Current Research (1991) Newfoundland Department of Mines and Energy,
Geological Survey Branch, Report 91-1, pages 69-78

SEDIMENTOLOGY OF QUATERNARY MARINE DEPOSITS IN THE SPRINGDALE–HALL'S BAY AREA

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ABSTRACT

The study area is located in the Springdale–Hall's Bay area of north-central Newfoundland. The origin and genesis of various waterlain sediments were studied in order to compile a history of sea-level changes for the area using a combination of sedimentological, paleontological, and geomorphological techniques.

Marine incursion, due to isostatic depression, was extensive throughout the Indian Brook and South Brook valleys, reaching at least 10 km inland. Marine clay in three sections was deposited under calm conditions, distal to the sediment source, as indicated by the absence of poorly sorted coarse material. Dropstones, indicative of ice rafting, were found in the clay. The clays were deposited by a combination of suspension settling and sediment-gravity flows. The sediment geochemical results suggest a brackish-marine environment. Shells of Mya arenaria, Balanus hameri, Macoma balthica, *and* Hiatella arctica *found in the clays, also indicate a similar brackish-water depositional environment.*

Sea-level history deduced from this study indicates that ice-contact deltas were formed and that a series of successively lower terraces (indicating isostatic rebound) are also present. Deltaic sequences with surfaces ranging from 14 to 75 m above the present sea level were a result of higher sea-level stands. Most of the deltaic sediments were formed as ice-contact fan-deltas, but two sites are interpreted as ice-distal fans. Terraces in this study indicate that ice-contact deltas were formed at elevations of 75, 72, 64, 51, 50, 30, 20, and 13 m above sea level.

Slope stability may represent a problem along Indian Brook, due to the presence of clays. The extent of clay, up to 10 km inland and up to 30 m thick, suggests it may be an economic resource for brickmaking or pottery. The large amounts of permeable sands and gravels in the area make the location of waste-disposal sites difficult.

INTRODUCTION

The study area is located in the Springdale–Hall's Bay area of Newfoundland, lying between 56°15'W and 56°00'W and 49°32'N and 49°20'N (part of NTS 12H/8 and 12H/9) (Figure 1). Following the Late Wisconsinan deglaciation of this area, raised sea levels, due to isostatic depression, resulted in marine inundation of areas lying below 75 m, above the present sea level (Tucker, 1973). As a result of subsequent isostatic rebound, raised-marine deposits occur along the shores of Hall's Bay and these marine and coastal sediments can be easily investigated. The objectives of the study are:

1) to describe fine-grained rhythmically bedded material and related sediments, in order to determine their origin and modes of genesis;

2) to describe the fossil assemblages present;

3) to study the geomorphology of the area; and

4) to integrate the sedimentology, paleontology, and geomorphology to determine the history of sea-level changes.

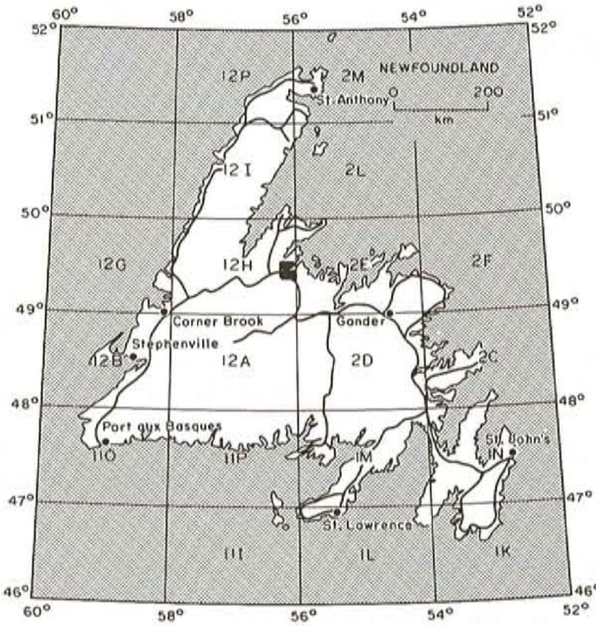

Figure 1. *Location map of study area.*

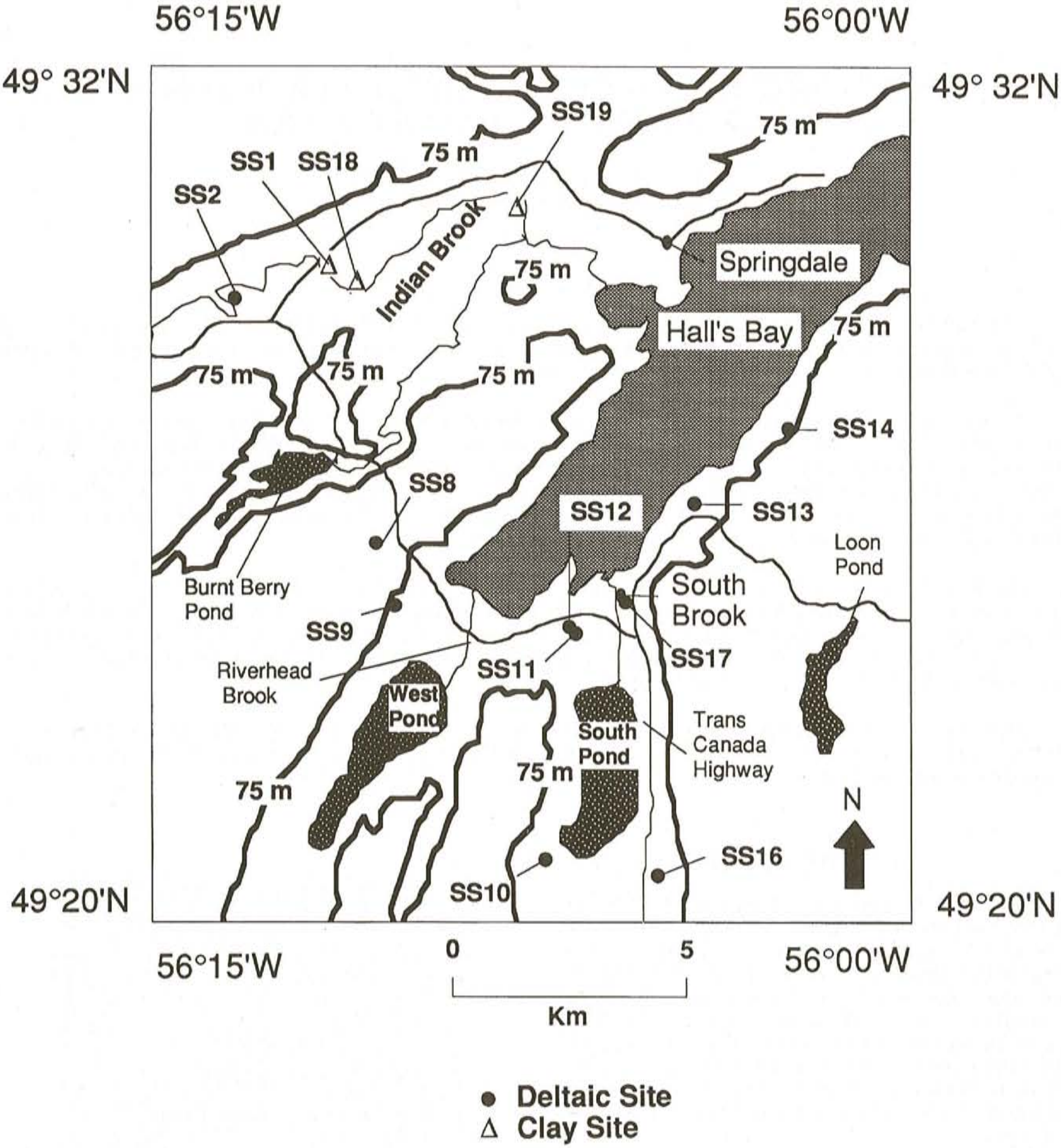

Figure 2. *Location of features and sections named in the text.*

Three sections consisting dominantly of clay and silt along Indian Brook were examined, as well as ten sections situated over the remainder of the study area.

PHYSIOGRAPHY

The study area includes Hall's Bay, South Brook, Springdale and Indian Pond Park. The major river in the area is Indian Brook and other rivers include Burnt Berry Brook, Riverhead Brook, and South Brook (Figure 2). Lakes are common and include South Pond, West Pond, Burnt Berry Pond and Loon Pond. Approximately 40 percent of the area lies below the 75 m contour.

PREVIOUS WORK

Richards (1940) identified two shells found by MacClintock and Twenhofel (1940), from red marine silts at

Springdale (Pelecypoda *Saxicava arctica* Linné and Crustacea *Balanus crenatus* Bruguiére). These species indicate a brackish-, probably shallow-water environment. MacClintock and Twenhofel (1940) briefly described large deltas at 75 m above sea level (a.s.l.) at Springdale and South Brook and interpreted them as outwash from glaciers draining into Hall's Bay. Jenness (1960) believed that these deltas were contemporaneous, interpreted them as glaciolacustrine features, and used their levels to construct an isobase system. Lundqvist (1965) accepted Jenness's glaciolacustrine origin for the deltas due to the presence of varved clays in the Indian Brook valley and also because the deltas were far above the highest marine limit. The western part of the delta at Springdale contain beds dipping to the east, which were believed to indicate sediment transport from ice in the Indian Brook Valley. Lundqvist (1965) believed 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 12000 ± 220 years BP (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 BP (GSC−2085; Lowden and Blake, 1975) on shells (*Mytilus edulis* and *Hiatella arctica*) found in gravels interpreted as delta bottomsets, near South Brook (Tucker, 1973), is also interpreted to date the glaciomarine deltas.

Tucker (1974) identified five marine terraces at 66, 60, 54, 15, and 9 m a.s.l., which formed as a result of isostatic rebound and suggested that the postglacial emergence has been 75 m. He interpreted that the calving of an ice front rapidly deglaciated Hall's Bay, until the ice became landfast in Indian Brook and in areas to the south. It remained in this position as the deltas were 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 (the clay was identified as a potential economic resource for the manufacture of red brick and possibly studio products). 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.

In 1987, the Newfoundland Department of Environment and Lands drilled a groundwater well at Indian River Provincial Park. Samples showed sands and gravels down to 2 m and clay from 2 to 2.5 m depth. Samples were not taken between 2.5 and 22 m. Sands and gravels were present at 22 m; clay at 23 m, and additional sands and gravels at 27.4 m depth. Liverman and Scott (1990) briefly described the exposures east of the bridge over Indian Brook 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. Surficial mapping of the 12H/8 map area was undertaken in conjunction with this project (see Liverman *et al., this volume*).

ACCESS AND FIELD METHODS

Access to the area is good, except for the area south of Indian Brook and east of the Springdale highway. Selected exposures were located and examined, and detailed descriptions recorded. Description was supplemented by sampling for textural and geochemical analysis. In addition, several samples were taken at each site for microfossil analysis. Shells found at some sections were described, identified, and have been submitted for ^{14}C dating. Box cores were taken from section SS1 (Figure 2), dried, and will be examined in detail at a later date. The orientations of all paleocurrent indicators were measured using a Brunton compass. An altimeter was used to measure the elevation of the tops of sections, with compensation for drift being made by recording the time of the reading at each location and subsequently returning to a known altitude. The resulting elevations are accurate to ± 5 m.

SEDIMENTOLOGY

Ten sections indicating deltaic deposition at higher than present sea levels were located; three sections containing clay units were also found. These exposures are described and interpreted below. The locations of these sections are shown on Figure 2.

DELTAIC SECTIONS

Of the ten sections showing deltaic features, (Table 1), sections SS2 (68 m), SS8 (72 m), SS9 (20 m), SS10 (50 m), SS11 (64 m), SS12 (64 m), and SS16 (51 m) consist of interbedded, poorly sorted, sands and gravels having some beds dipping 18 to 26° north or north-northeast. Sections SS13 (74 m), SS14 (72 m), and SS17 (13 m) also consist of interbedded poorly sorted sands and gravels, but these are generally better sorted and finer grained than the seven sections mentioned earlier. This distinction, along with the geomorphological setting, is sufficient to classify them as a separate group for discussion.

The first seven sections mentioned are, in general, composed of interbedded sands and gravels. The sand beds consist of well-sorted fine to medium sand, 5 to 50 cm thick, and contain less than 10 percent sub-angular to sub-rounded pebbles ranging from 1 to 5 cm in diameter. The sand beds are usually structureless, but some show a few fining or coarsening upward sequences and ripples. The gravel beds are poorly sorted, 5 to 50 cm thick, having sub-angular to sub-rounded pebbles and cobbles with long axes of 5 to 30 cm. The beds are generally structureless, and both sharp and gradational contacts are present.

Section SS12, at an elevation of 64 m, consists of interbedded, poorly sorted sands and gravels. This section is divided into three units. Unit 1 has beds, 1 to 70 cm thick,

Table 1. Deltaic section data and sedimentological interpretation

Section Number	Latitude and Longitude	Maximum Thickness of Exposure	Elevation of Surface	Comments
SS2	56°13'30" 49°29'02"	15 m	68 m	Rapid water flow, constructing a delta into a raised post glacial sea
SS8	59°08'20" 49°25'56"	2.1 m	72 m	Upper part of deltaic sequence
SS9	56°08'35" 49°25'10"	75 m	20 m	Detalic sediments studied by Tucker (1974)
SS10	56°08'56" 49°21'02"	2.3 m	50 m	Upper part of deltaic sequence
SS11 and SS12	56°06'40" 49°25'20" and 56°06'50" 49°25'25"	20 m	64 m	Deltaic, with top parts of the sequences showing braided channel characteristics
SS16	56°05'33" 49°21'00"	6.5 m	51 m	Upper part of deltaic sequence
SS17	56°04'41" 49°25'40"	5 m	13 m	Well-sorted sediment indicates distal location for the lower part of the complex
SS13	56°03'30" 49°26'40"	10 m	74 m	Ice-distal fan delta, slightly below wave base
SS14	56°02'30" 49°27'15"	10 m	72 m	Ice-contact fan delta, with braided channels

of structureless fine to coarse sand with less than 2 percent sub-angular to sub-rounded pebbles 1 to 3 cm in diameter. Some beds contain fining upward sequences. All the beds dip 18° north. At the base of 5 percent of the beds, there are pebble stringers containing pebbles 0.5 to 1 cm in diameter and are sub-angular to sub-rounded. The upper part of this unit contains an upwardly increasing number of medium pebbly sand beds with 45 percent sub-rounded to well-rounded pebbles, 0.5 to 8 cm in diameter.

Unit 2 consists of 10- to 70-cm-thick, well-sorted, fine- to coarse-sand beds. The beds dip from 26° in the northern part of the section to 18° in the southern parts. Many beds contain no large clasts, whereas others have less than 4 percent sub-rounded to rounded pebbles, 1 to 2 cm in diameter. Beds dip 18° north, with some pinching out laterally, and both the upper and lower contacts are sharp. Concave-convex channel cuts are visible at the base of this unit. Climbing ripples are present with an average wavelength and amplitude of 1.5 and 15 cm, respectively; the ripples indicate flow to the north.

Unit 3 consists of 2 m of poorly sorted, flat-lying, sand and gravel beds (20 cm to 1 m thick), with approximately 50 percent sub-angular to sub-rounded pebbles and cobbles, 0.5 to 12 cm in diameter. These beds truncate the underlying dipping beds.

Site SS16, at an elevation of 51 m, is perhaps more typical of the seven deltaic sites mentioned earlier. It is comprised of 15-cm to 1-m-thick interbedded, well-sorted, fine sand and pebbly sand beds that dip 22° north-northwest. The fine sand beds are mostly structureless except at the base of the section where some beds show horizontal laminations of 1 to 5 cm associated with fining upward sequences. Some of these fine sand beds contain plano-convex sand lenses with less than 2 percent medium to coarse pebbles. The pebbles in these lenses are sub-angular and range in diameter from 1 to 3 cm. Normal epigenetic faulting is visible in some sand beds. The pebbly sand beds range in thickness from 5 to 50 cm and consist of moderately sorted pebble sand containing sub-angular to sub-rounded clasts, 1 to 6 cm in diameter. Contacts are sharp and the beds are sometimes structureless whereas at other places they coarsen upward. Some beds also contain irregular shaped lenses, 1 to 3 cm thick and made of coarser, pebbly sand.

The three sections SS13 (74 m), SS14 (72 m), and SS17 (13 m), which generally have better-sorted and fine-grained sediment are treated as a group and are discussed separately. Sections SS13 and SS14 consist of interbedded sands and gravels, but SS13 contains fewer beds of coarse gravel than the other deltaic sequences from the earlier discussed sections. Beds at SS13 and SS14 range in thickness from 5 to 100 cm and dip 24 to 26° north. Both sections have trough crossbedding in gravels, soft sediment clasts, ripples and sub-rounded to rounded pebbles to cobbles, 1 to 50 cm in diameter. Although some beds are well sorted and rippled, in general, the sediments are poorly sorted and structureless. Contacts between beds are generally sharp.

Section SS13 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, 1.5 cm by 2 cm, of fine sand and silt that fines upward. There is less than 2 percent sub-angular to sub-rounded pebbles in the sand beds. The granule gravel beds are poorly sorted, range in thickness from 8 to 18 cm, and dip 28° north. The pebbly sands are moderately sorted and range from 5 to 10 cm thick, with sub-angular pebbles 1 to 6 cm in diameter. These units have pebble imbrication indicating flow to the northwest, and some show fining upward sequences 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. This unit has rippled beds in the upper 1.5 m. The sand beds show some fining upward sequences, contain less than 1 percent pebbles, and contain ripples indicating flow to the north or northeast with an average amplitude and wavelength of 2.5 cm and 9 cm, respectively. The granule–gravel beds are 5 to 70 cm thick, moderately sorted, and structureless. Contacts between all beds are sharp. Some of the sand beds in this unit contain syngenetic reverse faults with displacements of 1 to 4 mm at an angle of 25° that do not continue into the overlying sediments.

Plate 1. *Deltaic section SS13.*

Unit 3 is comprised of 80 cm, 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.

INTERPRETATION AND IMPLICATIONS FOR SEA-LEVEL HISTORY

Most of the deltaic sediments were deposited in contact with glacial ice, as indicated by the coarse clasts and poor sorting of the sediment (see Reading, 1978). The ice front is believed to have been at 75 m a.s.l. along the west side of Hall's Bay, but to the east, ice is believed to have been farther inland from the coast, as demonstrated by the expanses of gravel extending 1 to 2 km southward from sections SS13 and SS14.

The climbing ripple drift crosslaminations present in Unit 2, at section SS12, were oriented indicating flow to the northeast and are interpreted as depositional stoss features (type B of Jopling and Walker, 1969). These features 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 upward sequences common within the ripple drift indicate successively increasing suspended load/bedload ratios, as flow velocity declined during each discreet accumulation event. The combination of sediment grain-size, orientation of ripples, the dip of the beds, and the elevation of 64 m allows the interpretation of this section to be a deltaic sequence, showing braided channel characteristics.

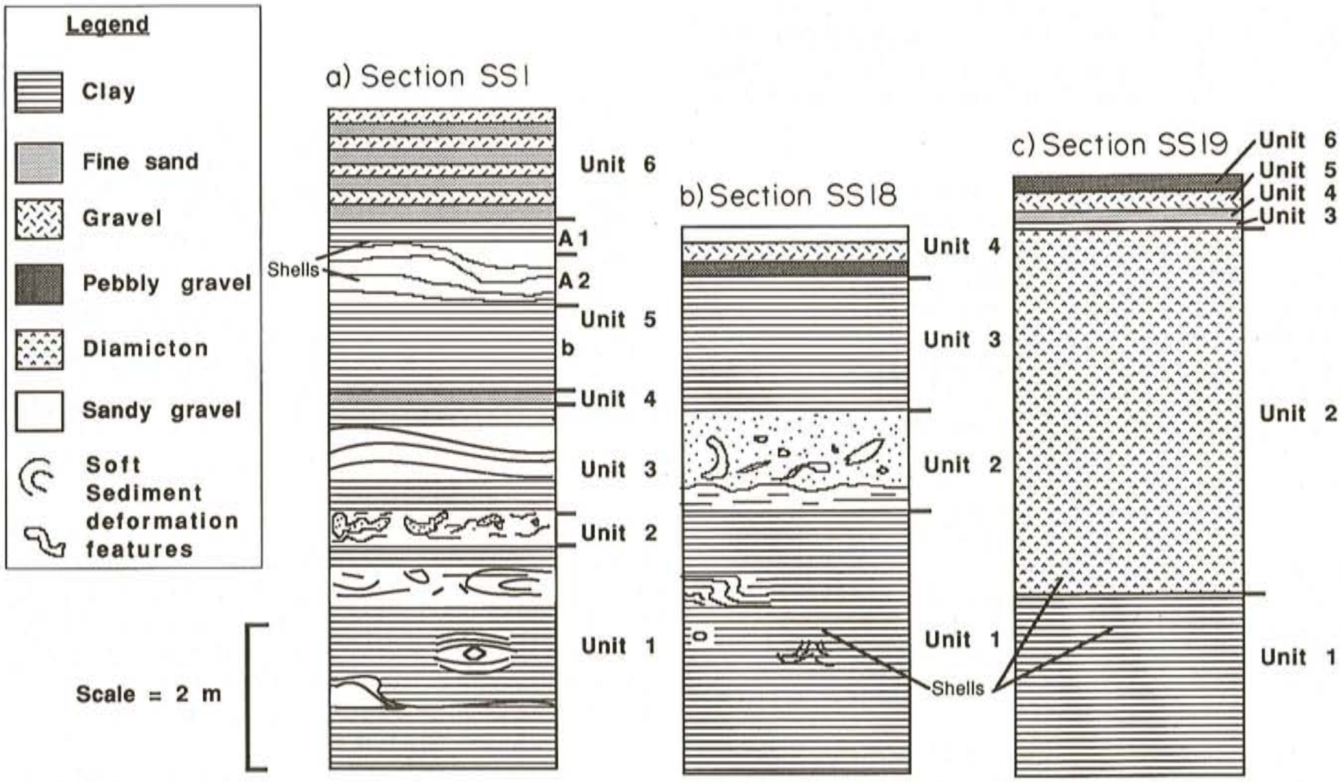

Figure 3. *a) Sedimentary column of SS1, b) sedimentary column of SS18, c) sedimentary column of SS19.*

Section SS16 (51 m) is interpreted to be the upper part of a deltaic sequence. Tucker (1974) identified deltas and terraces at 66, 60, and 54 m a.s.l. The delta surfaces of SS10 and SS16 at 50 m a.s.l. located south of South Pond maybe chronologically equivalent to the 54 m terraces at Springdale, Burnt Berry Brook, and West Pond, identified by Tucker (1974); in any event, they indicate a major sea-level stand.

At section SS13, the syngenetic reverse faulting in Unit 2 suggests loading of the sediment, possibly by flows. Ripples in Unit 2 indicate current flow to the north-northwest. The open-worked granule–gravel may be grain-flow sediments, and the presence of pebbles in silt and clay material suggests ice rafting. The overall assemblage 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. Thus, the sediments formed as an ice-distal fan-delta located just below wave base.

The conclusion drawn is that when the ice stood at 75 m, deltaic deposits were formed near West Pond, but on the east side of Hall's Bay, the ice was at least 2 km south of the coast. This is interpreted from the sediments deposited at sections SS13, SS14, and SS17, all of which appear to have characteristics indicating an ice-distal deltaic origin. The other seven deltaic sections have characteristics indicating ice-contact formation. The differing elevations indicate many were formed at different times but all seven indicate a proximity to the source of the sediment.

CLAY SECTIONS

Three rhythmically bedded sections were found along Indian Brook. These were examined in order to determine the limit of marine transgression.

Section SS1

This section of rhythmically bedded silt, clay, and sand, is located adjacent to the bridge over Indian Brook along Springdale Road at an altitude of 30 m a.s.l.. It is 8.9 m thick and extends for 20 m. The section is divided into six units (Figure 3a). The strata dips at 1 to 10° east.

Unit 1 consists of a minimum of 3.02 m of laminated silt and clay along 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 tops on the folds, indicating erosional contacts of the laminae and beds. Laminae of clay and silt alternate between reddish brown (2.5YR 5/4) and yellowish brown (10YR 5/4), when moist.

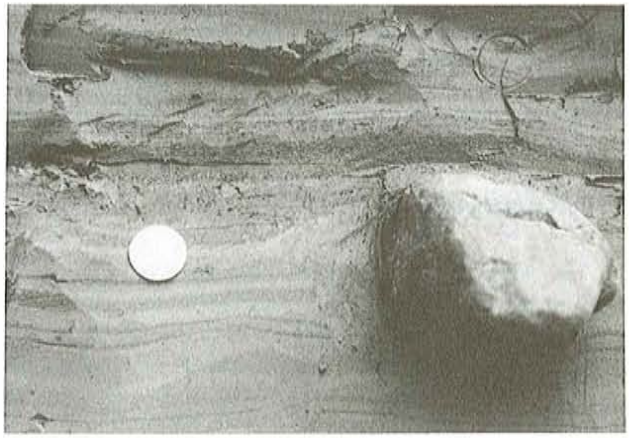

Plate 2. *Dropstone in sediment at SSl.*

Plate 3. *Deformation in sediment at SSl.*

Unit 2 ranges from 5 to 46 cm thick and is composed of deformed sand and clay. Locally derived sub-angular to sub-rounded granites 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 fold axes indicate deformation caused by flow to the northeast. The unit pinches out 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 and are 1 to 2 mm thick. In the upper part of the unit, laminae are folded, distorted and appear convoluted. The unit is not laterally extensive. Fold-axis measurements (analyzed using the techniques of Woodcock, 1979) indicate that deformation was produced by flow to the northeast.

Unit 4 is 0.15 to 0.40 cm thick and is composed of a laminated silty diamicton. Approximately 5 percent sub-angular pebbles are present. Some intraclasts (1 to 2 cm) of clay are present and fold-axis measurements indicate a 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 associated with some pebbles. These strata are internally structureless and have less than 1 percent pebbles scattered throughout. The pebbles deform underlying strata and are draped by overlying strata. Minor slumping and water-escape structures such as sags, dish structures and load-casts are found and the upper contact of the unit is sharp and erosional.

Shells were located at two elevations in Unit 5 at 27.4 and 28.5 m. These articulated *Mya arenaria* shells are in growth position. The shells range from 0.8 to 1.4 cm long and were extremely friable. They have been submitted for accelerator ^{14}C dating. *Mya arenaria* inhabits brackish-marine environments (Wagner, 1970).

Unit 6 consists of 1.47 m of interbedded sand and gravel. These beds are structureless and range from 10 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 diameter and are well-sorted. The unit is erosionally truncated at the upper surface of the exposure.

Section SS18

Site SS18 is located about 0.5 km east of SSl, on the north side of Indian Brook, at an altitude of 30 m (Figure 3b). This section has 8 m of exposure and is divided into four units.

Unit 1 is a minimum of 3 m thick and consists of laminated sand, silt, and clay beds ranging from 1 mm to 40 cm thick, and containing less than 1 percent sub-angular to sub-rounded pebbles. When moist, the clay has alternating colours of weak red (lOR 5/2) and light brownish-grey (2.5Y 6/2). There are rare coarse clasts present, which deform the underlying strata, and which are draped by the overlying beds. Water-escape structures are present in some laminae. Minor normal faults of 2 cm displacement are syndepositional in origin, as the upper parts of the faults are draped and do not persist in the overlying strata. All contacts were sharp. Shells were found in Unit 1 at 24.3 m. They were fragmented and may have been reworked. These shell fragments have been identified as bivalves, possibly *Mya arenaria,* but their poor preservation limits the confidence of the identification. The shells have been submitted for ^{14}C dating.

Unit 2 is 1.25 m thick and is composed of laminated silt, clay, and sand at the base, grading up into a well-sorted, fine sand. The basal laminae are flat-lying silt and clay, with rare sand laminae. The upper part of the unit is interbedded, convoluted, and folded sand, silt, and clay. Some granules and intraclasts (1 to 2 cm in diameter and composed of clay) are present in the sand. Fold-nose measurements and a 1 to 10° dip in the beds indicate an easterly deformation direction. The unit thins to the west and east; contacts between laminae are sharp.

Unit 3 consists of 1.87 m of laminated silt and clay and well-sorted (fine to medium) sand. The clay laminae make up 80 percent of the unit. The basal contact is sharp whereas the upper contact is gradational. Unit 4 consists 1.4 m of planar-bedded, poorly sorted pebbly gravel and pebbly sand. The pebbles are sub-rounded and 1 to 6 cm in size. The beds range in thickness from 10 to 40 cm.

Section SS19

Site SS19 is located on the south side of Indian Brook, at the falls, in the George Huxter Memorial Park near Springdale. Brief reconnaissance of this section shows that it is 19.9 m a.s.l. and consists of six units (Figure 3c).

Unit 1 is composed of 2.5 m of laminated silt and clay having sharp contacts between laminae. These alternate red and green laminae range from 1 to 2 mm thick (similar to those of sections SS1 and SS18; bivalve shells were located at 12.9 m, Unit 2, and at 12.45 m, Unit 1; Plate 4). Four different species were found: *Mya truncata Linne; Hiatella arctica; Macoma balthica;* and *Balanus hameri* (barnacles). Some of these shells were in growth position, whereas others were fragmented. The barnacle fossils were abundant in the lower 50 cm of Unit 2 and cobbles within the sediment had barnacle shells still attached to them. 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 located here have been submitted for ^{14}C dating. The upper contact is gradational with Unit 2.

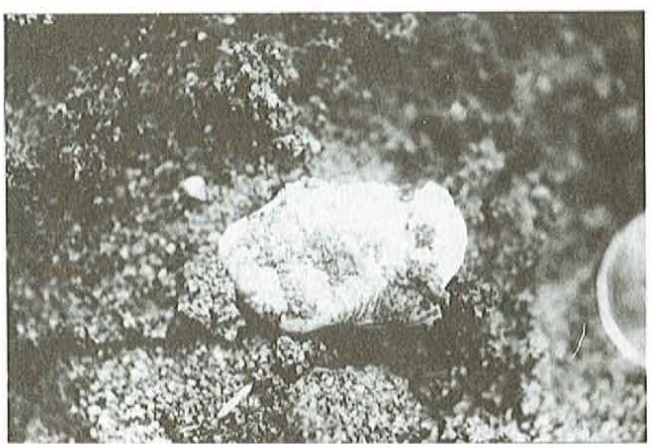

Plate 4. *Shell (*Mya truncata*) at section SS19. Shell is 2.8 cm by 4.5 cm in size.*

Unit 2 consists of a coarse to medium sand containing approximately 45 percent sub-angular to sub-rounded pebbles to cobbles 0.5 to 25 cm in diameter. The basal 65 cm of the unit has a high clay and shell content and is very compact. The upper part of the unit has less clay and the material is loose; the upper contact is sharp.

Unit 3 is 15 cm of massive diamicton consisting of a sandy silt matrix containing approximately 55 percent pebbles to boulders. The pebbles and boulders range from 1 to 70 cm in diameter; the upper contact is gradational.

Unit 4 consists of 20 cm of massive, poorly sorted medium sand continaing a few sub-angular to sub-rounded pebbles. The upper contact is sharp with Unit 5, which consists of 50 cm of a massive clast supported pebble gravel. Unit 6 has a lower gradational contact and consists of 30 cm of massive pebbly medium sand.

GEOCHEMISTRY

Geochemical data, in particular the concentration of boron and vanadium, can be interpreted to indicate the paleosalinity of the depositional environment (Shimp *et al.*, 1969). The results of preliminary vanadium analyses are shown in Table 2 and the paleosalinity of the depositional environment of the clays has been inferred on the basis of the vanadium content. From a study by Catto *et al.* (1981) done in the Ottawa valley, it was determined that vanadium concentrations in excess of 115 ppm indicate a marine depositional environment, whereas concentrations lower than 60 ppm indicate a freshwater environment. Thus, it can be deduced that all the samples tested for the Springdale area, which range between 84 and 109 ppm, fall within the range indicating brackish environments. The application of Catto *et al.'s* (1981) results to this area, is speculative, in the absence of data allowing the effect of background vanadium concentrations to be evaluated.

INTERPRETATION AND DISCUSSION

The three well-exposed, rhythmically bedded clay sections located along Indian Brook appear to have had similar depositional environments and modes of origin.

At section SS1, Units 1, 3, and 5, consisting of laminated, well-sorted silt and clay, suggest deposition by settling of sediment from suspension. Section SS18 Units 1 and 3, also laminated silt and clay, appear to have formed in the same way as those above. The same holds true for Unit 1 at section SS19. The well-sorted, fine-grained nature, lack of coarse debris, and lack of current indicators suggest suspension settling for these units. 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 appear to have about 10 percent soft-sediment deformation structures in the form of sag and drop, convolute laminations, loading, and dish structures. The sand laminae cause load-casts and other water-escape structures in these units. The units discussed here all contain coarse clasts that deform the strata. These may be dropstones from floating ice as were described by Thomas and Connell (1985).

At section SS1, Units 2 and 4, consisting of convoluted laminated sand and silty clay, suggest periods of current flow, allowing the deposition of these sand strata. Section SS18, Unit 2, is believed to be the same as the units described above. A variety of soft-sediment deformation features are present in these units. The ones identified here include gravitationally unstable features such as water-escape structures, convolute laminations, load-casts, and ball-and-pillow structures. These

Table 2. Vanadium concentrations in clay deposits

Section Number	Sample Number	Unit Number	Vanadium ppm
SS1	90003	unit 1 base	99
SS1	90014	unit 1 top	95
SS1	90024	unit 3	109
SS1	90031	unit 6b top	109
SS1	90036	unit 6a2	106
SS18	90045	unit 1 middle	92
SS18	90052	unit 1 throughout	84
SS18	90059	unit 3	103
SS19	90069	unit 1	106

were identified as similar to those described by Allen (1984). Allen (1984) suggests that these features reflect the early consolidation history more so than the depositional environment, but the depositional environment controls the consolidation history. He further states that such features are typical of waterlain sediments and arise where high sedimentation rates prevail to promote loose packing of sands and silts. It is possible that the units here are turbidites, hence, they represent both suspended settling and flow.

Paleoflow measurements made on fold axes indicate flow to the northeast and east in sections SS1 and SS18, respectively. No such measurements were made on section SS19. Preliminary geochemical evidence from all these units suggest a brackish environment at the time of their formation.

An interpretation of these sequences in section SS1 and section SS18, on a regional level, involves the following sequence of events. Initial calm suspension settling of clays, along with periodic influxes of fine sand from minor current flows. This is followed by low-density debris flows or turbidites, which deposited coarser, moderately sorted sandy units associated with minor slumping. Deposition then reverts to suspension settling again and finally concludes with a capping gravel deposit of outwash or stream origin. The preliminary interpretation at section SS19 is restricted to Units 1, 2 and 6. The result is a sequence wherein Unit 1 represents suspension settling, Unit 2 is possibly a debris-flow deposit, and Unit 6 is a gravel cap that may be fluvial or beach sediments.

SUMMARY AND CONCLUSIONS

The clay deposits described here indicate a brackish-marine environment, marked by downslope sediment movement and represent marine incursion up to 10 km inland. Sedimentologically, the clays were deposited by suspension settling and sediment-gravity flows. The sea-level chronology cannot be reconstructed until dates on the shells are received.

The deltaic sections also indicate a progressive lowering of sea level since deglaciation. Geomorphological and sedimentological 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 sections SS13 and SS14. Subsequently, the ice retreated south through South Pond, and marine deposits and terraces indicate that inundation was at 50 m a.s.l..

The marine clays pose slope-stability problems along Indian Brook, which should be taken into consideration in any construction (Plate 5). The clays may form an economic resource (Vanderveer, 1977).

Plate 5. *Modern slumping along Indian Brook.*

This work indicates that there is a substantial volume of marine sediment present. Due to the large amounts of sands and gravels in the marine deltas, care must be taken in planning the location of municipal dump sites due to seepage of the material. However, these sands and gravels are good sources of aggregate.

FURTHER WORK

The sediment descriptions will aid development of a model for glaciomarine sedimentation in this area. It is hoped that chronological data for sea-level changes, together with sedimentological analyses, will enable correlation with off-shore sedimentary assemblages. Analysis and interpretation of data for this area will continue.

ACKNOWLEDGMENTS

This project is being undertaken in part as a M. SC. Thesis in the Department of Geography at Memorial University of Newfoundland. The Newfoundland Department of Mines and Energy is thanked for financial and logistical support. Dr. David Proudfoot of the Department of Mines and Energy, and Dr. Norm Catto, Department of Geography, M.U.N. are thanked for their knowledgeable comments and guidance. Dr. Norm Catto, Dr. David Proudfoot and Martin Batterson made considerable improvements to the manuscript. Thanks also to Howard Vatcher for his very capable assistance in the quest for clay and gravel.

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