Quaternary marine deposits of the Springdale - Hall's Bay area, Newfoundland

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Quaternary glaciomarine deposits form a complex sedimentary succession in the Springdale - Hall's Bay area of north-central Newfoundland. Marine incursion due to isostatic depression was extensive throughout the Indian Brook and South Brook valleys, reaching at least 10 km inland. Sedimentological, palaeontological, and geomorphological analyses have permitted reconstruction of the history of sea level change for the area since 12,470 years B.P. Stratified coarse sediment sequences with surfaces ranging up to 75 m above the present sea level were a result of higher sea-level stands. A succession of ice-contact deltas, representing the proximal units associated with the marine incursion, and a series of successively lower terraces (indicating isostatic rebound) are present. Most of the deposits were formed in ice-contact fan-deltas, but deposits at two sites are interpreted as ice-distal fans.

Clay and silt were deposited by a combination of suspension settling and sediment gravity flows in low energy, distal locations. Dropstones indicative of ice rafting are present throughout the clay strata. Vanadium concentrations in these deposits indicate deposition in brackish-marine environments. Shells of *Mya arenaria*, *Bålanus hameri*, *Macoma balthica*, and *Hiatella arctica* found in life positions also indicate brackish depositional environments. Four ^{14}C dates were obtained from the marine fossils giving an age range of 11,300 ± 120 to 12,470 ± 380 years B.P. This suggests that the silt and clay deposits represent the distal sediments associated with glaciomarine delta formation.

Les dépôts glaciomarins d'âge Quaternaire forment une succession sédimentaire complexe dans la région Springdale - baie Hall, dans le centre nord de Terre-Neuve. L'incursion marine reliée à l'enfoncement isostatique a affecté de grandes surfaces dans les vallées des ruisseaux Indian et South, pénétrant jusqu'à 10 km à l'intérieur des terres. Les analyses sédimentologiques, paléontologiques et géomorphologiques ont permis de reconstruire l'histoire des variations du niveau marin pour la région depuis 12,470 B.P. La présence de séquences sédimentaires grossières et stratifiées sont le produit de niveaux marins plus élevés. Il y a une succession de deltas formés au contact du glacier et de la mer, qui représentent les unités proximales associées à l'incursion marine, et une série de terrasses à des niveaux successivement plus bas (qui indiquent un rebondissement isostatique). La plupart des dépôts se sont formés dans des cônes deltaïques au contact du glacier et de la mer mais, à deux endroits, les dépôts sont interprétés comme étant des cônes formés à distance du glacier.

L'argile et le silt ont été déposés par une combinaison de suspension et de courants de turbidité en des milieux distaux et de basse énergie. Des cailloux de délestage, indicateurs de transport par glaces flottantes, sont présents dans toutes les couches d'argile. Les concentrations en vanadium de ces dépôts indiquent des milieux marins saumâtres. Les coquilles de *Mya arenaria*, de *Balanus hameri*, de *Macoma balthica*, et de *Hiatella artica*, trouvées en position de vie, indiquent aussi des milieux de déposition saumâtres. Quatre datations par ^{14}C obtenues sur des fossiles marins ont donné un intervalle de 11,300 ± 120 à 12,470 ± 380 B.P. Ceci suggère que les dépôts de silt et d'argile représentent des sédiments distaux associés à la formation de deltas glaciomarins.

[Traduit par le journal]

INTRODUCTION

The sea level history of the northern shelf area of Newfoundland is relatively poorly known. The coastline is dominated by erosional processes, and therefore few exposures of glaciomarine sediment have been preserved. Analysis of the available exposures is thus crucial to an understanding of sea level changes post-dating deglaciation of the region. This study discusses the postglacial sedimentary record preserved in one of the few regions marked by extensive glaciomarine deposits, the Springdale - Hall's Bay region of north-central Newfoundland.

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Location and Physiography

The study area is located in the Springdale - Hall's Bay area of Newfoundland, lying between 49°20'N and 49°32'N and 56°00'W and 56°15'W (part of NTS 12H/8 and 12H/9) (Fig. 1). It covers a 400 km^2 area and includes Hall's Bay, South Brook, Springdale, and Indian River Provincial Park. The major river in the area is Indian Brook. Other rivers, separated by bedrock ridges up to 200 m in height, include Burnt Berry Brook, Riverhead Brook, and South Brook (Fig. 2). Lakes are common and include South Pond, West Pond, Burnt Berry Pond, and Loon Pond.

Elevations are low throughout the region, with 40% of the area lying below 75 m above sea level (a.s.l.). Lowlying areas are generally covered by sands and gravels of marine or glaciofluvial origin whereas the land above the 75 m level consists of bare or vegetated rock. A large expanse of sand and gravel crops out on the east side of Hall's Bay. Wave cut terraces are present along the shores of West and South ponds. The only visible constructional landforms appear to be deltas around South Brook, Springdale, Dock Point, and at the south end of South Pond. The distribution of glaciomarine sediments suggests that West Pond and South Pond were once connected to fiords and have subsequently been cut off from the sea.

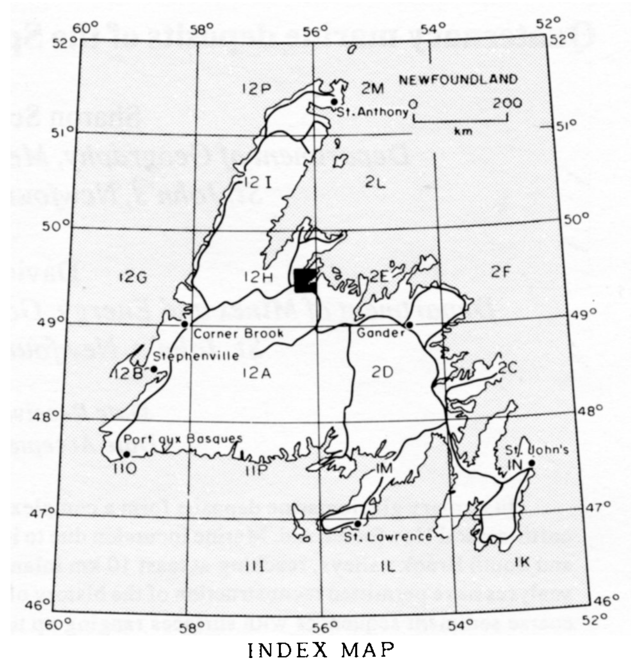

Fig. 1. Location Map of Study Area.

Objectives

The objectives of the study were:

(1) to study the geomorphology of the area;
(2) to describe the sedimentology of suspected lateglacial glaciomarine sediments, in order to determine their origins and modes of genesis;
(3) to describe the fossil assemblages present; and
(4) to integrate geomorphology, sedimentology, and palaeontology to determine the history of sea-level changes and the deglacial palaeogeography of the Springdale area.

Field work for this study was carried out over a four-month period during the summer of 1990 and 1991. Laboratory analysis took place over a two-month period during the winter of 1990-91. Natural river and road cuts in the area were examined, and detailed descriptions recorded. Samples were obtained for textural and geochemical analysis and small scale features in the sediment, such as loading and soft sediment deformation features, were examined. Shells were described, identified, and submitted for ^{14}C dating. The orientations of all paleocurrent indicators were measured using a Brunton compass according to Woodcock's (1979) method. An altimeter was used to measure the elevation of the tops of sections, with compensation for drift made by recording the time of the reading at each location and subsequently returning to a known altitude.

The results of this study permit the development of a model for glaciomarine sedimentation in the Springdale - Hall's Bay area. Chronological data for sea-level changes, together with the sedimentological analyses, will enable future correlation with off-shore sedimentary assemblages. This, in conjunction with other investigations along the northern shelf coast, will help in the eventual construction of a sea level curve for the area.

Previous Work

Following the Late Wisconsinan deglaciation of the Springdale - Hall's Bay area ±11,000 to 12,000 years ago, raised sea levels, due mainly to isostatic depression, resulted in marine inundation of areas lying below 75 m above present sea level (Tucker, 1973). As a result of subsequent isostatic rebound, raised marine deposits occur along the shores of Hall's Bay.

Richards (1940) identified two shells found by MacClintock and Twenhofel (1940), from red marine silts at Springdale as *Saxicava arctica* (now *Hiatella arctica* L.) and *Balanus crenatus* (barnacle). These species indicate a brackish, probably shallow-water environment. MacClintock and Twenhofel (1940) briefly described large deltas at 75 m a.s.l. at Springdale and South Brook and interpreted them as having formed from glaciers draining into Hall's Bay. Jenness (1960) believed that these deltas were contemporaneous and used their levels in the construction of an isobase system. The western part of the delta at Springdale contains beds dipping to the east, which were believed to indicate sediment transport from ice in the Indian Brook Valley. Lundqvist (1965) suggested that the delta at South Brook Valley was deposited in front of an ice tongue, as the existence of such a lobe was demonstrated by several lateral drainage channels on the southern side of West Pond.

A sample of *Balanus* sp., found by Grant (1974) in a terrace located at the head of Hall's Bay, was ^{14}C dated at

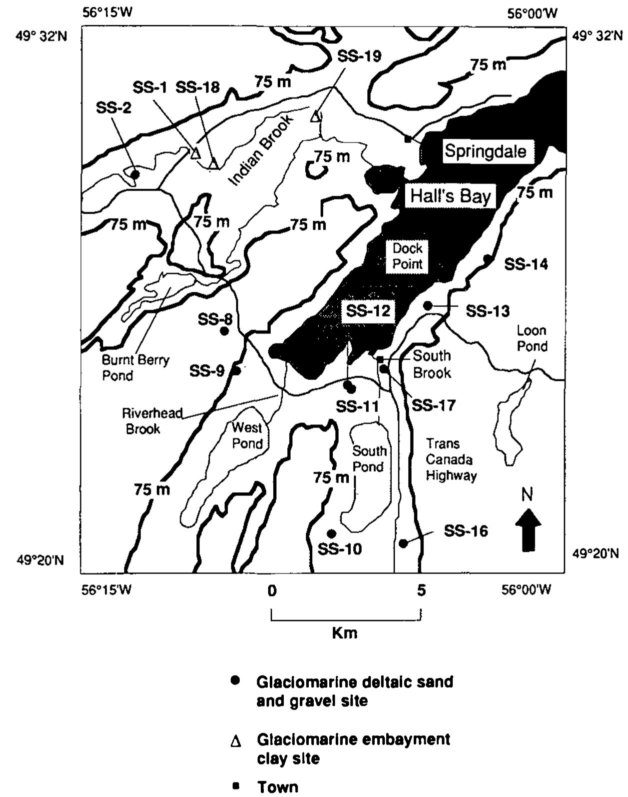

Fig. 2. Location of features and sites named in text.

12000 ± 220 years B.P. (GSC-1733). This date was interpreted to represent the time of formation of the 75 m a.s.l. glaciomarine deltas on the northeast coast of Newfoundland. A ^{14}C date of 11,000 ± 190 years B.P. (GSC-2085; Lowdon and Blake, 1975) on *Mytilus edulis* and *Hiatella arctica* shells found in gravels interpreted as delta bottomsets, near South Brook (Tucker, 1973) was also interpreted to date the glaciomarine deltas.

Tucker (1974) identified five marine terraces in the South Brook area at 66, 60, 54, 15, and 9 m a.s.l., which formed as a result of isostatic rebound. He suggested that the maximum postglacial emergence was 75 m, and that an ice front situated in Hall's Bay calved rapidly, resulting in recession, until the ice became landfast in Indian Brook and in areas to the south. The ice front remained in this position as the delta was being deposited.

Tucker (1973) described silt and sand rhythmites in the Springdale area but was unable to determine if they were marine or lacustrine in origin. Vanderveer (1977) described a clay deposit, located east of the bridge over Indian Brook near Springdale, as a varved sequence containing some lenses of silt and sand, which was overlain by sand and gravel. Grant (1986) published surficial maps for the NTS 12H/8 and 12H/9 map areas, which showed sand and gravel deltas around Hall's Bay.

At Indian River Provincial Park, a groundwater well was drilled in 1987 by the Newfoundland Department of Environment and Lands at a surface elevation of approximately 53 m. Samples showed sands and gravels to an elevation of 51 m a.s.l. and clay from 51 to 50.5 m a.s.l. Samples were not taken between 50.5 and 31 m a.s.l. Sands and gravels were present at 31 m, clay at 30 m, and a lower sand and gravel unit at the bottom of the test hole at 25.6 m a.s.l.

Liverman and Scott (1990) briefly described the exposures east of the bridge over Indian Brook along route 390 as consisting of a well sorted, laminated and bedded silt and clay unit up to 10 m thick. The deposit was interpreted to represent an ice-distal glaciomarine environment. Scott and Liverman (1991) gave detailed descriptions of several clay and sand and gravel deposits in the Springdale area. It was determined that the clays represented marine incursion and were deposited by suspension settling and sediment-gravity flows. The deltaic sections were interpreted to represent a progressive lowering of sea level since deglaciation.

SEDIMENTARY ASSEMBLAGES

Highest sea level in the area was 75 m above present sea level (Tucker, 1973). Ten sections indicating deltaic deposition above present sea level were located. Three sections containing marine clay units were also found. The ice proximal deltaic sediments are discussed first, followed by the more distal deltaic sediments and finally the distal clay deposits. The locations of these sections are shown on Figure 2.

Glaciomarine deltaic sand and gravel sections

The deltaic sections are divided into two distinct groups. Only a few type sections will be discussed for each group as these demonstrate common characteristics found in the other sections. A detailed description of all the sections would be repetitive.

Proximal deltaic sediments

Sections SS-2 (68 m) at Indian River Provincial Park; SS-8 (72 m) and SS-9 (20 m), both on the terrace between West Pond and Hall's Bay; SS-10 (50 m) at the southwest end of South Pond; SS-11 (64 m) and SS-12 (64 m), along the woods road between South Pond and Hall's Bay; and SS-16 (51 m) southeast of South Pond on east side of the Trans-Canada Highway, all consist of interbedded, poorly sorted, sands and gravels with beds dipping seaward to the north.

Site SS-12

In contrast to the well sorted sand and gravel beds at site SS-16, Site SS-12, at an elevation of 64 m, consists of interbedded, poorly sorted sands and gravels. This section is divided into three units and contains structures not seen at site SS-16. The basal unit, 1 (3.9 m thick), consists of structureless fine to coarse sand in beds ranging up to 70 cm in thickness, with less than 2% subangular to subrounded fine pebbles. Some beds contain fining upward sequences. All the beds dip at 18° north (seaward). Approximately 5% of the beds are marked by thin layers of subangular to subrounded pebbles 0.5 to 1 cm in diameter along the basal contacts. The upper part of this unit contains an upwardly increasing number of medium pebbly sand beds, containing about 45% subrounded to well rounded pebbles 0.5 to 8 cm in diameter.

Unit 1 is interpreted to represent proximal sedimentation in the embayment. The fining upward sequences in the horizontally laminated sands resulted from pulses of flow from delta foresets (e.g., Prior and Bornhold, 1988; Soegaard, 1990).

Unit 2 (1.9 m thick) consists of well sorted, fine to coarse sand beds 10 to 70 cm thick. The beds dip from 26° north in the northern part of the section to 18° north in the southern parts. Some beds pinch out laterally, have a channelized appearance and both the upper and lower contacts are sharp. Convexo-concave channel lag infill deposits are visible at the base of this unit. This may suggest some buried ice in the deposit (Miall, 1977). Many of these beds contain no large clasts, whereas others have less than 4% subrounded to rounded fine pebbles. Climbing ripples with preserved stoss laminations (type B of Jopling and Walker, 1969) are present, with an average wavelength and amplitude of 15 cm and 1.5 cm respectively. The ripples indicate flow to the north and northeast.

The depositional stoss climbing ripple drift cross-laminations develop where sediment loads exceed the transport capacity of flow, and where flow velocities are low (Stanley, 1974; Ashley *et al.*, 1982). Development of climbing ripples requires rapid, periodic sediment accumulation, and is common in glaciofluvial sequences marked by seasonal fluctuation in flow discharge and velocity. Fining upwards sequences commonly present within the ripple drift indicate successively increasing suspended load/bedload ratios, as flow velocity declined during each discrete accumulation event. This is typical of a braided stream deposit (Miall, 1977).

Foreset deposition is represented by the dipping beds of unit 2. The depositional stoss ripple lamination indicates that sediment fallout was high relative to the rate of ripple migration. These conditions would be expected to exist in an ice-proximal delta, where abundant sediment was in transport (Harms *et al.*, 1982). The seaward dip of the beds and the morphology of the area suggests that this deposit represents a delta sequence.

Unit 3 consists of 2 m of poorly sorted, flat lying, sand and gravel beds (20 cm to 1 m thick), with approximately 50% subangular to subrounded pebbles and cobbles, 0.5 to 12 cm in diameter. These beds truncate the underlying dipping beds of unit 2. There are channels cut throughout the unit.

The coarseness of this sediment, together with the erosional contact with the underlying deltaic units, suggest that unit 3 was either formed by postglacial fluvial activity unrelated to delta development or as topset outwash as the delta was prograding and isostatic uplift was occurring. The sedimentary structures and texture associated with this unit are typical of those found in modern stream sediments throughout the region. The orientation of the channels indicates that current flow was not related to the position of the former ice margin.

Site SS-16

The landform that occurs at site SS-16 is at an elevation of 51 m. It is typical of the seven deltaic sites mentioned in the introductory paragraph of the sand and gravel section. Geomorphologically, it has a fan shape with a sloping upper surface that has been channelized. The section is comprised of 7 m of interbedded, well sorted, fine sand and pebbly sand beds 15 cm to 1 m thick that dip 22° north-northwest (seaward). The fine sand beds are mostly structureless except at the base of the section, where some beds show horizontal laminations 1 to 5 cm in thickness. Fining upwards sequences are present. Some of these fine sand beds contain plano-convex sand lenses, with less than 2% medium to coarse pebbles. The pebbles in these lenses are subangular. Normal epigenetic faulting is visible in some sand beds.

The moderately sorted pebbly sand beds range from 5 to 50 cm in thickness. Clasts are subangular to subrounded, and are 1 to 6 cm in diameter. Contacts are sharp. The beds are generally structureless, although coarsening upward sequences were observed. Some beds also contain irregular shaped lenses, 1 to 3 cm in maximum length, made up of coarser, pebbly sand. Similar sedimentary successions are present at most of the other deltaic exposures.

Site SS-16 is interpreted as the proximal part of an ice-contact delta, developed along the southward-trending embayment currently occupied by South Pond. The gently sloping terrace abutted glacial ice at its eastern margin, as indicated by the absence of sand and gravel to the southeast of the section and by the flat, channelized upper surface. The lithology and shapes of the pebbles in the deposits are similar to those of glacigenic diamictons in the region.

Foreset deposition is represented by the north-northwest dipping beds. The coarsening-upward sequence and truncation surfaces suggest that deposition resulted from episodic, high velocity events. Similar sequences have been observed in many ice-proximal braided river systems (e.g., Boothroyd and Ashley, 1975; Miall, 1977; and Maizels, 1989). The irregularly-shaped pebbly sand lenses may represent partially preserved transitory dunes developed during periods of maximum flow, and subsequently eroded.

Proximal sedimentation in the embayment is represented by the horizontally laminated fine sand units at the base of the section. Successive pulses of flow from the delta foresets resulted in deposition of the fining-upward sequences, as energy levels diminished in each pulse (Ashley *et al.*, 1985). Suspension settling and turbidity current activity were thus jointly responsible for deposition of the sediments in the embayment. Similar successions have been observed in modern high-gradient deltaic systems (e.g., Prior and Bornhold, 1988). High sedimentation rates, which would be anticipated in an ice marginal setting (Powell, 1984), are indicated by the epigenetic normal faulting.

Distal deltaic sediments

Three sections—SS-13 (74 m), located at the South Brook waste disposal site; SS-14 (72 m), along the woods road 1 km from the waste disposal site; and SS-17 (13 m), in South Brook—consist of interbedded moderately to poorly sorted sands and gravels which are generally better sorted and finer grained than the two sections discussed above. These sections have expanses of sand and gravel extending for 1 to 2 km south of the outcrops.

Site SS-13 is divided into three units (Plate 1). Unit 1 consists of 6.4 m of well sorted, medium to fine sand beds, structureless interbedded pebbly sands, and granule gravel strata. Contacts range from gradational to sharp between sand beds. Within the sand beds at the base of this unit are convexo-concave lenses of fine sand and silt, 1.5 cm thick and 2 cm long, that fine upward. Pebble concentrations in the sand beds are less than 2%.

The granule gravel beds are poorly sorted, range from 8 to 18 cm in thickness, and dip 28° to the north (seaward). The pebbly sands are moderately sorted and range from 5 to 10 cm thick, with subangular pebbles 1 to 6 cm in diameter. These units have pebble imbrication indicating flow to the northwest, and some show fining upward sequences transitional to open worked gravel.

Unit 2 consists of 3.8 m of fine sand beds with silt and clay drapes and interbeds of granule gravel. The beds dip 24° to the northwest and are commonly laterally discontinuous. The sand beds show some fining upward sequences, and contain less than 1% pebbles. Ripples indicating flow to the north and northwest with an average amplitude and wavelength of 2.5 cm and 9 cm respectively are present in the upper 1.5 m.

The granule gravel beds are 5 to 70 cm thick, moderately sorted, lack matrix, and are structureless. Contacts between all beds are sharp. Some of the sand beds in this unit contain syngenetic reverse faults striking to the northwest with displacements of 1 to 4 mm at an angle of 25°. The faults do not continue into the overlying sediments.

The syngenetic reverse faulting in unit 2 suggests loading of the sediment, possibly by flows (e.g., McKee and Goldberg, 1969). Ripples in unit 2 indicate current flow to the north and northwest (seaward).

Units 1 and 2 are interpreted to represent a distal deltaic sequence. The energy levels represented by the granule gravel, medium sand, and rippled fine sand beds are lower than those responsible for the coarse, proximal deposits of SS-12 and SS-16. The greater proportion of silt and clay and the syngenetic reverse faulting suggest formation in the distal parts of a deltaic sequence, rather than in the fluvial channel-dominated proximal area. The fine to medium sediments, ripples, low angle dips, and deformational structures all suggest a fan style environment with deposition from underflows (Shaw and Ashley, 1988). Similar deposits have been discussed by Postma *et al.* (1988). The open-worked gravel beds were produced by subaqueous reworking of the deltaic sediment (Shaw and Ashley, 1988). Flow was towards the north-northwest, into the Hall's Bay Embayment.

Plate 1. Panoramic view of SS-13. The basal sand and gravel beds of unit 1, dipping to the north, are conformably overlain by the fine sand beds of unit 2. The sequence is capped by flat lying lateglacial fluvial sediment.

The proximal sediments associated with SS-13 are represented by the expanse of sand and gravel extending 1 to 2 km south of the site. Although no exposures are present in this area, the texture of the surface sediment is similar to that present at sites SS-12 and SS-16. On aerial photographs, the sand and gravel expanse resembles the terrain surrounding the proximal deltaic sections.

The uppermost unit, 3, is comprised of 80 cm of flat lying to channelized, pebble granule gravel interbedded with fine sand. The beds are well sorted and contain some silt and clay laminae. The basal contact is sharp, truncating the dipping beds in unit 2.

Unit 3 is interpreted to have formed by lateglacial fluvial activity. The coarse nature of the sediment and the erosional bottom contact suggests it is not related to the delta development. Structures in this unit are typical of modern stream sediments in the area.

Summary of Glaciomarine Deltaic Sand and Gravel Sections

The majority of the deltaic sediments, such as those exposed at SS-12 and SS-16, were deposited in contact with glacial ice, as indicated by the coarse clasts and poor sorting of the sediment. The ice front is believed to have been at 75 m a.s.l. along the west side of Hall's Bay (based on the presence of delta surfaces at 75 m). To the east of Hall's Bay, ice was further inland from the coast, as demonstrated by the presence of gravel extending 1 to 2 km southward from sites SS-13 and SS-14.

Site SS-16 (51 m) is interpreted to be the upper part of a deltaic sequence. Tucker (1974) identified deltas and terraces at 66 m, 60 m, and 54 m a.s.l. The delta surfaces of SS-10 and SS-16 at 50 m a.s.l. located south of South Pond may be chronologically equivalent to the 54 m terraces at Springdale, Burnt Berry Brook, and West Pond identified by Tucker (1974). Regardless of their precise chronological age, they indicate a major sea level stand at 50 m a.s.l.

The combination of sediment grain size, orientation of ripples, the dip of the beds, the geomorphology, and the elevation of 64 m a.s.l. at SS-12 indicates that it represents a deltaic sequence, showing braided channel characteristics.

The overall assemblage at SS-13 can be interpreted as an underflow fan deposit distal to the source. The presence of fine beds, the intertonguing of beds, their lateral discontinuity, and the dip of the beds suggest a distal, deltaic origin for the section (Shaw and Ashley, 1988). Thus the sediments formed as an ice distal fan delta located just below wave base.

Glaciomarine Embayment Clay Sections

Site SS-1: Description

Three exposures of glaciomarine clay were examined. The stratigraphic sequence at site SS-1 is typical for the region. This section of rhythmically bedded silt, clay, and sand is located adjacent to the bridge over Indian Brook along route 390 at an elevation of 30 m a.s.l.. It is 8.9 m thick and extends for 20 m. The section is divided into six units (Fig. 3a). The strata dip at 1° to 10° to the east. A similar sequence is present at SS-18, 0.5 km to the east.

Unit 1 consists of a minimum of 3 m of laminated silt and clay with some fine sand laminae and beds. These strata have sharp upper and lower contacts and are mostly internally structureless. There are some normally graded sand laminae in the unit. The unit contains rare coarse clasts ranging from 1 to 10 cm in diameter that deform underlying strata and are draped by the overlying strata (Plate 2).

Water escape and deformation structures consisting of beds or laminae which are broken apart and pushed up into the overlying strata or folded and pinched out are present (Plate 3). Several of these structures have eroded upper surfaces, indicating erosional contacts of the laminae and beds. Laminae of clay and silt alternate between reddish brown and yellowish brown when moist.

Correlative sediments crop out at SS-18, 0.5 km east of SS-1. Organic detritus of husks or epidermis of aquatic plants found in unit 1 at 24.3 m a.s.l. at section SS-18 have been ^{14}C-dated at 11,340 ± 150 years B.P. (TO-2306) by the Isotrace Laboratory of the University of Toronto.

Unit 2 ranges from 5 to 46 cm thick and is composed of deformed sand and clay. Locally derived subangular to subrounded granitic and felsic volcanic pebbles ranging from 1 to 2 cm in diameter are common. The upper contact of the unit is sharp and erosional, truncating deformation features. The orientations of the fold axes indicate deformation caused by flow to the northeast. The unit pinches out laterally to the east over 15 m.

Unit 3 is 1.5 m thick and consists of alternating red and green silt, sand, and clay laminae ranging from 1 to 5 mm thick. At the base of the unit, these laminae are flat lying with sharp upper and lower contacts. In the upper part of the unit, laminae are folded, distorted and appear convoluted. The unit is not laterally extensive. Fold axis measurements indicate that deformation was produced by flow to the northeast.

Unit 4 is a laminated silty diamicton 0.15 to 0.40 cm thick, containing approximately 5% subangular pebbles. Some intraclasts (1 to 2 cm) of clay are present. Axial measurements of folded laminated strata (analyzed using the techniques of Woodcock, 1979) indicate flow to the northeast. Both the upper and lower contacts are sharp.

Unit 5 is composed of 2.3 m of laminated silt and clay with rare pebbles. These strata are internally structureless. The pebbles deform underlying strata and are draped by overlying strata. Minor slumping and water escape structures such as sags and load casts are found. The upper contact of the unit is sharp and erosional.

Shells were located at two elevations in unit 5: 27.4 m and 28.5 m a.s.l. These articulated *Mya arenaria* shells were in growth position. The shells ranged from 0.8 to 1.4 cm long and were extremely friable. Accelerator ^{14}C dating at Isotrace Radiocarbon Laboratory in Toronto produced results of 7,890 ± 80 years B.P. (TO-2304) for the 27.4 m shell and 12,470 ± 380 years B.P. (TO-2305) for the 28.5 m sample. The date at 27.4 m is deemed to be spurious (possibly contaminated) due to the difference between its age and other dates at equivalent elevations in the area and so is not used in the final interpretation. Shell dates have potential hard-water problems associated with them (Mangerud and Gulliksen, 1975) which can cause the dates to be younger or older than the true age. *Mya arenaria* is commonly found in brackish glaciomarine environments (Wagner, 1970).

Unit 6 consists of 1.47 m of interbedded sand and gravel. These beds are structureless and range from 10 cm to 40 cm thick. The sand is medium to coarse grained and well sorted. Gravel beds have clasts ranging from 1 to 5 cm in size and are well sorted. The unit is erosionally truncated at the upper surface of the exposure.

Unit 6 is interpreted as a postglacial fluvial gravel. The deposit is coarser than all of the underlying units, and overlies them unconformably. Similar interbedded sand and gravel units are associated with the modern streams in the region.

Site SS-1: Interpretation

At site SS-1, units 1, 3, and 5, consisting of laminated, well sorted silt and clay, suggests deposition by settling of sediment from suspension. Catto *et al.* (1981) and Mackiewicz *et al.* (1984), among many other authors, indicate that marine sediments can be rhythmically bedded. The laminated clays of units 1 and 3 at SS-18, and unit 1 at SS-19, appear to have formed in the same way. The well sorted, fine-grained nature, lack of coarse debris, and lack of current indicators suggest deposition from suspension settling for these units.

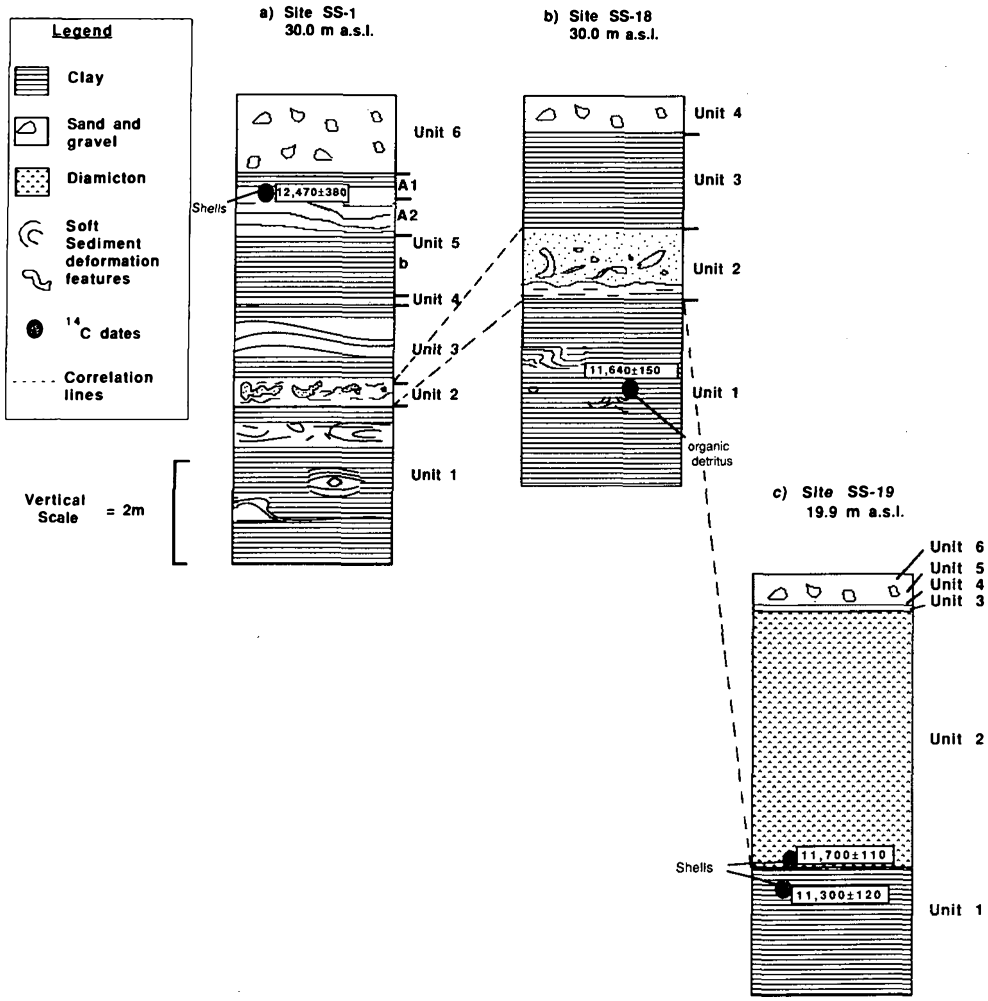

Fig. 3. Sedimentary successions at Glaciomarine Embayment Clay Sites SS-1 (a), SS-18 (b), and SS-19 (c). Suspension settling events represented by the clay units, are separated by episodes of current flow marked by soft sediment deformation features. The sequences are capped by post-glacial fluvial sand and gravel. See text for further discussion.

The rhythmically laminated silts and clays contain fine sand laminae in them. These laminae, due to their coarser nature, may have formed by small sediment flows downslope. All of these units have soft sediment deformation structures, including sag and drop features, convolute laminations, and loading structures. These structures were induced by pressure generated during the downslope flow events responsible for forming the fine sand laminae (Allen, 1984). It may be that these laminated silts and clays are the distal sediment of delta site SS-2. At the present time, however, the contact between silt and clay and the coarser sediment of the delta has not been observed.

The units all contain coarse clasts which deform the strata. These clasts are interpreted as dropstones from floating ice, similar to those described by Thomas and Connell (1985).

Units 2 and 4 at SS-1, and the correlative unit 2 at SS-18 (Fig. 3), consisting of convoluted laminated sand and silty clay, suggest periods of current flow, allowing the deposition of the sand strata. A variety of soft sediment deformation features such as water escape structures, convolute laminations, load casts, and ball and pillow structures, are present. Allen (1984) suggests that these features reflect the early consolidation history more than they do the depositional environment. Such features are typical of water lain sediments and arise where high sedimentation rates prevail, resulting in loose packing of sands and silts. It is possible that the units here are turbidites, and hence represent both suspended settling and flow.

Paleoflow measurements made on fold axes indicate flow to the northeast and east in sites SS-1 and SS-18 respectively. This implies that the flow followed the trend of the valley, and thus the paleodrainage flowed northeastward, the same way as does the present drainage.

An interpretation of these sediments involves the following sequence of events: (1) initial calm suspension settling with periodic influxes of fine sand from minor current flows; (2) followed by low density debris flows or turbidites which deposited coarser, moderately sorted sandy units; (3) followed by minor slumping; (4) then reverting to suspension settling; and (5) finally concluding with a capping gravel deposit of fluvial origin.

Plate 2. Dropstone, unit 1, SS-1. Deformation of the underlying clay and silt laminations, and draping of successive laminations over the clast, indicate that the clast was ice rafted. Maximum dimension of clast is 12 cm.

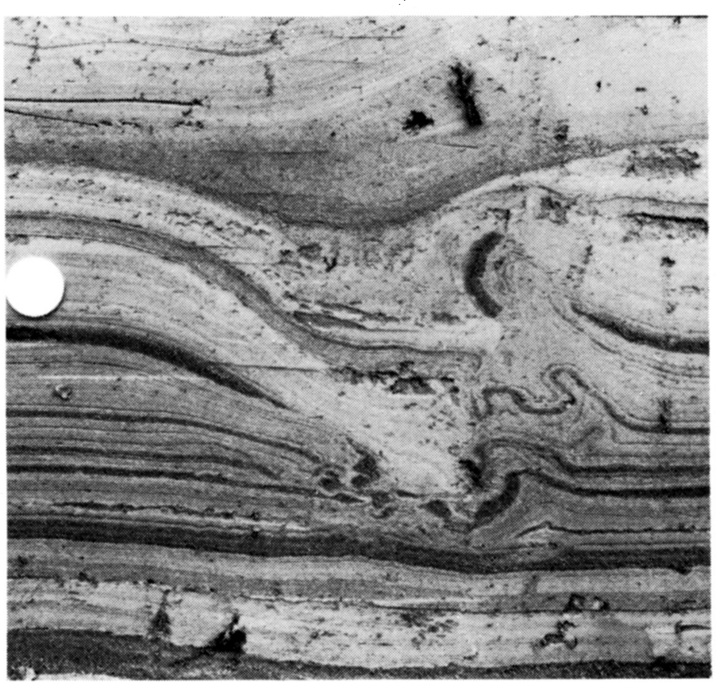

Plate 3. Deformation structures, unit 1, SS-1. This deformation indicates easterly flow downslope (to the right on the photograph). Similar deformation structures occur in units 3 and 5 at SS-1 and unit 1 at SS-18. See text for further discussion.

Site SS-19

A somewhat different sequence of glaciomarine sedimentation is preserved at section SS-19, located on the south side of Indian Brook, at the falls at George Huxter Memorial Park near Springdale. This section has an elevation of 19.9 m a.s.l. and consists of seven units (Fig. 3c).

Unit 1 is composed of 2.5 m of laminated silt and clay with sharp contacts between laminae. These alternate red and green laminae (similar to those of sections SS-1 and SS-18) range from 1 to 2 mm thick. Shells located at 12.45 m a.s.l. (Plate 4) include *Mya truncata*, *Hiatella arctica*, *Macoma balthica*, and *Balanus hameri* (barnacles). Some of these shells were in growth position, whereas others were fragmented. These species are indicative of cold, shallow (5.5 m) to deep (183 m) water. They are also believed to be indicative of a wide range of salinities (Wagner, 1970). The shells have been ^{14}C dated at 11,300 ± 120 years B.P. (GSC-5140) (this is a mixed species date). The upper contact is gradational with unit 2. The well sorted, fine-grained nature, lack of coarse debris, and lack of current indicators suggest deposition from suspension settling (Allen, 1984). The rhythmically laminated silts and clays contain fine sand laminae in them. These laminae, due to their coarser nature, may have formed by small sediment flows downslope.

Unit 2 is a diamicton consisting of 5 m of coarse to medium sand matrix with approximately 45% subangular to subrounded pebbles to cobbles 0.5 cm to 25 cm in diameter. The basal 65 cm of the unit has a 70% clay content and is very compact. The upper part of the unit has less clay and the material is friable. The upper contact is sharp. Crushed barnacle fossils were abundant in the lower 50 cm of unit 2 and cobbles within the sediment had barnacle shells still attached to them. Barnacle shells found at 12.9 m a.s.l. have been ^{14}C dated at 11,700 ± 110 years B.P. (GSC-5171). This unit is interpreted as a mass movement deposit, formed by sediment gravity flow into the embayment. This is a characteristic form of sediment movement in a calving glacier or ice shelf environment (Powell, 1984). The poorly sorted diamicton, including crushed and twisted shell debris, indicate that the sediment has undergone transportation.

The glaciomarine sediments are overlain by a structureless sandy silty diamicton (unit 3) with about 55% coarse clasts up to 70 cm in diameter. This diamicton is interpreted as a Holocene terrestrial mass movement deposit, based on its texture, lack of internal structure, and similarity to diamictons formed by modern terrestrial slope failure. Younger fluvial sediments (units 4, 5 and 6) cap the exposure.

Geochemical Palaeosalinity Analysis

Geochemical data, in particular the concentration of vanadium, can be interpreted to indicate the paleosalinity of the depositional environment (Shimp *et al.*, 1969; Catto *et al.*, 1981). The results of vanadium analyses are shown in Table 1. According to Shimp *et al.* (1969) and Catto *et al.* (1981) a vanadium value of less than 60 ppm equals fresh water; 60 to 115 ppm is brackish; and greater than 115 ppm is marine. On the basis of the vanadium content, the paleosalinity values of the depositional environment of all the clays in the Springdale area fall within the range indicating brackish environments. This confirms the brackish environments

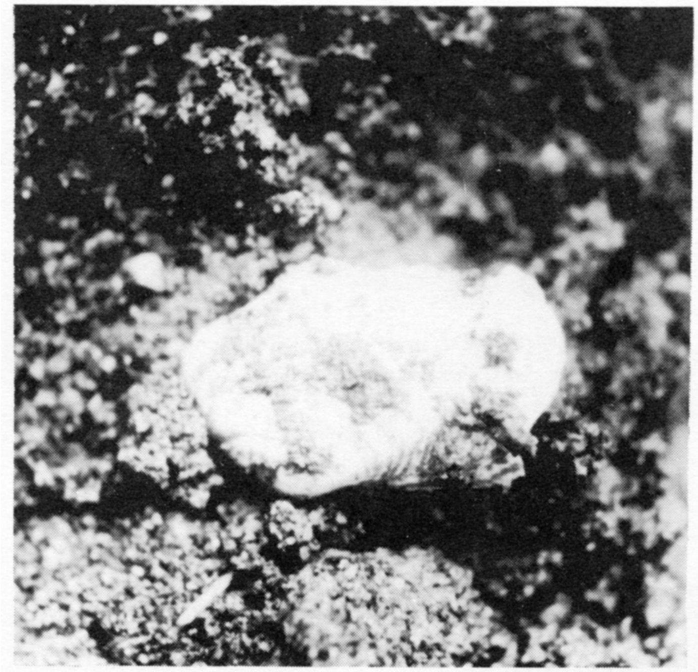

Plate 4. Shell (*Mya truncata*) obtained from unit 2, site SS-19. The shell is 2.8 cm by 4.5 cm. Shells from this unit have been ^{14}C dated at 11,300 ± 120 years B.P. (GSC-5140).

Table 1. Vanadium concentrations in clay deposits.

Sample #	Unit #	Vanadium ppm
SS-1 90003	1 base	99
SS-1 90014	1 top	95
SS-1 90024	3	109
SS-1 90031	6b top	109
SS-1 90036	6a2	106
SS-18 90045	1 middle	92
SS-18 90052	1 throughout	84
SS-18 90059	3	103
SS-19 90069	1	106

suggested by the mollusc and barnacle shells present in the sections.

It should be noted here that samples for this area have not been tested for background vanadium content. This is a potential problem in our interpretation. Additional geochemical analysis are being performed for boron concentrations but to date have not been completed.

Stratigraphic Correlations

A potential problem with the radiocarbon dates exist. Unit 5 at SS-1 is stratigraphically above unit 1 at SS-18, but the dates available would indicate that it is chronologically older. This may be explained by hard water errors in the dates, causing the date at SS-1 to be older than the true age of the sediment. Alternatively, downslope slumping may have caused sediment further out in the bay (at the location of SS-18) to be remobilized and thus younger shells could have been incorporated into the sediment. If remobilization has occurred, then the sediments at site SS-1 and SS-18 cannot be correlated.

The shell date of 11,700 ± 110 years B.P. (GSC-5171) in unit two of site SS-19 is approximately 400 years older than the date in the clay unit below. This can be explained based on the interpretation of unit two as being a downslope slump deposit which has incorporated shells from elsewhere into the flow.

Unit 1 of site SS-19 has been correlated with unit 1 of sites SS-1 and SS-18. Again the discrepancy in the dates may be explained based on the sedimentological evidence which suggests that the upper part of unit 1 (at SS-19) experienced downslope failure. It may be possible that the shells were incorporated into the slump from a higher stratigraphic level further up valley. Alternatively, unit 1 of SS-19 may represent a silt and clay deposit that is stratigraphically higher than units 1 in SS-1 and SS-18.

The marine silts and clays are interpreted to represent the distal parts of the deltas formed at 75 m elevation. However a complete sequence showing the contact of the silt and clay with the sand and gravel was not found. It is suspected that the contact is buried and only further drilling (such as was performed by the Newfoundland Department of Environment in 1987) in the Indian Brook Valley will aid in the understanding and interpretation. The clay deposits indicate a brackish marine environment, marked by suspension settling and downslope sediment movement. The clays represent marine incursion up to 10 km inland.

Palaeogeography and Sea Level History

Based on the sedimentological, palaeontological, and geomorphological data, a palaeogeographic model has been constructed for the Springdale - Hall's Bay area (Fig. 4). ^{14}C dates indicate that the deltas at 75 m have a minimum age of 11,300 years B.P. (Tucker, 1973). However the new date of 12,470 ± 300 years B.P. (TO-2305) on shells in marine clay at an elevation of 28.5 m suggests that the deltas pre-date 11,300 years B.P (Fig. 3). Depending on the rate of sediment transport and depositional conditions, the highest deltas could pre-date 12,470 years B.P. These 75 m deltas are located at Springdale, Dock Point, and South Brook.

The presence of a number of readily identifiable deltaic sequences at elevations of 75 to 68 m indicate that sea level was at 75 m in this area. The absence of expanses of sand and gravel to the south and southeast of these deposits indicate that the ice was proximal to the sites during their formation. Detailed sedimentological investigations of these deposits also indicates that they were formed proximal to the ice. Thus geomorphologic and sedimentologic data indicate that the ice front stood at the mouth of West Brook and South Brook and bordered Hall's Bay, but was 1 to 2 km south of sites SS-13

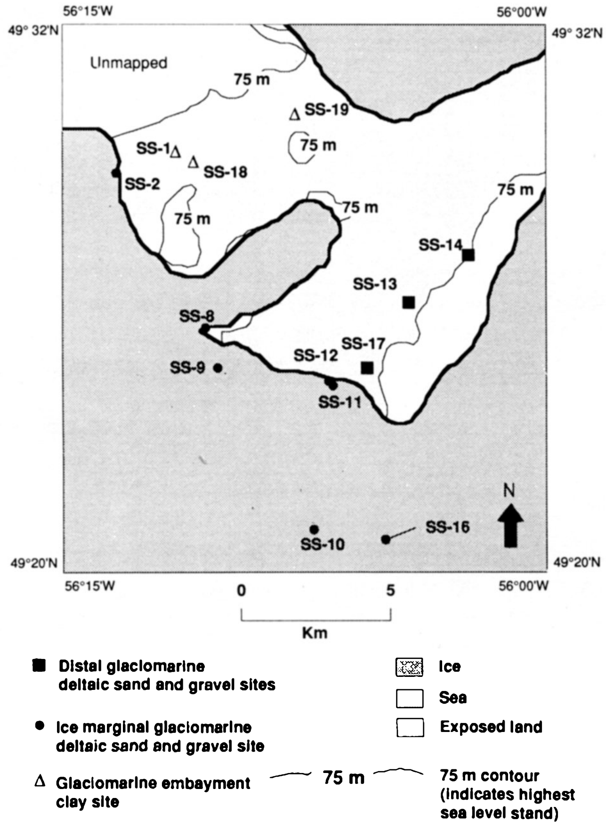

Fig. 4. Palaeogeographic reconstruction of the Springdale - Hall's Bay region c. 11,000-12,000 years B.P. Ice-contact deltas developed along the glacial margins in the south part of the region. Distal deltaic sediments are preserved at SS-13 and SS-14. Regions below the marine limit of 75 m above modern sea level were inundated, and glaciomarine embayment clays and gravity flow deposits formed at these locations. Subsequently, the deltaic sites below 75 m (SS-16, SS-10, SS-9) were exposed as glacial retreat and marine regression progressed. See text for further discussion.

and SS-14. The ice front was positioned at the 75 m contour at the north, west, and south parts of the map area but was 1 to 2 km south of the 75 m contour in the east (Fig. 4).

The deltaic sections also indicate a progressive lowering of sea level since deglaciation. At 11,000 to 12,000 years B.P. the sea stood at 75 m a.s.l. (Fig. 2) inferred from the highest deltas in the area. These deltas were deposited proximal to the glacial outlet. Subsequently the ice retreated south through South Pond, and marine deposits and terraces indicate that inundation was at 50 m a.s.l. when deltaic sediments were deposited at SS-10 and SS-16. Continued regression due to isostatic rebound resulted in the formation of successively lower terraces, to 9 m a.s.l.

The origin of these terraces were not studied in detail in this work. The absence of datable material from these sections places a limit on the sea level change chronology. Certainly data with respect to this regard is very pertinent to the understanding of sea level change for the Springdale - Hall's Bay area.

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