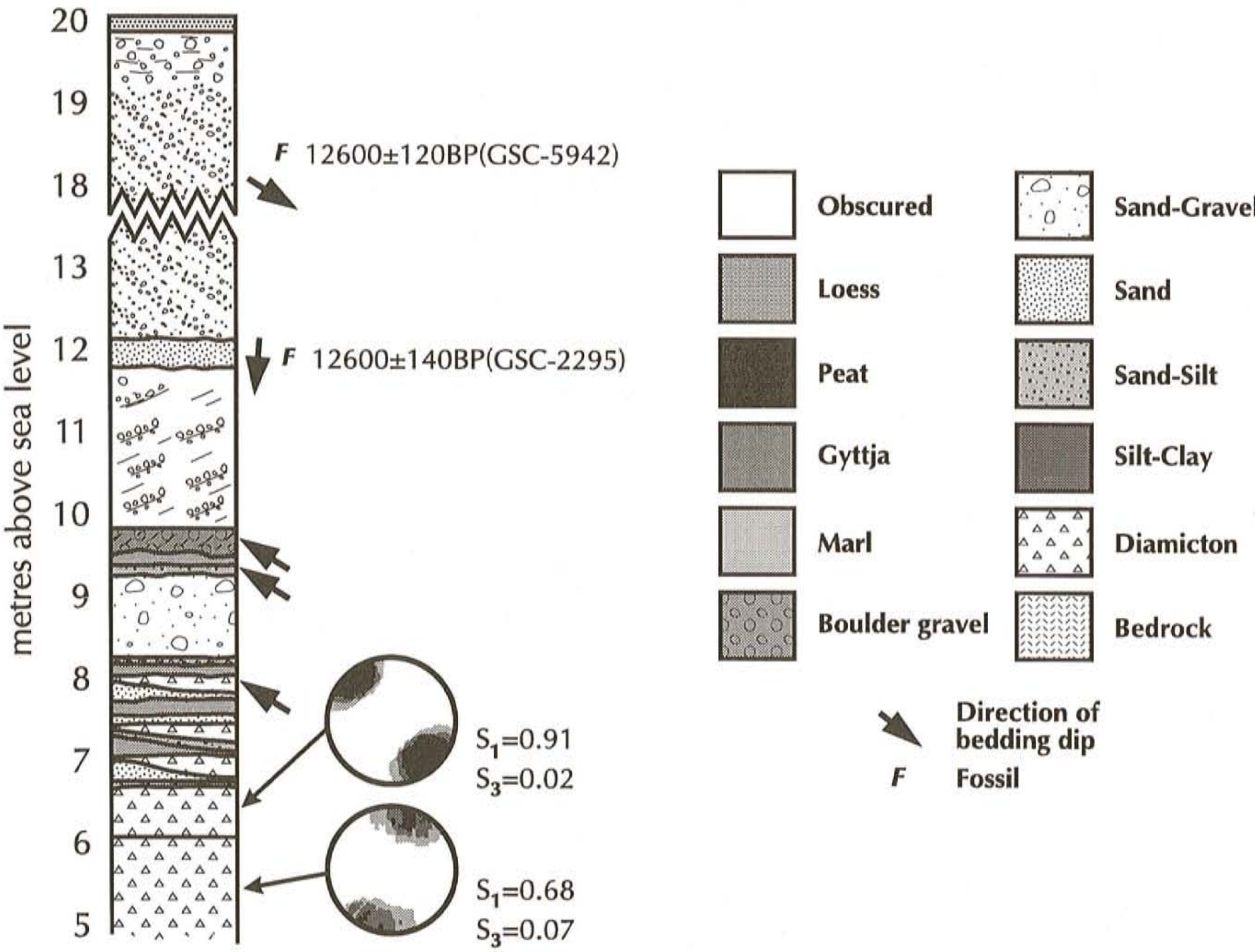

Figure 3. *Stratigraphic log of the exposure at Kippens (Site 5).*

barnacles (*Balanus* sp.) attached. The sand matrix contains shells (mostly *Mya truncata*), some in growth position. Shells from this section were dated at 12 600 BP (Brookes, 1977).

Overlying an irregular (loaded?) contact is about 7 m of interbedded sandy gravel and openwork pebble to cobble gravel. Beds are ungraded to normal graded, and commonly dip 20° toward 130°. Within one of the sandy gravel beds, whole *Hiatella arctica* shells were found (in 1994) and have been dated at 12 600 ± 120 BP (GSC-5942) (Table 1).

The gravels are overlain by about 2 m of poorly exposed, crudely horizontally stratified sandy gravel, commonly with imbricate clasts, dipping northward. The section is capped by 60 cm of loess.

Interpretation

Both the basal diamictons are interpreted as subglacial tills, although deposited by ice from different sources. The lower diamicton contains entirely locally derived clasts and were deposited by southward-flowing ice. The upper till contains more far-traveled material from sources to the southeast. This pattern of ice movement recorded by clast fabrics is consistent with striation patterns found on bedrock outcrops farther along the coast.

The overlying interbedded fine-grained sediment and diamicton are interpreted as being deposited in a subaqueous ice-proximal environment. Diamicton beds are interpreted as being deposited rapidly by sediment gravity flows. Rapid deposition is supported by loading structures found in the underlying sand–silt beds. Fine-grained sediments are mainly deposited by underflow currents, supported by the presence of rip-up clasts. Throughout the exposures, consistent shallow dips are more likely to be found associated with a subaqueous fan depositional environment, rather than a true delta.

Table 1. Radiocarbon dates discussed in text

Location	Latitude	Longitude	Laboratory Number	Adjusted 14C age (years BP)	Elevation (m asl)	Reference	Material
Romaines	48°33.26'N	58°41.1'W	GSC-4291	11500 ± 100	1	Grant, 1987; GSC Paper 87-7	Peat
Kippens	48°32.6'N	58°36.7'W	GSC-2295	12600 ± 140	10	Brookes, 1977	Marine shell
Kippens	48°32.57'N	58°38.00'W	GSC-5942	12600 ± 120	17	This paper	Marine shell
Romaines	48°33.3'N	58°41.1'W	GSC-4017	12700 ± 110	1.0	Grant, 1987; GSC Paper 87-7	Plant debris
Romaines	48°33.2'N	58°41'W	GSC-4858	12800 ± 130	6-8	GSC Paper 87-7	Marine shell
Romaines	48°33.2'N	58°41'W	GSC-4095	13100 ± 180	3	Grant, 1987; GSC Paper 87-7	Marine shell
Romaines	48°33'N	58°41'W	S-3074	13345 ± 230	6-8	Grant, 1991	Whalebone
Port au Port	48°33.8'N	58°42.6'W	GSC-1187	13400 ± 290	2	GSC Paper 71-7	Marine shell

– GSC Papers 71-7 and 87-7 refer to radiocarbon date lists

The gravelly sand to sand bed was deposited in a marine environment; the presence of marine bivalve and barnacle shells confirm this origin. Both *Mya* and *Hiatella* indicate cold water (<0°C) and salinities >30‰, and are typical of high-latitude pioneer assemblages following deglaciation (Dyke *et al.*, 1996). The laminated sediment, and the noticable absence of rip-up clasts, suggest that the laminated sediment was either deposited by suspension settling from overflow currents, or by underflow. Pebble to boulder clasts noted within the finer grained sediment were interpreted as dropstones from floating ice. This indicates that a glacier terminus was in contact with the water within St. George's Bay.

The overlying sediment is interpreted as being deposited within a subaqueous environment. Beds are inclined more steeply than the lower gravels, and may have been deposited within a marine fan or delta(?). However, the sediment source was different from that of the lower sediment. Bedding dips southeast, compared to northeast for underlying sediments. The absence of diamicton beds or faulting suggests an ice-distal environment. Such a transition in sediment type can be explained if the ice margin changes from marine to terrestrial, through either glacial retreat or sea-level fall. Sediments deposited near the top of the section have the characteristics of a glaciofluvial delta (Gilbert-type?), built by a proglacial outwash system. This is suggested by the grain size, inclined beds, bed continuity, and the presence of whole marine shells. Deposition was likely rapid, as shown by the loading of underlying fine-grained sediment. The alternative explanation of deposition as kame gravels within an ice-proximal environment (Brookes, 1977) is inconsistent with the exposed sediments. Structures and features of ice-proximal sedimentation, such as high-angle crossbeds, faults, diamicton interbeds or clasts, and rapid lateral and vertical grain-size variations are not found. The marine gravels grade up into fluvial gravels (topsets?).

The sequence suggests a history of initial ice-proximal glaciomarine sedimentation, followed by delta progradation produced by glacial retreat or a shallowing sea. The similarity of age on dated shells within the exposure suggests it was deposited over a short time period.

Romaines Section

Review

The section at Romaines lies at the western limit of the Robinsons Head moraine identified by Brookes (1969, 1974). At this location 'the kame moraine is a thrusted mass of sand and gravel. Large angular blocks of stratified sand "float" in structureless sand, along with huge crystalline erratics' (Grant, 1987, page 48). The flanks of this thrusted mass show marine silt overlain by freshwater marl. Dates from two marine shell samples and a whale bone (from the silt overlying the gravel) are 13 100 ± 180 BP (GSC-4095), 12 800 ± 130 BP (GSC-4858) and 13 345 ± 230 BP (S-3047), respectively (Table 1). These dates are from the sediment stratigraphically above those associated with the Robinsons Head readvance, and are thus not compatible with the 12 600 BP date from the Kippens section (Proudfoot *et al.*, 1988).

Description

This is a complex series of exposures within a large depression (Plate 4; Figure 4). The description here is summarized from 11 profiles completed over a lateral extent of 230 m. Figure 4 provides a sketch of the area, and the associated profiles.

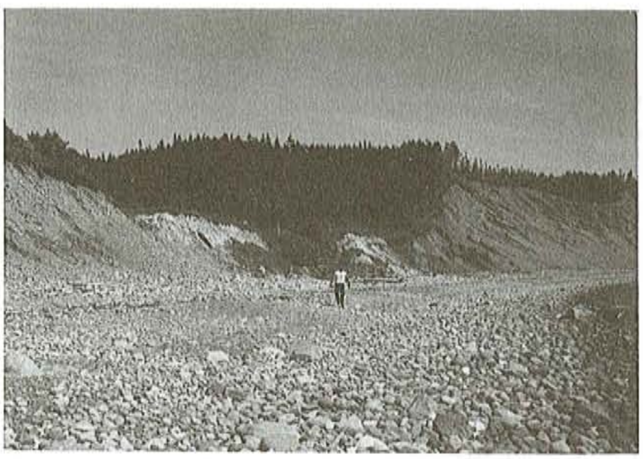

Plate 4. *Romaines section looking east. Marl underlain by sand and gravel occupies the central depression, flanked by interbedded sand, gravel, muds and diamicton.*

The eastern flank of the depression (Profile 1) shows interbedded sand and gravel and diamicton, with beds dipping 15 to 18° toward 270°, similar to the stratigraphy noted at Site 23 (Figure 2). The downdip margin of a diamicton bed is, however, steeply dipping (40°) and pinches out. Beds show a rapid lateral facies change downdip into pebbly sand, silty sand, and gravelly mud; some of the pebbly sand or gravelly mud beds are fossiliferous, with the highest found about 15 m asl. Both whole shells (mostly *Mya*) and fragments were found. Contorted and faulted beds are common. Individual beds are steeply dipping (up to 60°) and some beds are aligned parallel to the modern cliff face. The beds are discontinuous downdip, and are often not traceable for more than 10 m. The exception is a near-surface sand and gravel bed that is continuous over greater than 30 m downslope. It is underlain by fossiliferous sand to silt.

Cliff faces in the central part of the depression are generally obscured. Where exposed, the stratigraphy shows greater than 180 cm roughly horizontally stratified sand and gravel, commonly clast supported, and having open-worked granule to pebble gravel lenses. One sand bed, up to 30 cm thick, contains poorly developed current-flow ripples indicating a southward flow. Sand and gravel are overlain by pebbly mud having a bimodal grain-size distribution, and containing rare marine shells. The pebbly mud grades upward into weakly horizontally laminated sand and silt, gyttja, and up to 200 cm marl.

The western flank of the depression shows interbedded sand–silt, sand, sand and gravel, and diamicton. The fine-grained beds are weakly laminated, and faulted in places with offsets of up to 2 cm. Bedding is commonly contorted to disturbed. The diamicton bed is similar to that described from other areas along the coast, and contains numerous striated clasts of mixed rock type within a structureless matrix. Sand and gravel beds are crudely stratified, generally ungraded, with beds inclined roughly 15 toward 130° (i.e., toward the depression). Clasts have long axes commonly oriented parallel to bedding. Individual beds have sharp lower contacts.

Interpretation

The sediment in Profile 1 (Figure 4), composed of interbedded sand, sand and gravel, and diamicton, is similar to that found farther east (Site 23; Figure 2). The sediment is interpreted as an ice-proximal glaciomarine sediment, similar to those described previously. The area between Profiles 1 and 2 mark a change in the sedimentary environment. To the west, where there is no diamicton, sand and silt is common, some of which is fossiliferous, and some individual beds are steeply dipping. The sediment found on the eastern flank of the depression is generally subaqueous marine deposits. This is indicated by the presence of marine shells, many as whole, articulated specimens, found within these beds. The surface sand and gravel do not contain any shells and may be fluvial.

Preliminary interpretation of this area supports the concept of collapse into a depression. This is supported by the oversteepened beds, and the sheets parallel to the modern surface. Similarly, faulted and contorted beds are consistent with collapse. Brookes (1974) suggested that the rolling terrain from Romaines to Stephenville indicates kame and

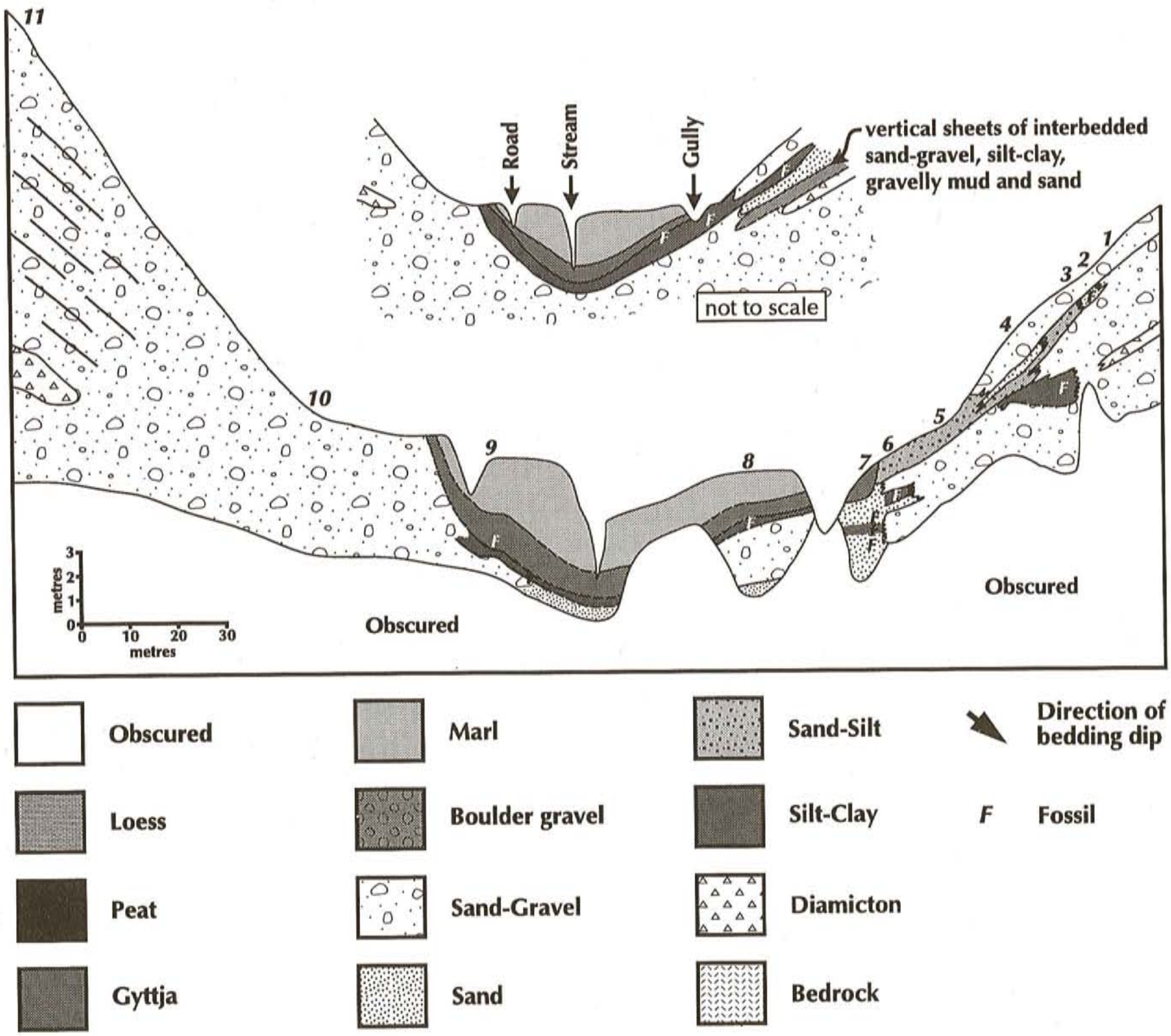

Figure 4. *Stratigraphic log of the exposure west of Romaines Brook (Site 24). Numbers 1 to 11 refer to individual section descriptions.*

kettle topography, supporting the concept of an ice-proximal environment. However, descriptions of sediment exposed in coastal bluffs does not indicate ice-proximal sedimentation. An alternative explanation is that the depressions are sinkholes from gypsum solution. Depressions are aligned roughly parallel with the strike of the gypsum bedrock exposed adjacent to Romaines Brook. Similarly, evaporite deposits are found around the Carboniferous St. George's Basin, particularly at Flat Bay, and it is possible that unmapped areas exist beneath Quaternary sediments between Flat Bay and Romaines Brook (I. Knight, personal communication, 1996). Grant (1989) maps a line of sinkholes east of Romaines Brook.

The base of the depression shows a relatively simple stratigraphy. The sand and gravel at the base are interpreted as glaciomarine. This is supported by upward grading of gravel-dominated beds into sand and fossiliferous mud. Beds are sub-horizontal, have a coarse texture, open-worked gravel lenses, normal grading within some beds, and rare ripples deposited by unidirectional current flow. The overlying sediment records a transition from a marine to freshwater environment (Grant, 1987).

The western flank of the depression has inclined interbeds of sand, sand and gravel, and diamicton, similar to that found in Profile 1 and farther east. The diamictons are interpreted as being deposited from sediment-gravity flows in an ice-proximal environment. The close association with subaqueously deposited sand and gravel suggests an ice-proximal glaciomarine fan or delta(?) environment.

The sediment at Romaines shows a complex depositional sequence. Sediment exposed on the flanks of the depression was deposited in an ice-proximal glaciomarine environment. The rapid facies change toward the centre of the depression indicates a change in depositional environment. The absence of diamicton beds, and the sequence of sand and gravel overlain by marine grading to freshwater mud, indicate a shallowing-marine to non-marine transition in which glacier ice is not in contact with standing water in this part of St. George's Bay.

SEDIMENT SEQUENCES

Preliminary interpretation of section logs is not consistent with the presented stratigraphy showing ice-contact sedimentation east of Romaines (Site 24), and deltaic sedimentation extending to the west (to about 44 m asl), with no evidence of a late-glacial readvance.

Sections near Romaines Brook and at Kippens show the contrast in sediment assemblages found along the coast. Sections west of Romaines Brook, particularly those between Berry Head and Romaines Brook, commonly contain diamictons interbedded with disturbed and loaded sand, and fine-grained sediment. Similarly, inclined beds of sand and gravel are generally ungraded, suggesting deposition by sediment gravity flow. The close relationship of fine-grained sediments, and diamicton beds, support an ice-proximal glaciomarine interpretation (Lønne, 1995). The gentle dip to inclined beds suggests deposition as an ice-contact submarine fan at the grounding line of a tidewater glacier (Figure 5). The glacier terminated in the sea, rather than on land because diamicton beds would otherwise have been reworked by glaciofluvial processes.

West of Berry Head, the sections appear to be sand dominated, and show no evidence of diamicton interbeds. Much of the cliff face in this area is vegetated, or obscured by slumping, and exposures are rare and small. To the north, in Port au Port Bay, coastal cliff exposure shows diamicton overlain by disturbed sand and silt, grading upward into crudely bedded sand and gravel. Beds dip 16 to 22° toward the west. The sections examined show no evidence of diamicton interbeds or ice-contact sedimentation, and are interpreted as a prograding deltaic sequence. Brookes (1974) reports a radiocarbon date on shells found at the base of the section at 13 400 ± 290 BP (GSC-1187), and is interpreted as a minimum date for deglaciation in this area.

The area east of Romaines Brook, away from the coastal lowlands (e.g., the Kippens section), shows basal diamicton overlain by interbedded sand, sand and gravel, and fine-grained sediments. Diamicton was generally not encountered above the basal till, except at Kippens, where interbedded diamicton and sand were found near the base of the exposure. Many other exposures have bases obscured by slumping, and thus it is possible that the stratigraphy exposed in the lower part of the Kippens section is repeated elsewhere.

Sand and gravel commonly form continuous beds that are inclined 15 to 20°; the direction of dip is variable. Gravel west of Romaines Brook dip toward 255 to 310°, whereas to the east, the gravel beds dip toward 120°. This may be interpreted to show fan or delta formation from a stream formerly occupying the Romaines Brook valley. Similar patterns are noted in sections on ether side of the Kippens lowlands (Sites 5 and 11), and in sections west of Gadons Brook. Gravel in the Kippens section dip roughly westward near the base, where close association with debris-flow diamictons show ice-proximal sedimentation. Beds are eastward dipping toward the top of the section. Individual beds are commonly continuous over tens of metres and are ungraded to normal graded, and were likely deposited by sediment gravity flow. Marine shells found within some gravel beds confirm a marine origin. The lack of diamicton, faulted or loaded sediments, and the rapid vertical and lateral changes in grain size suggest that the sediments are not ice proximal. As such, a glaciofluvial delta built by a proglacial outwash system is the preferred interpretation. The sand and gravel that caps most of the cliffs are interpreted as fluvial in nature.

Gravel sections, examined inland of the coast, generally show no evidence of near-ice conditions, and are interpreted as glaciofluvial. The exception is a small pit near the Stephenville dump that has a diamicton bed, interbedded with sand and gravel, and interpreted as a debris flow.

Liverman and Bell (1996) examined coastal exposures in southern St. George's Bay. They noted a contrast in sedimentary environment between 'ridged' and 'non-ridged' areas. Ridged areas were characterized by rapid vertical and lateral changes in sediment type, including sediments deposited from gravity flow, underflow, current flow and overflow, consistent with grounding-line deposition in an ice-contact glaciomarine environment. Non-ridged areas, found between the higher ridges are composed of sediment showing a relatively simple stratigraphy from a progressively shallowing marine to fluvial environment.

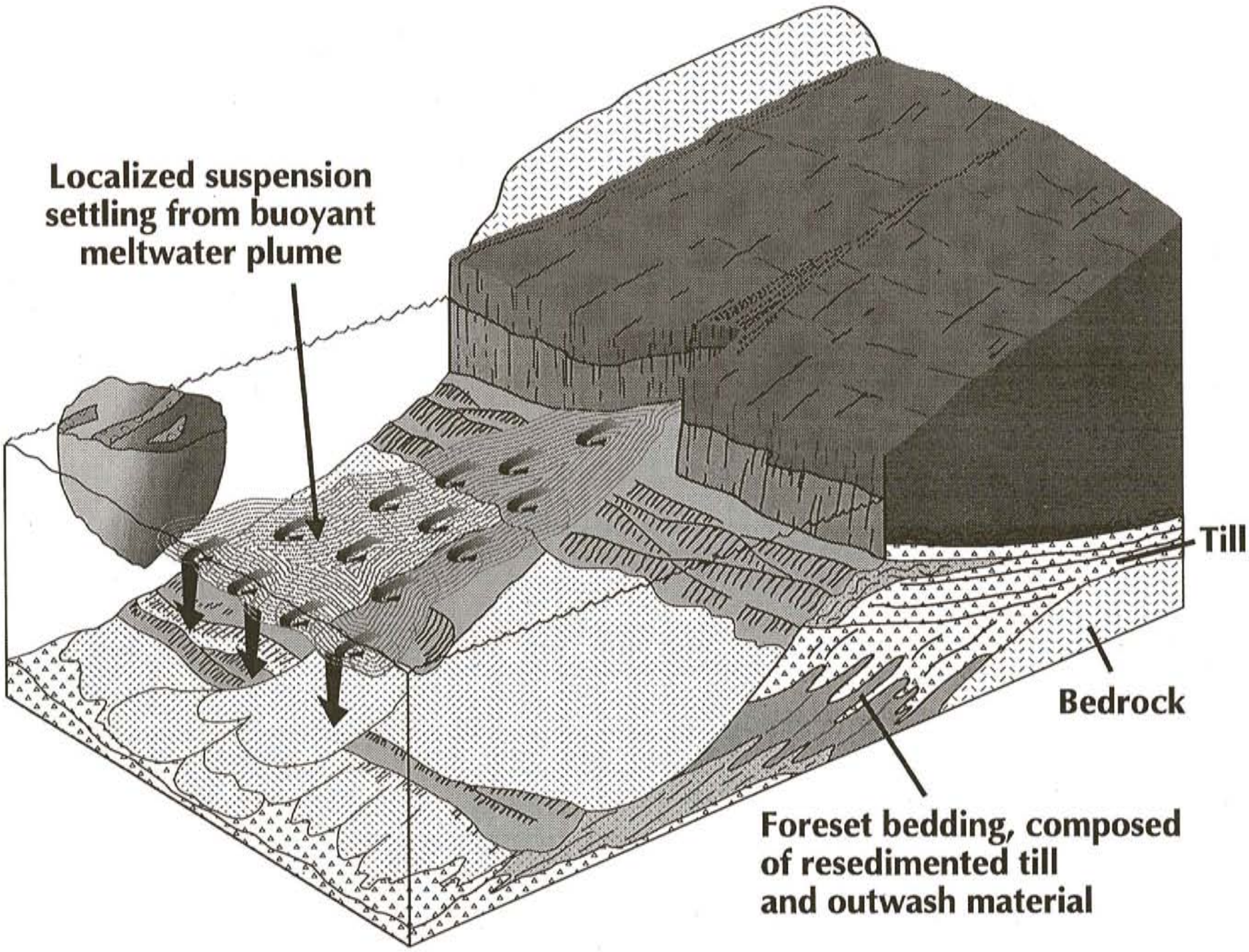

Figure 5. *Model of sedimentation at the margin of a tidewater glacier (after Lønne, 1995).*

Broad similarities exist between southern and northern St. George's Bay. Both areas record significant lateral variations in sediment type. Sections west of Romaines Brook bear a strong resemblance to the sections near Jeffrey's (Liverman and Bell, 1996) that characterize 'ridged' areas. The relatively simple stratigraphy, noted in the non-ridged areas at Fischells, Maidstone, and Journois (Liverman and Bell, 1996), is similar to that described near Kippens. Ridged areas in southern St. George's Bay are characterized by hummocky surface topography, whereas the non-ridged areas consist of gently sloping lowlands, dissected by a number of rivers. In the northern St. George's Bay area, the surface geomorphology differs in that areas west of Romaines Brook are slightly higher than those to the east, but eastern areas commonly contain adjacent hummocky areas, possibly related to the underlying gypsum bedrock. The provisional depositional model described by Liverman and Bell (1996) for southern St. George's Bay is a reasonable working hypothesis for events along the north shore.

Considerable erosion of the cliffs has occurred following deposition, and the position of the original cliff line is uncertain. The present cliffs have exposed a complex sequence of ice-proximal, non-glacial, and postglacial pond sediments and the cliffs west of Romaines Brook were formed in an ice-proximal environment. This area is adjacent to the foothills of Table Mountain, which may have been a source for the ice. Areas east of Romaines Brook are on a broad coastal plain that appears to be composed of sediment deposited in an ice-distal glaciomarine environment fed by glaciofluvial systems. Near-surface sand and gravel formed terraces that were part of fluvial systems graded to sea level. Glaciofluvial sediment is mapped for up to 7 km inland of the modern coast (Grant, 1991). Romaines Brook was likely a major conduit for ice flow, and sub- or proglacial drainage. The orientation of bedding in cliffs on the west and east sides of the brook show that a major delta was formed when sea level was at least 20 m higher than present.

DISCUSSION

MacClintock and Twenhofel (1940) and Brookes (1970, 1974, 1987) describe St. George's River Drift, St. George's Bay Delta (in restricted areas) and Robinson's Head Drift sediments that show the initial glacial advance, marine incursion and readvance (or at least late-glacial ice) in the northern St. George's Bay lowlands. The Robinsons Head readvance sediments were dated at 12 600 BP (Brookes, 1977).

In southern St. George's Bay, Liverman and Bell (1996) argued that the sediment sequences exposed there may represent deposition on grounding-line fans in an ice-proximal glaciomarine environment. Such a model shows progressive deglaciation of a coastline undergoing isostatic adjustment, and does not require glacial readvance. Sea level on this part of the coast is interpreted (Forbes *et al.*, 1993; Liverman, 1994) as dropping rapidly, falling below present about 13 000 BP.

Data from northern St. George's Bay suggests a similar conclusion to that of Liverman and Bell (1996). Sediment west of Romaines Brook is interpreted as being deposited on a grounding-line fan in a glaciomarine setting. They show gravity flow diamictons, interbedded with disturbed muds, and faulted sands, and sand and gravel deposited rapidly through a combination of underflow and channel flow. This area is beyond the limit of the Robinsons Head moraine mapped by Brookes (1970). Sediment to the east of Romaines Brook was deposited farther from the ice-front, and may be explained by a relatively simple deglacial sequence in a shallowing postglacial sea. The section at Kippens, previously interpreted as containing mostly ice-contact sediments, has been reinterpreted here as showing only initial ice-contact sedimentation, overlain by deltaic, then fluvial gravels. Marine shells found in foreset beds near the top of the sequence support this conclusion. In the Kippens area, surface geomorphology shows numerous near-coast depressions interpreted as kettle holes, supporting an ice-contact environment; these may be explained through an origin as gypsum karst sinkholes.

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REFERENCES

Ashley, G.M., Shaw, J. and Smith, N.D.
1985: Glacial sedimentary environments. Society of Paleontologists and Mineralogists, SEPM Short Course No. 16, 246 pages.

Batterson, M.J. and McGrath, B.
1993: Quaternary geology of the Deer Lake and Pasadena map areas (NTS 12H/3 and 12H/4). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 103-112.

Batterson, M.J. and Taylor, R.C.
1994: Quaternary geology of the upper Humber River area, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 1-9.

Batterson, M.J. and Vatcher, S.V.
1992: Quaternary geology of the Corner Brook–Pasadena area (NTS sheets 12A/13 and 12H/4). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 1-12.

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

1970: The glaciation of southwestern Newfoundland. Unpublished Ph.D. thesis, McGill University, Montreal, Quebec, 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 change. Canadian Journal of Earth Sciences, Volume 14, pages 2121-2126.

1987: Late Quaternary glaciation and sea-level change, southwest Newfoundland, Canada. *In* Geological Society of America. Centennial Field Guide, Northeastern Section, pages 445-450.

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

Dreimanis, A.
1988: Tills: their genetic terminology and classification. *In* Genetic Classification of Glacigenic Deposits. *Edited by* R.P. Goldthwait and C.L. Matsch. A.A. Balkema, Rotterdam, pages 17-83.

Dyke, A.S., Dale, J.E. and McNeely, R.N.
1996: Marine molluscs as indicators of environmental changes in glaciated North America and Greenland during the last 18 000 years. Geographié Physique et Quaternaire, Volume 50, pages 125-184.

Forbes, D.L., Covill, R.A., Feindel, R.D. and Batterson, M.J.
1995: Preliminary assessment of coastal erosion between Port au Port and Stephenville, St George's Bay, west Newfoundland. Geological Survey of Canada, Open File 3082, 10 pages.

Forbes, D.L., Shaw, J. and Eddy, B.G.
1993: Late Quaternary sedimentation and the postglacial sea-level minimum in Port-au-Port Bay and vicinity, west Newfoundland. Atlantic Geology, Volume 29, pages 1-26.

Grant, D.R.
1987: Quaternary geology of Nova Scotia and Newfoundland (including Magdalen 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.

1989: Quaternary geology of the Atlantic Appalachian region of Canada. *In* Quaternary Geology of Canada and Greenland. *Edited by* R.J. Fulton. Geological Survey of Canada, Geology of Canada, No. 1, pages 391-440.

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

Lawson, D.E.
1988: Glacigenic resedimentation: Classification concepts and application to mass-movement processes and deposits. *In* Genetic Classification of Glacigenic Deposits. *Edited by* R.P. Goldthwait and C.L. Matsch. A.A. Blakema, Rotterdam, pages 147-169.

Liverman, D.G.E.
1994: Relative sea-level history and isostatic rebound in Newfoundland, Canada. Boreas, Volume 23, pages 217-230.

Liverman, D.G.E. and Batterson, M.J.
1995: West Coast of Newfoundland Field Trip Guide. CANQUA-CCRG Joint Meeting, Programme, Abstracts, Field Guides, St. John's, Newfoundland, pages WC1-WC78.

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, Report 96-1, pages 29-40.

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

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

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

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

1984: Glacimarine processes and inductive lithofacies modelling of ice shelf and tidewater glacier sediments based on Quaternary examples. Marine Geology, Volume 57, pages 1-52.

Proudfoot, D.N., Grant, D.R. and Batterson, M.J.
1988: Quaternary geology of western Newfoundland. Field Trip Guidebook, Geological Association of Canada, St. John's, Newfoundland, 53 pages.

Taylor, D.M.
1994: Late Wisconsinan ice-flow patterns in southwestern Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 47-51.

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