QUATERNARY GLACIOMARINE EVENTS, SPRINGDALE-HALL'S BAY AREA, NORTH-CENTRAL NEWFOUNDLAND

SHARON SCOTT

0-612-47474-7

QUATERNARY GLACIOMARINE EVENTS, SPRINGDALE-HALL'S BAY AREA, NORTH-CENTRAL NEWFOUNDLAND

BY

(C) SHARON SCOTT

A thesis submitted to the
School of Graduate Studies
in partial fulfillment of the
requirements for the degree of
Master of Science

Department of Geography
Memorial University of Newfoundland
1999

St. John's Newfoundland

ABSTRACT

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 8 km inland. Sedimentological, palaeontological, and geomorphological analyses have permitted reconstruction of the history of sea level change for the area since ca. 12,500 B.P.

A succession of ice-proximal deltas, representing the proximal units associated with the marine incursion, and a series of successively lower terraces are present. Stratified coarse sediment sequences mark the marine limit of 75 m above present sea level.

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 indicate deposition in brackish-marine environments. Shells of *Mya arenaria, Mya truncata, Balanus 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 BP.

ACKNOWLEDGEMENTS

Several individuals and organizations provided assistance for this research. Their mention here is a small token of my enduring appreciation.

I am indebted to Dr. Norm Catto for his advice, encouragement and supervision throughout the course of the research and thesis writing. I also wish to thank Dr. David Liverman for suggesting the topic, his consummate support, guidance and for the constructive criticism which both assisted and enlightened me. Conventional radiocarbon dates were generously provided by Dr. John Shaw, at the Bedford Institute of Oceanography, Halifax, Nova Scotia. Other AMS dates were obtained through the Isotrace Laboratory of Toronto.

Howard Vatcher and Carmel Collins proved capable and valuable field assistants. Dr. Cliff Wood's sound advice and assistance on drafting and producing maps was invaluable. I am also grateful to Dr. John Shaw of the Bedford Institute of Oceanography and Dr. John Maunder of the Newfoundland Museum, both of who aided in shell identification. My fellow graduate students at the Geography Department provided advice and moral support. A special thanks to Mandy (Mazza) for her humor and to Kath (Katwoman) for enriching my life in her own unique way.

The Newfoundland Department Of Mines and Energy provided financial and logistical support for the project. The Memorial University Department of Geography also provided financial support by means of teaching assistantships.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1 INTRODUCTION

1.1 Introduction

Throughout Newfoundland detailed sedimentological description and interpretation of raised Quaternary marine sediments is far from complete. During the past ten years, increased awareness of the paucity of data, coupled with a recognition of problems in interpreting sea level history and isostatic deformation (recovery), has fostered increased study and interest. The compilations of ^{14}C dates by the Newfoundland Department of Mines and Energy and the Geological Survey of Canada together with other data, now provide a basis for the study of sea level history in Newfoundland.

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 the post-glacial geomorphology of the region. This study presents the post-glacial sedimentary record from one of the few areas in Newfoundland that contains extensive glaciomarine deposits, the Springdale-Hall's Bay region.

1.2 Objectives

This thesis research was designed to garner more sedimentological, geomorphological, and chronological information for the Springdale-Hall's Bay area of Newfoundland. Study of the raised marine clay and sand and gravel deposits of this area has provided essential data on the paleoenvironmental history and sea level change.

The objectives of the study were:

1) to study the geomorphology of the area;
2) to describe the sedimentology of suspected postglacial glaciomarine sediments, in order to determine their genesis and modes of deposition;
3) to describe the fossil assemblages present; and
4) to integrate geomorphology, sedimentology, and palaeontology, in order to determine the history of sea-level changes and the deglacial palaeo-geography of the Springdale-Hall's Bay area.

Sedimentological analysis has permitted development of a model for glaciomarine sedimentation in this area. Chronological data for sea-level changes, together with sedimentological analyses, enable correlation with offshore sedimentary assemblages. This, in conjunction with other ongoing investigations along the northern shelf coast, will help in the construction of a sea level curve for the area. At present, Quaternary paleoenvironments of the northern shelf region are largely matters of speculation.

1.3 Location and Physiography

The study area is located in the Springdale-Hall's Bay area of Newfoundland (Figure 1.1), lying between 49°20'N and 49°32'N and 56°00'W and 56°15'W (parts of NTS 12H/8 and 12H/9) (Figure 1.2). It covers a 400 km^2 and includes Hall's Bay, South Brook, Springdale, and Indian River Park (formerly a 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 (Figure 1.2). Lakes are common and include South Pond, West Pond, Burnt Berry Pond, and Loon Pond.

Forty percent of the area lies below 75 m above sea level, and is generally covered by sand and gravel of marine or glaciofluvial origin, whereas the land above 75 m 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 inland appear to be deltas near 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 embayments and have subsequently been cut off from the sea.

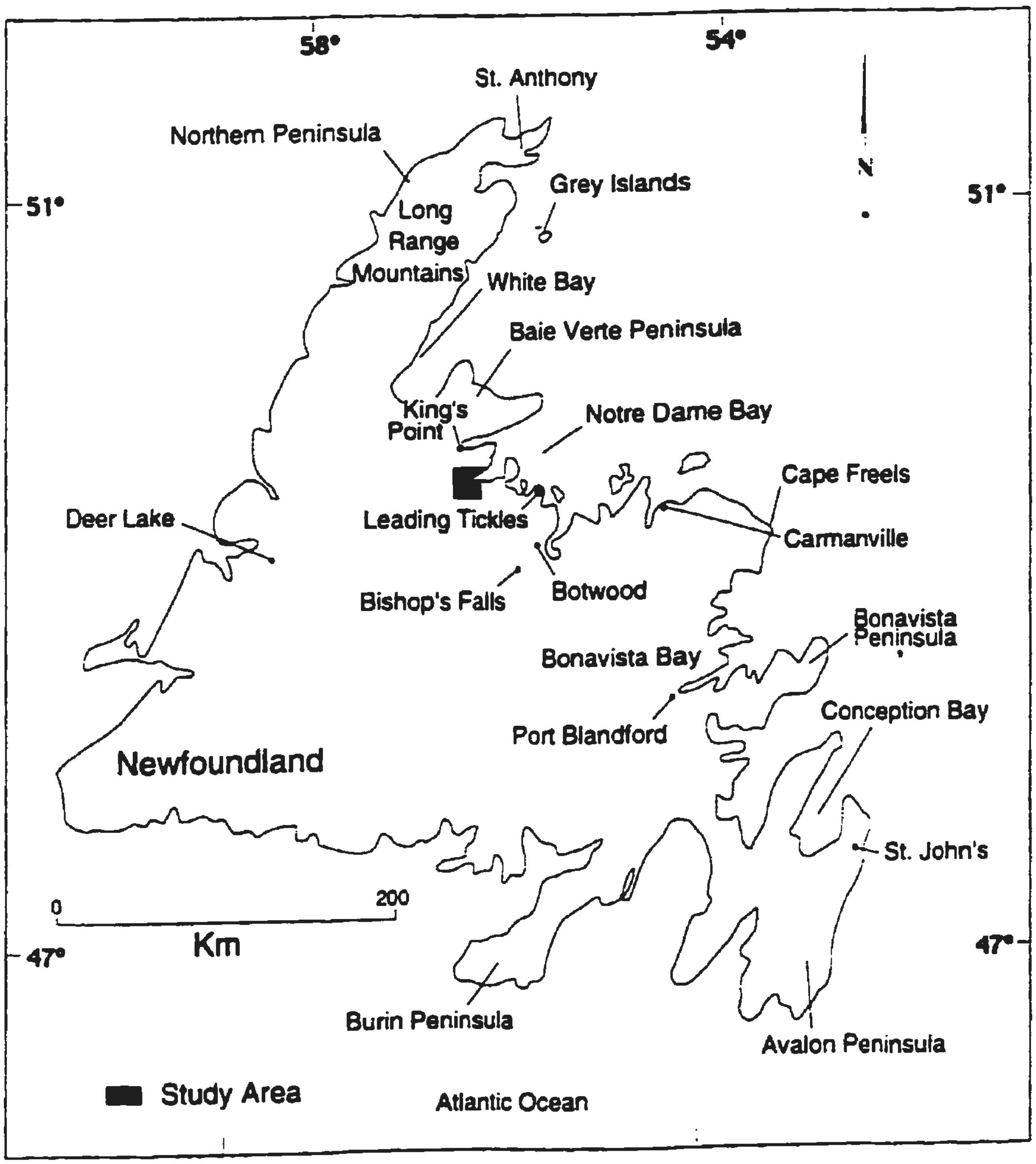


Figure 1.1: Map showing the location of the study area (black shading) and place names named in text.

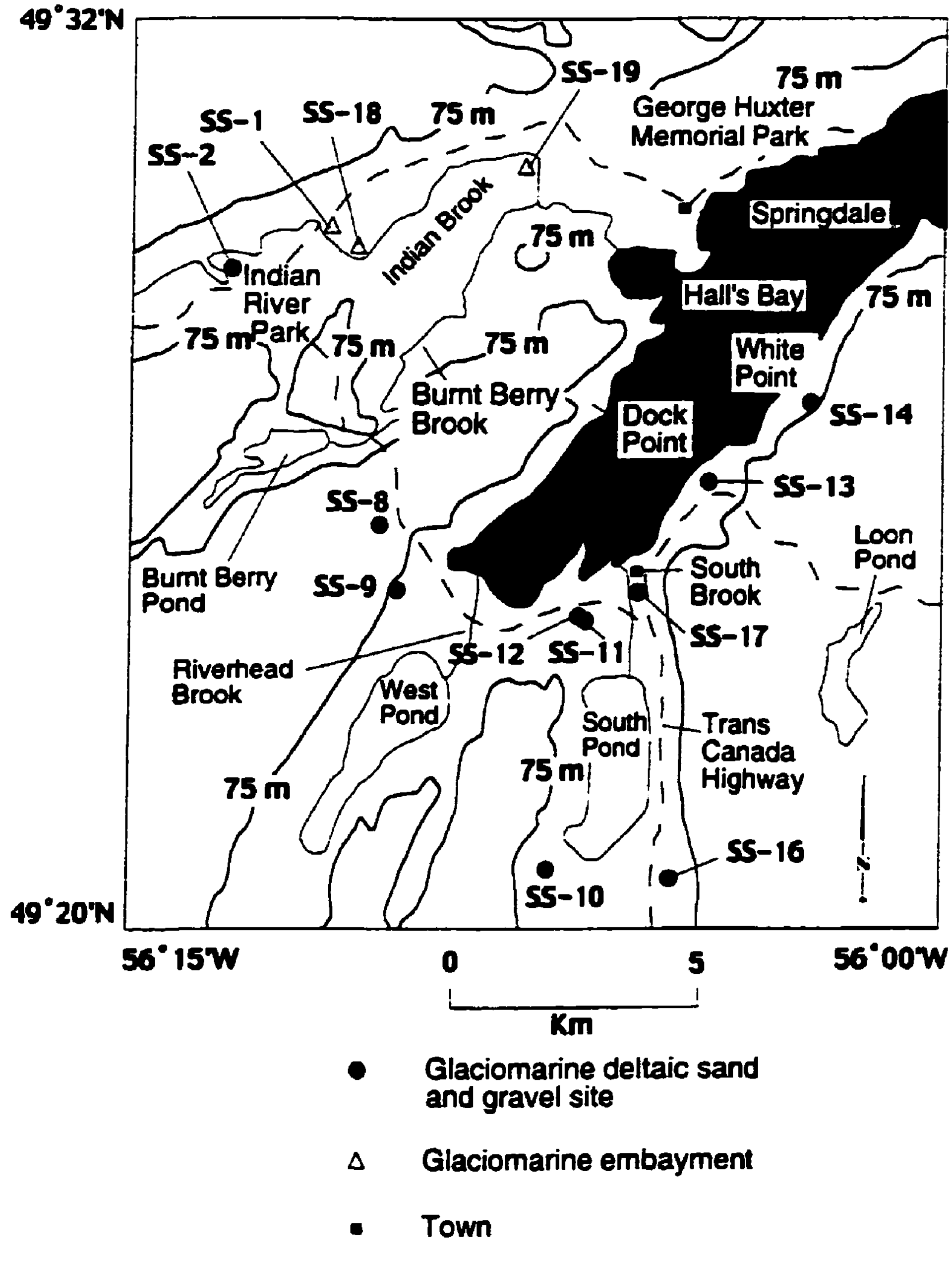


Figure 1.2: Map of the study area showing drainage, place names and sites named in the text.

1.4 Bedrock Geology

The bedrock geology was mapped by Dean (1977), Kean (1977), Swinden (1987), Coyle and Strong (1987) and Bostock (1988). Figure 1.3 depicts a simplified version of the bedrock geology of the area.

The main rock units in the northern and western part of the map area are the Cambrian to Ordovician Lush's Bight Group, the Lower to Middle Ordovician Catchers Pond Group, and the Silurian to Devonian Springdale Group. The Lush's Bight Group (located in the northeast corner of the region) contains pillow basalt, breccia, chert, tuff, diabase, and gabbro, whereas the Catchers Pond Group (cropping out in the northwest corner of the region) consists dominantly of acidic volcanic rocks (Dean, 1977; Kean, 1977). The Springdale Group (located in the central, western and southern parts of the area) is composed of conglomerates, sandstone and mudstone (Dean, 1977; Kean, 1977) and a number of crystal-lithic and ash-flow tuffs (Coyle and Strong, 1987). The Topsails Granite is exposed just north of South Pond. In addition unnamed diabase, gabbro, granite, amphibolite and diorite rocks outcrop around South Pond (Coyle and Strong, 1987).

The rocks in the eastern and southeastern parts of the region consist predominantly of the Silurian to Middle Ordovician Robert's Arm Group and the Devonian Hall's Bay Pluton. The Robert's Arm

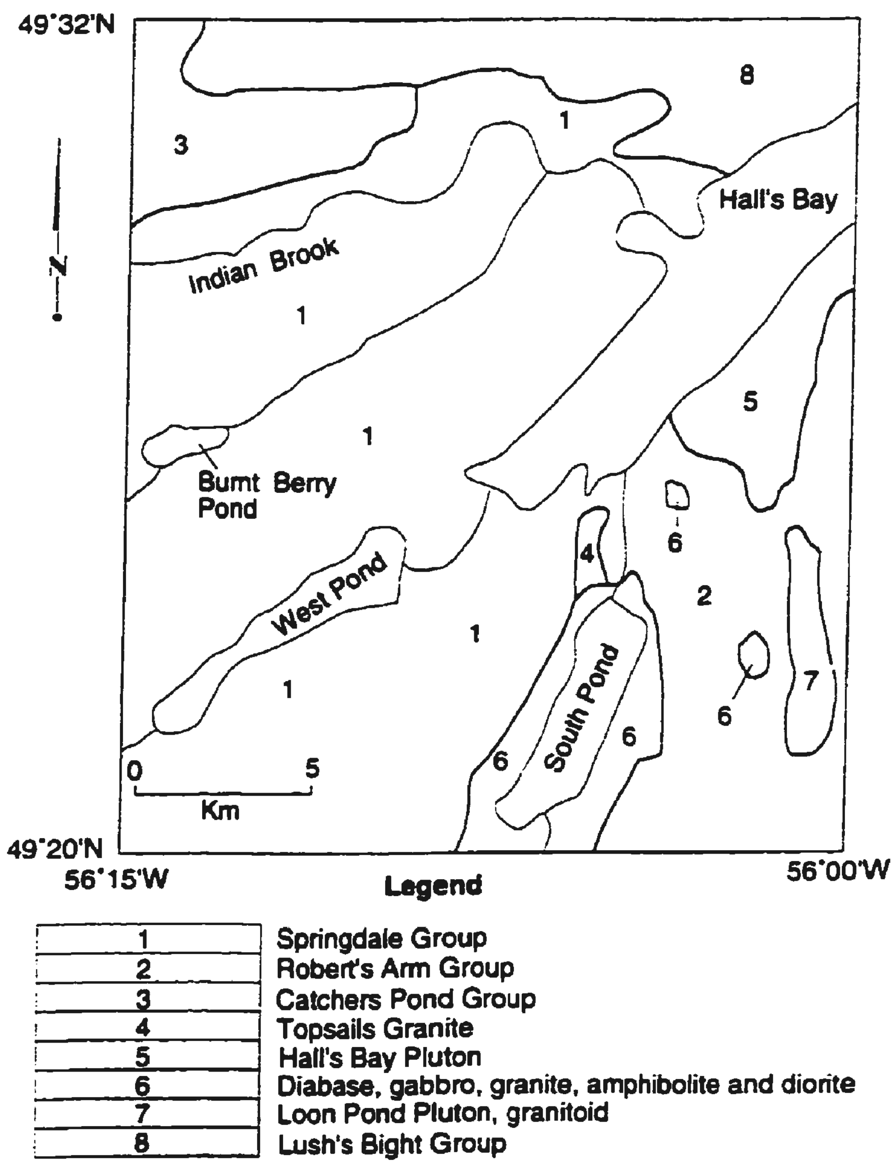


Figure 1.3: Simplified bedrock geology map of the area. [Adapted from Dean (1977), Kean (1977), Swinden (1987), Coyle and Strong (1987) and Bostock (1988)].

Group contain mafic and felsic volcanic rocks with some minor mudstone and chert (Swinden, 1987; Bostock, 1988). Mapped with the Robert's Arm Group on Figure 1.3 are pillow lava and mafic intrusive rocks of the Hall Hill Complex, plagiogranite of the Mansfield Cove Complex and the Loon Bay Pluton (Swinden, 1987).

The Springdale-Hall's Bay region was once part of the early Paleozoic ocean floor near an island arc system, which was intruded at a later time by a series of plutons (Coyle and Strong, 1987; Dean, 1977; Bostock, 1988). The region has been subjected to mineral exploration in the Loon Pond area and around Hall's Bay. Most of the mineralization consists of disseminated pyrite, magnetite, pyrrhotite, and chalcopyrite in basalt and other volcanic rocks, but it is of insufficient grade and tonnage to support mining (Dean and Strong, 1975).

1.5 Climate and Vegetation

The Springdale area is located in the Central Lowlands zone, which has the greatest continentality on the Island (Banfield, 1981). The winters are cold with the mean temperature of the coldest month being -8°C at Springdale (Environment Canada, 1993). The mean temperature of the warmest month is 16.8°C (Environment Canada, 1993). The annual precipitation for this area ranges between 1000-1200 mm (Banfield, 1981). Banfield (1981) indicates that amount of winter precipitation falling as snow is 65-75%.

The present Newfoundland climate is cool boreal which is controlled by dominantly westerly winds and the proximity of the relatively cold waters of the Labrador Current system of the Atlantic Ocean (Banfield, 1993). Thus, climate of this area is affected by southward drifting pack ice in the winter and spring. Farmer (1981) indicates that the presence of ice carried on this current causes delays in the onset of spring in coastal areas. Ice appears in December and does not dissipate until June or later.

The region falls within area four of Macpherson's vegetational zone classification (Macpherson, 1981). This zone consists of mature boreal forest containing spruce (*Picea*), fir (*Abies balsamea*), poplar (*Populus*) and larch (*Larix*). It is because of this mature forest that much of the area is actively being logged. The Springdale area is classified within forest region number three by the Newfoundland Provincial Government (Government of Newfoundland, 1974). This region has 63.3% productive coniferous forest, 1.1% hardwood scrub, 13% softwood scrub, 10.2% bog, 3.4% rock barrens, 1.1% cleared land, 0.1% agricultural land, and 7.5% water. The forested areas contain black spruce, white spruce, balsam fir, white pine, larch, and birch. Damman (1983) classified the Springdale-Hall's Bay area as dominated by black spruce (*Picea mariana*), and balsam fir (*Abies balsamea*) forests, in part as a result of the abundance of forest fires. This vegetation extends to the coast due to the sheltered nature of Hall's Bay. Consequently there is no distinct break in the vegetation sequence, with the exception being areas inhabited by man or where active logging is occurring.

Woodrow and Heringa (1987) subdivided the island of Newfoundland into ten pedoclimatic zones which are differentiated on the basis of vegetation, soils and climate data. The study area lies within the Central zone, which is characterized by warmer summers and colder winters as compared to the other zones. The general characteristics of the zone are: shallow, medium to coarse textured, stony humo-ferric podzols, gleyed podzols, brunisols and gleysols; and black spruce and balsam fir as the most dominant tree species.

1.6 Outline of Thesis

As a background to this study, a review of relevant previous research is given in Chapter 2. Chronological data establishing previous sea levels are also presented. The field work, laboratory procedures and other analytical methods employed in the project are discussed in Chapter 3. This precedes discussion of the geomorphology of the area, covered in Chapter 4. Chapter 5 presents the detailed description and interpretation of the deltaic deposits in the area, and Chapter 6 is an analysis of the embayment clays found in the Indian Brook Valley. This information provides a basis for Chapter 7, the correlation of the deltaic and embayment sites and their relationships in terms of geomorphology, regional chronology, and sea level history and includes a paleoenvironmental model focusing on sea level history in the Springdale-Hall's Bay area. In the conclusion, suggestions will be made as to useful avenues for further research.

CHAPTER 2 PREVIOUS WORK

2.1 Introduction

Although a substantial amount of research has been conducted in this region, not all aspects pertinent to a thorough understanding of the deglacial and post-glacial history have been investigated. This chapter is subdivided into five sections:

a) the late glacial and early postglacial events;

b) the deltaic sediments;

c) the marine embayment sites;

d) the sea level history data; and

e) all other pertinent previously collected data that relate to the development of a palaeo-geographical model for the area, including geomorphological, and offshore sediment data.

2.2 Late Glacial And Early PostGlacial History

The Island of Newfoundland has been extensively glaciated during the Quaternary Period. Grant (1989) indicated that four or more ice advances occurred on the Island with the last two advances occurring during Late Wisconsinan time.

At present, debate still prevails over the extent of Late Wisconsinan glaciers. Two basic models exist:

1) Minimum concept of Laurentide ice extent (Figure 2.1). Labradorian ice impinged on the northerly part of the

Northern Peninsula. but insular ice did not cover the Grey Islands. the Burin Peninsula or the southernmost part of the Avalon (Grant. 1977 and 1989). Grant based this model on geomorphological features and suggested that deeply weathered terrain could represent areas not covered by late Wisconsinan ice.

2) Maximum concept (Figure 2.2). Laurentide ice completely covered the Island. extended several kilometers offshore (onto the continental shelf) and completely covered the Grey Islands and the remainder of Newfoundland. This reconstruction was based on geophysical ice sheet reconstruction in conjunction with other data, such as sea level curves, that measured isostatic rebound (Mudie and Guilbault, 1982). Under this concept. zones of intensely weathered rock represented terrain covered by cold-based ice.

With respect to the Springdale area, Murray (1883). Brookes (1970), Grant (1972. 1974), and Rogerson (1982) all indicated that during the Late Wisconsinan, several independent ice caps were located in central Newfoundland. The pattern of Late Wisconsinan deglaciation is difficult to discern due to the presence of several ice caps on the island as well as the lack of reliable ^{14}C dates. The basic premise in all reconstructions for the Springdale area is that the area was covered by local Newfoundland ice, not by the Laurentide Ice

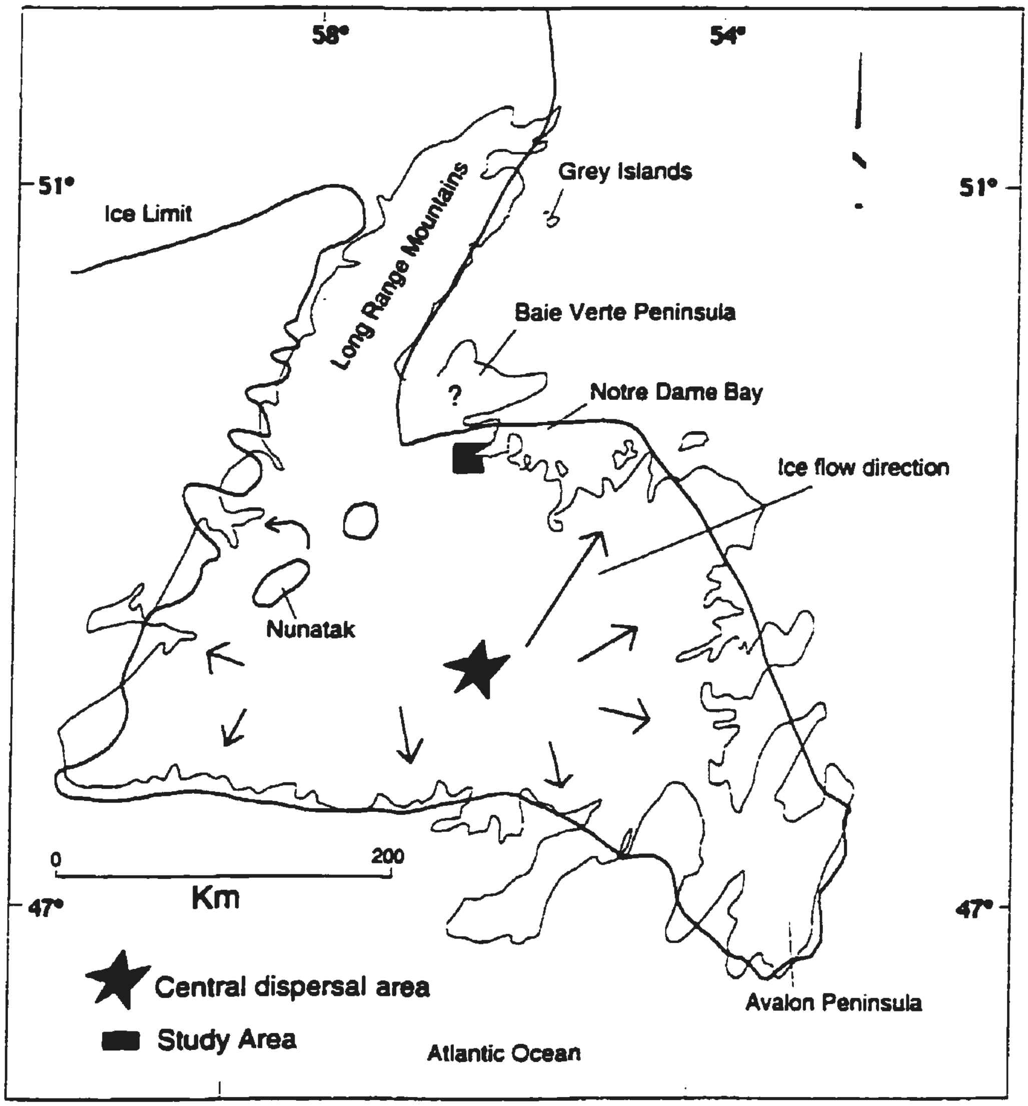


Figure 2.1: Minimum model of Late Wisconsinan ice extent. Adapted from Grant, 1977, 1989; Prest 1984; and Dyke and Prest 1987.

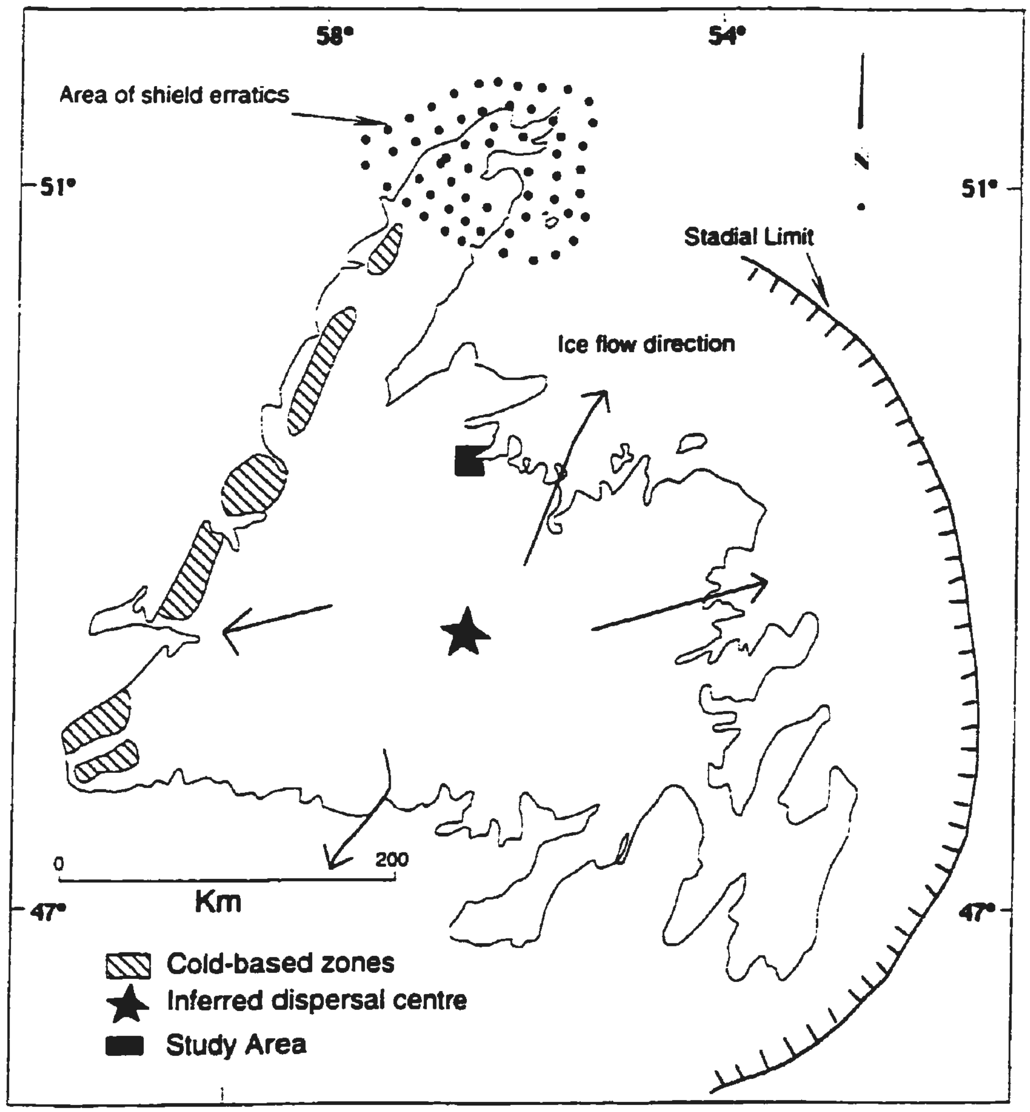


Figure 2.2: Maximum model of Late Wisconsinan ice extent. Adapted from Grant, 1977, 1989; Prest 1984; and Dyke and Prest 1987.

Sheet during the Late Wisconsinan. The evidence for this premise comes from the lack of granitic erratics from Labrador in central Newfoundland which would be expected if the Laurentide ice covered the island south of the tip of the Northern Peninsula.

Based on striation mapping, St. Croix and Taylor (1990, 1991) suggested that ice flowed eastward from the Northern Peninsula as far as central Newfoundland (Figure 2.3). As part of their four phase model, St. Croix and Taylor (1991) proposed that during the Late Wisconsinan maximum, ice caps were centered on the Long Range Mountains and in central Newfoundland. These ice masses merged in Notre Dame Bay causing ice radiating from central Newfoundland to be deflected to the east towards Bonavista Bay (Figure 2.3). During early stages of deglaciation, the Long Range ice retreated and ice from central Newfoundland began to flow to the north. Liverman (1991) indicated that an ice divide developed on the Baie Verte Peninsula at this time, with flow moving towards the coast. With progressing deglaciation, the central Newfoundland ice cap split into several independent ice caps.

Grant (1989) indicated that in Newfoundland the Late Wisconsinan Stadial Maximum occurred between 14,000 and 13,000 BP, as determined by ^{14}C dates and analysis of onshore deposits and landforms. Dyke and Prest (1987) (using both onshore and offshore data) indicated that the maximum occurred ca. 13,000 to 18,000 BP. Palynological evidence from a peat bog core located at Leading

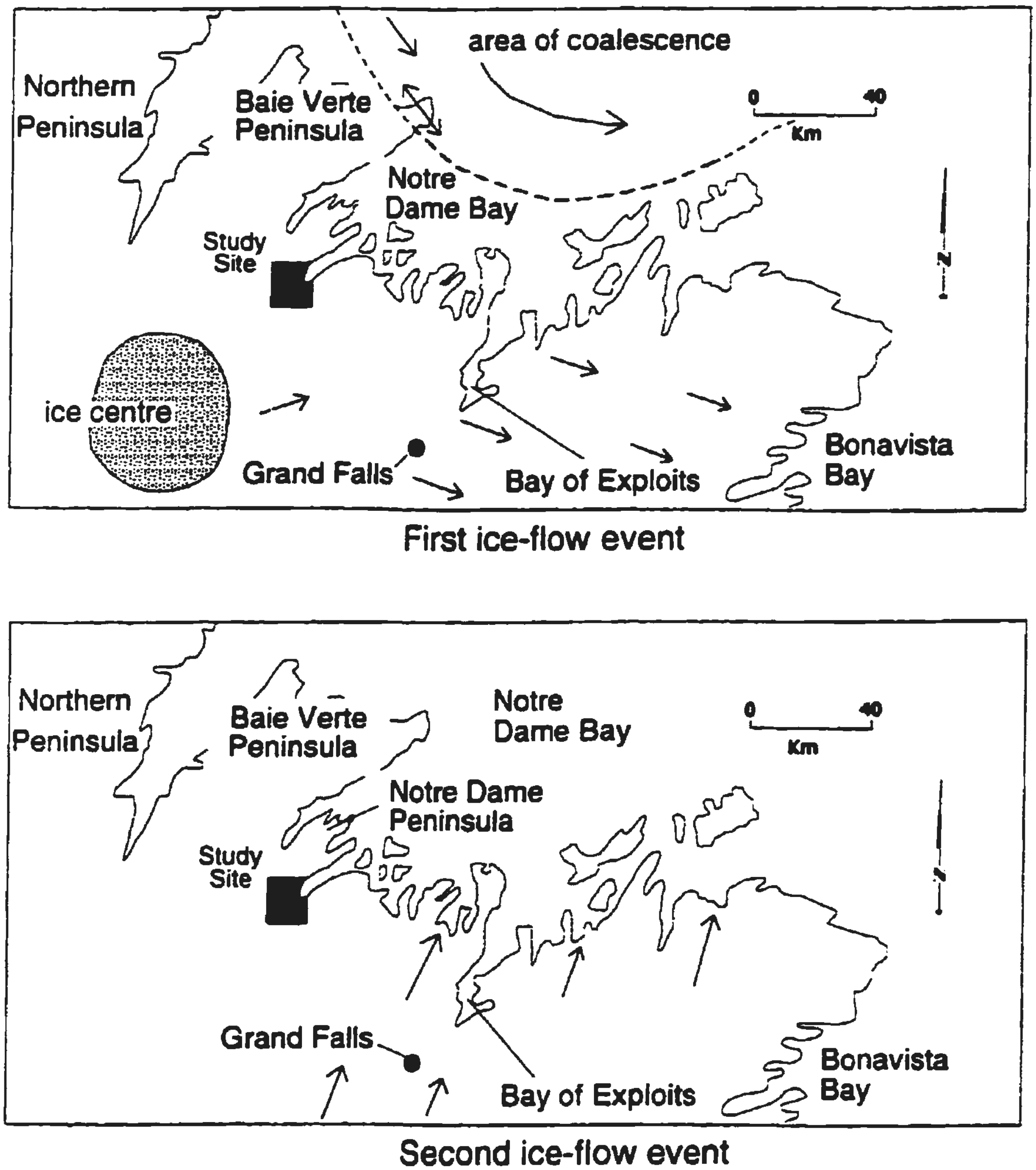
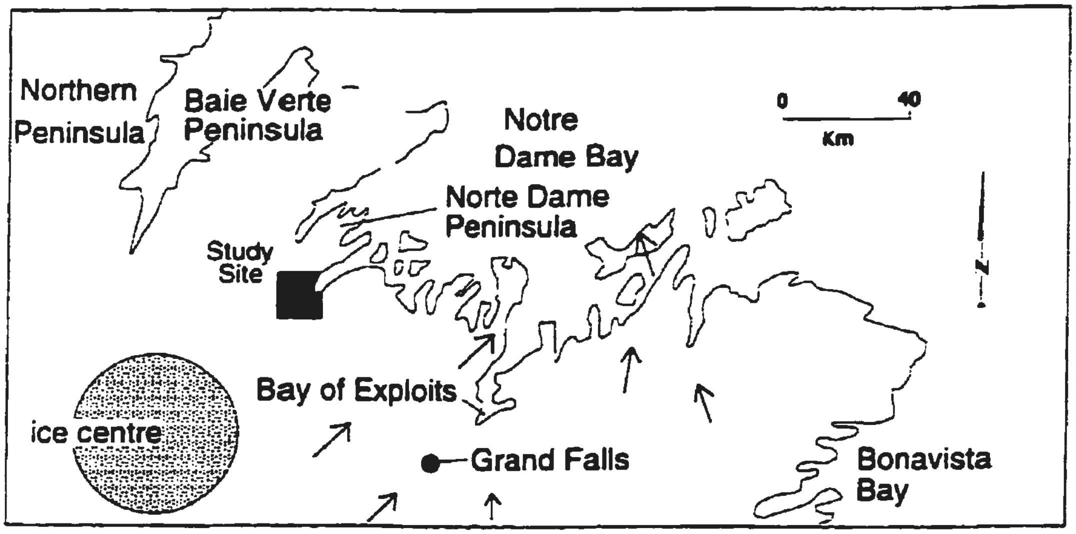
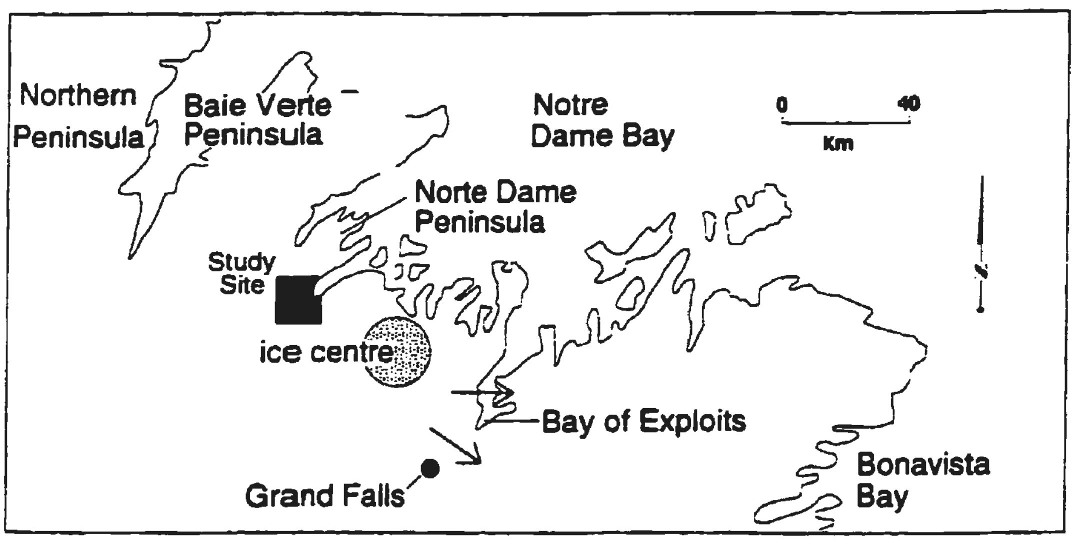


Figure 2.3: Four phase model of ice flow in central Newfoundland (adapted from St. Croix and Taylor, 1991).



Third ice-flow event



Fourth ice-flow event

Figure 2.3 continued: Four phase model of ice flow in central Newfoundland (adapted from St. Croix and Taylor, 1991).

Tickles, Notre Dame Bay, indicated that initial Late Wisconsinan warming began 13,500 BP (Anderson and Macpherson, 1994; Macpherson and Anderson, 1985). Cumming and Aksu (1992) indicated that retreat of ice from Bonavista Bay in the North central part of the island began approximately 13,000 years BP.

A study of the Deer Lake basin, a large interior basin in west-central Newfoundland, by Batterson *et al.* (1993) resulted in the postulation of a style of deglaciation that differs from the previously accepted models. The previous models put forward by Dyke and Prest (1987) and Grant (1989) suggested gradual progressive retreat from the coast to remnant ice centres on the topographic highs. Batterson et al's study indicated that the large low-level interior basin was deglaciated early, possibly at the same time that ice retreated to coastal positions from offshore. This pattern of deglaciation could be found in other areas of Newfoundland that have similar topographic settings.

A basal date of 11,800 +/- 200 BP (GSC-3957 in Blake, 1988) at King's Point, supports the minimum date of deglaciation at the head of Hall's Bay suggested by Grant (1974). Dyer (1986) stated that dates from terrestrial sites indicate the course of ice recession in central Newfoundland. Dyer also indicated that by 11,800 BP ice had receded inland in the Bishop's Falls area and that by 11,300 BP the central plateau was ice-free. A series of raised deltas deposited in the region indicate that the ice retreated along successive subparallel land-sea margins. A date of 11,500 +/- 110 BP (GSC-5527) was interpreted as a minimum for the time of deglaciation in the Botwood area (MacKenzie and Catto, 1993). Tucker (1974) interpreted a ^{14}C date of 12,000 +/- 220 BP (GSC-1733) to indicate the time of formation of a deltaic sequence at the head of Hall's Bay.

On the basis of a radiocarbon date from silty clay gyttja from a lake sediment core, Macpherson and Anderson (1985) indicated that the coast of the Notre Dame Peninsula was deglaciated by 13,200 +/- 300 BP (GSC-3608). Macpherson and Anderson (1985), Anderson and Macpherson (1994) and Wolfe and Butler (1994) all presented palynological evidence of post glacial cooling episodes. Anderson and Macpherson (1994) indicated that three cooling episodes occurred after deglaciation including: a minor episode which occurred prior to 11,200 BP ; a second cooling event, dated between 11,100 +/-120 (GSC-5001) and 10,400 +/-110 BP (GSC-4999), which is correlated to the Younger Dryas event; and a third event which lasted from 9700 BP to 8500 BP. Liverman *et al* (in preparation) indicated that ice wedge casts in the deltaic sediments in the northeast portion of the island are evidence of climate cooling and periglacial activity after delta formation.

Grant (1973, 1986) published surficial geology maps at 1:125,000 and 1:50,000 respectively, including the NTS 12H/8 and 12H/9 areas which showed sand and gravel deltas around Hall's Bay. Detailed 1:50,000 maps of the surficial geology of the area were published by Liverman and Scott (1990a) and Liverman *et al.*

(1991a). Marine and glaciofluvial deposits were recognized within the Hall's Bay Region in the course of the detailed mapping.

2.3 Deltas in the Hall's Bay Area

The first comprehensive description of deltas in the Hall's Bay region was by MacClintock and Twenhofel (1940). These authors briefly described the large delta at Springdale as an "extensive deltaic deposit of sand and gravel with scattered boulders on top" (page 1749) which measured 1500 ft (450 m) long, 800-900 ft (240 m-270 m) wide and 200-260 ft (60-78 m) thick. MacClintock and Twenhofel (1940) interpreted this deposit to be a remnant of a much more extensive deposit of outwash deltaic gravel that at one time filled all the valleys in the vicinity. They indicated that the large expanse of collapsed topography pointed to the presence of large ice blocks during deposition of the outwash. The delta located at South Brook was measured at an elevation of 240 ft (72 m above sea level (asl)) and was interpreted to be a fragment of the delta deposit at Springdale.

MacClintock and Twenhofel (1940) also indicated that these deltaic deposits had a series of lower terraces associated with them. The terrace at Springdale was measured at an elevation of 30 ft (9 m asl) on the seaward side and 55 ft (16.5 m asl) to the rear of the houses in the town. Two terraces observed in the South Brook region measured 15 ft (4.5 m asl) and 55-65 ft (16.5-19.5 m asl). These terraces were interpreted as wave cut features. The highest deltaic surfaces were believed to have formed by meltwater from glaciers draining into Hall's Bay.

Jenness (1960) believed that the 75 m asl deltas in this area were contemporaneous and formed in a glaciolacustrine environment, and used their levels to construct an isobase system. Lundqvist (1965) agreed with this glaciolacustrine interpretation. He noted beds dipping easterly in the western part of the 75 m asl delta at Springdale, and argued that these beds indicated sediment transport from ice in the Indian Brook Valley. For this reason Lundqvist (1965) rejected the premise of MacClintock and Twenhofel (1940) that the deltas at Springdale and South Brook were related. Lundqvist (1965) believed the 75 m asl delta at South Brook was deposited in front of an ice tongue in the valley, as the existence of such a lobe was demonstrated by several lateral drainage channels on the southern side of West Pond. Lundqvist (1965) also identified several deltas which could belong to the same system as those at Springdale and suggested that they may be used in constructing isobase lines.

Tucker's (1973, 1974, and 1976) work in the Springdale-Hall's Bay area is the most detailed sedimentologically. Tucker identified foreset gravels dipping at 15°-25° near the southwest end of the Springdale delta and indicated that the delta was deposited from meltwater flowing along Huxter's Brook. The presence of a modified kettle hole on the east side of the delta and a meltwater channel in bedrock suggested that ice blocked the Indian Brook valley during the deposition of the delta at Springdale. Tucker (1973) observed several deltas in the area, including those at Springdale, Burnt Berry Brook, Dock Point, West Pond, Sugarloaf, South Brook, and White Point. Marine shells located in some of these deltas indicated that the deltas were not deposited in ice dammed lakes as was suggested by Jenness(1960) and Lundqvist (1965).

Tucker (1974) identified additional marine terraces at 66, 60, 54, 15, and 9 m asl which formed as a result of isostatic rebound. His interpretation was that a calving ice front rapidly deglaciated Hall's Bay until the ice became landfast in Indian Brook and in areas to the south. The ice remained in this position while the deltas were deposited.

A sample of *Balanus*, found by Grant (1974) in a terrace with an elevation of 20 m asl located at the head of Hall's Bay, was ^{14}C dated at 12000+/-220 BP (GSC - 1733). The shell confirmed that the sediments formed in a marine environment. This date was interpreted to represent the time of formation of the 75 m glaciomarine deltas on the north east coast of Newfoundland. A ^{14}C date of 11,000 +/-190 BP (GSC - 2085) 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 75 m asl glaciomarine deltas.

2.4 Marine Embayment Data

Richards (1940) identified two shells, found by MacClintock and Twenhofel (1940) in red silts at Springdale as Pelecypoda *Saxicava arctica* Linne and Crustacea *Balanus crenatus* Bruguiere. These shells were interpreted to indicate a brackish, probably shallow marine environment. The shells were found by MacClintock and Twenhofel (1940).

Tucker (1973) described rhythmites of silt and sand 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, that 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.

Liverman and Scott (1990b) 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.

In 1987, the Newfoundland Department of Environment and Lands drilled a groundwater well at Indian River Park which was formerly a Provincial Park (Keith Guzzwell, Dept. of Environment, personal communication, 1990). The surface elevation was at approximately 48 m. Sand and gravel was obtained at the base of the drill hole which had a depth of 27.4 m and at an elevation of 18.4 m asl Clay was encountered at 23 m depth, at an elevation of 22.5 m asl Overlying this, at a depth of 22 m (23.5 m asl) is more sand and gravel. Samples were not taken between depths of 2.5 and 22 m (45.5 m to 23.5 m asl). Clay was present at a depth of 2.5 m (45.5 m asl) up to 2 m (46 m asl). Sand and gravel was obtained from the drill hole at a depth of 0 to 2 m (46 to 48 m asl).

Seismic surveys by Shaw and Wile (1990), indicated that over 150 m of stratified sediment underlies Hall's Bay. This large thickness of sediment attests to an abundant source. Stratigraphically, postglacial mud is underlain by glaciomarine sediments which are highly contorted, probably due to slumping.

Jenner and Shaw (1992) cored the sediment within Hall's Bay and found that within the main portion of the bay, the sediment was as much as 170 m thick. Southwest of Springdale the sediment thins and shows evidence of deformation and slumping. They concluded, based on dated shells (11,600+/-80 years BP [TO-2395]; 38250 +/- 80 years BP [TO-2398]; and 6050 +/- 70 years BP [TO-2396]) found in the sediment, that the sediment was deposited at the same time as raised glaciomarine deltas in the area.

2.5 Sea Level History

Data concerning relative sea level history are relatively sparse. A combination of data from Hall's Bay with data from the west coast and Northern Peninsula were used by Grant (1989) to construct isobase lines which predicted the range of postglacial emergence for the entire island. Sea level curves for these areas are shown in Figure 2.4 (adapted from Grant, 1989).

The general pattern consists of a series of delevelled water planes which are tilted up to the north-west in the direction of greatest load (Grant, 1977). Grant indicated that this pattern was expected when emergence is a product of glacio-isostatic crustal rebound. Theoretical models of sea level change by Quinlan and Beaumont (1982) agree with ice retreat from the maximum limit of ice cover postulated by Grant (1977). Figure 2.5 shows the postulated isobases on marine limit over the Island of Newfoundland.

Quinlan and Beaumont (1981, 1982) utilized geophysical modelling to compare observed and theoretical postglacial relative sea level in Atlantic Canada. Their modelling led to the suggestion that distinct zones exist that are characterized by distinct sea level history as defined by their position relative to the former ice sheet. Their work suggested that the Northern Peninsula of Newfoundland should have a "Type A" sea level curve which is defined as sea level continuously falling since deglaciation from the marine limit to present sea level. The central portion of the island was suggested to have a "Type B" curve where sea level falls from marine limit to below present and then rises again. The southeast portion of the island should have "Type C and D" curves where sea level always falls below present following initial deglaciation.

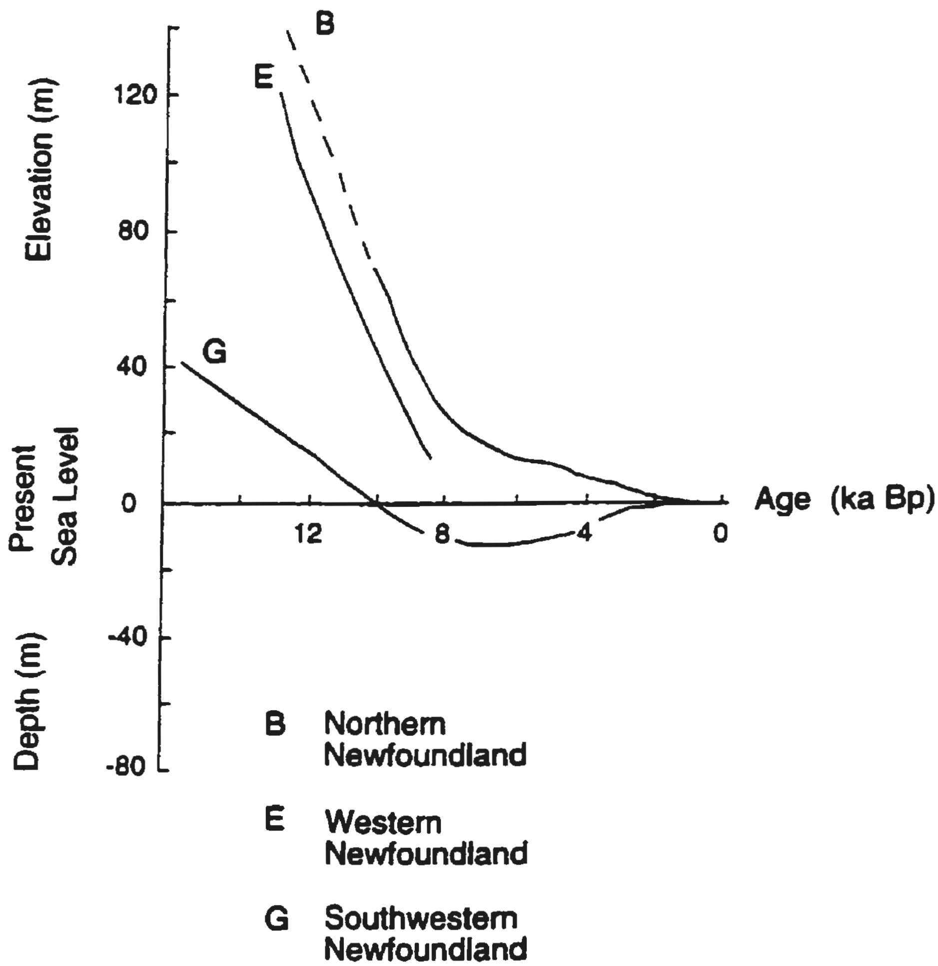


Figure 2.4: Sea level curves (adapted from Grant, 1989).

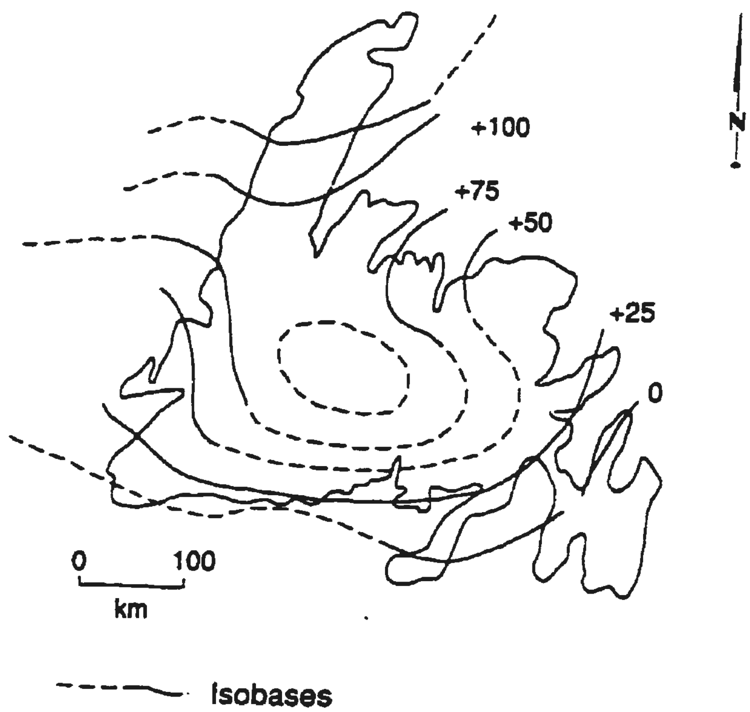


Figure 2.5: Postulated isobases on marine limit over the Island of Newfoundland (adapted from Grant, 1989).

Shaw and Forbes (1990) studied relative sea level change on the northeast part of the island. Their research led to the development of a Type B sea level curve showing that relative sea level fell below present between 12.000 to 10.000 BP and then rose to approximately 0 m around 2.000 BP. According to Liverman (1994) and Shaw and Forbes (1995). sea level fell to its present position by approximately 9.000-10.000 yrs BP along the northeast Newfoundland coast. Figure 2.6 shows the distribution of postglacial relative sea-level minima.

Liverman (1994) reviewed the distribution of radiocarbon dates over the island of Newfoundland. He suggested that an examination of the temporal and geographical distribution of these dates in combination with geomorphological indicators of past sea levels indicate regional trends of relative sea-level change. A regional distribution of marine shell dates in the northeast portion of the Island of Newfoundland. see Table 2.1. were interpreted to indicate Type B curves (Liverman, 1994).

Liverman and Batterson (1995) reiterated the suggestion that the north central portion of the coast of Newfoundland has a Type B sea level curve record. Figure 2.7 shows limits of minimum age of post-glacial sea level for northeast and west coasts of Newfoundland and suggested relative sea level curves

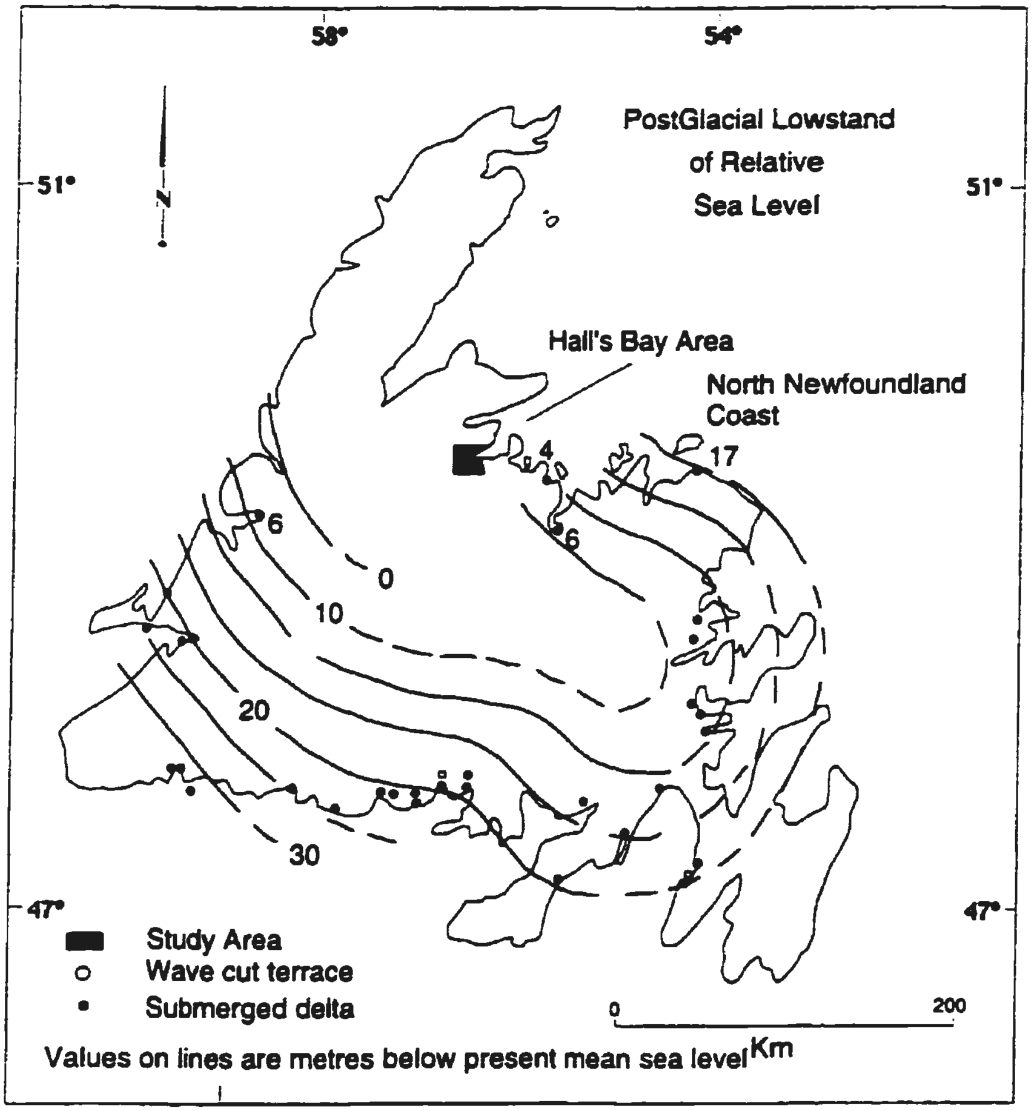


Figure 2.6: Distribution of postglacial relative sea-level minima (adapted from Shaw and Forbes, 1995)

Table 2.1: Shell dates used to indicate Type B sea level curves.

Dates shown follow the conventions as reported by the original authors and have not been corrected from the originally reported values.

Shell Type	Date	Lab #	Locality	Reference
Hiatella arctica	11500+/-110	(GSC-5527)	Botwood area	MacKenzie and Catto (1993)
Balanas sp.	12000+/-220	(GSC1733)	Hall'sBay area	Grant (1974)
Hiatella arctica	11000+/-190	(GSC-2085)	Hall'sBay area	Tucker (1973)
Mya truncata	10200+/-100	(GSC-4023)	Sop's Arm	Blake (1988)
Mya truncata	11700+/-110	(GSC-4311)	Rattling Brook	Blake (1988)
marine *Pelecypod*	11880+/-190	(GSC-87)	Southwest Arm	GSC Paper 63-21

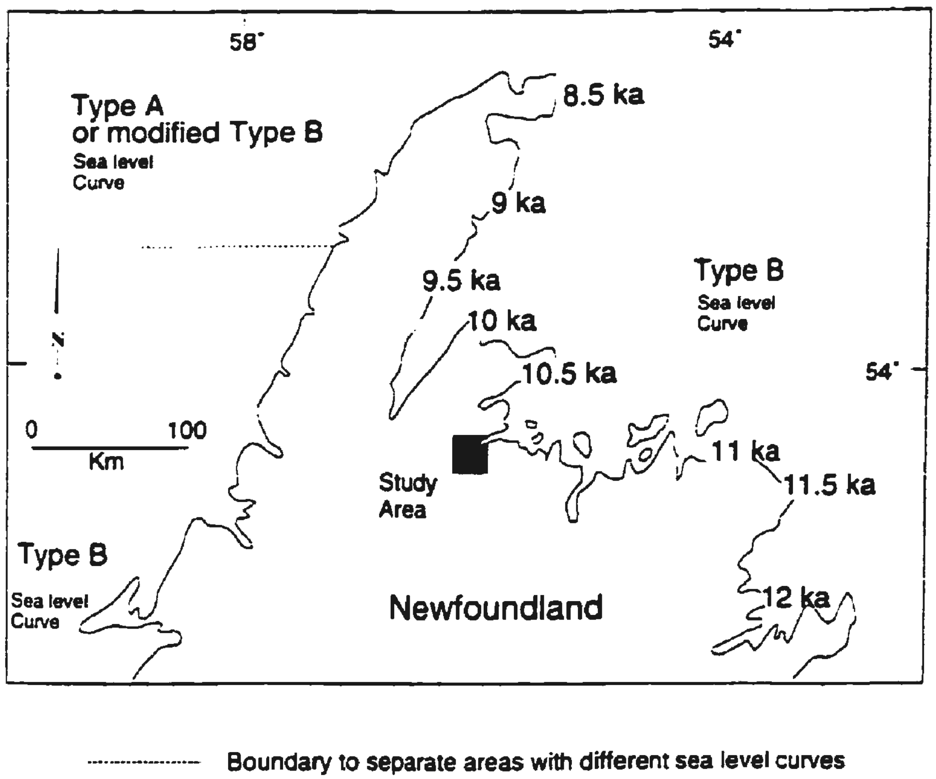


Figure 2.7: Limits of minimum age for northeast and west coasts of Newfoundland and suggested relative sea level curves (adapted from Liverman, 1994). Ages (12 through 8 ka) are expressed in ^{14}C years BP.

In summary, the Springdale Hall's Bay region was glaciated as evidenced by glacial sediments and striations within the region. During the Late Wisconsinan ice flowed to the north and northeast. Work on the sea level history of the island has provided a rough idea regarding sea level in the Hall's Bay area but detailed sedimentology studies of deposits is limited.

CHAPTER 3 FIELD AND LABORATORY METHODS

3.1 Introduction

Field work for the thesis was performed during the summers of 1990 and 1991. Natural river and road cuts in the area were examined, and detailed descriptions of deposits were recorded. Box cores were taken from one section, dried, and examined in detail. Small scale features in the sediment, such as loading and soft sediment deformation features, were also examined. Description was supplemented by sampling for textural and geochemical analysis. In addition, several samples were taken at each site for microfossil analysis, to test for the presence of any foraminifera and diatom assemblages. Mollusc and arthropod 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 being made by recording the time of the reading at each location and subsequently returning to a known altitude. The resulting elevations are thought to be accurate to +/-3 m. The total number of exposures studied was eleven.

For discussion purposes the methodologies are divided into two categories: field methods and laboratory methods.

3.2 Field Methodology

Analysis of the sections was carried out by conducting detailed sedimentological descriptions on a millimetre to centimetre scale. This was necessary due to the scale of bedding and laminations present in each unit. Sections were prepared by scraping off the surface of vertical faces and allowing the underlying material to dry. This allowed the smallest sedimentary structures to become more prominent. Once a section was cleared, sketches and photographs of the overall section were made and distinct changes in sedimentology were noted. The thickness of each section was measured and the sedimentology described in detail working from the basal unit. As part of these detailed descriptions, photographs of each unit and features in the sediment were taken. Abundant descriptive detail was needed in order to analyse sedimentologically complex units.

In an effort to supplement the descriptive detail, box cores were taken at one location, Site SS-1. These box cores were obtained by pounding an aluminum sided box (30 cm X 10 cm X 10 cm) into the vertical face of the section with a rubber headed mallet and then prying the box and sediment out. Figure 3.1 is a sketch of the box corer and Plate 3.1 is a photograph of the sedimentary section after the box corer is removed. This method was only used for clay units due to their cohesiveness and the general paucity of stones. These samples were then transported back to the lab where they were air dried.

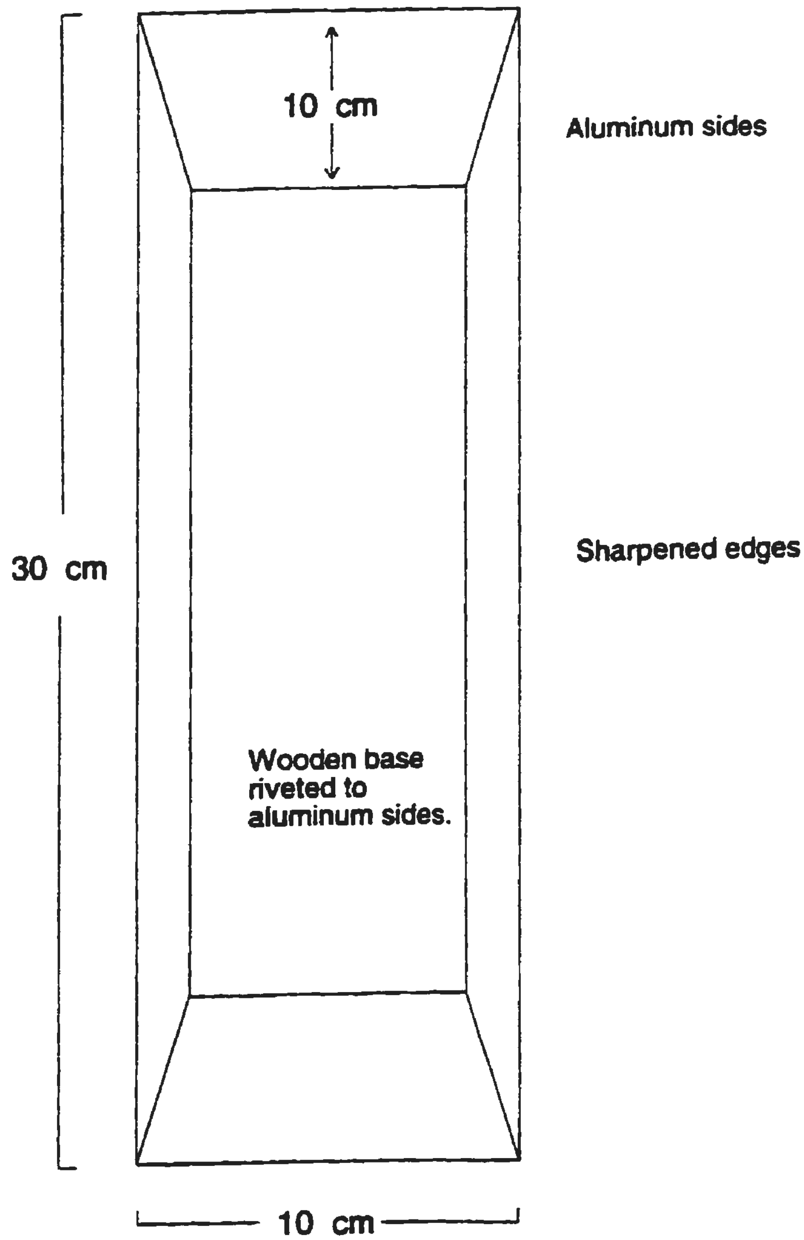


Figure 3.1: Sketch of the box corer.

Plate 3.1: Sedimentary section, Units 1 and 2, within Site SS-1, after the box corer was removed. Box corer is 30 cm in length. The plate shows where several cores have been removed sequentially.

A Wallace-Tiernan altimeter (model number FA-181220) was used to measure the elevations of the uppermost surfaces of the sections investigated. Compensation for drift was made by recording the time of the reading at each location and subsequently returning to a known altitude. Any change in elevation could then be calibrated to the correct height. The resulting elevations were accurate to +/-3 m.

The orientations of all paleocurrent indicators were measured using a Brunton compass. Utilizing Woodcock's (1979) method, flow nose axes and plunges were measured. These data allow the direction of movement (flow) to be determined. Appendix 1 shows the field measurements and plots of flow direction.

3.3 Laboratory Methods

Sections were sampled in detail for textural, lithological, palaeontological, and geochemical analytical purposes. Some units were sampled at 0.5 m intervals, whereas others were sampled every 1 m. The detail of the sampling depended on the complexity of the section and on the level of detail necessary to analyse the units throughout the sections. More than 50 separate samples for textural and geochemical analysis were taken throughout the deltaic and clay sections at varying intervals. In addition, fourteen samples were taken for palaeontological identification from the clay sections. For the clast lithology portion of the study, three samples were taken at one clay section. The low stone concentrations in the silt and clay deposits presented a problem for this part of the analysis. The deltaic sites were not sampled in detail because preliminary lithological analyses indicated local clasts were predominant. The texture and geochemistry samples were stored in paper bags while the palaeontological samples were stored in plastic bags or containers.

3.3.1 Textural Analysis

Samples were analyzed for texture using a wet and dry sieving method as outlined in Folk (1974). This first entailed splitting the samples and recording the mass (not less than 100 grams and not more than 140 grams). Samples were then placed in containers. submerged in hydrogen peroxide and allowed to stand overnight. The samples were then wet sieved using Canadian standard sieve series No. 60 (250 μm) and No. 230 (63 μm). After sieving. the two sieves were rinsed into an aluminum foil pan. This sediment was then drained and oven-dried in a Fisher Isotemp oven 200 series model at 350 degrees. The remainder of the sample was placed in a bucket with a magnesium chloride solution at a concentration of 101.65 g/l, to induce settling, and allowed to stand overnight. The water in the bucket was then siphoned off. and the sediment rinsed into a previously weighed and oven-dried bowl. After drying and cooling, the sediment was weighed again. Following this, samples were crushed and placed in vials.

The oven-dried portions trapped in the aluminum foil pans were weighed and then sieved. The following sieve series was used in the sieving process: No.5 (4.00 mm) -2ø; No. 10 (2.00 mm) -1ø; No. 18 (1.00 mm) 0ø; No. 35 (500 µm) +1ø; No. 60 (250 µm) +2ø; No. 120 (125 µm) +3ø; No. 230 (63 µm) +4ø; and a base pan for catching material. Appendix 2 shows the raw sieve data.

To complete the grainsize analysis, the -230 mesh portions were analyzed by coulter counter. Appendix 3 shows the coulter data. Once this was complete, the data were graphed using the Macintosh computer package Microsoft Excel. The proportions of sand, silt and clay were determined for each sample. Appendix 4 shows the sand, silt and clay values for each sample.

3.3.2 Geochemical Analysis

Samples were also subjected to geochemical analysis. A standard analysis for boron, vanadium, gallium, niobium, thorium, yttrium, strontium, lanthanum, cerium, iron, barium, lithium, scandium, dysprosium, manganese, copper, zinc, lead, nickel, rubidium, chromium, beryllium, molybdenum, cobalt and cadmium was undertaken for the samples (see Appendix 5 for results). Concentrations of boron and vanadium were determined as the concentrations of both of these elements, in particular vanadium, can be interpreted to indicate the paleosalinity of the depositional environment (Shimp *et al.*, 1969; Catto *et al.* 1981). The samples were analysed for vanadium and boron by the Newfoundland Department of Mines and Energy using the Inductively Coupled Mass Spectrometer. A mixed acid digestion was used to determine total vanadium in the samples. The results are discussed in Chapter 6. Appendix 5 contains the data from the geochemical analysis of the samples.

Boron analysis was undertaken by two different laboratories (Newfoundland Department of Mines and Energy Geochemical laboratory in St. John's and Bondar-Clegg Geochemical Laboratory based in Ottawa) with inconsistent results. Samples were assessed by the laboratory in St. John's and the same samples were then sent to Bondar-Clegg in hopes of yielding similar chemical values. Both analyses resulted in different determinations of boron concentrations in the same samples. Duplicate samples from the originals that were subsequently sent for analyses, were run by these laboratories, and also produced inconsistent results, both between and within each laboratory. Due to the inconsistency of these results, they were not used to determine paleosalinity in this study.

Some testing for background vanadium and boron levels was undertaken by sampling the surrounding sediments within the study region. This sampling did not cover a wide area. This may be a potential problem for interpretation of the geochemical results.

3.3.3 Palaeontology Analysis

A total of 18 samples were analyzed for foraminifera content. This involved washing and sieving the sample in order to aid microscopic analyses, as a microscopic field with a well sorted sample of grains makes it easier to identify any foraminifera. The decantation method as described by Boltovskoy and Wright (1976) was utilized as this method works well for argillaceous samples. The samples were placed in buckets. water and calgon (to act as a dispersant for the clay) were added, and the mixtures were agitated. These clay-water mixtures were then poured through the finest sieve size (63 μm, No. 230) until the finest fraction had been eliminated. Following this, the samples were wet sieved and dried. The samples were then examined under a binocular stereoscopic microscope with x8, x12.5 and x18 oculars and x4, x8, and x12 objectives. No foraminefera were detected.

3.3.4 Shells

All invertebrate Mollusc and Arthropod shells were stored in plastic bags or containers until they were analyzed. After preliminary identification of the shell species was made, the taxa were verified by John Shaw (Bedford Institute of Oceanography. Atlantic Geosciences Centre). Two samples were radiocarbon dated by the conventional ^{14}C method at the Geological Survey of Canada. The standards for ^{14}C analysis for the Geological Survey involved a del13 C correction of 0% PDB. Three other samples were sent to Isotrace Laboratory in Toronto for accelerator mass spectrometry ^{14}C dating. The procedures for ^{14}C analysis followed the standards outlined for Isotrace (Litherland and Beukens 1995).

CHAPTER 4 SURFICIAL GEOLOGY AND GEOMORPHOLOGY

4.1 Introduction

Analysis of the surficial geology and geomorphology of the Springdale region involved the identification of landforms and surficial geological units, and assessment of their areal distribution. The primary methods involved were aerial photograph interpretation and ground surveying. These investigations, in conjunction with previously undertaken geological studies (Liverman and Scott, (1990a, b), Liverman *et al.* (1991a, b)), allowed assessment of the nature of Quaternary sedimentation and landform development, the direction of glacial flow, the extent of glaciomarine inundation, and the location of glaciofluvial and deltaic deposits and landforms.

Stereographic pairs of 1966 black and white air photos at scales of 1:44,000 (available for the entire area) and 1:12,500 (only available for the Indian Brook area) were analysed using a mirror stereoscope. A thorough analysis of topography, drainage patterns, erosional features, sediment texture and tone was undertaken in order to identify different terrain conditions and their boundaries. This yielded information on genetic types of deposits and material transport.

Aerial photograph analysis facilitated the selection of suitable sites for detailed sedimentological investigation. The photographic and field analyses were conducted between June and August 1990 and June and August 1991, and the initial results were published by

Liverman and Scott (1990 a, b). Additional field investigations were conducted in 1991 and preliminary results published in Scott and Liverman (1991) and Scott *et al.* (1991).

4.2 Surficial Geology

Figure 4.1 illustrates the surficial geology map of the region, based on the investigations reported by Liverman and Scott (1990b) and Liverman *et al.* (1991b). Note that only the dominant surficial material within each polygon is noted in this map. Additional Quaternary sediments are located within these units but their areal extents are too small to illustrate at this scale. Detailed surficial geology maps of the area were produced by Liverman and Scott (1990a) and Liverman *et al.* (1991a).

Following the initial mapping, the air photos were further reviewed. This, along with field investigation of the area surrounding Hall's Bay and the Indian Brook valley, confirmed that glaciomarine silt and clay was more extensive than was indicated on the surficial geology maps of Liverman and Scott (1990a) and Liverman *et al.* (1991a).

Figure 4.2 is a map of the region, illustrating major terrain units within the region. Six major map units were identified, including: bedrock (exposed and concealed), glacial veneers to blankets (including hummocky or eroded or drumlinoid till), glaciofluvial (deltas and outwash), glaciomarine (sand, gravel with

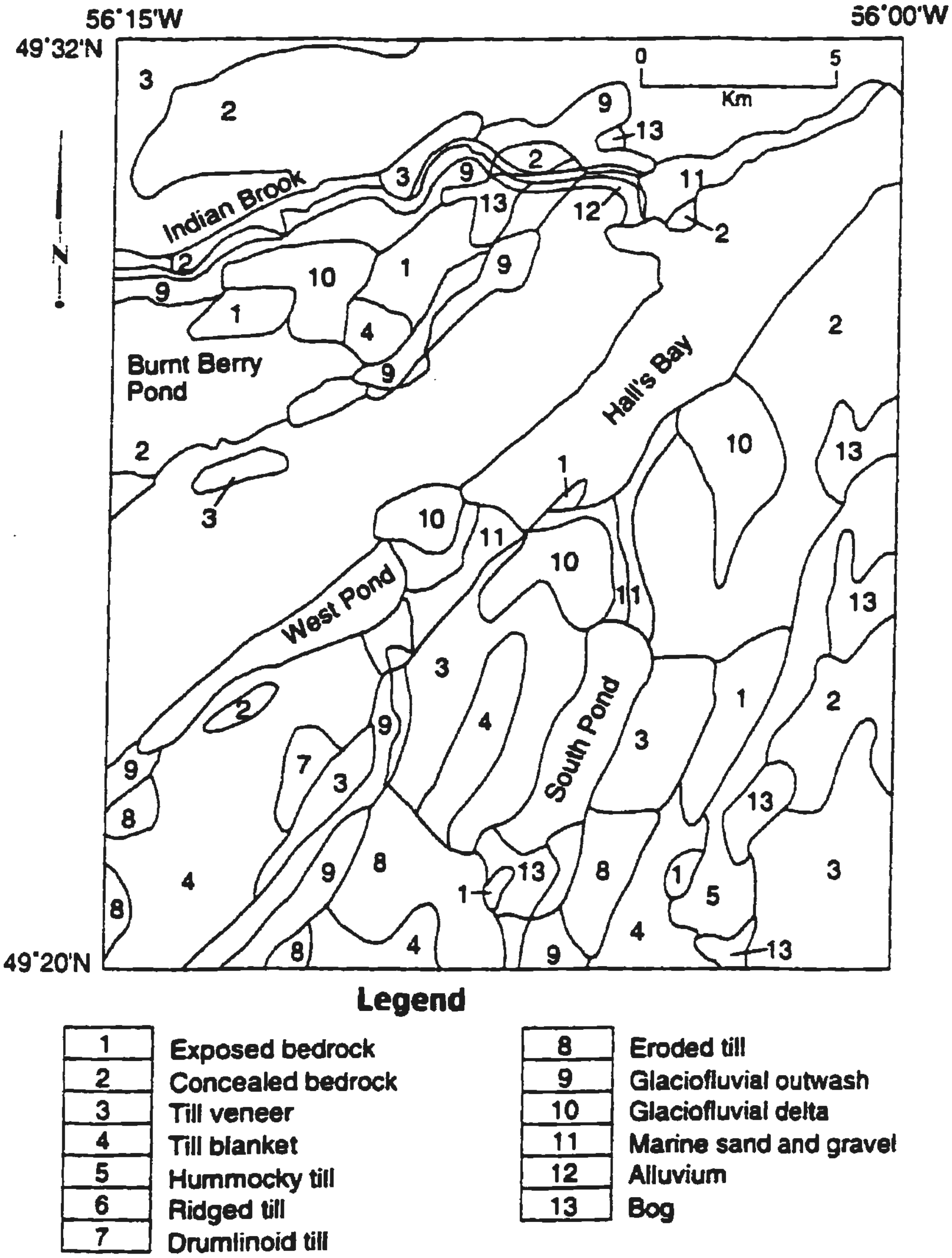
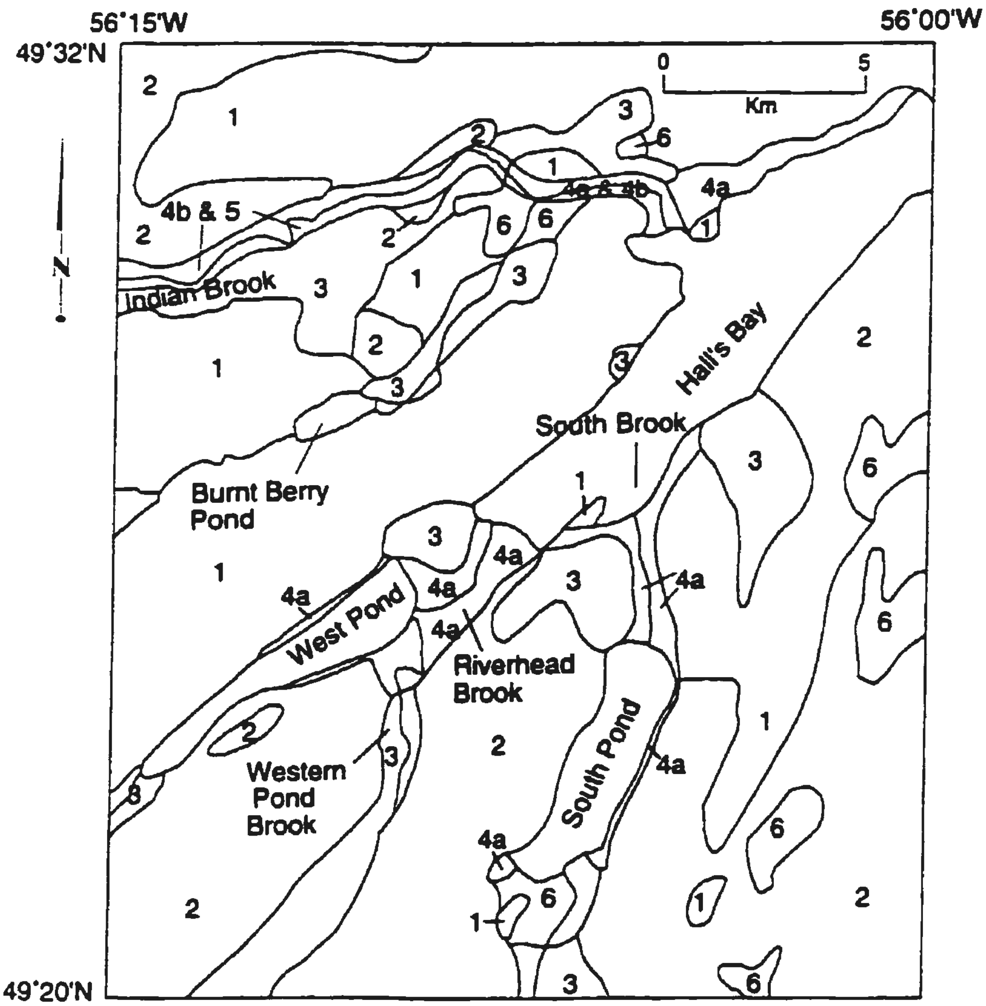


Figure 4.1: Surficial geology of the region adapted from Liverman and Scott (1990b) and Liverman, *et al.* (1991b).



Legend

1	Exposed and concealed bedrock
2	Till veneer, blanket, hummocks, ridged, drumlinoid
3	Glaciofluvial outwash
4a	Marine sand and gravel
4b	Glaciomarine silt and clay
5	Fluvial
6	Wetlands

Figure 4.2: Map of the major material units in the region.

silts and clays), modern fluvial, and organic (wetland). Table 4.1 lists these major units and the characteristics used for their identification.

Unit 1 is bedrock, including exposed and concealed areas. It makes up approximately 35% of the map area with approximately 10% exposed and 25% concealed (defined as covered in vegetation). On aerial photographs the bedrock is usually represented by lighter tones. Bedrock is located on topographic highs and on the valley bottom at the mouth of Indian Brook. There is some coverage by soil and vegetation as well as by < 5% of other sediment such as till veneer and sand and gravel. Felsenmeer is not developed in exposed bedrock areas.

Unit 2 is till and modified diamicton (which may include diamicton of other than primary glacial origin). These sediments include till veneer, till plain or blanket, eroded till, and hummocky till. This material covers over 35 % of the map region, but only about 5% of the area below the 75 m contour. On aerial photographs these sediments range from light to dark and mottled tones. Glacial indicators such as striations and erratics indicate that ice flow was to the north and northeast within the region during the Late Wisconsinan (Liverman *et al.*, 1991b).

Thin till veneer, composed of sandy diamicton with 50-70% clasts (>2 mm in diameter), up to 1 m thick, typically overlies bedrock. Till plains or blankets are located in the southwestern part

Table 4.1: Characteristics of Map units on Figure 4.2

(note units are standard mapping units used by the provincial geological survey)

Unit	Description	% Area	Pattern on Aerial Photographs	Topography	Origin
1	bedrock exposed and concealed	35	lighter tones	higher elevation locations and on steep slopes in river valleys	bedrock
2	a mixture of sand, silt and gravel (diamicton)	35	light to dark and mottled tones	hummocks, ridges and plains	glacial
3	deltaic sand and gravel	10	lighter tone	terraces and plains; deltaic deposits	glacio fluvial
4	sand and gravel terraces and plains of silt and clay	5-10	lighter tone for sand and gravel and darker even tones for silt and clay	irregular pitted hummocks with steep slopes and gentle slopes and plains with little relief	glacio marine
5	gravel, sand and silt	5	lighter tones at the base of river valleys	flat to terraced	modern fluvial
6	wetland	5	dark tones	gentle depressions	organic

of the study region, and typically consist of silty sandy diamicton up to 3 m thick.

Eroded till (0.5 -3 m thick) commonly occurs in the vicinity of West and South ponds where numerous meltwater channels resulted in erosion of the diamicton. Hummocky till, typically 2-10 m in relief and similar in composition to till veneer, is located in the southeast part of the region.

The till and modified diamicton have varying morphologies. Veneers are thin till units, where the morphology of the underlying unit is evident. Till plains to blankets are flat and level or slightly undulating where underlying units are masked but the major pre-existing topographic form is still evident. Eroded till typically has a gullied or channeled surface. Hummocky tills consists of random assemblages of mounds, ridges and depressions.

Unit 3 is glaciofluvial sand and gravel. This material covers approximately 10% of the land area and locally interfingers with the glaciomarine deposits of sand and gravel. This type of relationship typically occurs where sediment extends landward from the marine sediments, as near site SS-2 at Indian Brook Park. This sediment has the same topographic appearance, drainage pattern, and erosional features. The tones of the glaciofluvial sediments on the photos are usually much lighter than other types of material due to the better drainage. Glaciofluvial deposits are geomorphically expressed as a series of terraces around lake shores and as expanses of outwash located landward of deltas. It is not found in proximity to the glaciomarine silt and clay. The deposits consist of bedded sand and gravel, exhibit current indicators indicating flow towards the sea, and some have beds dipping at 25° NE. Several of these deposits are being utilized as aggregate pits. Generally this unit where exposed is > 2 m thick and ranges from 20-70 m in relief.

Unit 4 is composed of glaciomarine sediments including sand, gravel (4a), and silt and clay (4b). The sediment covers approximately 25% of the mapped area, with sand and gravel comprising 20% and silt and clay 5%. On air photographs the silt and clay material forms planar topography and has a darker tone than the surrounding better drained material. These deposits differ from the glaciofluvial as these deposits are associated with sea level positions.

The silt and clay sediments range from 1-8 m in thickness and consist predominantly of 50% silt and 30% clay with 20% fine sand beds. Larger clasts are present, deforming the underlying sediment and draped by the overlying material.

These sediments were prevalent in the lowest area of Indian Brook Valley and were exposed up to 8 km inland at Site SS-1 (see Figure 1.2). Indian Brook follows a meandering course over the sediment. In addition, there is evidence of slope failure (slumping) in some areas. Typically, failures occur where a tributary stream enters the Indian Brook river valley and erodes the silt and clay in semi- circular patterns around the stream outlet. Effectively this creates gullied portions within the slope, producing retrogression of the upslope headwalls. The gullies generally extend from 5 m to 15 m upslope from the edge of Indian Brook. The active gullies typically have a stream width of 1 m, a stream channel slope gradient of 19°, sidewall heights ranging up to 7 m with sidewall slope gradients >35°. The mechanism for the failure is a combination of oversteepening due to surface water erosion, and weathering of the exposed faces that lowers the cohesiveness of the sediment. Where exposed, the sediments pose a stability concern.

On aerial photographs, sands and gravels within Unit 4 are contiguous landward of the silts and clays. They typically have a lighter tone, due to better drainage and poorer vegetation coverage, than the darker toned silt and clay material.

The sand and gravel range from 1 to 50 m thick and are exposed in the valleys and lowland areas between 5 and 75 m asl These deposits consist of alternating beds of sand and coarse gravel, which have dips up to 25°. Individual bluffs range up to 75 m in elevation. Two morphologies of sand and gravel sediments are present: triangular in plan view with braided steam patterns visible on the surface; and irregular shaped mounds of material with pitted surfaces and steep slopes.

The area covered by sand and gravel is typically poorly vegetated. Land use in areas with these sediments includes farming, or aggregate extraction. Both uses have caused the morphology of the original material to be altered somewhat.

Unit 5 is modern fluvial sediments. This material covers <5% of the map area. On aerial photographs the material generally has lighter tones, and is found at the base of river valleys. Sediment in this unit consists of structureless to stratified, well-sorted, rounded pebble to cobble gravel with crude horizontal bedding, imbrication, or trough cross-stratification. Lesser amounts of structureless or cross-stratified sand with ripples, fine horizontal laminations or erosional scours are also present. The deposits are thin with a maximum thickness of 1 m.

Unit 6 is wetlands which cover approximately 5% of the map area. On the aerial photographs these areas have dark even tones. They are made up of degraded organic material and located in poorly drained areas. Their thickness was not determined.

CHAPTER 5 SEDIMENTOLOGY OF DELTAIC DEPOSITS

5.1 Introduction

The study region has several exposures of sand and gravel. Ten sections dominated by sand and gravel were investigated in detail (Figure 5.1). These sediments have all been interpreted as deltaic deposits, on the basis of evidence discussed below.

The deltaic exposures are divided into two groups with respect to the source of the glaciofluvial outflow: proximal and distal. This subdivision is based on geomorphology, sedimentology and relationships with adjacent sedimentary deposits and landforms.

The stratigraphic successions at sites SS-12 and SS-16 (both proximal to the ice front) and SS-13 (distal to the ice front) are representative of the variety of sand and gravel deposits throughout the study region. An analysis of the sedimentology of these sites will be presented as a detailed description of the sediments from bottom to top, followed by the assignment of facies to packages of sediment and finally using the architecture of these facies to interpret the mode of formation of the deposit and the depositional environment. In the section description, packages of facies are referred to as units. Descriptions (sedimentary columns) for all sections not presented in this chapter are located in Appendix 6.

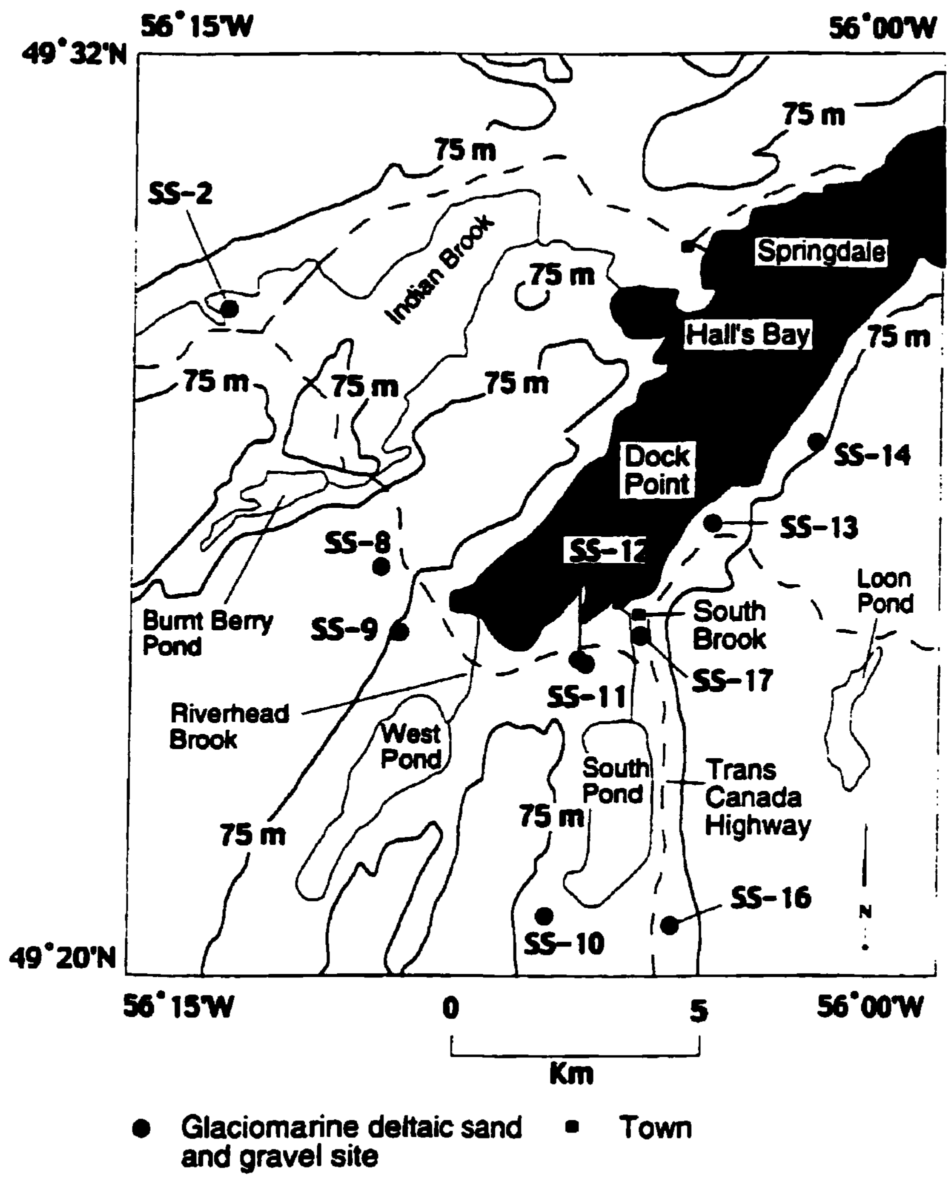


Figure 5.1: Location of sand and gravel deposits investigated during this study.

5.2 Lithofacies Designations

The lithofacies assignments are based on sediment texture and structure, similar to that of Eyles and Miall, 1984. The sedimentary facies are grouped according to a modified lithofacies code (see legend on Figure 5.2; also note that the legend is used for all three sections and not all facies or features are present in each section). It should also be noted that near the top of each section, provided the soil horizon has not been removed, the beds exhibit pedogenic alteration. Typically contacts are blurred where pedogenic processes have been active.

5.2.1 Gravel Facies (G_1, G_2, G_3)

Gravel facies vary in particle size distribution and degree of clast support. They are subdivided into three groups: clast supported structureless pebble gravel (G_1), stratified graded sand and gravel (G_2), and structureless granule supported pebble-granule gravel (G_3).

Clast supported structureless pebble gravel (G_1), typically exhibits a pebble gravel texture that is moderately sorted, contains no structures, has sharp to gradational lower contacts, and ranges from 50 to 60 cm in thickness.

Stratified graded sand and gravel (G_2), typically exhibits a sandy gravel texture (85-95% granules and 5-15% pebbles) that is poorly to moderately sorted, is stratified, has sharp lower contacts, and ranges from 80 cm to 2 m in thickness.

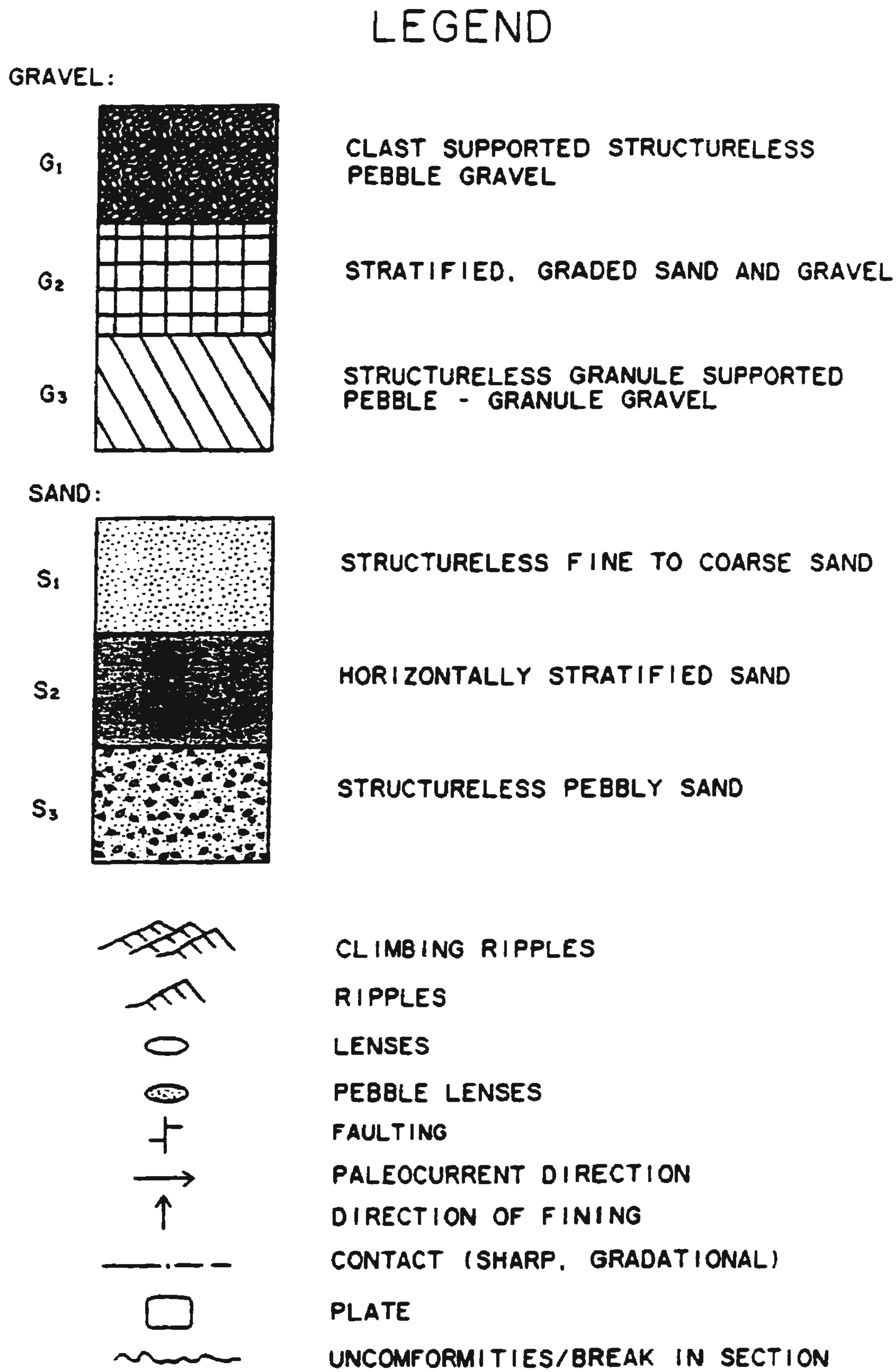


Figure 5.2: Legend for sedimentary columns presented in Figures 5.3, 5.4 and 5.5.

Structureless granule supported pebble-granule gravel (G_3), typically exhibits a pebble granule texture (with up to 40% pebbles) that is moderately sorted, contains no structures, has sharp lower contacts, and ranges from 10 to 80 cm in thickness.

5.2.2 Sand Facies (S_1, S_2, S_3)

The sand facies are texturally diverse but predominantly are comprised of well sorted fine to coarse sand. They are divided into three groups: structureless fine to coarse sand (S_1), horizontally stratified sand (S_2), and structureless pebbly sand (S_3).

The structureless fine to coarse sand (S_1), typically exhibits a sandy (90-100% sand) that is moderately to well sorted, has sharp lower contacts, and ranges in thickness from laminae (<10mm) to beds (30-50 cm).

The horizontally stratified sand (S_2), has a texture between 90-100% sand, is moderately to well sorted, has sharp lower contacts and strata with laminae (<10mm thick) to beds (30-50 cm thick). Typically fining upward sequences occur, lenses of coarse pebbly sand are present and occasionally ripples occur.

The structureless pebbly sand (S_3) facies is a matrix supported pebbly fine to medium sand (20-30% subangular to subrounded pebbles with 70-80% sand). These beds also contain scattered cobbles. The contacts are typically planar and sometimes the beds show coarsening upward sequences. These beds range from 5 cm to 1.25 m thick. Lenses of coarse pebbly sand sometimes occur.

5.3 Ice-Proximal Deltaic Sediments

Seven sites consist of interbedded, moderately to well sorted sand and gravel with beds dipping seaward to the north. These sites include SS-2 (68 +/- 3 m asl) at Indian River Park; SS-8 (72 +/- 3 m asl) and SS-9 (20 +/- 3 m asl), both on the terrace between West Pond and Hall's Bay; SS-10 (50 +/- 3 m asl) at the southwest end of South Pond; SS-11 (64 +/- 3 m asl) and SS-12 (64 +/- 3 m asl), along the woods road between South Pond and Hall's Bay; and SS-16 (51 +/- 3 m asl) southeast of South Pond on east side of the Trans Canada Highway. Plate 5.1 shows typical dipping beds from Site SS-8.

Sites SS-12 and SS-16 are representative of all the ice-proximal deltaic sites and are presented in detail here. Site SS-16, discussed first, is the most complete and laterally continuous exposure of all these localities.. Site SS-16 is similar in morphology and sedimentology to SS-2, SS-8, SS-9, SS-10, and SS-11.

5.3.1 Site SS-16

Site SS-16 is located approximately 1.5 km southeast of the southern end of South Pond on the east side of the Trans Canada Highway. This site represents a glaciomarine deltaic deposit surrounded by till. The deposit has a surface area of approximately 200 m^2 , and extends north-south for 200 m^2. The uppermost surface of the section has an elevation of 51 +/- 3 m asl (Figure 5.3).

Plate 5.1: Site SS-8 at 72 +/-3 m asl (highest point of section). Beds (G_1, G_2) dip 25° to northeast. The person in the picture is standing approximately 20 m below the surface.

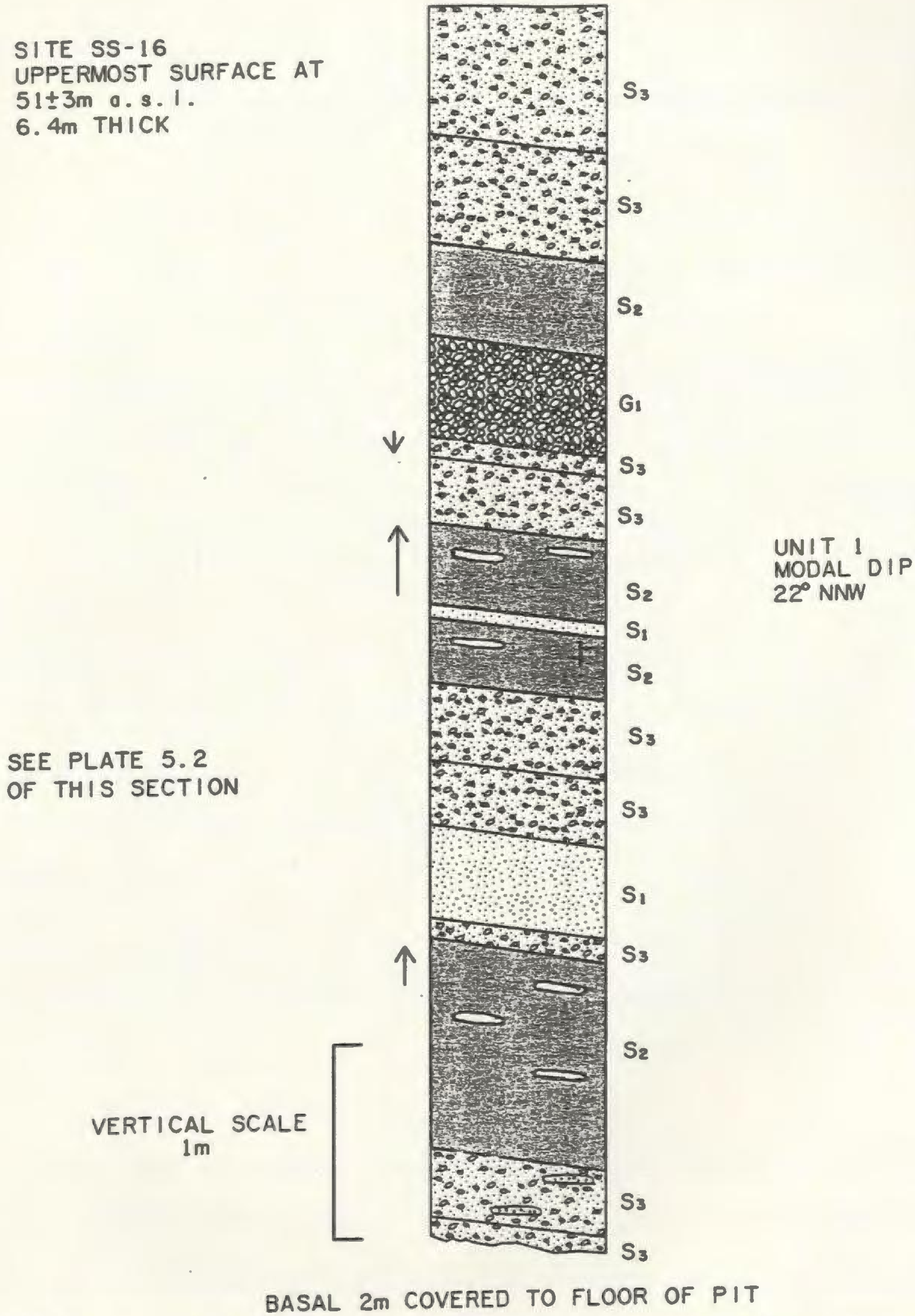


Figure 5.3: Sedimentary column of Site SS-16. Plate 5.2 shows this entire exposure. See Figure 5.2 for legend.

As the upper surface of this deposit are sloping, the elevation measurement refers to the highest point of the deposit. The exposure consists of interbedded sand and pebble sand to gravel with a thickness of 6.4 m (Plate 5.2). Bedrock is not exposed at the base of the section, and there may be at least 5 m of Quaternary sediment covered beneath the base as this is the distance from the top of the sediment cover to the pit floor. There is no till/diamicton exposed at the pit site. Morphologically, this site has a fan shape with a sloping and channelized upper surface. The sedimentary section is divided into one unit based on the lithofacies architecture (Figure 5.3).

5.3.1.1 Unit 1 Description

Unit 1 consists of 5.7 m of interbedded, well sorted structureless fine sand (S_1), horizontally stratified fine sand (S_2), and moderately sorted structureless pebbly sand (S_3) beds 15 cm to 1 m thick. Beds dip 20° to 25° (modal 22°) north-northwest (seaward). The proportion of sand to pebbly sand beds is roughly 30 : 70. There is no consistent succession or relationship among the beds and contacts range from sharp to gradational.

The six fine sand beds (S_1 and S_2) within the section contain 90-100% sand and 0-10% granules. They range in color from 10YR 3/2 to 10YR 5/2. Contacts with over and underlying beds are typically sharp. Internally the beds range from structureless to stratified with <1 cm thick horizontal laminations. Fining upwards sequences and

Plate 5.2: Site SS-16, showing beds dipping towards the north northeast at 20° to 25°. The surface of the section is at 51 +/-3 m asl. Exposure is approximately 6.4 m from the top to the pit floor.

plano-convex sand lenses are also present. These lenses are typically 10 cm wide and 20 cm in length with a modal thickness of 10 cm, have long axes inclined at 20° to 25°, and consist of medium to coarse pebbly sand. They are scattered throughout beds within the lower half of the unit. The pebbles within the lenses are subangular and typically make up 2% of each lens.

A single sand bed shows normal high angle epigenetic faulting with little displacement. The faulting does not extend through the pebbly sand bed located above.

The eight moderately sorted structureless pebbly fine to medium sand beds (S_3) range from 5 cm to 1.25 m in thickness. Colors vary from 10YR 3/2 to 10YR 5/2. The proportion of pebbles to sand is 20-30% large clasts to 70-80% sand. Clasts are subangular to subrounded, equant to spherical, 1 to 6 cm in diameter and lithologically consist of granite, basalt, and rhyolite. Contacts between beds are planar. Two beds show coarsening upward sequences, with clasts ranging from pebbles (1 cm long axes) to cobbles (up to 5-8 cm long axes) at the upper contacts. The matrix within these beds also coarsens upwards. Several beds contain irregular shaped lenses, 1 to 3 cm in maximum length and 3-5 cm in thickness. The lenses have long axes inclined at 20° to 25°, and are made up of coarser, pebbly sand. The 1.25 m thick bed near the base of the section contains a 50 cm by 2 m long medium pebbly sand lens, oriented at 22°.

The single clast supported structureless pebble to gravel bed (G_1) is 50 cm thick and moderately sorted. The uppermost contact is sharp whereas the lower is gradational with the coarsening upward pebbly sand bed.

The uppermost bed consists of 70 cm of pedogenically altered pebbly sand (S_3). Three soil horizons are exposed including a 15 cm thick B horizon, a 30 cm thick B/C horizon and the C horizon. These horizons consist of poorly sorted sandy to silty pebbly material with 95% fine sediment. Subrounded spherical pebbles and cobbles, with diameters ranging from 1 to 20 cm, comprise 5% of the strata.

5.3.1.2 Unit 1 Interpretation

Site SS-16, and similar sedimentary successions present at sites SS-2, SS-8, SS-9, SS-10, and SS-11, are interpreted as the proximal parts of ice-contact deltas. The sediments at SS-16 developed along the southward-trending embayment currently occupied by South Pond. The gently sloping fan abutted glacial ice at its eastern margin, as indicated by the absence of sand and gravel to the southeast of the section, the presence of till in this area and by the channelized upper surface of the sand and gravel sediments.. Foreset deposition is represented by the north-northwest dipping beds in the section. The lithology (granite, basalt, and rhyolite) and shapes (subangular to subrounded equants) of the pebbles in the deposits are similar to those of glacigenic diamictons in the region. Due to their size (1-3 cm long), the irregularly-shaped pebbly sand lenses may be relict ripples.

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). Perhaps the structurelessness of the sand beds results from loading. Suspension settling occurred in association with the waning turbidity flows, similar to events described by Komar (1985). Similar successions have been observed in modern high-gradient deltaic systems (eg. Prior and Bornhold, 1988). High sedimentation rates (influx and loading), which would be anticipated in an ice marginal setting (Powell, 1984), are indicated by the epigenetic normal faulting.

Dropstones were not identified within this section. The environment of deposition for this deposit is likely as a sandur developed along the fringes of the ice with the toe at or slightly below marine limit, but with the ice not in direct contact with maritime waters hence no dropstones.

The topmost bed of the section was developed as a result of post-glacial pedogenic processes. The horizons represented are typical of those associated with the brunisolic soils of the region (Woodrow and Heringa, 1987).

5.3.2 Site SS-12

Site SS-12 is located approximately 300 m south of Hall's Bay. The uppermost surface of this section is at an elevation of 64 +/- 3 m

(Figure 5.4). Bedrock is not exposed at the base of the section and talus covers a minimum of 5 m of Quaternary sediment beneath the lowermost exposed sediment to the floor of the pit. Morphologically, this site has a fan shape with a sloping and channelized upper surface, similar to that of site SS-16. This 9.8 m thick exposure is divided into three units of interbedded, poorly sorted sands and gravels which dip between 18-26° to the north. There is a 3-4 m slumped section between units 1 and 2, where the face of the section was impossible to clear off. This slumped section is denoted as a break in the stratigraphic column.

5.3.2.1 Units 1, 2 and 3 Description

Unit 1 consists of 5.72 m of interbedded, structureless to horizontally stratified fine to coarse sand (S_1, S_2) and moderately sorted structureless pebbly sand (S_3) beds ranging from 10 cm to 70 cm thick that dip 18° north (seaward). The proportion of sand to pebbly sand beds is roughly 55 : 45. There is no evident cyclicity in the bedding successions, and contacts range from sharp to gradational.

The structureless to horizontally stratified fine to coarse sand beds (S_1, S_2) range in color from 10YR 3/2 to 10YR 5/2. These beds consist of fine to medium grained sand, with both structureless and fining upward sequences. The fining upward sequences are located throughout the section. Textural analyses indicate that there is approximately 90% sand and 10% granules

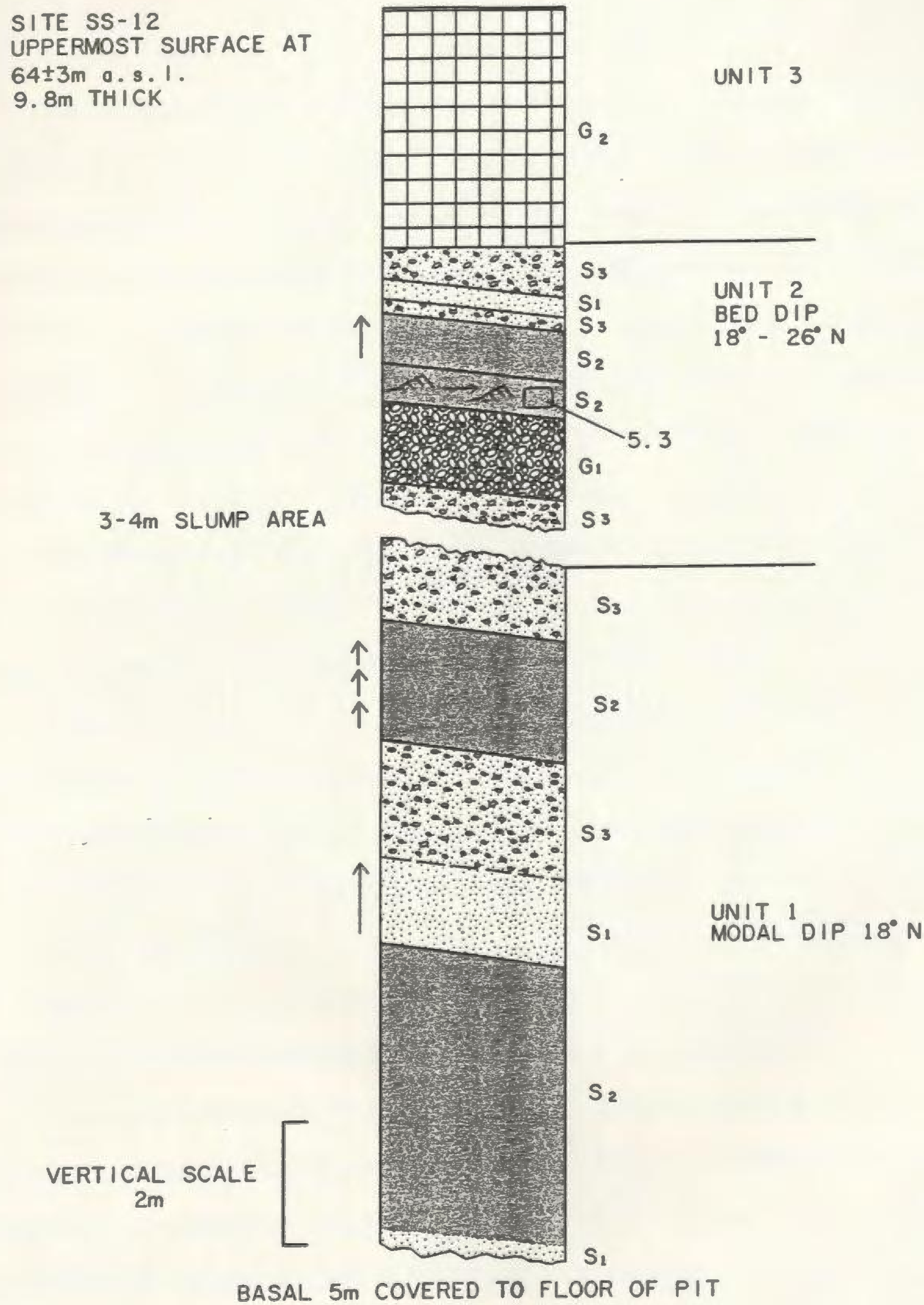


Figure 5.4: Sedimentary column of Site SS-12. See Figure 5.2 for legend.

within these beds.

The structureless pebbly sand beds (S_3) contain 20-45% granules and larger clasts and 55-80% sand. The proportion of pebbles within the beds increase upwards, with the uppermost beds containing 45% subrounded to well rounded pebbles (0.5 cm in diameter) to cobbles (8 cm in diameter). The clasts consist of subangular to subrounded, equant to spherical, granite, basalt and rhyolite. Several beds have thin layers of subangular to subrounded pebbles 0.5 to 1 cm in diameter along the basal contacts.

Above unit one the exposure is covered for a 3-4 m interval. The division between unit 1 and unit 2 is based on caution with respect to this covered interval.

Unit 2, which is 2.1 m thick, consists of well sorted, structureless to horizontally stratified fine to coarse sand beds (S_1, S_2) and structureless pebbly sand beds (S_3) ranging from 10 to 70 cm thick. These beds are similar to those described in unit 1. Some beds pinch out laterally and have a channelized appearance, with sharp upper and lower contacts. The beds dip from 26° N in the northern part of the section to 18° N in the southern parts.

A convexo-concave channel lag infill deposit of fine to medium sand, approximately 50 cm wide and 2.5 m long, is visible in the clast supported structureless pebble to gravel bed (G_1) near the base of this unit. This channel dips northwards, similar to the other beds in the unit.

Climbing ripples with preserved stoss laminations (type B of Jopling and Walker, 1969) are present in the fine sand bed overlying the channel feature described above (Plate 5.3). These ripples have a modal wavelength of 15 cm, amplitude 1.5 cm, stoss of 3-4°, lee of 26.5°, and indicate flow to the north and northeast. The angle of climb of the ripples ranges from 45 to 75°. The ripples are draped by 1 mm thick silt and clay layers.

Unit 3 consists of 2 m of stratified poorly sorted, gently sloping (0-5°), stratified, graded sand and gravel beds (G_2) (20 cm to 1 m thick). Colors range from 10YR 3/2 to 10YR 5/2. These beds contain approximately 50% subangular to subrounded granite, basalt and rhyolite pebbles and cobbles, 0.5 to 12 cm in diameter. The basal contact truncates the underlying dipping beds of Unit 2.

The lithology and minerology of clasts within all these units is similar to the mineralogy and lithology of clasts located in the adjacent glacial and marine sediments. No dropstones were noted in these units.

5.3.2.2 Units 1, 2 and 3 Interpretation

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

Convexo-concave channel lag infill deposits in the base of Unit 2 may suggest that some buried ice was present during deposition

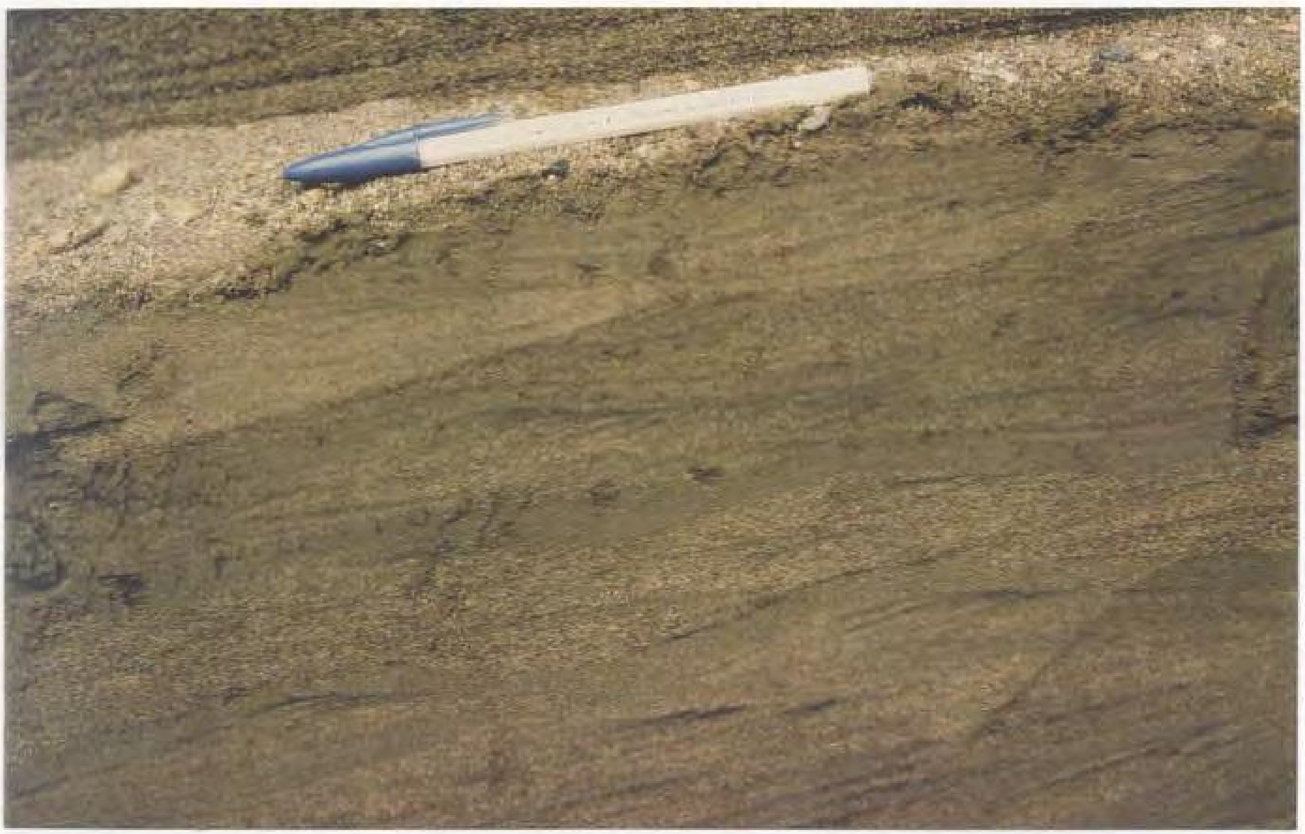


Plate 5.3: Climbing ripples within Unit 2 of Site SS-12. The Type B ripples indicate flow towards the north (to the left in this picture). Pen is 15 cm long.

(Miall, 1977). The sandur environment would have blocks of ice that had become detached from the glacier during retreat sitting on the surface. Surface water would have flowed around and beneath the ice blocks, creating small channels adjacent to and beneath the buried, stagnant ice. The convex upper surfaces of some cut-and-fill structures indicate that the flowing water eroded upward into the stagnant ice block, as well as downwards into the substrate. Although the form of the lenses resembles those described by Shaw (1987) resulting from subglacial water erosion, these lenses developed under isolated blocks of stranded ice in the sandur environment. As slope angles are greater in the north than in the south it suggests marine limit is to the north. The gravel lens is to the south which also fits with this hypothesis.

The ripple forms noted within Unit 2 can develop either as a consequence of high sediment supply, relatively low flow velocities, or as a combination of both factors acting simultaneously. Based on the grain size and form of the ripples, the estimated flow velocity was approximately 10-20 cm/s (Myrow and Southard, 1991). The presence of laminated sand units suggests that abundant fine sand was available. The depositional stoss climbing ripple drift cross-laminations develop where sediment load exceeds 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. The presence of the ripples in conjunction with multiple channels marked by truncated cut and fill structures is typical of a braided stream deposit (Rust, 1972; Miall, 1977; and Aitken, 1995). Although this is typical for a braided stream system there isn't necessarily enough evidence of multiple channel at this one place to fully support a braided hypothesis.

The dipping beds of Unit 2 contain depositional stoss ripple lamination indicating 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. Dropstones are not noted within this sediment.

The coarseness of the sediment in Unit 3, together with the erosional contact with the underlying deltaic units, suggest that this unit 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. In addition, channel cut and fill structures indicating flow towards the north are present through the unit. The northward orientation of the channels indicates that current flow was not related to the position of the former ice margin.

5.3.3 Summary of Sedimentary Sequence at Site SS-12

The sedimentary sequence located at site SS-12 was formed as a result of proximal sedimentation in an embayment, as evidenced by the bedded sands and pebbly gravel in unit 1 followed by deposition of the rippled sands, pebble gravel and coarse gravel of unit 2. The sequence is then capped by very gently sloping post glacial fluvial sediments. Figure 5.5 illustrates the formation of this site.

5.4 Ice-Distal Sediments

Three sections including: SS-13 (74 m asl), located at the South Brook waste disposal site; SS-14 (72 m asl), 1 km northeast of SS-13; and SS-17 (13 m asl), in South Brook; also consist of interbedded, moderately to poorly sorted sands and gravels. Figure 5.1 shows the locations of these sites. Plates 5.4 and 5.5 depict the sediment and the flat upper surfaces of sites SS-14 and SS-17 respectively. These sections have beds that are generally better sorted and finer grained than sediments at sections SS-12 and SS-16. In addition, these three sections have expanses of sand and gravel extending for 1-2 km south of the outcrops.

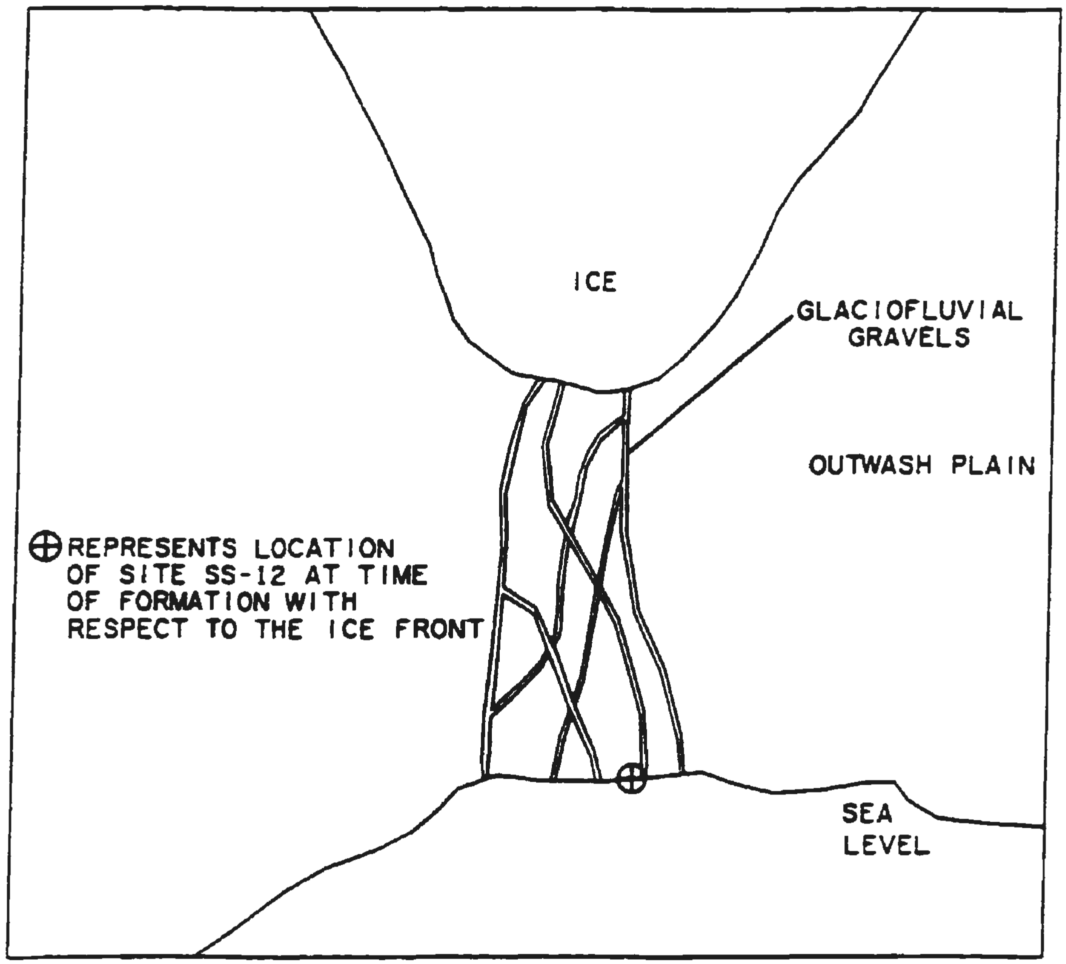


Figure 5.5: Figure illustrating formation of sediments at Site SS-12.

Plate 5.4: Deltaic sediment, Site SS-14. The flat-topped upper surface is located at 72 +/- 3 m asl. The exposure is approximately 300 m long. View is looking south.

Plate 5.5: Flat bedded upper sediments within Site SS-17. The coarser sediments capping the section are fluvial in nature. Top of section is at 13 +/-3 m asl. Pick handle in right side of photo is approximately 1 m long. South is to the right in the photo.

Site SS-13 is representative of all three, and has the most vertically complete and laterally continuous exposure. The sedimentology of this site is thus presented in detail.

5.4.1 Site SS-13

Site SS-13 is located approximately 1.5 km northeast of the community of South Brook. within the waste disposal site for the community. The uppermost surface of the section has an elevation of 74 +/-3 m asl. Plate 5.6 depicts Site SS-13. The exposure consists of 11 m of interbedded sand, pebbly sand and gravel. Three units are present: inclined lower sands and gravels (unit 1) and fine sands with interbedded gravel (unit 2) are overlain by planar upper gravels (unit 3), as illustrated in Figure 5.6 and Plate 5.7.

5.4.1.1 Unit 1 Description

Unit 1 consists of 5.8 m of well sorted, medium to fine structureless to horizontally stratified sand beds (S_1, S_2), massive pebbly sand (S_3), and stratified granule supported pebble-granule gravel (G_3) strata that dip between 20-24° to the north. These beds are present in a ratio of 60 : 20 : 20. Bedrock is not exposed at the base of the section, and covered Quaternary sediment probably exists beneath the base of the section.

The fourteen structureless to horizontally stratified sand beds (S_1, S_2) within Unit 1 range from 3-37 cm thick and typically have gradational contacts. Texturally they consist of 85-90% fine to

Plate 5.6: Flat topped sediments at Site SS-13. Elevation of surface is 74 +/-3 m asl but the highest point of the section is off to the left and not depicted in this photo. Exposure is approximately 400 m long, 11 m high and approximately 1-2 m of the surface material has been disturbed anthropogenically. This photo faces west.

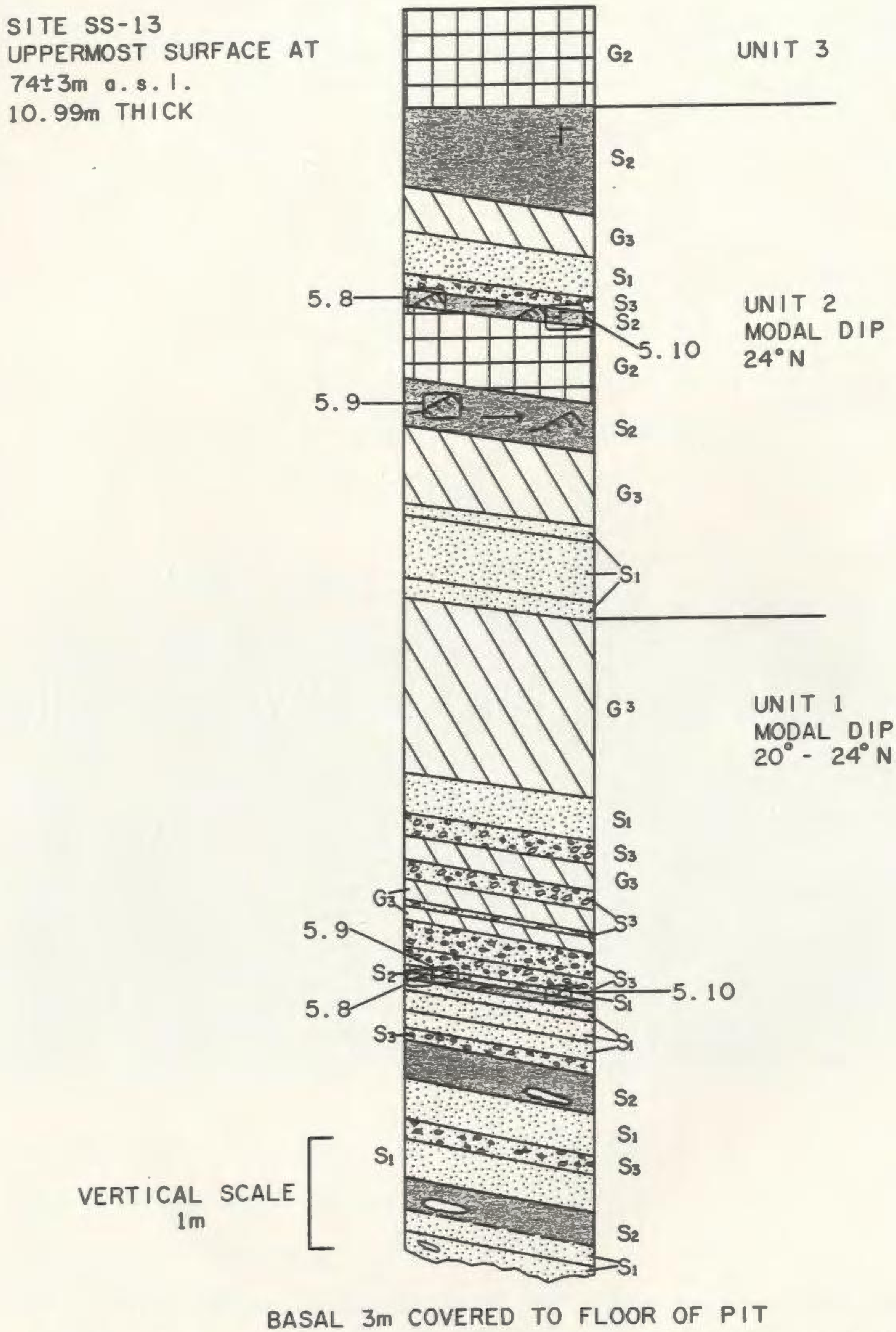


Figure 5.6: Sedimentary column of Site SS-13. See Figure 5.2 for Legend.

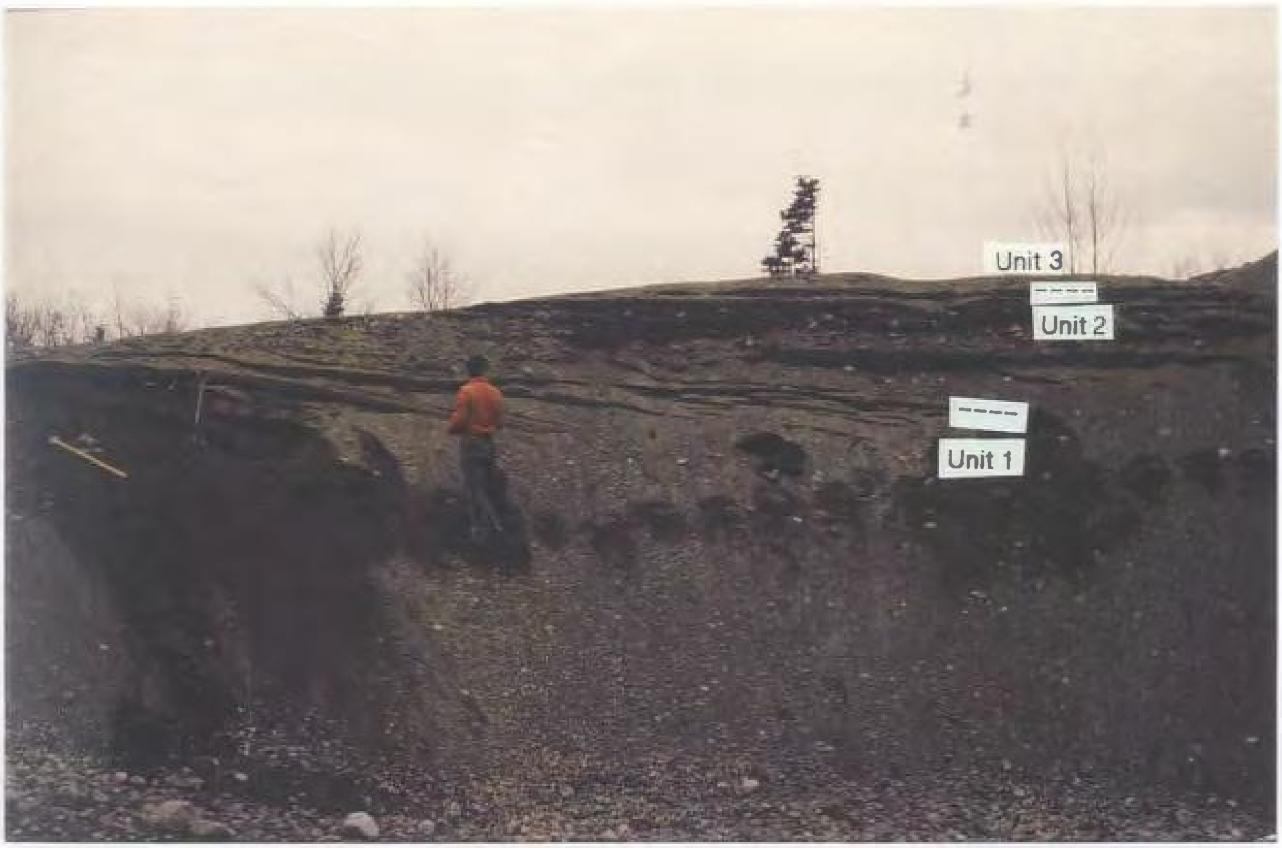


Plate 5.7: Upper planar unit overlying the lower units at Site SS-13. Beds in lower units dip 20-24° north-northwest. This photo faces west.

medium sand and 10-15% silt. They also contain < 2% subrounded, equant, spherical and blade shaped volcanic and ultramafics pebbles.

Fining upward convexo-concave lenses of fine sand and silt, ranging from 1.5 to 5 cm thick and 2 to 50 cm long, are located near the upper contact of four of the fourteen sand beds within this unit. The sand beds range in color from 10YR 3/2 to 10YR 5/2, whereas the lenses are 7.5YR 5/7. One sand bed had biconvex lenses of open work pebble gravel that measured 30 cm wide and 14 cm long. The long axes of these lenses are oriented at 20°.

Ripples are preserved in two sand beds within this unit. In the lower bed the ripples measured 5 mm amplitude by 8 mm wavelength, with 8° stoss and 12-15° lee angles. In the upper bed the ripples measured 9-12 mm amplitude by 7-12 mm wavelength, with 6° stoss and 8° lee angles. Syngenetic reverse faults with little displacement (1-4 mm) were also noted in the upper rippled bed.

The structureless pebbly sand beds (S_3) are moderately sorted and range from 5 cm to 10 cm thick. They generally have sharp contacts with underlying beds. Subangular volcanic and ultramafic spherical, equant and roller shaped pebbles 1 to 6 cm in diameter are located within the pebbly sands. Three of these beds have imbricated pebbles, suggesting flow to the northwest. Two of the beds have fining upward sequences of pebbly sand to granule gravel.

The structureless granule supported pebble to granule gravel beds (G_3) are moderately sorted, range from 8-18 cm in thickness, and contain subrounded equant, rollers and spherical volcanic and ultramafic pebbles 1-2 cm in diameter. Contacts with other beds are typically sharp although as the upper bed in this unit has a more gradational contact with the beds below the top of this structureless granule supported pebble to granule gravel bed was used as the break between units one and two.

5.4.1.2 Unit 2 Description

Unit 2 consists of 4.3 m of fine sand beds and interbeds of granule to pebble gravel at proportions of 55 : 45. The beds are generally laterally discontinuous and dip 24° to the northwest. In a few spots the beds intertongue. It has a sharp contact with unit 1 below.

The sand beds (S_1. S_2 and S_3) range from 10-60 cm thick and contain less than 1% subrounded. equant. spherical and roller volcanic pebbles. Some of the beds have laminations that parallel the upper and lower contacts and dip at 24°. and within the laminae fining upward sequences of medium to fine sand are exposed. Contacts between some sand beds are gradational. Texturally these beds range from 80-90% sand, 5-10% silt to 1-5% pebbles.

Ripples are preserved in two sand beds within this unit and the ripples are draped by the overlying beds. The ripples in the lower bed have 5 cm amplitude, 8-14 cm wavelength with 8° stoss and 12-15° lee angles. In the upper bed, the ripples have amplitudes of 2.5 cm, 8-10 cm wavelength, and 2° stoss and 31° lee angles. Plates 5.8 and 5.9 depict the ripples in the lower and upper beds respectively.

Plate 5.8: Ripples in the lower sand bed within Unit 2 of Site SS-13. These ripples indicate flow to the northwest. Card for scale measures 9 cm long. Arrow indicates flow direction.

Plate 5.9: Ripples in the upper sand bed within Unit 2 of Site SS-13. These ripples indicate flow to the northwest. Card for scale measures 9 cm long.

The ripple dimensions suggest low flow velocities in both beds. These ripples indicate that modal flow was to the northwest (342°).

In the upper rippled bed, syngenetic reverse faults with displacement of 3-5 cm at an angle of 25° were noted (Plate 5.10). These faults do not continue into the overlying beds.

The stratified, graded sand and gravel and structureless granule supported pebble to granule gravel beds (G_2, G_3) are 5 to 70 cm thick, moderately sorted, and range from structureless to stratified. Clasts within the beds range are typically subrounded spherical to equant volcanics, 1-10 cm in size. Contacts between most beds are sharp. Textural analyses indicate that these beds contain 85-95% granules and 5-15% pebbles.

5.4.1.3 Unit 3 Description

The uppermost Unit, 3, is comprised of 80 cm of flat lying to channelized stratified, graded sand and gravel (G_2) beds. The beds are well sorted and contain some silt and clay laminae. Texturally these beds contain approximately 40% subrounded to round spherical and equant volcanic clasts ranging from 0.5 to 20 cm in diameter. The basal contact is sharp. truncating the underlying dipping beds in Unit 2.

Plate 5.10: Syngenetic reverse faulting (and normal faulting) with angles of dip ranging from 30-40° in the upper sand bed within Unit 2. Displacement is approximately 3-5 cm. Card for scale is 9 cm long. North is to the right in the photo.

5.4.1.4 Units 1, 2 and 3 Interpretation

Units 1 and 2 are interpreted to represent a more distal deltaic sequence although they are not truly "distal" embayment or bottomset sediments. The energy levels represented by the granule gravel, medium sand, and rippled fine sand beds are lower than those responsible for the coarse, more proximal deposits of SS-12 and SS-16. The greater proportion of silt and clay and the syngenetic reverse faulting suggest formation in the more distal parts of a deltaic sequence, rather than in the fluvial channel-dominated proximal area. The fine to medium sediments, ripples, moderate angle dips, deformational structures, channelized surface, and shape of deposits all suggest a fan style environment with deposition from channelized flows (Shaw and Ashley, 1988). Similar deposits have been discussed by Postma *et al.* (1988). The granule to pebble gravel beds were produced by subaqueous reworking of the deltaic sediment similar to that reported by Shaw and Ashley (1988). Flow was towards the north-northwest, into the Hall's Bay Embayment.

The syngenetic reverse faulting in Unit 2 suggests loading of the sediment, possibly by flows (eg. McKee and Goldberg, 1969). Ripples in Units 1 and 2 indicate current flow to the north and northwest (seaward).

Unit 3 is interpreted to have formed by subaerial fluvial activity. The sediment texture (40% subrounded to round spherical and equant volcanic clasts ranging from 0.5 to 20 cm in diameter) and the erosional bottom contact suggest it is not related to the delta development. No evidence of ice proximal sedimentation is present. Structures in this unit are typical of modern stream sediments in the area.

5.4.2 Summary of Sedimentary Sequence at Site SS-13

The sedimentary sequence located at site SS-13 was formed as a result of sediment deposition in the more distal portion of a deltaic sequence that was located below wave base. The finer grained granule gravels and sand beds of units 1 and 2 are a result of lower energy levels, but deposition is still in a deltaic environment hence the dipping beds. These beds are at approximately 7 m depth. The beds in unit 3 are flat lying and likely are the result of subaerial fluvial activity as evidenced by the coarser nature of the sediment.

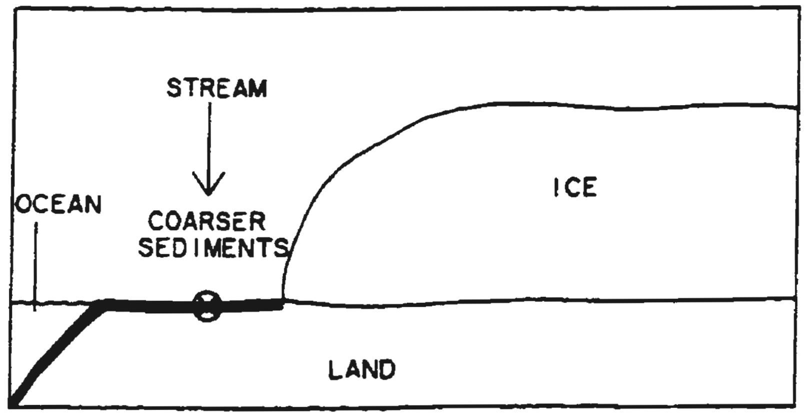
5.5 Discussion of Glaciomarine Deltaic Sand and Gravel Sections

Based on the assessment of the sand and gravel sediments within the study area, two types of deposits were identified:

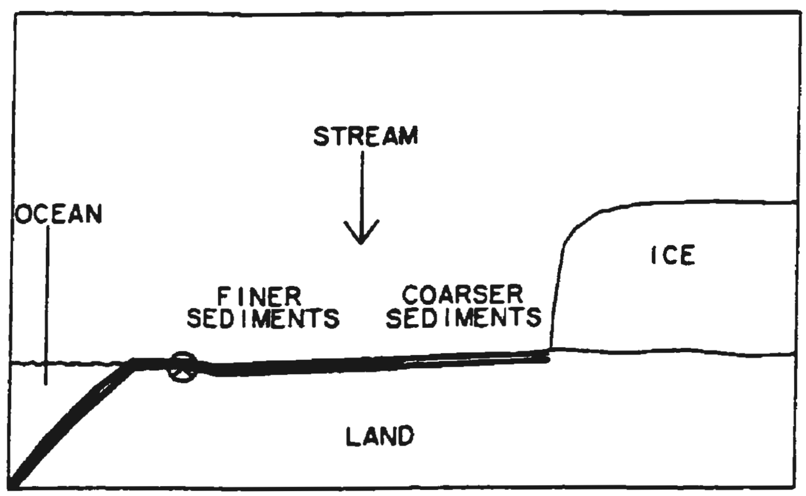
- those associated proximally to the glaciofluvial outflow; and
- those associated distally to the glaciofluvial outflow.

Figure 5.7 illustrates the formation of these deposits. Proximal and distal are terms used to indicate position with respect to the ice front and not water depth or glaciofluvial outflow.

Tucker (1974) identified glaciomarine deposits at 15, 54, 63, 66 and 75 m asl The sand and gravel deposits with flat topped upper



"PROXIMAL" DEPOSITS (⊗) FORMED FROM SEDIMENT NOT TRANSPORTED GREAT DISTANCES FROM STREAMS



"DISTAL" DEPOSITS (⊗) FORMING FROM FURTHER TRANSPORTED OUTFLOW DEBRIS FROM STREAM.

Figure 5.7: Diagram to illustrate the "proximal and distal" formation of the sand and gravel deposits.

surfaces assessed in this study, represent temporary pauses in marine regression not necessarily related to glacial activity: 68-74 +/-3 m and 50 +/-3 m. These deposits are located between 0.5 to and 5.5 km inland of the modern coastline.

Based on the interpretation of the sediments at Sites SS-12 and SS-16, the majority of the deltaic sediments were deposited proximally to the glaciofluvial outflow, as indicated by the presence of coarse clasts and the general poorer sorting of the sediment. In general, these deposits had fewer fine sediment beds than the successions exposed at Site SS-13.

Site SS-16 (51 +/- 3 m asl) is interpreted to represent the upper part of a deltaic sequence. The delta surfaces of SS-10 and SS-16 south of South Pond have elevations of 50 +/- 3 m asl, and are chronologically equivalent to the 54 m terraces at Springdale, Burnt Berry Brook, and West Pond identified by Tucker (1974).

The combination of sediment grain size, orientation of ripples, the dip of the beds, the geomorphology, and the elevation of 64 +/- 3 m asl at SS-12 indicates that it represents a deltaic sequence, showing braided channel characteristics. This deposit is some distance below sea level (approximately 7 m) at the time of formation.

The overall assemblage at SS-13 can be interpreted as an channelized pro-delta 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 more distal origin of the sediment, similar to that described by Shaw and Ashley (1988).

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, SS-14 and SS-17.

One of the sections, SS-9, containing more poorly sorted sediments is at a lower elevation than the "distal" sections. As noted it has sediments similar to that at Site SS-16. The sediments at Site SS-9 may be reworked proximal sediments which had been deposited earlier or possibly due to deposition from a stranded ice block which had proximal sediment upon its surface and when downwasted deposited the coarser sediment. A more likely alternative is that the sediment at Site SS-9 was deposited by more powerful underflows reaching out into the bay. This would require an area of runout for the sediment. West Pond is located southwest of this deposit and may represent the runnout zone required. Terraces with similar coarse grained sand and gravel at a similar elevation to site SS-9 are located along the east and west sides of the pond but were not examined in this study.

CHAPTER 6 SEDIMENTOLOGY AND PALEOGEOGRAPHY OF EMBAYMENT SEDIMENTS

6.1 Introduction

The floor of Indian Brook valley is covered in outwash sand and gravel, which overlies silt and clay units (as indicated by drill log data from the Department of Environment, Keith Guzzwell, personal communication, 1990). Three large exposures of the fine sediment strata along the lowermost 5 km of Indian Brook were examined in detail (Figure 6.1).

The stratigraphy of sections SS-1, SS-18, and SS-19 is typical of the fine sediment deposits in the Indian Brook valley. Analysis of the sedimentology of these sections will be presented as detailed descriptions of the sediment from base to top, followed by the assignment of facies designations to the sediment packages. Finally the architecture of these facies will be used to interpret the mode of formation of the deposit and a summary of the depositional environment will be presented. This is followed by a comparison and discussion of all the silt and clay sections. In the section description, packages of facies are referred to as units.

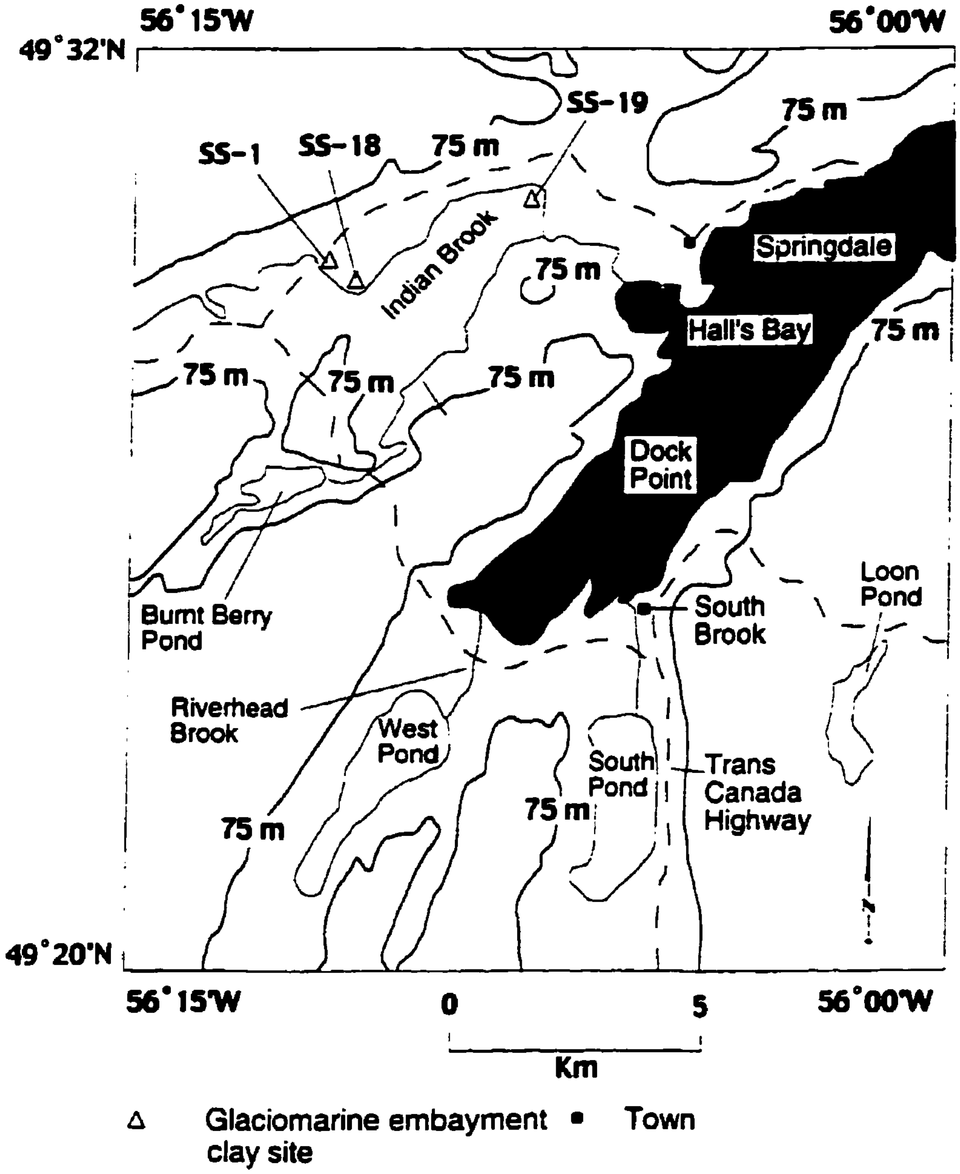


Figure 6.1: Location of silt and clay Sites SS-1, SS-18 and SS-19 within the Indian Brook Valley.

6.2 Lithofacies Designations

The lithofacies designations will be based on sediment texture and structure, again similar to that in Eyles and Miall, 1984. The sedimentary facies are grouped according to the modified lithofacies code depicted on Figure 6.2. Note that the legend depicted on Figure 6.2 is the same for all sedimentary sections in this chapter, however not all facies are present in each section.

6.2.1 Gravel Facies (G_2, G_3)

Gravel facies vary in particle size distribution and degree of clast support. They are subdivided into two groups: stratified graded sand and gravel (G_2), and structureless granule supported pebble-granule gravel (G_3).

Stratified graded sand and gravel (G_2), typically exhibits a sandy gravel texture (85-95% granules and 5-15% pebbles) that is poorly to moderately sorted, is stratified, has sharp lower contacts, and ranges from 80 cm to 2 m in thickness.

Structureless granule supported pebble-granule gravel (G_3), typically exhibits a pebble granule texture (with up to 40% pebbles) that is moderately sorted, contains no structures, has sharp lower contacts, and ranges from 10 to 80 cm in thickness.

6.2.2 Sand Facies (S_1)

The sand facies, structureless fine to coarse sand (S_1), typically exhibits a sandy (90-100% sand) that is moderately to well sorted,

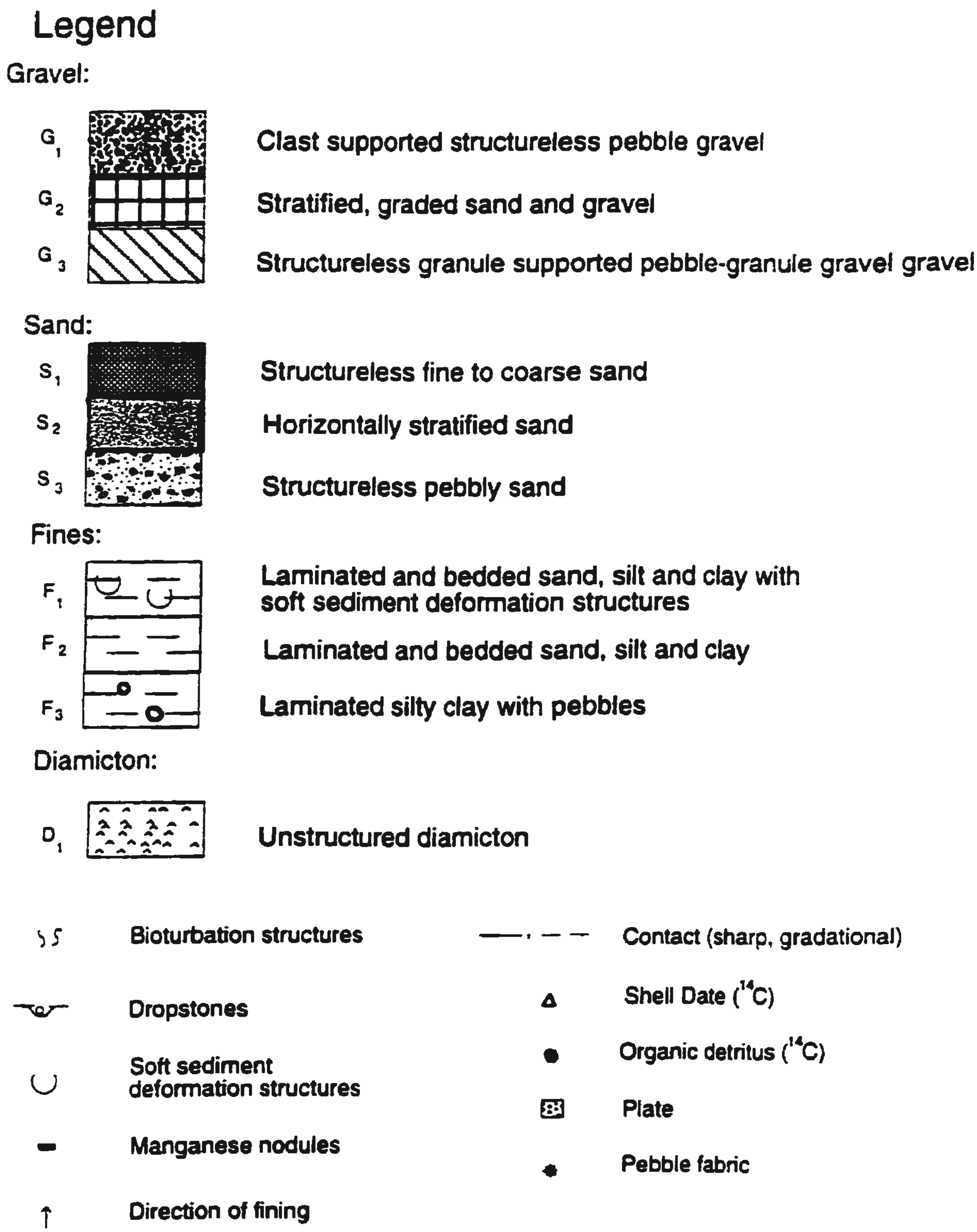


Figure 6.2 Legend used for sedimentary columns in Figures 6.3, 6.4 and 6.5.

has sharp lower contacts, and ranges in thickness from laminae (<10mm) to beds (30-50 cm). Typically fining upward sequences occur, lenses of coarse pebbly sand are present and occasionally ripples occur.

6.2.3 Fine facies (F_1, F_2, F_3)

The laminated to bedded sand, silt and clay with soft sediment deformation structures (F_1) typically has a texture of 19% sand, 49-64% silt and 17-32% clay in the laminae and 60-86% sand and 11-32% silt in the beds. Typically basal contacts are sharp. The laminae ranges from one grain to 1 cm thick and the beds range from 1.5 to 5 cm thick. Typically fining upward sequences are common within the laminae and beds. Isolated drop stones and loading features are located within these sediments. Soft sediment deformation structures typically are comprised of convoluted bedding and rip up clasts.

The laminated to bedded sand, silt and clay (F_2) is similar to the F_1 facies except it does not contain the soft sediment deformation structures.

The laminated silty clay with pebbles (F_3), typically is comprised of 42% sand, 35% silt and 14% clay and contains 5% subangular pebbles. The laminations are typically contorted and contains intraclasts of clay.

6.2.4 Diamicton Facies (D_1)

The structureless diamicton (D_1) contains subangular to subrounded clasts in a sandy mud matrix. Clasts range in size from granules to cobbles. The facies is typically poorly sorted and unstructured with thicknesses ranging from 15 cm to 5.35 m and has sharp contacts with underling beds.

6.3 Glaciomarine Embayment Clay Sections

6.3.1 Site SS-1

Site SS-1 is located directly to the east of the bridge over Indian Brook, along route 390. The uppermost surface of the section has an elevation of 30 m asl (Figure 6.3). The exposure consists of rhythmically bedded silt, clay, and sand with a thickness of 8.9 m and a lateral extent of 20 m (Plate 6.1). The strata dip from 1-10° to the east. The section is divided into six units based on the facies architecture (Figure 6.3). A similar sequence is present at Site SS-18, 0.5 km to the east.

6.3.1.1 Unit 1 Description

Unit 1 consists of 3 m of interlaminated to interbedded silt, clay and fine sand (F_1) exposed at the base of the section. The basal contact of Unit 1 is not visible as it is buried beneath slumped sediment from the section. Due to the absence of bedrock within the stream bed of Indian Brook located approximately 4-5 m lower in

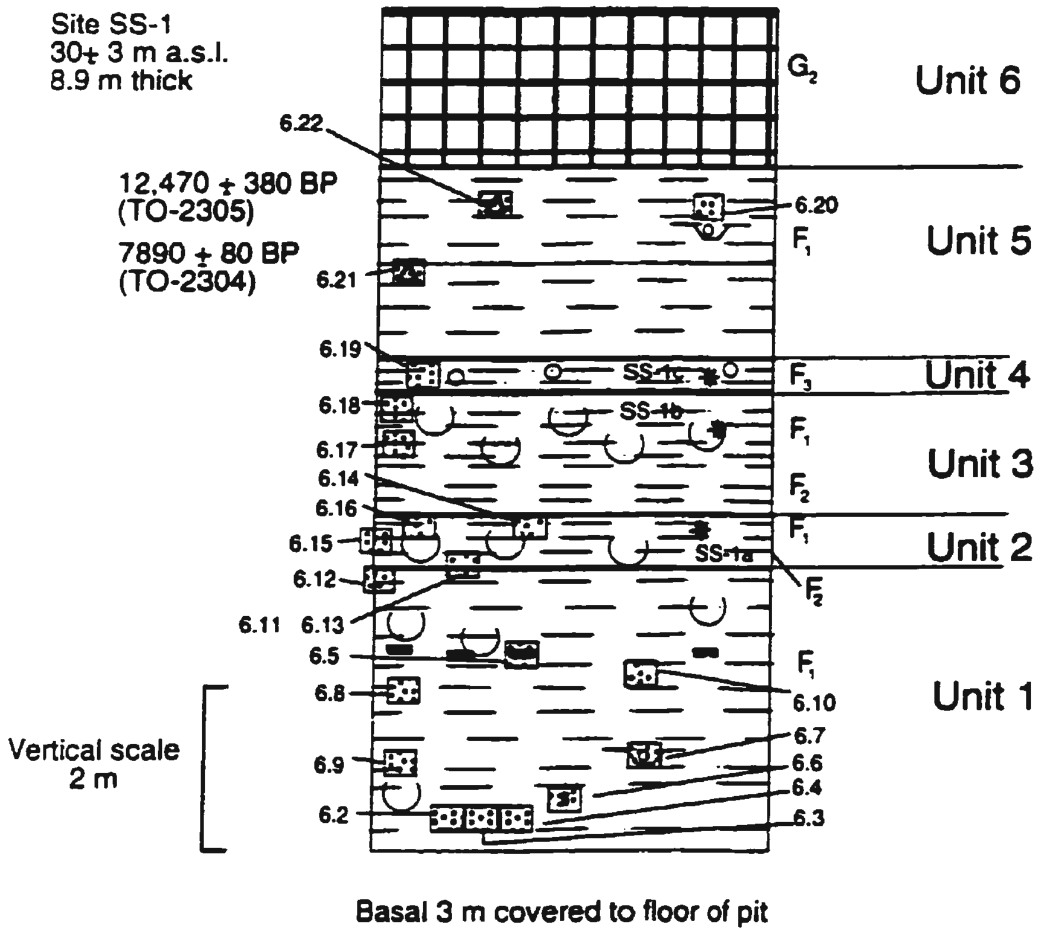


Figure 6.3: Sedimentary column of Site SS-1. See Figure 6.2 for legend.

Plate 6.1: Sediment exposed at Site SS-1. The top of the sequence (at vegetation line) is 30 +/- 3 m asl. The section is approximately 8.9 m thick and has a 20 m lateral extent: 1 cm =1.1 m on photo. Photo is a view to the north.

elevation from the section, it is likely that there is at least 5 m of Quaternary sediment covered below the section base.

The strata are separated into two types: laminae and beds. The laminae range from 1 sand grain to 1 cm thick, and are generally internally structureless, although a few laminae show fining upward sequences, and a few pebbles are located in the sediment. Rhythmically laminated strata, ranging from fine sand to silt and clay, are common. The silt and clay laminae alternate in color between reddish brown (2.5YR 5/4) to yellowish brown (10YR 5/4). Contacts between the laminae are typically sharp, although some show irregular undulations of between 0.5 to 1 cm. These irregularities manifest themselves as breaks in the laminae where the upper contacts are deformed by sediment pushed up into the overlying laminae. The basal sandy members are locally truncated and boudinaged or loaded, and parts of the overlying laminae are displaced. Plate 6.2 shows boudinaged and truncated laminae. Plate 6.3 shows upper contacts deformed as sediment is pushed up into the overlying laminae. Plate 6.4 shows loading of the overlying sediment into lower laminae. Some of the features shown in Plates 6.2, 6.3 and 6.4 were dug out in the third dimension and noted to have a planar rather than tubular geometry. However not all were and it is possible that some of these are bioturbation structures.

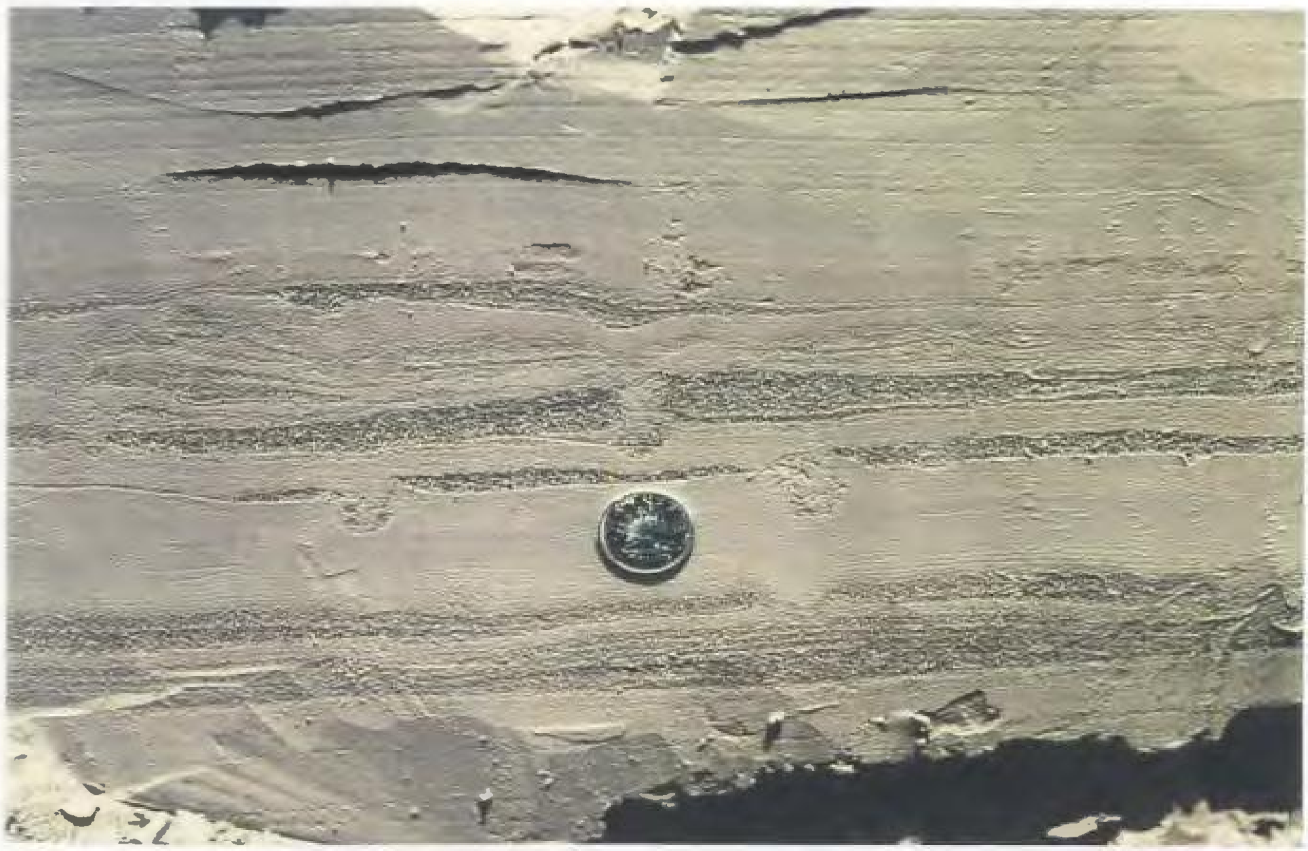


Plate 6.2: Boudinaged and truncated sand laminae within Unit 1 of Site SS-1. Coin has a diameter of approximately 2 cm.

Plate 6.3: Upper contacts of sand laminae are deformed as sediment is pushed up into the overlying laminae (within Unit 1 of Site SS-1). Coin for scale is approximately 2 cm in diameter.

Plate 6.4: Loading of the overlying sand beds into lower silt and clay laminae within Unit 1 of Site SS-1. Coin for scale is approximately 2 cm in diameter.

Approximately 70 cm below the upper contact of Unit 1 with Unit 2, dark brown manganese oxide nodules were located at irregular intervals along the laminae (Plate 6.5). The nodules are aligned along a horizontal surface.

Some small irregular to U-shaped structures (< 3 mm in width and < 3 mm in height) are present within the silt and clay rhythmites. These stand out due to their different color (10R 5/2) as opposed to the 10YR 5/4 and 2.5YR 5/4 color of the silt and clay laminae. Material in the U-shaped structures is sandier than the silt and clay of the surrounding laminae (Plate 6.6).

Precise textural sampling of individual laminae was difficult, due to their thinness. Several bulk samples were taken from Unit 1 for texture analysis. Two samples, 90-9006 and 90-9009, taken from the predominantly silt/clay laminae each contained 19% sand, with 49% and 64% silt and 32% and 17% clay, respectively (see Appendix 4). Textural analyses of two sand laminae (90-9001 and 90-9008) were dominated by fine sand, with combined silt and clay percentages of 14% and 38% and 33% and 5%, respectively (see Appendix 4).

The beds are 1.5 to 5 cm thick and consist of structureless silt and clay or fining upward medium sand. Bulk textural analysis of these beds (samples 90-9001 and 90-9005), indicated that the sediment consists predominantly of sand (between 60-86%) and silt (between 11 to 32%) (see Appendix 4). Small proportions (<2%) of

Plate 6.5: Dark brown manganese oxide nodules are located at irregular intervals along the silt and clay laminae within Unit 1 of Site SS-1. The nodules are located approximately 70 cm below the upper contact of Unit 1 with Unit 2. Coin for scale is approximately 2 cm in diameter.

Plates 6.6: Irregular to U-shaped structures are found in silt and clay laminae within Unit 1 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

subrounded, sphere shaped, felsic volcanic clasts (0.5 to 10 cm in maximum diameter) are also present. These clasts deform the underlying sediment and are draped by the overlying material (Plate 6.7). The individual silt and clay laminae and beds do not increase in thickness vertically upwards through the unit.

These bedded strata have sharp, frequently erosional, upper and lower contacts and are mostly internally structureless. Several styles of deformation structures are present, including some beds which are fractured or folded, and have been pushed up into the overlying strata. The broken ends of other sand and silt beds have been deformed upwards, forming flame-like structures. Some beds are truncated, due either to deformation during folding or subsequent erosion prior to the deposition of the overlying sediment, and boudinage structures are present. Plates 6.8, 6.9 and 6.10 illustrate some of these features.

In addition, the nose of the drag folds of individual portions of the beds with folded sediment appears to trend 085°, easterly (see Appendix 1 SS-1a).

Field and laboratory investigations determined that no shells, skeletal remains, foraminifera, or diatoms were present. Geochemical analysis for vanadium yielded values of 99 ppm from a bulk sample of sand, silt, and clay taken approximately 2.8 m below the upper contact with Unit 2. A value of 95 ppm from a similar sample taken approximately 0.1 m below the upper contact with Unit 2 (see Appendix 5).

Plate 6.7: Basalt cobble, which deforms the underlying laminated silt and clay, and is draped by overlying laminated material is located within Unit 1 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

Plate 6.8: A folded sand bed with an eroded upper surface within Unit 1 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

Plate 6.9: Folded and deformed sand bed and silt and clay laminae within Unit 1 of Site SS-1. Card for scale is 9 cm in length.

Plate 6.10: Deformational features within Unit 1 of Site SS-1. A water escape structure and associated folding (centre), and loading deformations (base of succession) are depicted here. Coin for scale is approximately 1 cm in diameter.

Contacts between both the laminae and beds were typically sharp.

6.3.1.2 Unit 1 Interpretation

The well sorted, laminated silt and clay beds of Unit 1 are interpreted to have been deposited by settling of sediment from suspension whereas the sand beds are interpreted to have formed from underflows. Their fine grained, well sorted nature, scarcity of coarse debris, and lack of current indictors suggests this kind of deposition. Powell (1981), Mode *et al.* (1983), Allen 1984, Domack (1984), and Stewart (1991) all describe similar features.

The rhythmically laminated silts and clays contain interbedded fine sand laminae. These laminae, due to their coarser nature, and the preservation of some fining upward sequences, may have formed by small sediment gravity flows downslope similar to ones described by Philips *et al.* (1991). The gentle 1-10° dip of these strata, conforming to the local topography, supports the turbidite interpretation.

Many of the bedded strata contain features interpreted as penecontemporaneous soft sediment deformation structures. The wavy convoluted nature of the beds, the boudinage, the overturned recumbent folds which have been erosionally truncated, and the flame like appearance of the beds when they are broken and the truncated edges of the beds are similar to sedimentary structures described as deformation features by Reinck and Singh (1973) Mills

(1983), Allen (1984) Stewart (1991) and Merritt *et al.* (1995). These features include sag and drop features, convolute laminations, slumping, loading and water escape structures. These structures may have been induced by pressure generated during the downslope flow events responsible for forming the fine sand laminae (Allen, 1984). Hamby (1994) indicates that the convolute laminations in rhythmically laminated silts and clays can occur due to overpressurization (by weight of overlying sediment) of saturated sediment.

The unit also contains coarse clasts which deform the strata. These clasts are interpreted as dropstones from floating ice, similar to those described by Thomas and Connell (1985). Although clast fabric has been utilized to distinguish between iceberg drop and dump material (Domack and Lawson, 1985), clast fabric measurements were not taken within this unit due to the paucity of clasts and due to the fact that the clasts were spherically or equant shaped.

The presence of small scale, irregular to U-shaped structures within the silt suggests bioturbation (Aitkin and Howard, 1988). They resemble the escape structure of a juvenile *Mya arenaria* similar to that as described by Bromley (1990). The type of structure (escape) and the paucity may indicate that the high sedimentation rate was not conducive for organisms to thrive in this environment.

Geochemical analysis determined vanadium concentrations of 95 and 99 ppm. Shimp *et al.* (1969) and Catto *et al.* (1981) determined that vanadium concentrations in excess of 115 ppm indicates a marine depositional environment, whereas concentrations lower than 60 ppm indicates a freshwater environment. The values measured in this unit suggest that the sediment was formed in a brackish marine environment.

6.3.1.3 Unit 2 Description

The contact between Units 1 and 2 is sharp and erosional. Unit 2 ranges from 5 to 46 cm thick. It is laterally continuous over 15 m, and thins to the west. It is composed of two subunits: a basal laminated silty clay and sand (F_2) and an upper deformed sand and clay (F_1) (Plate 6.11).

The basal 9 cm of this unit consists of flat lying, well sorted, rhythmically bedded silty clay and sand laminae similar to the laminae found in Unit 1. The laminae in Unit 2 range from 1-3 mm thick, with those composed of silty clay being thicker than those of fine sand. Where traced laterally, these laminae appear distorted and are locally truncated (Plate 6.12). In some instances the beds are distorted and fractured, with the ends turned upwards into overlying sediment (similar to the flame structures seen in Unit 1). In addition, the upper 2-3 cm of the basal 9 cm sequence of laminae are overlain by convoluted sand beds of the upper subunit.

Plate 6.11: The two subunits of Unit 2 of Site SS-1. The basal laminated silty clay and sand is overlain by an upper deformed sand and clay.

Plate 6.12: Truncated sand laminae in the lower 9 cm of Unit 2 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

The overlying folded and convoluted subunit (Plate 6.13) varies from 33.5 to 42 cm in thickness. A bulk sample of the matrix of this unit (sample 90-9017) contains 5% granules, 26% sand, 50% silt and 19% clay (see Appendix 4). The subunit also contains approximately 10-15% subangular to subrounded felsic volcanic pebbles, generally ranging from 1 to 2 cm in size. The larger clasts are concentrated at the base of the convoluted "ripped up" sandy strata. Interspersed with the sandy beds are rounded silty clay intraclasts 1 X 2 cm in size. Laminated silt and clay horizons, 2-5 mm thick are also interstratified within the subunit. The silty clay laminae are folded and deformed as part of the structures incorporating the sandy material (Plate 6.14). These normal and recumbent folds have an amplitude of up to 10 cm with the fold noses oriented in several directions but predominantly to the northeast (see Appendix 1). This indicates that the deformation was caused by flow to the northeast.

This bed thins to the west (Plate 6.15). The upper contact of the unit is sharp and erosional, truncating deformation features (Plate 6.16).

6.3.1.4 Unit 2 Interpretation

The presence of the sand strata in both subunits of Unit 2 suggests periods of traction sedimentation by flowing bottom currents. The lower finer grained unit was deposited from a lower energy bottom current whereas the coarser nature of the overlying

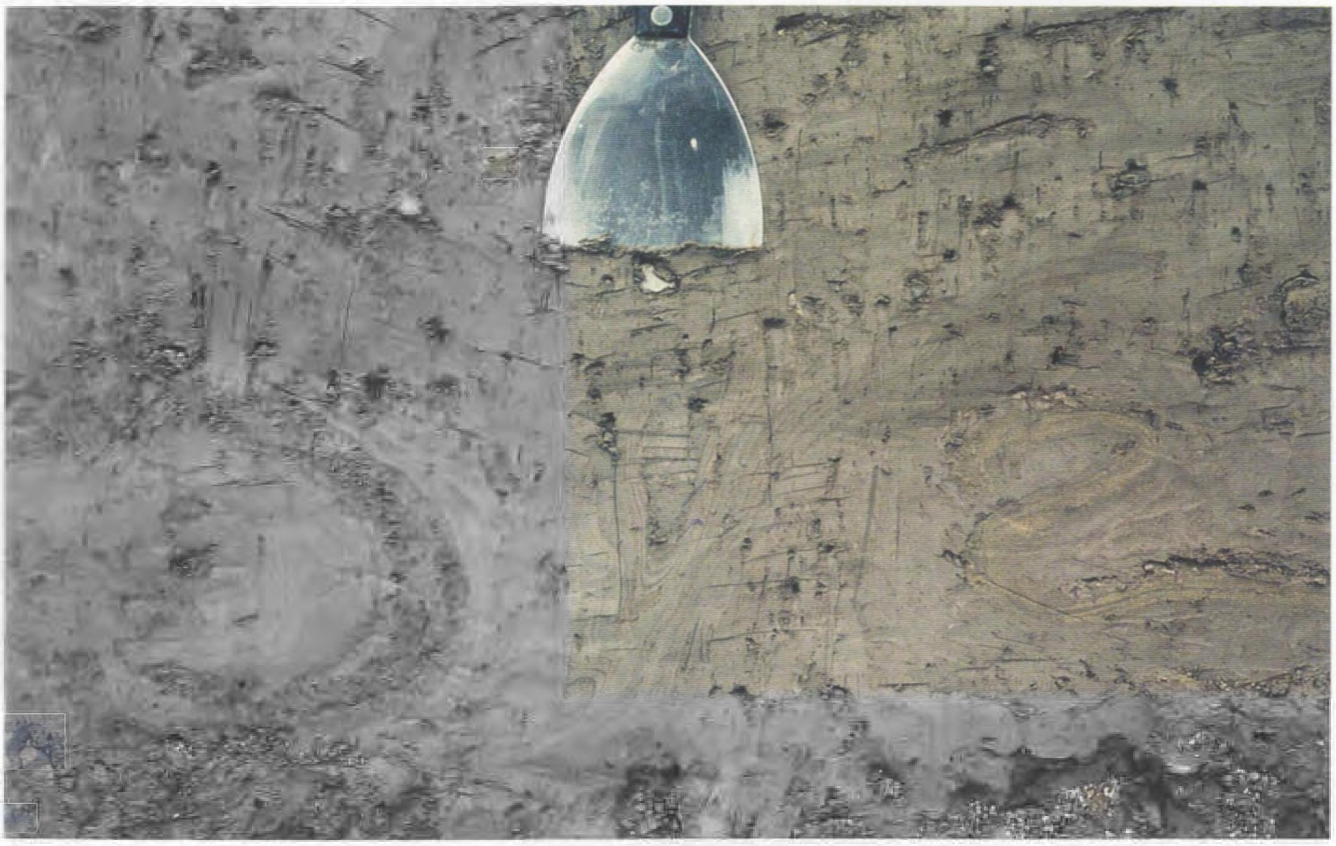


Plate 6.14: Folded and deformed silt and clay laminae within the upper portion of Unit 2 of Site SS-1. Trowel blade for scale is approximately 5 cm long.

Plate 6.15: Beds of Unit 2 of Site SS-1 thin to the west. Card for scale is 9 cm long.

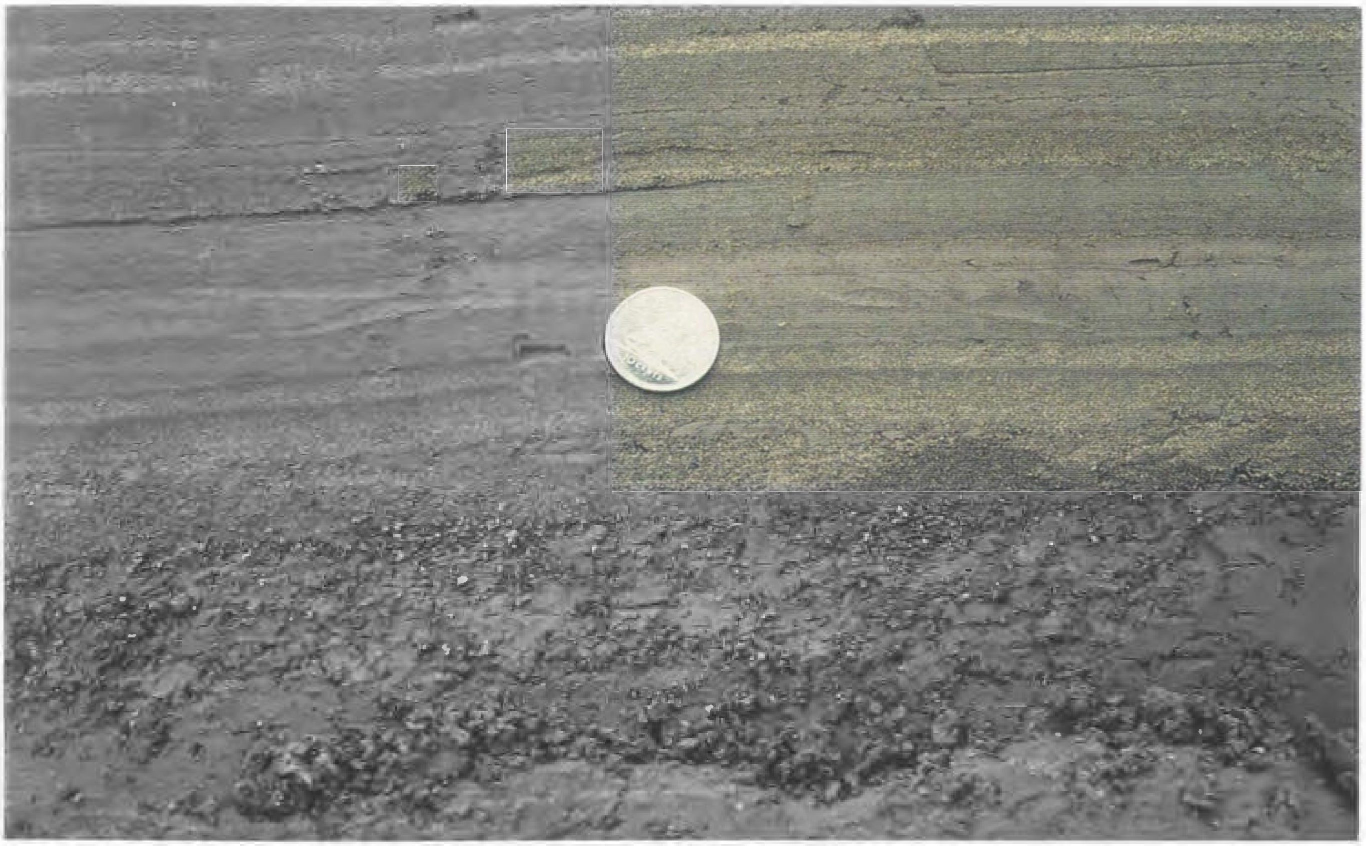


Plate 6.16: The lower contact of the with sand bed of Unit 3 with the silt and clay of Unit 2 of Site SS-1. Note rip-up clasts in base of Unit 3. Coin for scale is approximately 1 cm in diameter.

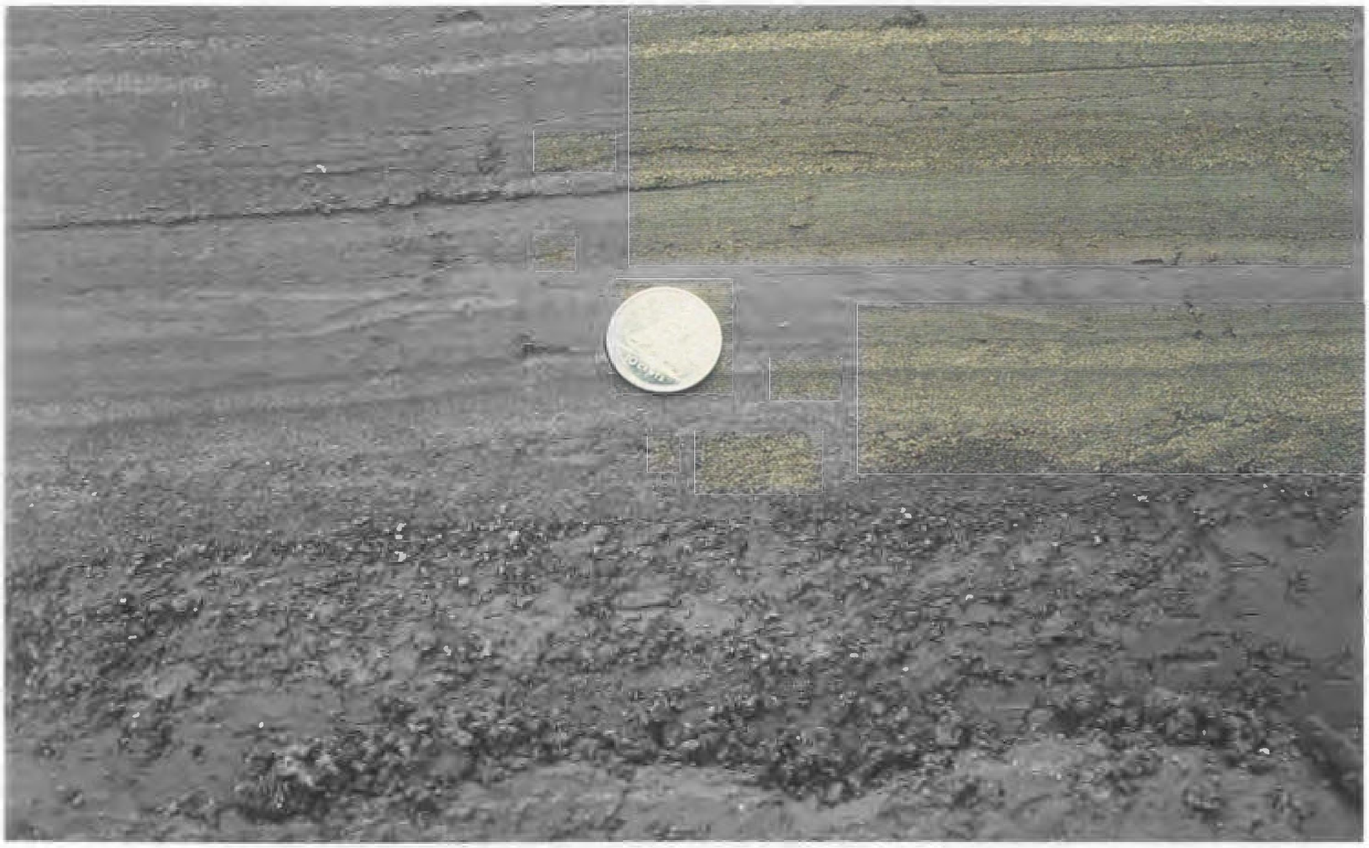


Plate 6.16: The lower contact of the with sand bed of Unit 3 with the silt and clay of Unit 2 of Site SS-1. Note rip-up clasts in base of Unit 3. Coin for scale is approximately 1 cm in diameter.

unit suggests higher energy. The subunits here are interpreted as turbid underflows involving basal deposition from traction flow in contact with the underlying sediment, and simultaneous settling of material in suspension in the nose of the flow. This is similar to features noted in Catto, 1987. An underflow model is more compatible with a brackish water environment than with an open marine environment with normal salinity.

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 form where high sedimentation rates prevail, resulting in loose packing of sands and silts.

Paleoflow measurements made on fold axes followed the topography of the Indian Brook valley axis. The direction of sediment transport and bottom current movement was downslope, towards Hall's Bay (see Appendix 1).

6.3.1.5 Unit 3 Description

Unit 3 has a maximum thickness of 1.5 m, thinning towards the west until it is 10 cm thick. The contact with the underlying Unit 2 is sharp and erosional. The sediment consists of alternating 10YR 5/4 and 2.5YR 5/4 colored silt, sand, and clay strata (F_1, F_2).

At the base of the unit (the lower 21 cm)(F_2), the laminae are internally structureless, and are flat lying with sharp upper and lower contacts. The individual laminae range from 1 mm to 3 cm thick. Large clasts are not present.

In the upper part of the unit, the laminae are folded, distorted and appear convoluted (F_1). These laminae are similar to those described in the upper subunit of Unit 2, although the proportion of subangular to subrounded felsic volcanic granules is 5%, less than half the concentration of coarse clasts in Unit 2. Four bulk texture samples taken from the upper part of Unit 3 (samples 90-9019, 90-9020, 90-9021, 90-9022), indicated that 8-19% of the sediment is sand, 58-67% is silt and 20-34% is clay (see Appendix 4). The laminae are fractured, distorted, and boudinaged with the ends of beds either pulled up into overlying laminae or folded under themselves (Plate 6.17). Others have been subjected to recumbent folding. Fold axis measurements (SS1-b) indicate that deformation was produced by flow to the northeast (see Appendix 1).

These contorted laminae are overlain by flat lying, internally structureless, rhythmically laminated silt, clay and sand ranging from one grain to 1 cm in thickness. Some of the sand laminae fine upwards. Deformed laminae and loading structures, similar to ones in the lower part of Unit 1, are visible in these generally flat lying sediments. Plate 6.18 depicts loading structures in these laminae.

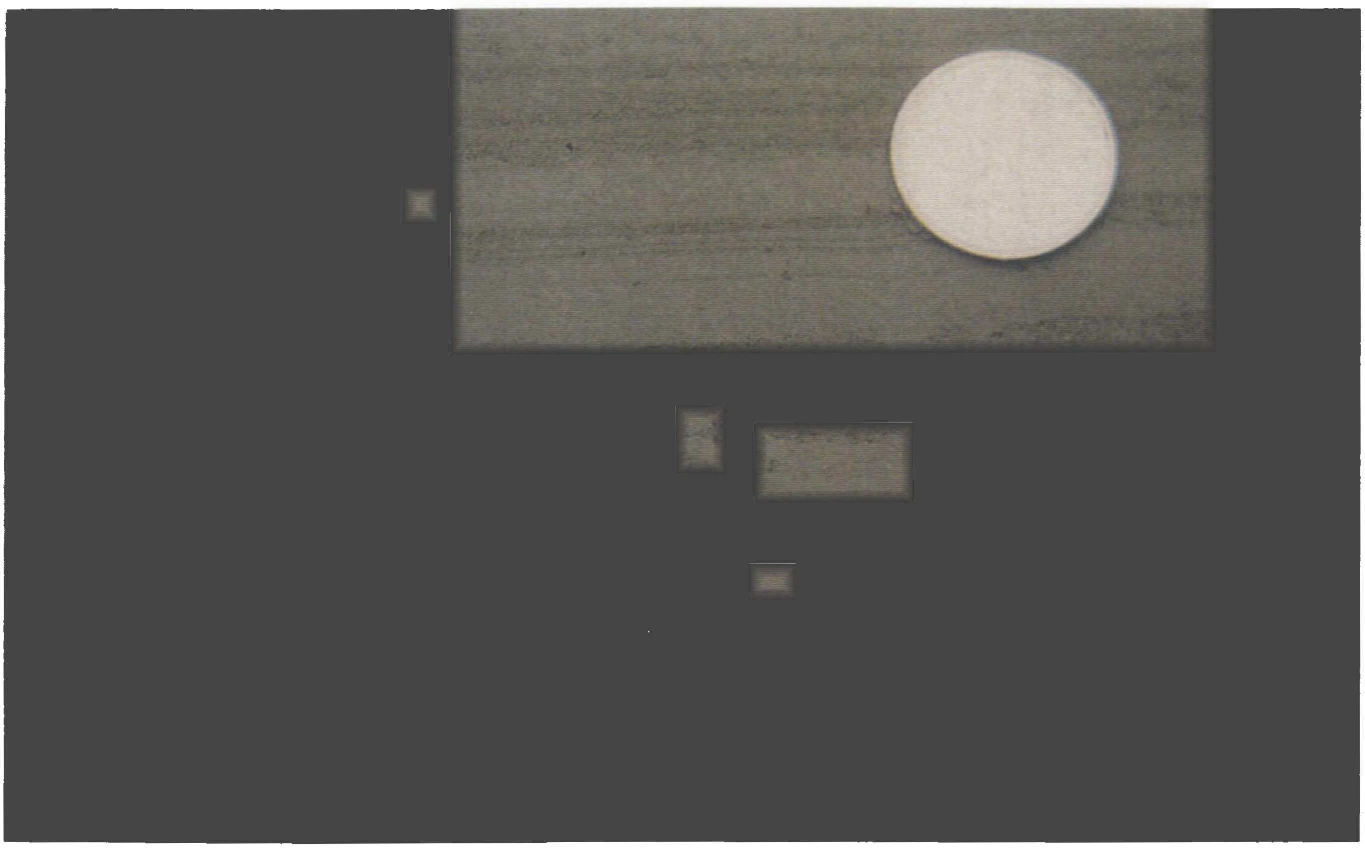


Plate 6.18: Loading structures in sand beds in the upper portion of Unit 3 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

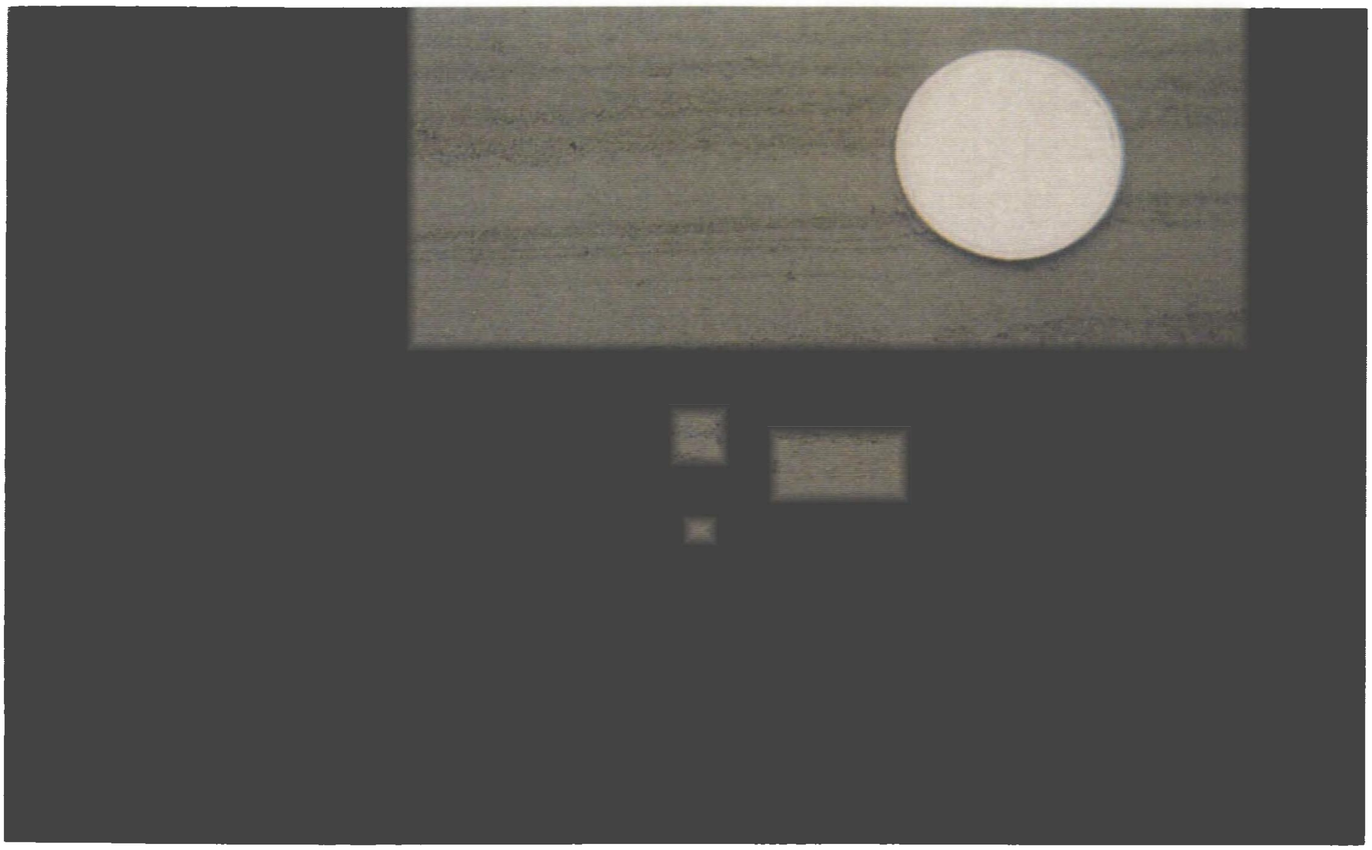


Plate 6.18: Loading structures in sand beds in the upper portion of Unit 3 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

A geochemical sample (90-9024) taken in this unit yielded a vanadium concentration of 109 ppm (see Appendix 5). Analysis revealed that no foraminifera or diatoms were present.

6.3.1.6 Unit 3 Interpretation

Unit 3 has similar sedimentary features to those of Unit 1, and it is therefore interpreted to have formed in a similar manner. The rhythmically laminated silt and clay suggested deposition by suspension due to its fine grained, well sorted nature, lack of coarse debris, and lack of current indictors (Powell, 1981; Mode *et al.*, 1983; Allen, 1984; Domack, 1984; and Stewart, 1991).

The fine sand laminae, due to their coarser nature, and isolated fining upward sequences, may have formed by small sediment gravity flows downslope similar to ones described by Philips *et al.* (1991).

The folded sub-unit is likely similar to the convoluted sediments seen in Unit 1 and are typical of water lain sediments and form where high sedimentation rates prevail, resulting in loose packing of sands and silts.

The vanadium values measured in this unit suggest that the sediment was formed in a brackish marine environment (Shimp *et al.*, 1969).

6.3.1.7 Unit 4 Description

Unit 4 is a laminated silty clay with pebbles (F_3), 15 to 40 cm thick (Plate 6.19), which thins to the west. It has a sharp, erosional contact with Unit 3 below and the upper contact with Unit 5 is irregular in form. The laminated material exhibits drag folding and convolutions, similar to those within Unit 2. The unit contains approximately 5% subangular pebbles. Some intraclasts (1 to 2 cm) of clay are present. Rip-up clasts are abundant in this unit. Bulk textural sampling of this unit (sample 90-90025) indicated that the sediment consists of approximately 42% sand, 35% silt and 14% clay (see Appendix 4).

Axial measurements of folded laminated strata (analyzed using the techniques of Woodcock, 1979) indicate flow to the northeast (see Appendix 1: SS1-c). Both the upper and lower contacts are sharp.

6.3.1.8 Unit 4 Interpretation

Unit 4, with its similar sedimentary features to those of Unit 2, is interpreted to have formed in a similar manner. The material in this unit appears to be more disturbed than that of Unit 2 which perhaps indicates a more turbid current or bottom flow.

Paleoflow measurements made on fold axes within this unit also followed the topography of the Indian Brook valley axis. As with Unit 2, the direction of sediment transport and bottom current movement was downslope, towards Hall's Bay.

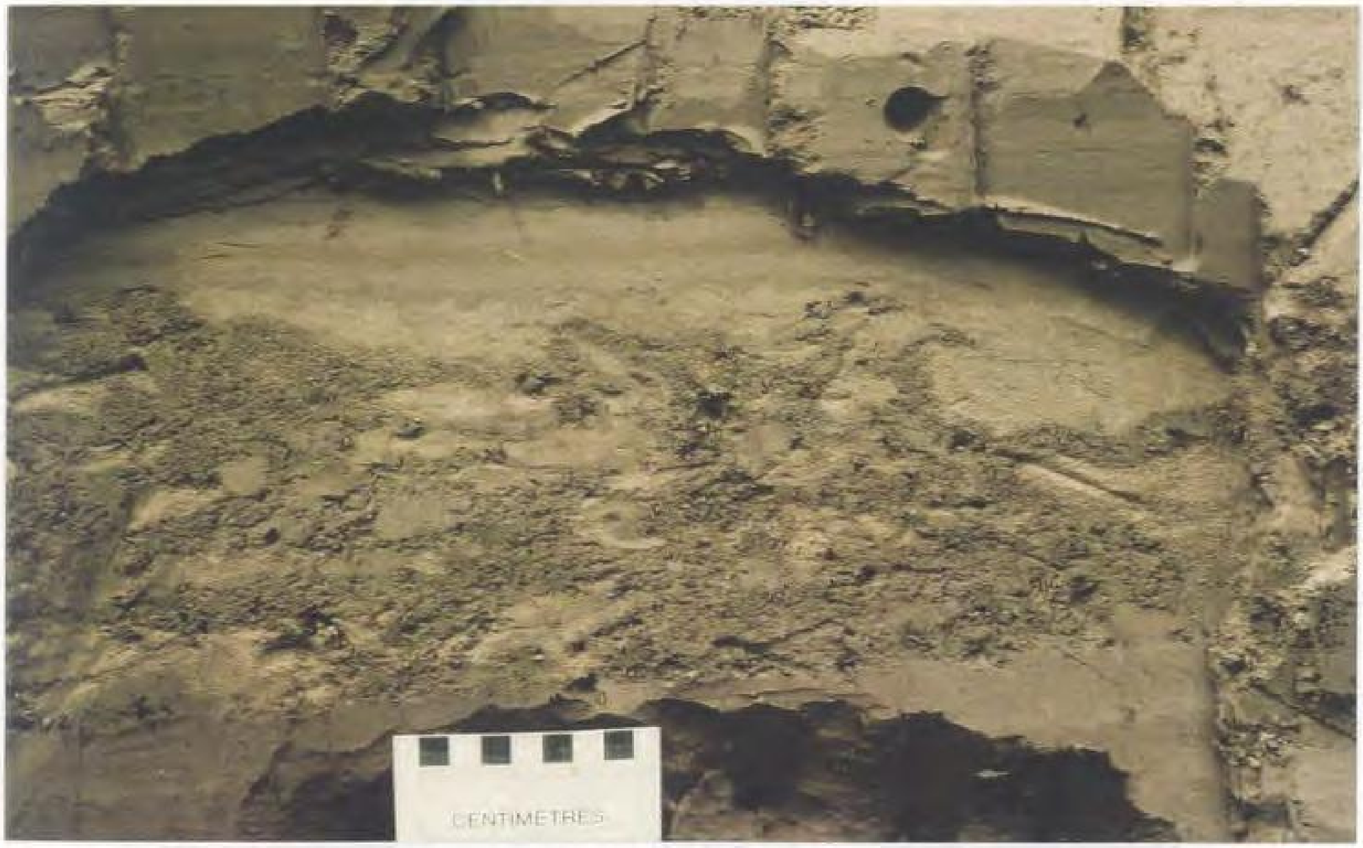


Plate 6.19: Silty diamicton of Unit 4 of Site SS-1. Card for scale is 9 cm long.

6.3.1.9 Unit 5 Description

Unit 5 is composed of 2.3 m of laminated 10YR 5/4 and 2.5YR 5/4 colored silt and clay (F_l) with trace amounts of subangular to subrounded pebbles of various shapes. These strata are internally structureless. The strata range from 1 mm to 2.5 cm in thickness, and within the unit there are more fine textured laminae than sandy strata. Contacts between the laminae are sharp. The pebbles within the unit deform underlying strata and are draped by overlying strata (Plate 6.20). Minor slumping and water escape structures such as sags and load casts, similar to those described in Unit 1, are located throughout this unit.

Bulk textural sampling of the silt and clay laminae within unit 5 (sample 90-90033) indicated that the sediment consists of approximately 7% sand, 61% silt and 30% clay (see Appendix 4). A textural sample from a sandy silt laminae within this unit (sample 90-90027), indicated that the sediment consists of approximately 35% sand, 49% silt and 16% clay (see Appendix 4). The upper contact of the unit is sharp and erosional.

Shells were located at two elevations in unit 5: approximately 97 cm and 200 cm above the basal contact of Unit 5 which is at an elevation of 26.4 +/- 3 m a.s.l. These articulated *Mya arenaria* shells were in growth position. The shells ranged from 0.8-1.4 cm long and were extremely friable. Accelerator ^{14}C dating at Isotrace Radiocarbon Laboratory in Toronto produced results of 7,890 +/- 80

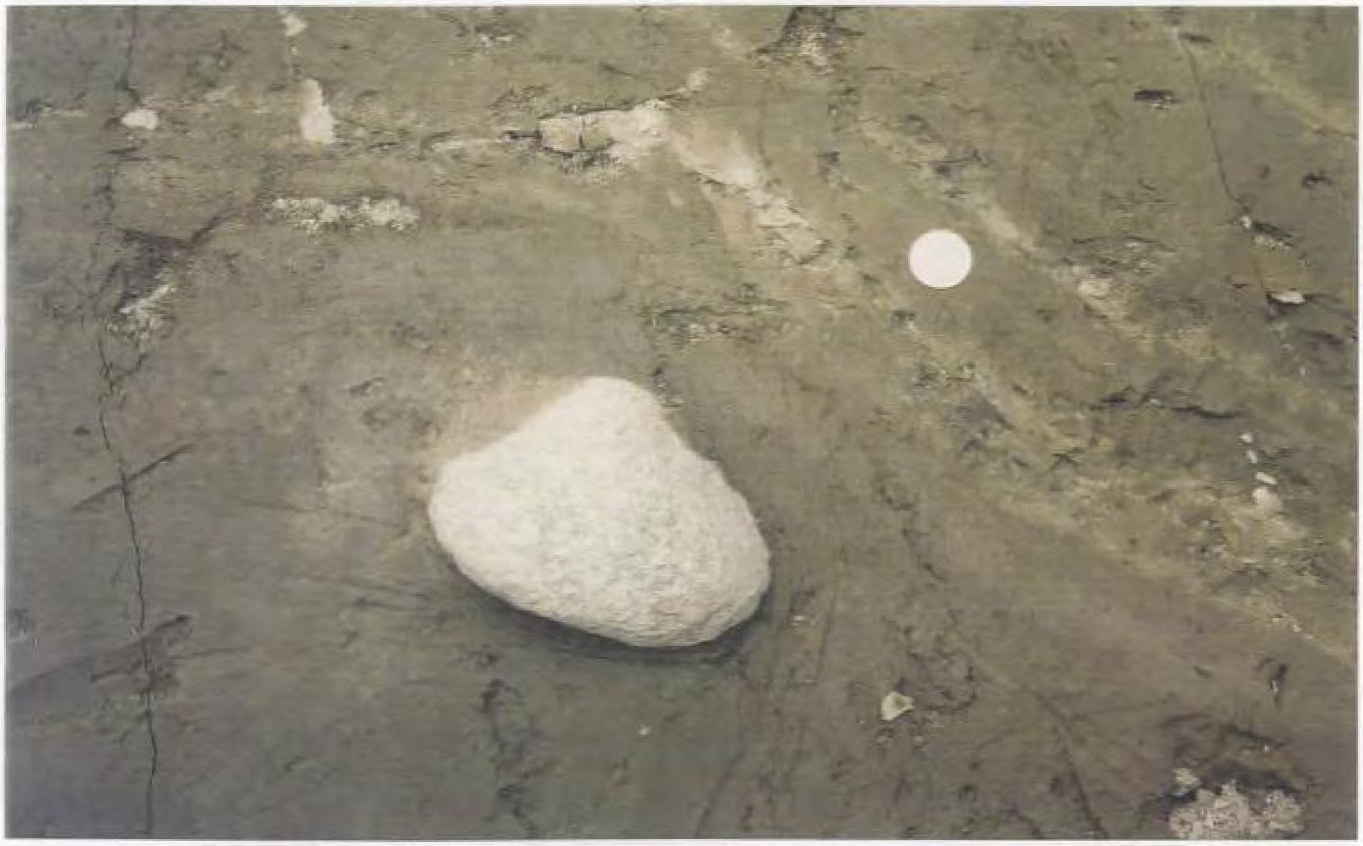


Plate 6.20: Basalt cobble, which deforms the underlying stratified silt and clay, and is draped by overlying stratified material is located within Unit 5 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

years BP (TO-2304) for the 27.4 m shell (Plate 6.21) and 12,470 +/- 380 years BP (TO- 2305) for the 28.5 m sample (Plate 6.22). *Mya arenaria* is commonly found in brackish glaciomarine environments (Wagner, 1970).

Geochemical samples, 90-9031 from the lower part and 90-9036 from the upper part of Unit 5, taken in this unit yielded vanadium concentrations of 109 and 106 ppm, respectively (see Appendix 5). Analysis revealed that no foraminifera or diatoms were present.

6.3.1.10 Unit 5 Interpretation

Unit 5, with its similar sedimentary features to those of Unit 1 and 3, is interpreted to have formed in a similar manner. The rhythmically laminated silt and clay suggested deposition by suspension due to its fine grained, well sorted nature, lack of coarse debris, and lack of current indictors (Powell, 1981; Mode *et al.*, 1983; Allen, 1984; Domack, 1984; and Stewart, 1991). In addition, clasts within the unit are interpreted as dropstones from floating ice, similar to those described by Thomas and Connell (1985). The presence of the shells indicate that conditions were calm enough for marine shell life to settle in for a brief period.

As with Units 1 and 3, the fine sand laminae within this unit may have formed by small sediment gravity flows downslope similar to ones described by Philips *et al.* (1991).

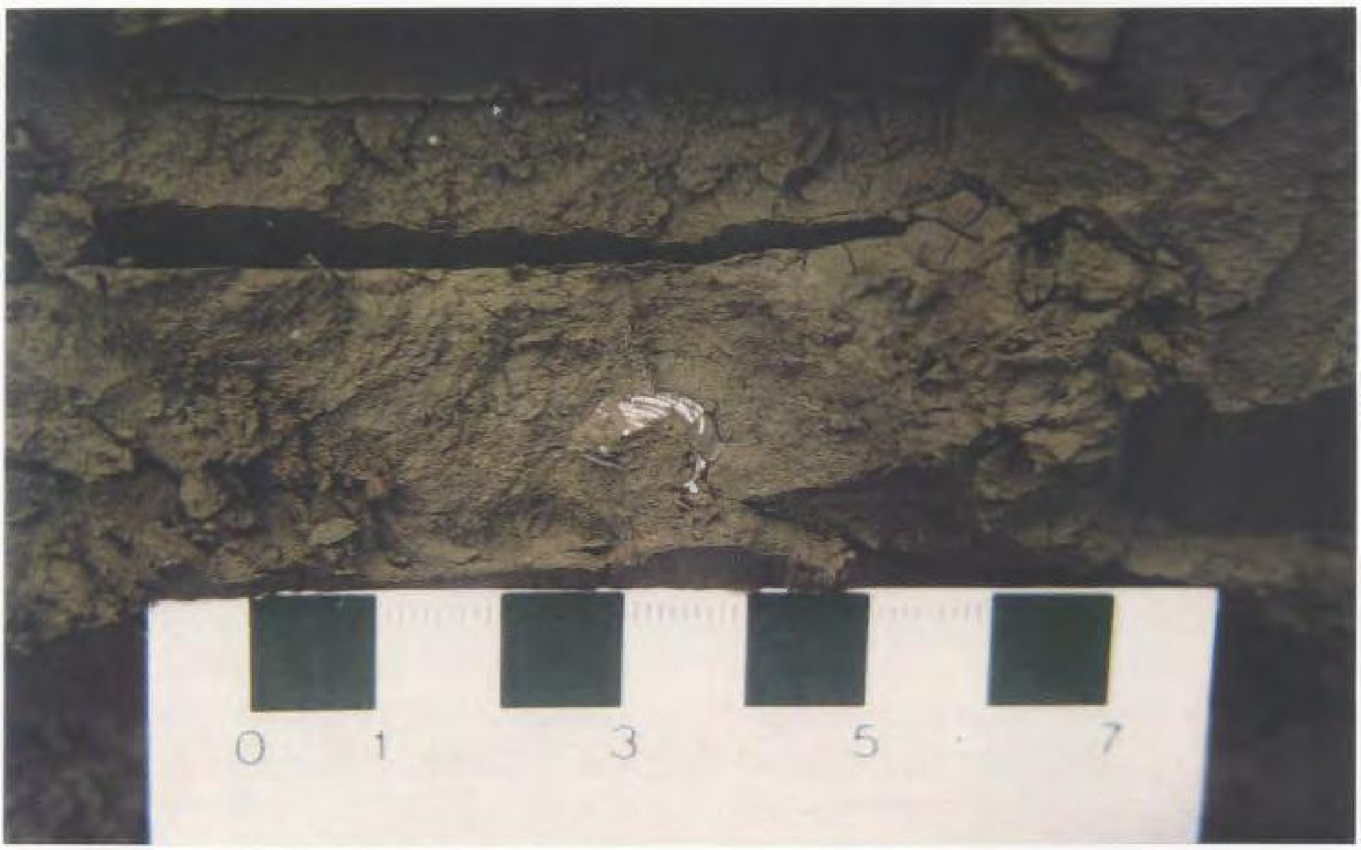


Plate 6.21: *Mya arenaria* shell at 27.4 m asl within silt and clay laminae of Unit 5 of Site SS-1.

Plate 6.22: *Mya arenaria* shell at 28.5 m asl within silt and clay laminae in Unit 5 of Site SS-1. Coin for scale is approximately 1 cm in diameter.

The vanadium values measured in this unit suggest that the sediment was formed in a brackish marine environment (Shimp *et al.*, 1969).

6.3.1.11 Unit 6 Description

Unit 6 consists of 1.47 m of interbedded sand and gravel (G_2). These beds are structureless and range from 10 to 40 cm thick. The sand is medium to coarse grained and well sorted. Gravel beds are well sorted and have subangular to subrounded clasts of various lithologies, ranging from 1 to 5 cm in size. The unit has a sharp lower contact with underlying unit 5 and is erosionally truncated by natural causes at the upper surface of the exposure.

6.3.1.12 Unit 6 Interpretation

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 as discussed in Chapter 4.

6.3.2 Summary of sedimentary sequence at Section SS-1

The sedimentary sequence at site SS-1 formed in the following sequence of events. A period of suspension settling followed by low energy underflows and small sediment gravity flows (Unit 1) and a period of turbid underflows with traction flow and settling of suspended sediment (unit 2). This is evident from the interbedded and interlaminated sand, silt and clay overlain by convoluted silty clay and sand beds with rip up clasts. Another period of suspension settling followed by low energy underflows and small sediment gravity flows (unit 3) and a period of turbid underflows (unit 4) Suspension settling (unit 5) followed by a cap of fluvial sediment (unit 6).

6.3.3 Site SS-18

Site SS-18 is located approximately 0.5 km to the east of Site SS-1, on the north side of Indian Brook (Figure 6.1), at an elevation of 30 +/-3 m asl. The exposed part of this section consists of rhythmically bedded silt, clay, and sand with a thickness of 8 m (Figure 6.4). The total thickness of sediment at this section is approximately 15 m, but the lower 7 m is covered with thick colluvium which could not be cleared. Plate 6.23 shows the lower part of the section. The bottom of the exposure was placed where the section was able to be cleared from a safety perspective, as the near vertical exposure dropped to the colluvium and then into the river below. The exposed part of this section is divided into four units.

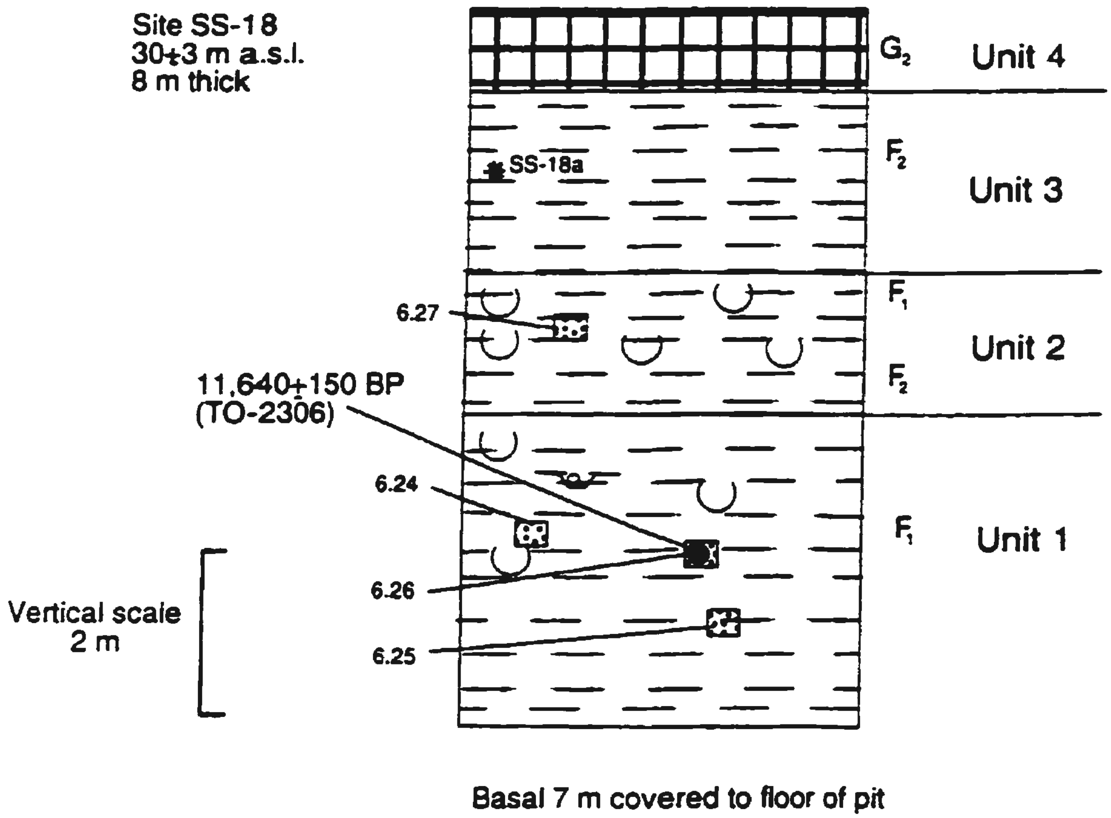


Figure 6.4: Sedimentary column of Site SS-18. See Figure 6.2 for legend.

Plate 6.23: Lower covered 7 m of the silt and clay exposure at Site SS-18. At the base of the section, Indian Brook flows to the east.

6.3.3.1 Unit 1 Description

Unit 1 is a minimum of 3 m thick. It consists of laminated sand, silt, and clay strata (F_l) ranging from 1 mm to 40 cm thick with less than 1 percent subangular to subrounded granules. The clay has alternating colours of weak red (10R 5/2) and light brownish grey (2.5Y 6/2) when moist. In places throughout the unit, the laminae have a spotted black coloration and a sulphurous odor. Contacts between laminae are typically sharp.

Water escape structures, approximately 5 cm in length and 5 cm in height (Plate 6.24), and soft sediment deformation structures such as loading, similar to those found in Unit 1 and 3 at Site SS-1 are also present. Minor normal faults with 2 cm displacement (Plate 6.25), located within the laminated sediment are syndepositional in origin, as the upper parts of the faults are draped and do not persist through the overlying strata. Coarse clasts present in the sediment deform the underlying strata and are draped by the overlying beds, similar to clasts noted in SS-1 units 1 and 5.

Bulk textural samples taken in the basal and upper 10 cm of Unit 1 (samples 90-90037 and 90-90050) indicated that the laminated sediment consists of 6% sand, 39% silt, 55% clay and 5% sand. 29% silt, 66% clay, respectively (see Appendix 4). Sample 90-90040 from a sandy clay laminae consists of 35% sand, 18% silt and 47% clay (see Appendix 4).

Shell fragments were found in Unit 1 at 24.3 m asl, approximately 3.25 m from the bottom of the unit (Plate 6.26).

Plate 6.24: Water escape structure, approximately 5 cm in length and 5 cm in height (to right and below the coin) and soft sediment deformation structures such as folding (in lower right part of plate) located within Unit 1 of Site SS-18. These features are similar to those found in Unit 1 and 3 at Site SS-1. Coin for scale is approximately 2.5 cm in diameter.

Plate 6.25: Syndepositional normal faulting within the laminated silt and clay and sand beds of Unit 1 within Site SS-18. Coin for scale is approximately 2.5 cm in diameter. Fault is marked with an arrow.

Plate 6.26: *Mya arenaria* shell fragments in Unit 1 of Site SS-18 at 24.3 m asl, approximately 3.25 m from the bottom of the unit. The shell fragments are the white colored flecks in the sandy ball at the center of the photograph.

These shell fragments have been identified as bivalves, possibly *Mya arenaria*, but their poor preservation limits the confidence of the identification. Although the shells were submitted for ^{14}C dating, there was insufficient sample for analysis. Organic detritus of husks or epidermis of aquatic plants were found during processing of the sediment in which the shell fragments were located. This material has been ^{14}C-dated at 11,340 +/- 150 years BP (TO-2306).

Field and laboratory investigations determined that no foraminifera or diatoms were present in Unit 1. Bulk samples, samples 90-90045 and 90052, taken for geochemical analysis for vanadium yielded values of 92 and 84 ppm, respectively (see Appendix 5).

6.3.3.2 Unit 1 Interpretation

The well sorted, laminated silt and clay of Unit 1 is interpreted to be deposited by settling of sediment from suspension, similar to sediment found in Units 1, 3 and 5 of Site SS-1. The fine grained, well sorted nature, scarcity of coarse debris, and lack of current indictors suggests this kind of deposition. Powell (1981), Mode *et al.* (1983), (Allen, 1984), Domack (1984), and Stewart (1991) all describe similar features. Sand lamina, due to their coarser nature, may have formed by small sediment gravity flows downslope similar to ones described by Philips *et al.* (1991).

As with Units 1, 3 and 5 of site SS-1, the strata in Unit 1 contain wavy convoluted beds, boudinaged sand beds, and fold and flame like structures. These features are interpreted as penecontemporaneous soft sediment deformation structures similar to sedimentary structures described as deformation features by Reineck and Singh (1973) Mills (1983), Allen (1984) Stewart (1991) and Merritt *et al.* (1995). In addition, the unit contains coarse clasts which deform the strata which are interpreted as dropstones from floating ice (Thomas and Connell, 1985).

The presence of a black coloration and strong sulfurous odor to the laminated silt and clay is similar to sediment described by Powell (1989). Powell attributed this phenomenon to either a decay of organics or reduction of iron-hydroxide to iron-monosulphides under anoxic conditions beneath the sediment surface. The presence of organic detritus or husks of aquatic plants within the sediment at site SS-18 suggests the black coloration is attributable to the decay of organics.

The vanadium values measured in this unit suggest that the sediment was formed in a brackish marine environment Shimp *et al.*, 1969).

6.3.3.3 Unit 2 Description

Unit 2 ranges from 0.5 to 1.25 m thick and consists of laminated sand, silt and clay (F_2), overlain by convoluted sand, silt and clay laminae (F_1) which grades up into a fine to medium well sorted sand. The unit thins to the west and east.

The basal 10 cm of the unit consists of laminated and bedded sand silt and clay ranging from 1 mm to 1-2 cm thick. Generally these laminae and beds are internally structureless and the silt and clay laminae alternate in color between weak red (10R 5/2) and light brownish grey (2.5Y 6/2). Small proportions of subrounded volcanic pebbles (1-2 cm) draped by overlying sediment and water escape structures similar to those in Unit 1 site SS-1 are present. Contacts between the laminae are sharp.

A bulk sediment sample (Sample 90-90054) taken from this part of the unit for textural analysis, contained 8% sand, 33% silt and 59% clay (see Appendix 4).

Overlying this sediment is approximately 1 m of interbedded, convoluted and folded sand, silt, and clay (Plate 6.27). Small proportions of subrounded volcanic pebbles (1-2 cm) and intraclasts (1 to 2 cm in diameter and composed of clay) are present in the sand.

Fold nose measurements and a 1°-10° dip in the beds indicate an easterly deformation direction. Small proportions of subrounded volcanic pebbles (1-cm) are also present.

This part of the unit grades up into 1-10 cm thick, internally structureless, well sorted fine to medium sand. A bulk sediment sample (Sample 90-90055) taken from this portion of the unit for textural analysis, contained 88% sand, 7% silt and 5% clay (see Appendix 4).

Plate 6.27: Interbedded convoluted and folded sand, silt and clay within Unit 2 of Site SS-18. Coin is approximately 2.3 cm in diameter.

6.3.3.4 Unit 2 Interpretation

Unit 2 has strata and sedimentary features similar to sediment found in Unit 2 at SS-1. The material in this unit, with its more convoluted and folded nature, wavy undulating contact with the sand and the presence of clay intraclasts and cut off laminae, suggest that the flow event which formed these sediments is similar in nature but more powerful than that which affected Unit 2 in SS-1. The units here are interpreted as turbidites, and hence represent both suspended settling and flow.

Paleoflow measurements made on fold axes followed the topography of the Indian Brook valley axis, similar to site SS-1 (see Appendix 1: SS-18a). The direction of sediment transport and bottom current movement was downslope, towards Hall's Bay.

6.3.3.5 Unit 3 Description

Unit 3 consists of 1.87 m of laminated to bedded silt and clay and well sorted (fine to medium) sand (F_2). The silt and clay strata make up 80 percent of the unit and alternate in color between weak red (10R 5/2) and light brownish grey (2.5Y 6/2) when moist. The silt and clay strata are internally structureless and range from 1 to 30 cm thick. The sand strata are massive and range from 1-10 cm thick. Isolated (<1%) subangular to subround coarse clasts which deform the underlying strata and are draped by the overlying beds are present. These are similar to clasts noted in SS-1 Units 1 and 5.

The contacts between strata and beds are sharp. The lower contact is undulatory and occasionally truncates strata.

Bulk textural samples were taken from both the silt and clay laminae and the sand laminae (samples 90-90056 and 90-90057, respectively). The laminated silt and clay contained 12% sand, 31% silt and 57% clay, whereas the sand laminae consist of 59% sand, 23% silt, 18% clay (see Appendix 4).

Field and laboratory investigations determined that no foraminifera or diatoms were present in Unit 3. A bulk sample, 90-90059, taken for geochemical analysis for vanadium yielded a value of 103 ppm (see Appendix 5).

6.3.3.6 Unit 3 Interpretation

Unit 3 has similar sedimentary features to those of Unit 1, and it is therefore interpreted to have formed in a similar manner. The rhythmically laminated silt and clay suggested deposition by suspension due to its fine grained, well sorted nature, lack of coarse debris, and lack of current indictors (Powell, 1981; Mode *et al.*, 1983; Allen, 1984; Domack, 1984; Stewart, 1991; Hambry, 1994).

The fine sand laminae, due to their coarser nature, and isolated fining upward sequences, may have formed by small sediment gravity flows downslope similar to ones described by Philips *et al.* (1991).

The vanadium values measured in this unit suggest that the sediment was formed in a brackish marine environment Shimp *et al.*, 1969).

6.3.3.7 Unit 4 Description

Unit 4 consists 1.4 m of planar bedded, poorly sorted pebbly gravel and pebbly sand (G_2) (Plate 6.28). This unit has 40 cm of poorly sorted clast supported pebble cobble gravel with <1% fines in the matrix of fine to medium sand. The clasts range from 2-5 cm in maximum diameter and are generally subrounded. This grades into 20 cm of a structureless, poorly sorted, clast supported pebble gravel. Clasts are subrounded and 2-5 cm in size. This grades into 40 cm of a matrix supported sandy gravel. The lower contact is gradational and this unit is capped by approximately 40 cm of pedogenically altered sediment.

6.3.3.8 Unit 4 Interpretation

Unit 4 is interpreted as a postglacial fluvial gravel, similar to that which caps the sedimentary sequence at site SS-1. Unit 4 is coarser than the underlying units, and overlies them unconformably. Similar interbedded sand and gravel units are associated with the modern streams in the region as noted in Chapter 4.

Plate 6.28: Planar bedded, poorly sorted pebbly gravel and pebbly sand of Unit 4 of Site SS-18. Stick in the center of the photo is approximately 10 cm in length.

6.3.4 Summary of sedimentary sequence at Section SS-18

The sedimentary sequence at site SS-18 formed in the following sequence of events. A period of suspension settling (unit 1) followed by low energy underflows (unit 1) and a period of minor slumping (unit 2). This is evident from the interbedded and interlaminated sand, silt and clay overlain by convoluted silty clay and sand beds with rip up clasts. A second period of suspension settling followed by low energy underflows (Unit 3) followed by a cap of fluvial sediment (unit 4).

6.3.5 Site SS-19

Site SS-19 is located on the south side of Indian Brook, at the falls, within the George Huxter Memorial Park near Springdale (Figure 6.1). This site, at an altitude of 20 +/-3 m asl, is approximately 3.6 km east of Site SS-1 and 3.1 km east of Site SS-18. The exposed part of this section, approximately 8.65 m thick, consists of laminated silts and clays overlain by diamicton which is in turn capped by pebble-granule gravel (Figure 6.5). The total thickness of sediment at this location is 13.65 m but the lowermost 5 m of the section is covered in slumped debris. Plate 6.29 depicts the section.

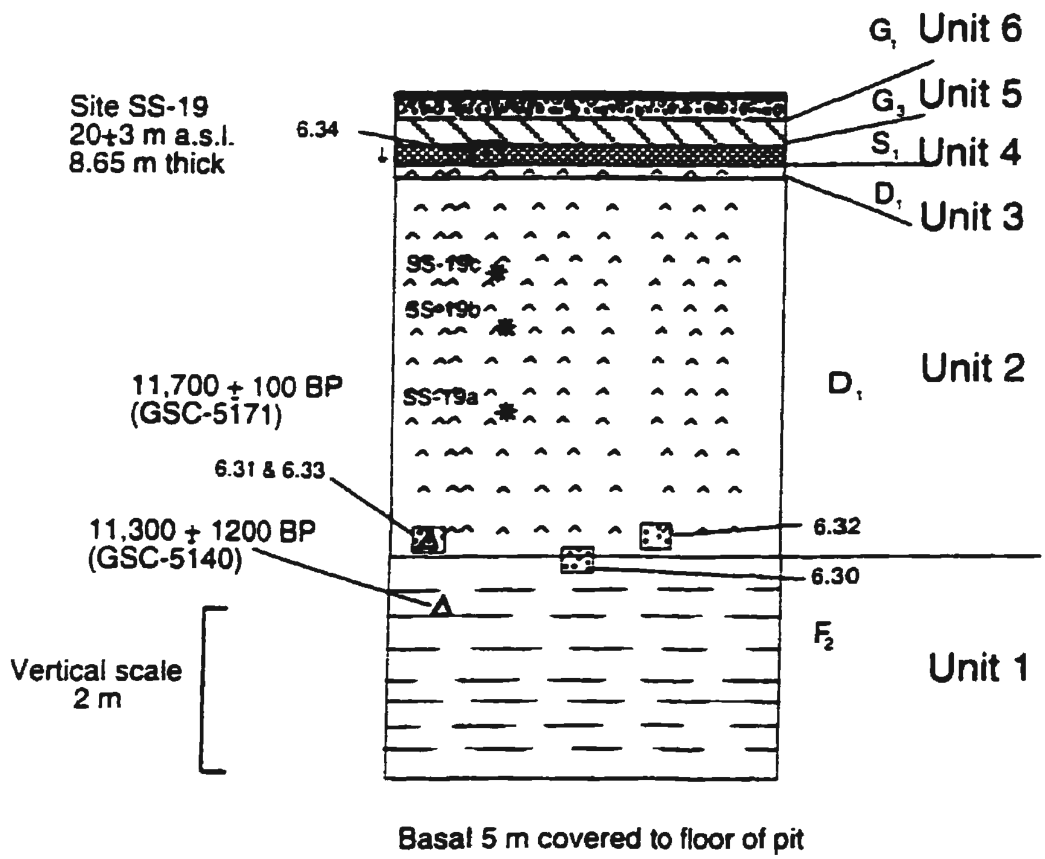


Figure 6.5: Sedimentary column of Site SS-19. See Figure 6.2 for legend.

Plate 6.29: Site SS-19 on south side of Indian Brook near the George Huxter Memorial Park. The top of the exposure is at an elevation of 20 +/- 3 m asl. Total thickness of the exposure is approximately 8.65 m.

6.3.5.1 Unit 1 Description

Unit 1 is composed of 2.5 m of laminated silt, clay and sand (F_2) exposed at the base of the section. The basal contact is not visible as it is buried beneath slumped sediment from the section. Bedrock outcrops just below the toe of this slumped material within the riverbed.

The alternating red and green laminae of reddish brown (2.5YR 5/4) and yellowish brown (10YR 5/4) silt and clay are similar to laminated sediment at sections SS-1 and SS-18. The laminae range from 1 to 2 mm thick, are internally structureless and contacts between laminae are sharp. The sand laminae range from 5-6 mm thick and are internally structureless.

Two samples, 90-90063 taken from near the contact with the overlying Unit 2 and 90-90067 taken approximately 1.5 m below the contact with Unit 2, were taken for bulk textural analysis. Analyses indicated that the samples consists of 22% sand, 57% silt, 19% clay and 10% sand, 67% silt and 23% clay, respectively (see Appendix 4).

Shells were located at 12 m asl (approximately 10 cm below the contact with Unit 2). Plate 6.30 shows the contact between Unit 1 and 2. The white coloration in the photo are shells. The shells ranged from 1 to 3.5 cm long and included the following species types: *Mya truncata*, *Hiatella arctica*, *Macoma balthica*, and *Balanus hameri* (barnacles). Some of these shells were found in growth position (hinge end oriented down with both halves of the shells

Plate 6.30: Contact between the silt and clay of Unit 1 and the sandy diamicton of Unit 2 of Site SS-19. The top of the wooden handle, as shown in the photo, is approximately 20 cm long.

articulated). Other shells were fragmented and consisted of 1 cm by 1 cm pieces of shells and individual valves oriented in all directions. A mixed species sample from this unit was ^{14}C dated at 11,300 +/- 120 BP (GSC- 5140).

Analysis revealed that no diatoms or foraminifera were present. Geochemical analyses for vanadium, from a bulk sample taken approximately 1.5 m below the upper contact with Unit 2, yielded a value of 106 ppm (see Appendix 5). The upper contact is gradational with unit 2.

6.3.5.2 Unit 1 Interpretation

This unit is interpreted to have been deposited from suspension settling. The well sorted, fine grained nature, lack of coarse debris, and lack of current indicators is similar to sediment described by Powell (1981), Mode *et al.* (1983), Allen (1984), Domack (1984), and Stewart (1991) which was interpreted to have been deposited from suspension settling. The rhythmically laminated silts and clays contain fine sand laminae. These laminae, due to their coarser nature, may have formed by small sediment flows downslope similar to ones described by Philips *et al.* (1991).

The shell species found within this unit 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 vanadium value measured in this unit suggests that the sediment formed in a brackish marine environment (Shimp *et al.*, 1969).

6.3.5.3 Unit 2 Description

Unit 2 consists of 5.35 m of a sandy diamicton (D_1). The diamicton is structureless and consists of poorly sorted material with a coarse to medium sand matrix. The sediment contains approximately 45% subangular to subrounded pebbles to cobbles which range from 0.5 cm to 30 cm in diameter. The lithologies of these clasts vary, but most of the clasts have granitic, rhyolitic and basaltic compositions. The basal 65 cm of the unit is very compact, whereas the upper part of the unit has less clay and the material is friable.

Textural sampling of the matrix of this unit (sample 90-90061) indicate that the diamicton consists of 20% gravel, 70% sand, 6% silt and 4% clay (see Appendix 4).

Shells are located in the first 80 cm of this unit above the contact with Unit 1. The shells range from crushed pieces to whole half shells and shells in living position (similar to those in Unit 1). Plate 6.31 depicts half of a *Mya truncata* shell located in the lower 80 cm of Unit 2. Barnacle fossils (identification verified by John Shaw of the Bedford Institute of Oceanography), were abundant in the lower

Plate 6.31: Depicts half of a *Mya truncata* shell located in the lower 80 cm of diamicton Unit 2 of Site SS-19. Coin for scale is approximately 2.5 cm in diameter.

50 cm of unit 2 and cobbles within the sediment had barnacle shells still attached to them (Plate 6.32). Barnacle shells found at 12.9 m asl (approximately 35 cm above the lower contact with Unit 1) have been ^{14}C dated at 11,700 +/- 110 years BP (GSC-5171). Plate 6.33 depicts barnacles (identified by John Maunder of the Newfoundland Museum).

Three sites within this unit were measured for clast fabric analysis (see Appendix 1: SS-19a, b and c).

6.3.5.4 Unit 2 Interpretation

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 and 1991). The poorly sorted diamicton, including crushed and twisted shell debris, indicate that the sediment has undergone transportation. The presence of some shells in life position suggests either that there are multiple events preserved here with buried shells overlain by debris with shell hash or that a single event transported shell hash from the nearshore (wave base) than then was deposited with the rest of the sediment over the in situ shells.

The analyses of the clast fabric measurements indicates that clast orientation is random within this unit (see Appendix 1). This lack of preferred orientation suggests that the diamicton was either

Plate 6.32: Basalt cobbles in the lower 50 cm of Unit 2 of Site SS-19 with barnacle shells still attached. Card for scale is 9 cm in length.

Plate 6.33: Barnacles (identified by John Maunder of the Newfoundland Museum) within Unit 2 of Site SS-19. The green square in the card in the upper right part of the photo is 1 cm.

ice rafted or a result of sediment flow, similar to that described by Domack and Lawson(1985).

6.3.5.5 Unit 3 Description

Unit 3 consists of approximately 15 cm of a massive diamicton (D_1). The diamicton consists of a sandy silt matrix with about 55% coarse clasts up to 70 cm in diameter. Textural sampling of the matrix of this unit (sample 90-91003) indicates that the diamicton consists of <5% gravel, 80% sand, 10-15% silt and 5% clay (see Appendix 4). The lower contact with Unit 2 is sharp. Plate 6.34 shows Unit 3 (just below the card) and its contacts with Unit 2 and Unit 4. No shells were found in this unit. A fabric analysis was not performed.

6.3.5.6 Unit 3 Interpretation

The similarity of this diamicton with respect to the diamicton in Unit 2 suggests that this diamicton is also a mass movement deposit. The unit lacks internal structure, the matrix is comprised of sand, silt and similar to diamicton sediment reported by Stewart (1991) which were interpreted to have formed by mass movement.

6.3.5.7 Unit 4 Description

Unit 4 consists of 20 cm of a coarsening upward, well sorted medium sand (S_1) (see Plate 6.34). The unit contains <1% sub-

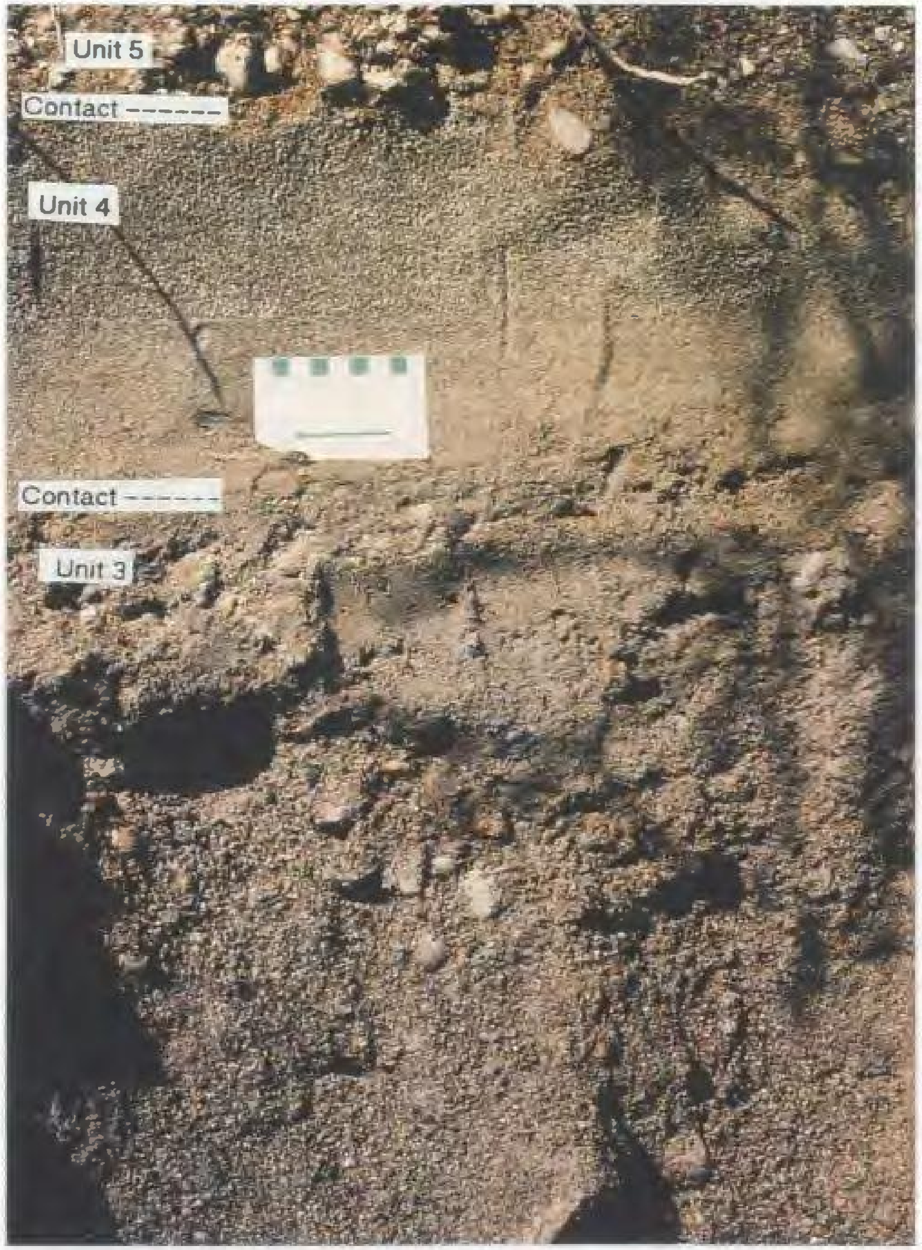


Plate 6.34: Coarsening upward, well sorted medium sand of Unit 4 and contact with diamicton of Unit 3 located just below the card. At the very top of the photo the contact of the sand of Unit 4 with the pebble gravel of Unit 5 is visible.

angular to sub-rounded pebbles of various lithologies. The lower contact is gradational.

6.3.5.8 Unit 4 Interpretation

The sediment in Unit 4 is similar to reverse graded sand beds that were reported by Stewart (1991). The unit is interpreted to have formed from a high-density turbidity current and mass flow environment similar to those described by Lowe (1982). The proximity to the other sediments in this section which are interpreted to have formed by sediment flows supports this supposition.

6.3.5.9 Unit 5 Description

Unit 5 consists of 50 cm of a structureless pebble gravel (G_3) (Plate 6.35). Subangular to subrounded equant clasts range from 2-5 cm. A bulk texture sample (91002) indicated a 80% gravel and 20% sand content (see Appendix 4). The lower contact is sharp and undulatory.

6.3.5.10 Unit 5 Interpretation

Unit 5 is interpreted as post glacial fluvial gravel. Similar interbedded sand and gravel units are associated with the modern streams in the region as noted in Chapter 4.

Plate 6.35: Structureless pebble gravel of Unit 5 of Site SS-19. Card for scale is 9 cm in length.

6.3.5.11 Unit 6 Description

Unit 6 consists of 30 cm of a structureless clast supported pebble granule gravel (G_1). Plate 6.36 shows Unit 6 and its contact with the underlying Unit 5. The pebbles to cobbles are subangular to subround granite and basalt, and range from 0.5 to 5 cm in long axis length. The matrix is a coarse sand with $<2\%$ silt. A texture sample (910001) from this unit indicated a 80% gravel and 20% sand content (see Appendix 4). The lower contact is gradational.

6.3.5.12 Unit 6 Interpretation

Unit 6 is interpreted as a postglacial fluvial pebbly granule gravel, which caps the sedimentary sequences at Sites SS-1 and SS-18. Unit 6 is coarser than the underlying silt and clay and diamicton units, and overlies them unconformably. Similar interbedded sand and gravel units are associated with the modern streams in the region as noted in Chapter 4.

6.3.6 Summary of sedimentary sequence at Section SS-19

The sedimentary sequence at site SS-19 formed in the following sequence of events. A period of suspension settling (unit 1) followed a subaqueous debris flow or other mass movement (unit 2) followed by another debris flow or mass movement deposit (unit 3. This was then capped by high density debris flow (unit 4) and

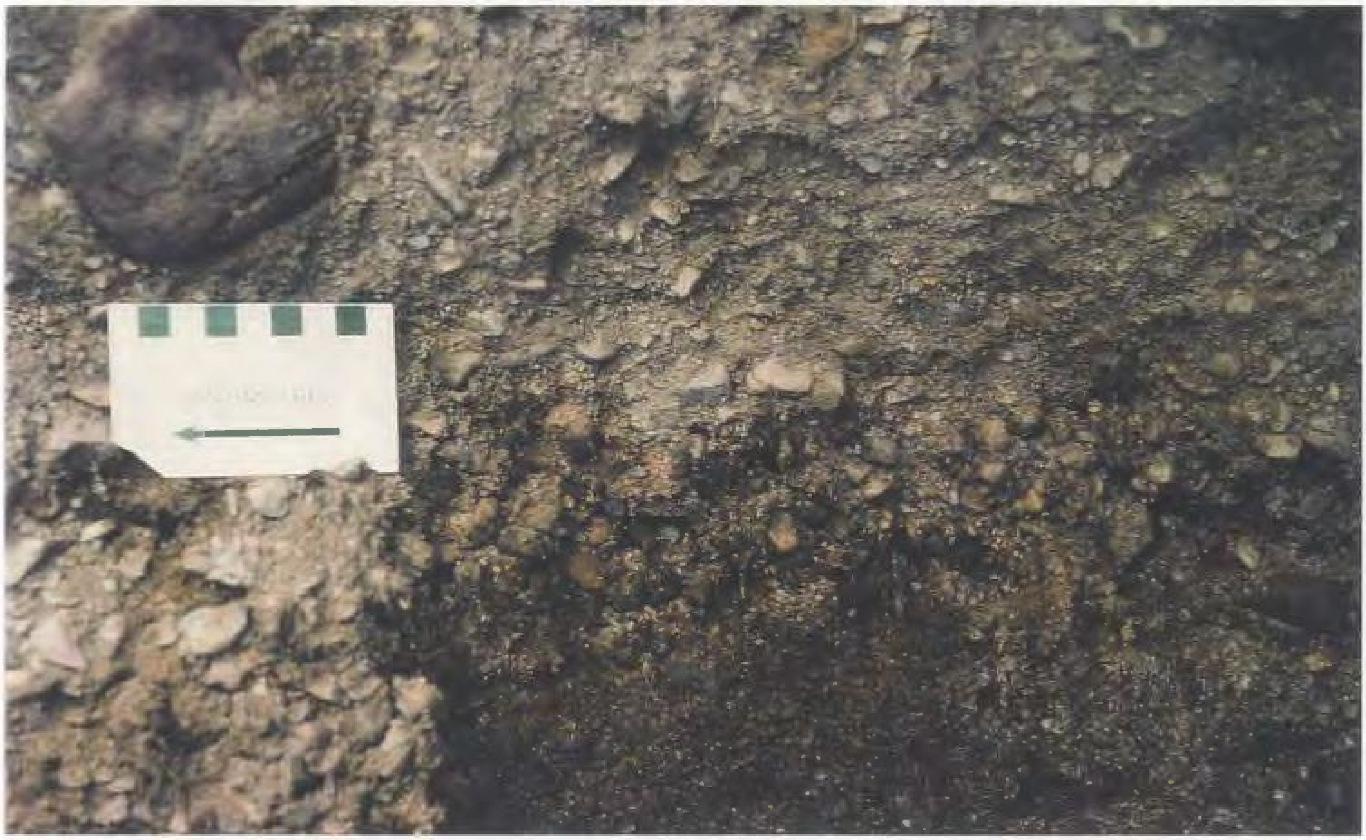


Plate 6.36: The contact of the structureless pebble to granule gravel of Unit 6 with the underlying structureless pebbly gravel of Unit 5 of Site SS-19. Card for scale is 9 cm in length.

finally the whole sequence is capped by gravel (units 5 and 6) of a fluvial origin.

6.3.7 Discussion

Based on the interpretation of the sediments at Site SS-1 and Site SS-18, the following sequence of events is postulated:

1) initial calm suspension settling with periodic influxes of fine sand from small sediment gravity flows; Units 1, 3 and 5 at Site SS-1 and Units 1 and 3 at Site SS-18;
2) followed by low energy turbid underflows or viscous grain flows which deposited coarser, moderately sorted sandy units; Units 1, 3 and 5 at Site SS-1 and Units 1 and 3 at Site SS-18;
3) followed by turbid underflows; Units 2 and 4 at Site SS-1 and Unit 2 at Site SS-18;
4) then reverting to suspension settling; Unit 5 at Site SS-1 and Unit 3 at Site SS-18; and
5) finally concluding with a capping gravel deposit of fluvial origin; Unit 6 at Site SS-1 and Unit 4 at Site SS-18.

The event sequence postulated at Site SS-19 is slightly different than that of sites SS-1 and SS-18. At SS-19 the following sequence is proposed:

1) initial calm suspension settling with periodic influxes of fine sand from minor current flows; Unit 1.

2) subaqueous debris flow or other mass movement deposit; Unit 2; followed by;

3) another debris flow or mass movement deposit; Unit 3;

4) high-density turbidity current and mass flow environment; Unit 4;

5) capped by gravel of fluvial origin; Units 5 and 6.

As none of the sediments observed within Sites SS-1 and SS-18 contain diamicton, the sediments could not have been deposited by low density debris flows. In contrast, diamicton is exposed at Site SS-19. As the diamicton is attributed to mass movement it may explain why the chronology at Site SS-19 is inverted. Catto *et al.* (1981) and Mackiewicz *et al.* (1984), among many other authors, indicate that marine sediments can be rhythmically bedded. Two possible environments where these types of sediments are located: ice margin (Domack, 1983) or delta margin (Domack, 1983; Smith *et al.*, 1990; Philips *et al.*, 1991). The fact that an ice marginal delta is preserved only 4-5 km away, however, suggests that these sediments were deposited as a result of failure down the delta front or by failure induced by tide changes (either of which would cause a pulse of material to be injected into the system where sand could be deposited by sediment gravity flows and silty clays form as flocculation occurred in the brackish water and suspension settling began. Small turbidites may extend laterally and distally from debris flows at the ice front to reach these sections.

The low percentage of pebble concentrations within these sediments is puzzling in terms of ice rafting, delta margin/ice front margin. It is possible that a sandur environment was in place for at least part of the time as iceberg calving does not occur in this type of environment. There is also no indication that this area is in a shadow sediment-starved zone.

CHAPTER 7 DISCUSSION, CORRELATIONS AND SEA LEVEL HISTORY

7.1 Introduction

The objective in this chapter is to develop a paleogeographical and depositional model, based on the data presented in chapters 4, 5, and 6. This model will facilitate discussion of sea level change in the region. Finally, suggestions will be made for further research.

7.2 Depositional Model

Based on the sedimentological, palaeontological, and geomorphological data, a paleogeographic model can be constructed for the Springdale-Hall's Bay area (Figure 7.1). Investigations of all the exposures show that the deposits formed between the time of initial deglaciation, when sea level was at marine limit, and the time when sea level had dropped to 0 m asl. Immediately following deglaciation, sea level stood at 75 m asl. Several terrace surfaces underlain by deltaic sequences, including those at sites SS-2 and SS-8, are located at or within 5 m of 75 m asl. Sediments exposed at these sites exhibit characteristics indicative of ice proximal environments. The ice front was adjacent to these deposits, but was not in direct contact with the marine waters. Sand and gravel sequences at Sites SS-13 (upper surface 74 +/- 3 m asl) and SS-14 (upper surface 72 +/- 3 m asl) are also associated with this marine

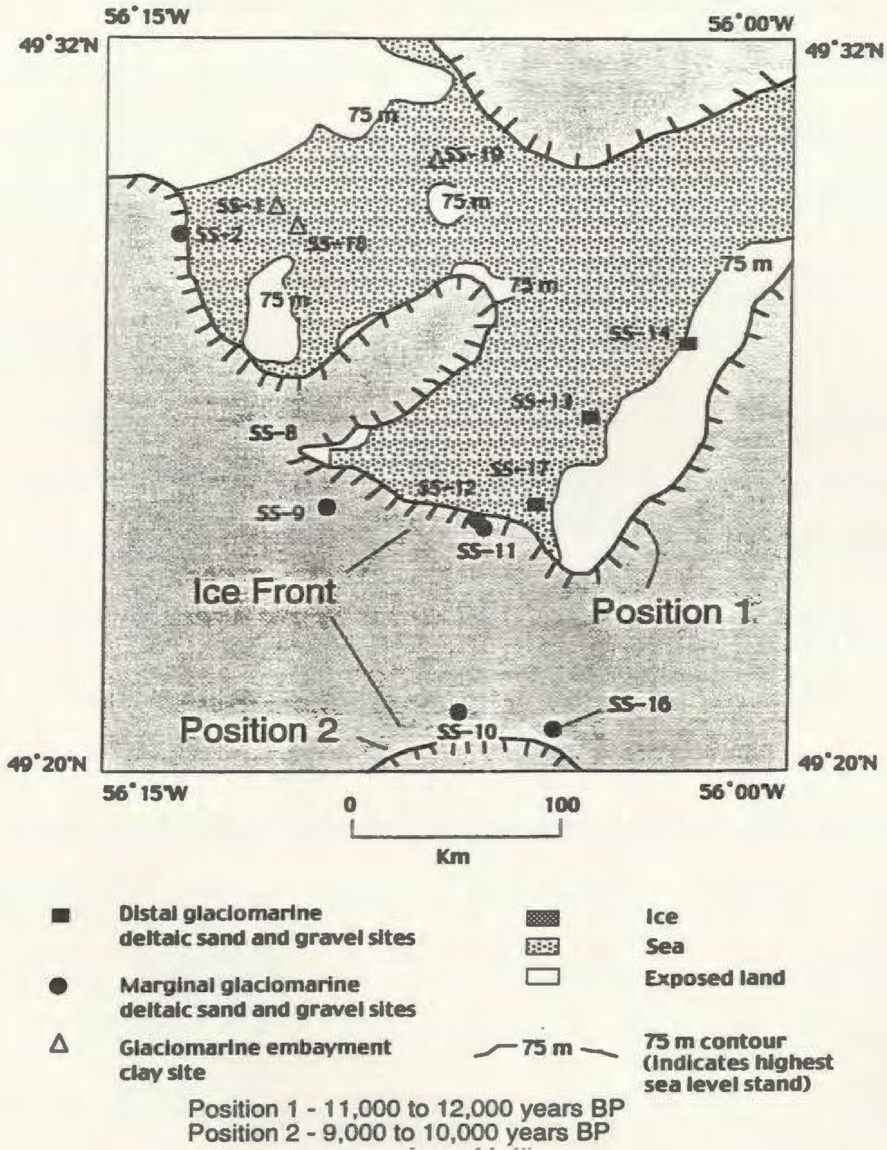


Figure 7.1: Reconstruction of the Hall's Bay region ca 11,000 to 12,000 years BP.

position, although the sedimentology of the sediments indicates that these sites were not located directly adjacent to the ice front. Therefore, the retreating ice front was located near Sites SS-2 and SS-8 (approximate elevation of 75 m a.s.l) at the mouth of West Brook and South Brook and was adjacent to Hall's Bay, but was at least 1 km south of Sites SS-13 and SS-14 during formation of these deposits. The approximate location of the ice front at this time is illustrated on Figure 7.1 as Position 1.

As deglaciation continued, sequences of sand and gravel were produced at elevations of 64 m asl, at Sites SS-11 and SS-12. The surface elevation of 64 m +/- 3 m asl would have been located near the sea level at this time, as glacioisostatic recovery resulted in recession from the 75 m marine limit. These sediments are interpreted to represent marine deltaic sequences formed in shallow waters but below the contemporaneous sea level, separated from the ice front by a narrow band of exposed terrain, but nevertheless influenced by glaciofluvial sedimentation. As the ice retreated to Position 2 (Figure 7.1), approximately 10 km south of the modern shoreline of Hall's Bay, marine regression led to the formation of lower terrace surfaces at 50 m +/- 3 m asl. This phase of marine regression is represented by the coarse grained, flat-topped deltaic sequences located at sites SS-10 and SS-16.

Figure 7.2 depicts the postulated depositional environment. The silt and clay deposits are interpreted to have formed primarily from turbidity flows and suspension settling in an embayment.

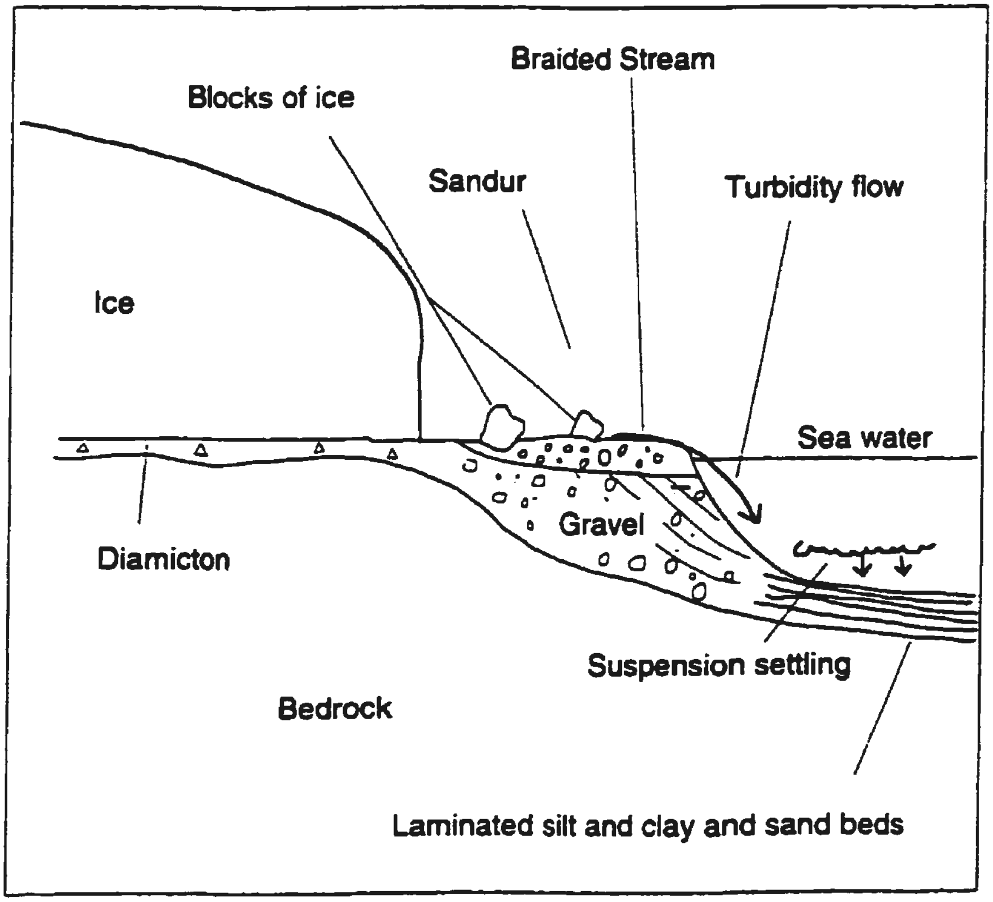


Figure 7.2: Depositional Model for the Hall's Bay region refers to settings where there is exposed ground between the ice and the sea.

Their very fine grained nature suggests that they were formed at some distance from the ice front. 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. The contact may be buried, and further drilling, resuming the efforts of the Newfoundland Department of Environment in 1987 in the Indian Brook valley may locate it. The fine-grained deposits indicate a brackish marine environment, marked by suspension settling and downslope sediment movement. The relationship of these very fine grained deposits to the sand and gravel deposits indicates that the depositional succession began with glacial ice floating in Hall's Bay to the northeast. Local deglaciation coincided with the recorded marine limit, resulting in marine inundation. When the ice retreated landward above the 75 m asl contour, deltaic features and gravel deposits at lower elevations were formed along the shorelines, removed from the ice front. The absence of glaciomarine deltaic sediment at low elevations overlying the silt and clay deposits suggests that rapid regression characterized sea level change during the latest Wisconsinan, as sea level fell from ca. 50 m asl to 0 m asl.

7.3 Comparison with other glacio-marginal marine models

The model of deposition suggested above lies somewhere between a classic fjord model without permanent ice cover (similar to that of Powell, 1981, 1984, and 1990); a system heavily dominated by debris flows along an open marine coastline (similar to that of Liverman and Bell, 1996); and a boreal marine system somewhat isolated from direct input from the glaciers (similar to the Champlain Sea as described by Rust, 1988 and Prichonnet, 1988 or from the Baltic Sea as described by Jensen, 1995).

The sedimentary successions described in this study indicate that sedimentation had both terrestrial and subaqueous components.. In the case of the marine silt and clay successions, deposition was primarily due to turbidity currents. Successive pulses of flow of varying energy levels into the embayment caused variations in the grain size and structure of the strata. Calm periods following the pulses of flow allowed for suspension settling. This sequence is similar to those responsible for fine-grained sedimentary successions reported by Domack (1991), Cowen and Powell (1990), Merritt *et al.* (1995) and Liverman and Bell (1996).

The difference between the system in Hall's Bay and a fjordal one is that there are fewer diamictons and very few dropstones within the silt and clay succession in the Hall's Bay region. Fjordal environments typically have large numbers of icebergs dropping material into the fine sediments at the base of the embayment. There is also more meltwater outflow at the front of the ice which contributes to subaqueous flows, depositing diamictons.

The presence of the two diamicton beds at Site SS-19 indicates some subaqueous debris flows occurred in the embayment area. Subaqueous debris flows were relatively uncommon, in contrast to the debris flow-dominated sediments described by Liverman and Bell (1996). The differences between these successions are due to their differing positions with respect to the ice front. In contrast to the ice-marginal successions recognized by Liverman and Bell (1996) the successions in Hall's Bay were deposited by turbid flows that originated from delta fronts separated from the ice margin by expanses of sandur sediments. The embayment was thus subject to lower energy turbidity currents, carrying finer grained sediments and permitting the development of rhythmically laminated strata. Moncreiff and Hambrey (1990) describe similar distal glaciomarine sedimentary sequences.

The sediments in Hall's Bay are not identical to those formed in the Champlain or Baltic Seas. The fine grained sediments deposited in larger marine basins contained abundant material, in the form of dropstones, contributed by icebergs calved off the glaciers. The Hall's Bay area is a small embayment and the paucity of dropstones indicates a lack of ice rafting.

Salinity measurements obtained from vanadium geochemical analyses suggest that the silt and clay was deposited in a brackish marine environment. The presence of *Mya arenaria*, *Hiatella arctica*, *Balanus hameri*, and *Macoma baltica* within the silt and clay also indicate a brackish environment (Jensen, 1995). The estimated salinity within the embayment is 20-30 ppm. This indicates that this depositional environment involved some contact and exchange of marine waters with the open sea, unlike the lacustrine environments of the deglacial Baltic Ice-Lake (Morner, 1995) or the Lampsilis Lake in the St. Lawrence valley (Rodrigues, 1988).

The sand and gravel successions were developed along a marine coastline, but are formed primarily of terrestrial sediments of glaciofluvial origin. The sand and gravel deposits exhibit characteristics of differing energy levels of flow, ranging from channelized coarse grained gravelly sediments to finer grained beds of sand. For example the granule gravel, medium sand and rippled sand at Site SS-13 suggest lower energy levels than those indicated by sediments at Site SS-12 and SS-16 which are coarser grained. Merritt *et al.* (1995) describe similar sediments, stressing their proximity to the glaciofluvial outflow as opposed to an ice marginal position.

7.4 Chronology of events

Five ^{14}C dates were obtained from shells and organic detritus located within the three silt and clay exposures investigated during this study. Interpretation of these dates requires initial assessment of the precision, accuracy, and significance of any possible errors. Table 7.1 documents the dates obtained during this study.

- Statistically the error quoted on a date indicates the probability that the numerical age lies within two standard deviations of the central value for the GSC dates and one within two standard deviations of the central value for the TO dates. Realistically, the

Table 7.1 ^{14}C dates obtained during this study

Sample Location and Elevation	Description	Lab Number	Age (years BP)	del-^{13}C (o/oo)
SS1 Unit 5 27.4 m asl	*Mya arenaria* in growth position	TO-2304	7,890 +/- 80	-25
SS1 Unit 5 28.5 m asl	*Mya arenaria* in growth position	TO-2305	12, 470 +/-380	-25
SS-18 Unit 1 24.3 m asl	organic detritus of aquatic plants	TO-2306	11,340 +/- 150	-25
SS-19 Unit 1 12.5 m asl	*Balanus* and *Mya truncata*	GSC-5140	11,300 +/- 120	+0.6
SS-19 Unit 2 12.9 m asl	*Hiatella arctica* and *Mya truncata*	GSC-5171	11,700 +/- 110	+2.3

entire range of values with error added or subtracted is a reasonable estimate for the numerical age of each of the shells dated in this study. As a result, the dates of material obtained range from:

- 7,810 to 7,970 years BP TO-2304
- 12,090 to 12,850 years BP TO-2305
- 11,190 to 11,490 years BP TO-2036
- 11,180 to 11,420 years BP GSC-5140
- 11,590 to 11,810 years BP GSC-5171

The delta ^{13}C values indicated by the labs which dated the material are relatively low (see Table 7.1). These dates have been corrected for the delta ^{13}C values of 0, whereas TO dates are normalized to a value of -25 ppt.

Consideration of the range of error indicates that three dates: 11,190 to 11,490 years BP (TO-2306); 11,180 to 11,420 years BP (GSC-5140); and 11,590 to 11,810 years BP (GSC-5171), are statistically indistinguishable. TO-2305 is statistically older than these three dates, and TO-2304 is significantly younger.

Mangerud and Gulliksen (1975) indicated that marine shells obtained from the North Atlantic Ocean may be enriched in 12 C, producing a 'reservoir effect'. The shells of all of the species dated in this study are potentially subject to this effect, which may cause the numerical dates to be older than the true age. Mangerud and Gulliksen (1975) dated molluscs that were collected while alive from the Norwegian Sea prior to the advent of nuclear bomb testing, and suggested a range of 250 - 600 years for the reservoir effect in this environment. Thus, carbonate shells may yield ^{14}C dates as much as 600 years older than their actual age. The effect is not uniform, however, and some shells show no increase in apparent age.

Consideration of the reservoir effect, in conjunction with the differences in reporting procedure from the GSC and TO laboratories, indicates that four of the ^{14}C dates (TO-2035, TO-2036, GSC-5140, and GSC-5171) statistically overlap in the range of numerical values. The only date which falls outside the 10, 600 BP-12, 800 field is TO-2304.

The result is that four of the ^{14}C dates statistically overlap in the range of numerical values, when both the analytical precision and potential hard water effects are considered. The only date which falls outside the 10,580 - 12,850 BP field is TO-2304.

Interpretation of ^{14}C dates is further complicated by plateau effects. The plateau effect causes samples of differing actual ages to produce similar numerical dates upon analyses. The plateau effect is caused by variation in the cosmogenic ^{14}C which becomes incorporated. This effect is particularly apparent from dates in the 12,000 to 10,000 BP range, the time frame that the Younger Dryas falls within. The consensus among ^{14}C lab analysts is that dates in this time range are not fully reliable. Several authors including Bard and Broecker (1992) and Sulerzhitsky(1997) consider dates within this time frame to be problematic in terms of age relative to each other. This argument would suggest that a numerical date of 11,000 BP is statistically indistinguishable from dates of 12,000 to 10,000

BP. A specimen dated at 11,000 BP could theoretically be in reality either older or younger than one dated at 12,000 BP. Numerical dates within the 10,000 - 12,000 BP range cannot be regarded as 'absolute' indicators of age relative to each other, although samples dated within this range are older than those dated younger than 10,000 BP. Although the degree of the plateau effect is debated within the Quaternary community, it is apparent that strict quantitative assessment of dates within the 10,000 - 12,000 BP range is inadvisable.

Consideration of the potential for error indicates that four of the five ^{14}C dates represent events which occurred very rapidly in geological terms. Statistically, these dates overlap, and indicate that the marine incursion occurred at some time between approximately 12,800 BP and 10,600 BP. The ^{14}C date of 11,000 +/- 190 BP obtained previously by Tucker (1973) is compatible with this interpretation. The marine incursion occupied some or all of the time interval within these limits. Incursion to the marine limit coincided with deglaciation. Subsequent emergence resulted in substantial reworking and modification of the marine sediments, and deposition of subaerial fluvial deposits.

The date of 7,890 +/- 80 years BP (TO-2304) is thought to be contaminated with younger carbon due to the difference between its age and other dates at equivalent elevations in the area. Palynological evidence (Macpherson, 1995) indicates that the climate ca. 7900 BP was marked by forested vegetation. Data collected by

Liverman (1994) and Shaw and Forbes (1995) indicate that sea level ca. 7900 BP was at least 10 m below present.

7.5 Regional chronology and Marine limit

If we look at the direct region surrounding the study site several ^{14}C dates have been previously reported from the vicinity of the study region (see Table 7.2). As noted in the table, the four older dates are interpreted to date the formation of deltas at Springdale, South Brook and King's point as well as the minimum date of marine incursion. Jenner and Shaw (1992) indicate that the two younger dates are from sediments that overlie the Hall's Bay deposits, hence the Hall's Bay deposits are older than 8870 +/- 80 BP.

As noted in section 7.4, the dates suggest that the delta formations are older than 12,470+/-380 as the fined grained glaciomarine sediments that the shells are located in likely form the distal parts of the deltas at 75 m asl. Four of the five dates fit within the deglaciation time frame indicated by the dates in table 7.1.

The dates obtained from the Springdale area are also in agreement with the regional chronology established for northeastern and western Newfoundland. Based on ^{14}C dated marine shells (Mollusc shell dated 12,790+/-115 years BP [Beta 27227]) overlying

Table 7.2: Table of radiocarbon dates within the immediate vicinity of the Hall's Bay study site.

Date	Lab #	Location and elevation	Collector	Comments
12,000 +/-220	GSC-1733	South Brook 20 m	Grant (1989)	postglacial marine overlap
11,800 +/-200	GSC-3957	King's Point 102 m	Macpherson (1986)	Climate/deglaciation
11,600 +/-80	TO-2395	Sunday Cove - Top of ocean core	Jenner and Shaw (1992)	top of glaciomarine sediments
11,000 +/-190	GSC-2085	South Brook 4.5 m	Tucker (1974)	fixes age of glaciomarine deltas
10,300 +/-170	GSC-4003	King's Point 102 m	Macpherson (1986)	postglacial organic sediment
8870+ /-80	TO-2398	Hall's Bay- from core 90-035-180	Jenner and Shaw (1992)	thick deposits in Hall's Bay coeval raised glaciomarine deltas
8250+ /-80	TO-2397	Hall's Bay- from core 90-035-180	Jenner and Shaw (1992)	as above

glacial till, Cumming and Aksu (1992) estimated the initiation of deglaciation in the Bonavista area to have occurred prior to 13,500 years BP. In the Deer Lake region, Batterson *et al.* (1993, 1995) estimated the onset of deglaciation to have occurred prior to 12, 220 years BP, based on the presence of ^{14}C dated *Balanus hameri* fossils. Deglaciation has also been linked to sea level rise resulting from the Laurentide recession at about 14,000 BP based on offshore data from Piper *et al.* (1990).

The deltaic and terrace successions investigated during this study suggest that two successive marine shorelines developed as deglaciation proceeded in the Hall's Bay area: the initial marine limit at 75 m a.s.l and a subsequent position at +/-50 m asl. To the east of Springdale, MacKenzie and Catto (1993) reported that marine deltaic and terrace deposits indicated a marine limit of 58 m asl at Lawrencetown, north of Botwood. Munro and Catto (1993) recognized a marine limit of 67 m asl, based on erosional features, in the Carmanville area. Sommerville (1997) recognized a marine limit of 35-45 m asl in the Port Blandford/Eastport area. West of the Hall's Bay study area, Batterson *et al.* (1993, 1995) indicate that the Deer Lake basin was inundated by the sea to an elevation of approximately 45 m asl Along the west coast of Newfoundland, the marine limit increases systematically northward, from 40 m at Stephenville (Brookes, 1974) to 75 m at Bonne Bay, 100 m at Cow Head, and 140 m at Port-au-Choix (Grant, 1987). The marine limits here are time-transgressive in nature not time equivalent. Liverman (1994) demonstrates the time transgressive nature of these limits.

Liverman (1994) compiled a Newfoundland-wide synthesis of radiocarbon dates on marine shells. Interpolation from his assessment suggests that the date at which sea-level fell to below present in the Hall's Bay area would have been 10-10.5 ka BP. All the ^{14}C dates obtained at the three silt and clay sites, except TO-2304 (7,890 +/- 80 years BP) in addition to Tucker's (1974) 11,000 BP date, conform with Liverman's data and interpretation. Thus, the data obtained from the Springdale region conforms to the regional picture, and is compatible in an island wide context. The dates from this study all fit into this 2000 year time frame.

7.7 Summary

The geomorphology of the Springdale region is dominated by flat plains in the valley bottoms and by terraced deltas with channelized upper surfaces surrounding Hall's Bay. Above the 75 m asl contour the region is dominated by eroded and hummocky glacial sediments and bedrock.

The sediments deposited in the Hall's Bay area include ice distal and proximal deltaic glaciomarine sand and gravel, and glaciomarine silt and clay deposited in embayments connected to the open Atlantic Ocean. The deltaic materials indicate that sea level once stood at 75 m asl. Subsequently, the sea regressed and terraces were formed at 50 m asl. Sea level reached 0 m asl approximately 10,000 BP (Shaw and Forbes, 1995).

The geochemistry and shell assemblages within the embayment deposits indicate a brackish marine environment. The sequence of formation of these sediments involved suspension settling of clays with periodic influxes of fine sand from minor current flows, interspersed with low density turbidity flows marked by downslope sediment movement. Deposition reverted to suspension settling following each turbidite event. As sea level fell, the marine deposits were capped by fluvial gravels.

Paleogeographic reconstruction of the region indicates that at some time between 10,580 and 12, 850 B.P. sandurs and deltas developed adjacent to the glacial margins in the southern part of the region. Marine waters were at their highest position, 75 m asl Regions below the marine limit were inundated and glaciomarine silts and clays formed at these locations. As marine regression progressed, deltaic sites below 75 m were exposed and subject to reworking and fluvial modification.

7.8 Further Work

Although this research presents a model of the deglacial history of the area, further research is necessary. More detailed sedimentological studies of the glaciomarine sand and gravel deposits are required. The sedimentary dynamics of the glaciomarine deposits could be further investigated in comparison with other successions in Newfoundland. The scarcity of datable material from these deposits imposes limitations on chronological analysis. Such data would be very pertinent to the understanding of sea level change for the Springdale-Hall's Bay area.

REFERENCES

Aitken, A.E and Howard, J.D. 1988. Animal-sediment relationships on a subartic intertidal flat, Pangnirtung Fjord, Baffin Island, Canada. Journal of Sedimentary Petrology, 58: pp. 969-978.

Aitken, J.F. 1995. Lithofacies and depositional history of a Late Devensian ice-contact deltaic complex, northeast Scotland. Sedimentary Geology, 99: pp. 111-130.

Allen, J.R.L. 1984 Sedimentary Structures Their Character and Physical Basis. Developments in Sedimentology 30. Unabridged one-Volume edition, Elsevier, 663 pages.

Anderson, T.W. and Macpherson, J.B. 1994. Wisconsinan Late-glacial environmental change in Newfoundland: a regional review. Journal of Quaternary Science, 9: (2), pp 171-178.

Ashley, G.M., Southard, J.B., and Boothroyd. J.C. 1982. Deposition of climbing-ripple beds: a flume simulation. Sedimentology, 29: pp. 67-79.

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

Banfield, C.C. 1981. The Climatic Environment of Newfoundland. *In*: The Natural Environment of Newfoundland Past and Present. Edited by A.G. Macpherson and J.B. Macpherson, Memorial University of Newfoundland, pp. 83-153.

Banfield, C.C. 1993. Newfoundland climate:past and present: In Robertson, A., Porter, S. and Brodie, G. (eds.). Climate and weather of Newfoundland. St. John's, Creative Publishing, pp. 13-32.

Bard, E. and Broecker, W.S., 1992. The last deglaciation: absolute and radiocarbon chronologies. NATO ASI series: Series 1: Global Environmental Change, Vol. 2, Springer. Berlin.

Batterson, M.J., Liverman, D.G.E. and Kirby, G. 1993. Glacial lake development and marine inundation, Deer Lake area, Newfoundland, Canada: topographically controlled deglaciation of an interior basin. Journal of Quaternary Science, 8: (4), pp. 327-337.

Batterson, M.J., Liverman, D.G.E. and Kirby, G. 1995. Glacial lake development and marine inundation, Deer Lake area, Newfoundland, Canada: topographically controlled deglaciation of an interior basin -reply. Journal of Quaternary Science, 10: pp. 182-184.

Blake, W., Jr. 1988. Geological Survey of Canada radiocarbon dates XXVII; Geological Survey of Canada, Paper 87-7.

Boltovskoy, E. and Wright, R. 1976. Recent Foraminifera. Dr. W. Junk b.v.-Publishers- The Hague, pp. 299-318.

Boothroyd, J.C. and Ashley, G.M. 1975. Processes, Bar Morphology, and Sedimentary Structures on Braided Outwash Fans, Northeastern Gulf of Alaska. *In* Jopling, A.V. and McDonald, B.C., eds, Glaciofluvial and Glaciolacustrine Sedimentation. Society of Economic Palaeontologists and Mineralogists, Special Publication 23, pp. 193-222

Bostock, H.H. 1988. Geology and petrochemistry of the Ordovician volcanic-plutonic Robert's Arm Group, Norte Dame Bay, Newfoundland. Geological Survey of Canada, Bulletin 369, 84 pages.

Bromley, R.G. 1990. Trace fossils. Biology and taphonomy. Published by Unwin Hyman Inc.

Brookes, I.A. 1970. New Evidence for an independent Wisconsinan ice cap over Newfoundland. Canadian Journal of Earth Sciences, 7: pp. 1374-1382.

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

Catto, N.R., Patterson, R.J. and Gorman, W.A.; 1981. Late Quaternary marine sediments at Chalk River, Ontario. Canadian Journal of Earth Sciences, 18: 1261-1267.

Cowan, E.A. and Powell, R.D. 1990. Suspended sediment transport and deposition of cyclically interlaminated sediment in a temperate glacial fjord, Alaska, U.S.A. In: Glacimarine Environments: Processes and Sedimentation, edited by Dowdeswell, J.A. and Scourse, J.D. Geological Society Special Publication No 53, pp. 75-89.

Cumming, E.H. and Aksu, A.E. 1992. Late Quaternary glacial and sedimentary history of Bonavista Bay, northeast Newfoundland. Canadian Journal of Earth Science, 29: pp. 222-235.

Coyle, M. and Strong, D.F. 1987. Geology of the Springdale Group: a newly recognised Silurian epicontinental-type caldera in Newfoundland. Canadian Journal of Earth Sciences, 24: 1135-1148.

Damman, A.W.H. 1983. An ecological subdivision of the Island of Newfoundland. *In*: Biogeography and Ecology of the Island of Newfoundland. G.R. South (ed.), Dr. W. Junk: The Hague, pp. 163-206.

Dean, P.L. 1977 . A report on the metallogeny of the Norte Dame Bay area, Newfoundland. Department of Mines and Energy, Mineral Development Division, Report 77-10, 17 pages, and accompanying maps.

Dean, P.L. and Strong, D.F. 1975. Point Leamington map-area: map and explanatory text; Geological Survey of Canada, Open File 375.

Domack, E., W. 1983. Facies of Late Pleistocene glacial marine sediments on Whidby Island, Washington: an isostatic glacial marine sequence. *In*: B.F. Molnia (editor), Glacial-Marine Sedimentation, Plenum, New York, N.Y., pp. 535-570.

Domack, E., W. 1984. Rhythmically Bedded Glaciomarine Sediments on Whidbey Island, Washington. Journal of Sedimentary Petrology, 54: (2), pp. 589-602.

Domack, E., W. and Lawson, D.E. 1985. Pebble Fabric in an ice-rafted diamicton. Journal of Geology, 93: pp. 577-591.

Dyer, A.K. 1986. A Palynological Investigation of the Late Quaternary Vegetational History of the Baie Verte Peninsula, Northcentral Newfoundland. Unpublished M.Sc. thesis. Department of Geography, Memorial University, Newfoundland, 182 pages.

Dyke, A.S. and Prest, V.K. 1987. Late Wisconsinan and Holocene history of the Laurentide Ice Sheet; Geographie physique et Quaternaire, 41: 237-263.

Environment Canada, Atmospheric Environment Service 1993. Canadian Climate Normals, 1961-1990, Atlantic Provinces. A publication of the Canadian Climate Program. Minister of Supply and Services Canada, 136 pages.

Eyles, N. and Miall, A.D. 1984. Glacial Facies, *In*: Walker, R.G., ed., Facies Models:Geoscience Canada, Reprint Series 1, pp.15-38.

Farmer, G.H. 1981. The Cold Ocean Environment of Newfoundland. *In*: The Natural Environment of Newfoundland Past and Present. Edited by A.G. Macpherson and J.B. Macpherson, Memorial University of Newfoundland, pp. 56-76.

Folk, R.L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Company. Austin, Texas. 180 pages.

Gilbert, R. 1983. Sedimentary processes of Canadian Artic Fjords. Sedimentary Geology. 36: pp. 147-175.

Grant D.R. 1972. Postglacial emergence of Northern Newfoundland. Report of Activities. Part B. Geological Survey of Canada. Paper 72-1.

1973. Surficial Geology of St. Anthony-Blanc Sablon. Newfoundland. Geological Survey of Canada. Open File 180. Scale 1:125,000

1974. Terrain studies of Cape Breton Island, Nova Scotia and the Northern Peninsula, Newfoundland. *In* Report of Activities, Part A. Geological Survey of Canada, Paper 74-1A, pp. 241-246.

1977. Glacial Style and Ice Limits, The Quaternary Stratigraphic Record, and Changes of Land and Ocean Level in the Atlantic Provinces, Canada. Geographie Physique et Quaternaire, 31: pp. 247-260.

1986. Surficial geology of the King's Point and Springdale 1:50,000 map sheets. Geological Survey of Canada, Open File Map 1312.

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, R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada, no. 1, v. k-1.

Government of Newfoundland 1974. 1960 Inventory Statistics of Forests and Forest Lands on the Island of Newfoundland. Crown Publications, St. John's, Newfoundland.

Hamby, M. 1994. Glacial Environments. UBC Press, University of British Columbia, Vancouver. 296 pages.

Harms, J.C., Southard, J.B. and Walker, R.G. 1982. Structures and Sequences in Clastic Rocks. SEPM Short Course No. 9. Society of Economic Paleontologists and Mineralogists. 249 pages.

Jenner, K.A. and Shaw, J. 1992. Inner shelf Quaternary sediments off northeast Newfoundland. *In*: Current Research. Part D; Geological Survey of Canada, Paper 92-1D, pp. 189-198.

Jenness, S.E. 1960. Late Pleistocene Glaciation of Eastern Newfoundland. Geological Society of America Bulletin. 71: pp. 161-179.

Jensen, J.B. 1995. A Baltic Ice Lake transgression in the Southwestern Baltic: Evidence from Fakse Bugt. Denmark. Quaternary International, 27: pp. 59-68.

Jopling, A.V. and Walker, R.G., 1969. Morphology and origin of ripple-drift cross laminations, with examples from the Pleistocene of Massachusetts. Journal of Sedimentary Petrology, 38: pp. 971-984.

Kean, B.F. 1977. Geological compliation of the Newfoundland Central Volcanic Belt, Newfoundland Department of Mines and Energy, Mineral Development Division, Map 7730.

Komar, P.D., 1985. The hydraulic interpretation of turbidites from their grain sizes and sedimentary structures. Sedimentology, 32: pp. 395-407

Liverman, D.G.E. 1991. Application of regional Quaternary mapping to mineral exploration, northeastern Newfoundland, Canada. Transactions of the Institute of Mining and Metallurgy (Section B: Applied Earth Sciences), 101: pp. B89-B98.

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

Liverman, D.G.E., and Scott, S. 1990a. Landform Classification and Surficial Geology Kings's Point (NTS 12H/9). 1:50 000 scale. Open File 12H/9(1143), Map Number 90-09. Geological Survey Branch, Department of Mines and Energy, St. John's, Nfld.

Liverman, D.G.E. and Scott, S. 1990b. Quaternary Geology of the King's Point Map Sheet (NTS 12H/9). *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 90-1, pp. 27-38.

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, pp. 29-40.

Liverman, D.G.E., Scott, S. and Vatcher, H. 1991a. Landform Classification and Surficial Geology of the Springdale Map Sheet (NTS 12H/8). 1:50 000 scale. Open File 12H/8(1216) Map Number 91-12. Geological Survey Branch, Department of Mines and Energy, St. John's, Nfld.

Liverman, D.G.E. , Scott, S. and Vatcher, H. 1991b. Quaternary Geology of the Springdale Map Sheet (NTS 12H/8). *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 91-1, pp. 29-44.

Liverman, D.G.E., Catto, N., Batterson, M, MacKenzie, C., Scott, S. and Sommerville, A. (in prep.). Evidence of late glacial permafrost in Newfoundland.

Liverman, D.G.E., and Batterson, M. with contributions from J. Gosse, D.R. Grant, J.B. Macpherson, J. Maunder, M.A. Renouf and J. Shaw. 1995. West coast of Newfoundland Field Trip Guide. Canadian Quaternary Association and Canadian Geomorphological Research Group Joint meeting Programme, Abstracts and Field Guides, published by the Department of Geography, Memorial University of Newfoundland, St. John's Newfoundland.

Lowe, D. R. 1982. Sediment Gravity Flows: II. Depositional Models With Special Reference to the Deposits of High-Density Turbidity Currents. Journal of Sedimentary Petrology, 52: (1), pp. 279-297

Lundqvist, J. 1965. Glacial Geology in Northeastern Newfoundland. Geologiska Foreningens i Stockholm Forhandlingar, 87: pp. 285-306.

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

MacKenzie, C. and Catto, N. R. 1993. Quaternary Geology of the Botwood (NTS 2E/3) Map Area. *In* Current Research. Newfoundland Department of Mines, Geological Survey Branch, Report 93-1, pp. 139-148.

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, 57: pp. 113-147.

Macpherson, J.B. 1981. The Development of the Vegetation of Newfoundland and Climate Change during the Holocene. *In*: The Natural Environment of Newfoundland Past and Present. Edited by A.G. Macpherson and J.B. Macpherson, Memorial University of Newfoundland, pp. 189-211.

Macpherson, J.B. 1995. A 6 ka BP reconstruction for the island of Newfoundland from a synthesis of Holocene lake-sediment pollen records. Geographie Physique et Quaternaire, 49, (1): pp. 163-182

Macpherson, J.B. and Anderson, T.W. 1985. Further evidence of late glacial climatic fluctuations from Newfoundland: pollen stratigraphy from a north coast site. *In*: Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 383-390.

Maizels, J. 1989. Sedimentology, palaeoflow dynamics, and flood history of jokulhlaup deposits: Palaeohydrology of Holocene sediment sequences in Southern Iceland sandur deposits. Journal of Sedimentary Petrology, 59: pp. 204-223.

Mangerud, J. and Gulliksen, S. 1975. Apparent Radiocarbon Ages of Recent Marine Shells from Norway, Spitsbergen, and Arctic Canada. Quaternary Research, 5: pp. 263-273.

McKee, E.D. and Goldberg, M. 1969. Experiments on formation of contorted structures in mud. Geological Society of America Bulletin, 80: pp. 231-244.

Merritt, J.W.; Auton, C.A. and Firth, C.R. 1995. Ice-Proximal Glaciomarine Sedimentation and Sea-Level Change in the Inverness Area, Scotland: A Review of the Deglaciation of a Major Ice Stream of the British Late Devensian Ice Sheet. Quaternary Science Reviews, 14: pp. 289-329.

Miall, A.D. 1977. A Review of the Braided-River Depositional Environment. Earth-Science Reviews, 13: pp. 1-62.

Mills, P.C. 1983. Genesis and diagnostic value of soft-sediment deformation structures-a review. Sedimentary Geology. 35: pp. 83-104.

Mode, W.M., Nelson, A.R., and Brigham, J.K. 1983. A facies model of Quaternary glacial marine cyclic sedimentation along eastern Baffin Island, Canada. *In*: B.F. Molnia (editor), Glacial-Marine Sedimentation, Plenum, New York, N.Y., pp. 495-533.

Moncrieff, A.C.M. and Hambrey, M.J. 1990. Marginal-marine glacial sedimentation in the late Precambrium succession of East Greenland. In: Glacimarine Environments: Processes and Sedimentation, edited by Dowdeswell, J.A. and Scourse, J.D. Geological Society Special Publication No 53, pp. 387-410.

Morner. N.-A. 1995. The Baltic Ice Lake-Yoldia Sea Transition. Quaternary International, 27: pp. 95-98.

Mudie, P.J. and Guilbault, J.-P. 1982. Ecostratigraphic and Paleomagnetic studies of Late Quaternary Sediments on the Northeast Newfoundland Shelf; *In* : Current Research, Part B, Geological Survey of Canada, Paper 82-1B, pp. 107-116.

Munro. M. and Catto, N. R. 1993. Quaternary Geology of the Carmanville Map Area (NTS 2E/8). *In* Current Research. Newfoundland Department of Mines. Geological Survey Branch. Report 93-1, pp. 149-159.

Murray, A. 1883. Glaciation of Newfoundland. Proceedings and Transactions of the Royal Society of Canada. 1: pp. 55-76.

Myrow, P.M. and Southard, J.B. 1991. Combined-flow model for vertical stratification sequences in shallow marine storm deposited beds, Journal of Sedimentary Petrology, 2: pp. 202-210.

Phillips, A.C.; Smith, N.D. and Powell, R.D. 1991. Laminated sediments in prodeltaic deposits, Glacier Bay, Alaska. In: Glacial marine sedimentation; Paleoclimatic significance. Edited by J.B. Anderson and G.M. Ashley. The Geological Society of America, Special Paper 261, pp. 51-60.

Piper, D.J.W., Mudie, P.J. Fader, G.B., Josenhans, H.W., Maclean, B. and Vilks, G. 1990. Quaternary Geology. In Keen, M.J. and Williams, G.L. (eds): Geology of the Continental Margin of eastern Canada. Geological Survey of Canada, Geology of Canada, no. 2. pp 472-607.

Postma, G., Babic, L., Zupanic, J. and Roe, S.L. 1988. Delta-front failure and associated bottomset deposition in a marine, gravelly Gilbert-type delta. *In* Nemec, W. and Steel, R.J., 1988. Fan Deltas: Sedimentology of tectonic settings. Blackie and Sons, London, pp. 91-102.

Powell, R.D. 1981. A Model for Sedimentation by Tidewater Glaciers. Annals of Glaciology 2: pp. 129-134.

Powell, R.D. 1983. Glacial-Marine Sedimentation Processes and Lithofacies of Temperate Tidewater Glaciers, Glacier Bay, Alaska. *In* Glacial-Marine Sedimentation. Edited by Bruce Molina, Plenum Press, New York and London, pp. 185-232.

Powell, R.D. 1984. Glaciomarine Processes and Inductive Lithofacies Modelling of Ice Shelf and Tidewater Glacier Sediments Based on Quaternary Examples. Marine Geology, 57: pp. 1-52.

Powell, R.D. 1990. Glacimarine processes at glacial grounding-line fans and their growth to ice-contact deltas. *In* Glacimarine Environments: Processes and Sediments. Edited by J. A Dowdeswell and J.D. Scourse. Geological Society of London, Special Publication, Number 53, pp 53-74.

Powell, R.D. 1991. Grounding-line systems as second-order controls on fluctuations of tidewater termini of temperate glaciers. *In* , Glacial marine sedimentation; paleoclimatic significance . Edited by Anderson, J.B., and Ashley, G.M. Geological Society of America Special Paper 269, pp. 75-93.

Prest, V.K. 1984. The Late Wisconsinan Glacier Complex. Geological Survey of Canada, Paper 84-10, pp. 21-36 and Map 1584A.

Prichonnet, G. 1988. Glacial marine facies of the late Wisconsinan Champlain Sea (southern Quebec). *In*: The Late Quaternary Development of the Champlain Sea Basin, edited by N.R. Gadd. Geological Association of Canada Special Paper 35.

Prior, D.B. and Bornhold, B.D. 1988. Submarine morphology and processes of fiord fan deltas and related high-gradient systems: modern examples from British Columbia. *In* Nemec, W. and Steel, R.J., 1988. Fan Deltas: Sedimentology of tectonic settings. Blackie and Sons, London, pp. 125-143.

Quinlan, G. and Beaumont, C. 1982. The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record. Canadian Journal of Earth Sciences, 19: pp. 2232-2246.

Reinick, H.E. and Singh, I. B. 1973. Depositional Sedimentary Environments. Springer-Verlag. Berlin.

Richards, H.G. 1940. Marine Pleistocene Fossils From Newfoundland. Geological Society of America Bulletin, 51: pp. 1781-1788.

Rodrigues, C.G. 1988. Late Quaternary invertebrate faunal associations and chronology of the western Champlain Sea basin. *In*: The Late Quaternary Development of the Champlain Sea Basin, edited by N.R. Gadd. Geological Association of Canada Special Paper 35.

Rogerson, R.J. 1982. The Glaciation of Newfoundland and Labrador. *In*: Prospecting in Areas of Glaciated Terrain - 1982. Edited by P.H. Davenport. The Canadian Institute of Mining and Metallurgy. St. John's. 339 pages.

Rust, B.R. 1972. Structure and process in a braided river, Sedimentology, 18: pp. 221-245.

Rust, B.R. 1988. Ice proximal deposits of the Champlain Sea at South Gloucester, near Ottawa, Canada. *In*: The Late Quaternary Development of the Champlain Sea Basin, edited by N.R. Gadd. Geological Association of Canada Special Paper 35.

St. Croix, L. and Taylor, D.M. 1990. Ice Flow in North-Central Newfoundland. *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 90-1, pp. 85-88.

St. Croix, L. and Taylor, D.M. 1991. Regional Striation Survey and Deglacial History of the Notre Dame Bay Area, Newfoundland, *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 91-1, pp. 61-68.

Scott, S, and Liverman, D.G.E. 1991. Sedimentology of Quaternary Marine Deposits in The Springdale-Hall's Bay Area. In Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 91-1, pp. 69-78.

Shaw, J. 1987. Glacial sedimentary processes and environmental reconstruction based on lithofacies. Sedimentology, 43: pp. 103-116.

Shaw, J. and Ashley, G. M. 1988. Glacial Facies Models. Geological Society of America. 90 pages.

Shaw, J. and Forbes, D.L. 1990. Relative Sea-Level Change and Coastal Response, Northeast Newfoundland. Journal of Coastal Research, 6: pp. 641-660.

Shaw, J. and Forbes, D.L. 1995. The postglacial relative sea-level lowstand in Newfoundland. Canadian Journal of Earth Sciences, 32: pp. 1308-1330.

Shaw, J. and Wile, B. 1990. Marine Geological Surveys in the Nearshore of Northeast Newfoundland: White Bay, Baie Verte, Green Bay and Hall's Bay. Geological Survey of Canada, Open File 2311, 32 pages.

Shimp, N.F., Witters, J., Potter, P.E., and Schleicher, J.A. 1969. Distinguishing marine and fresh water muds. Journal of Geology, 77: pp. 566-580.

Smith, N.D., Phillips, A.C. and Powell, R.D. 1990. Tidal Drawdown: A mechanism for producing cyclic sediment laminations in glaciomarine deltas. Geology, 18, pp. 10-13.

Soegaard, K. 1990. Fan-delta and Braided-Delta Systems in Pennsylvanian Sandia Formation, Taos Trough, northern New Mexico: Depositional and Tectonic Implications. Geological Society of America Bulletin, 102: pp. 1325-1343.

Sommerville, A.A., 1997. The late Quaternary history of Terra Nova National Park and vicinity, Northeast Newfoundland. Unpublished M.Sc. Thesis, Department of Geography, Memorial University of Newfoundland.

Stanley, K.O. 1974. Morphology and hydraulic significance of climbing ripples with superimposed micro-ripple-drift cross-lamination in Lower Quaternary lake silts, Nebraska. Journal of Sedimentary Petrology, 44: pp. 472-483.

Stewart, T.G. 1991. Glacial-marine sedimentation from tidewater glaciers in the Canadian High Artic. In: Glacial marine sedimentation; Paleoclimatic significance. Edited by J.B. Anderson and G.M. Ashley. The Geological Society of America, Special Paper 261, pp. 95-106.

Sulerzhitsky, L.D. 1997. Peculiarities of radiocarbon chronology of Younger Dryas deposits in the Taymyr Peninsula. Quaternary International, 41/42: pp. 119-123.

Swinden, H.S. 1987. Geology and mineral occurrences in the central and northern parts of the Robert's Arm Group, central Newfoundland. *In*: Current Research, Part A, Geological Survey of Canada, Paper 87-1A, pp. 381-390.

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, 55: pp. 243-249.

Tucker, C.M. 1973. The glacial geomorphology of west-central Newfoundland; Halls Bay to Topsails. Unpublished M.Sc. thesis, Department of Geography, Memorial University, Newfoundland, 132 p.

1974 . A series of raised Pleistocene deltas in Halls Bay, Newfoundland. Maritime Sediments, 10: pp. 1-7.

Vanderveer, D.G. 1977. Clay Deposits of Newfoundland and Labrador. Mineral Development Division, Department of Mines and Energy, Government of Newfoundland and Labrador. Report 77-9. St. John's, Newfoundland. 41 pages.

Wagner, F.J.E. 1970. Faunas of the Pleistocene Champlain Sea. Geological Survey of Canada, Department of Energy, Mines and Resources. Bulletin 181. 141 pages.

Wolfe, A., P. and Butler, D. L. 1994. Late-glacial and early Holocene environments at Pine Hill Pond, eastern Newfoundland. Evidence from pollen and diatoms. Boreas, 23: pp. 53-65.

Woodcock, N.H. 1979. The use of structures as palaeoslope orientation estimators. Sedimentology, 26: pp. 83-99.

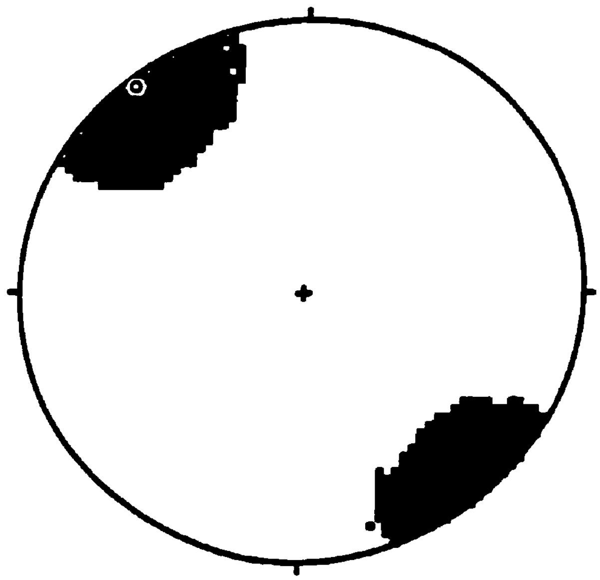
Woodrow, E.H. and Heringa, P.K. 1987. Pedoclimatic Zones of the Island of Newfoundland. Report Number 32. Canadian Soil Survey, St. John's, Newfoundland.

APPENDIX 1: PALEOFLOW MEASUREMENTS AND PLOTS.

Table of trend and plunges of flow noses for Site SS-1a Unit 2.

Trend	Plunge	Trend	Plunge
328	01	298	03
326	03	265	04
038	02	334	01
029	05	302	01
027	01	269	02
342	03	308	02
022	02	278	03
006	04	292	03
349	02	322	04
304	03	304	01
012	01	311	02
012	01	322	02
326	04	292	03
322	03	332	01
349	02	295	03
318	02	005	02
354	01	320	01
307	03	322	04
339	04	352	05

317	06	335	08
314	08	246	02
313	01	252	06
329	01	269	04
290	02	251	01
318	02	305	05

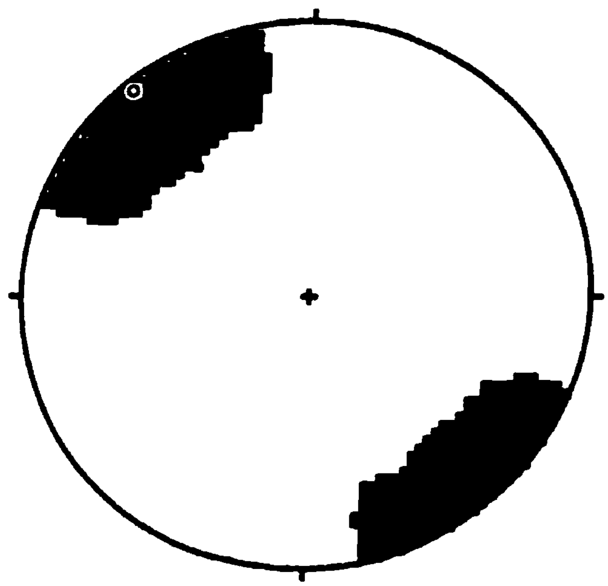


Data	Schmidt Equal Area Projection	Statistics
SS-1a Unit 2.		o Mean Lineation Vector 320.3 3.2
1.0-3.0sd		E1 = 0.725
3.0-5.0sd		E2 = 0.274
5.0-6.0sd		E3 = 0.001
		r1 = 0.98 r2 = 5.58 K = 0.17
	N = 50	s. var. = 0.179 Rbar = 0.821

Table of trend and plunges of flow noses for Site SS-1b Unit 3.

Trend	Plunge	Trend	Plunge
228	03	311	05
226	02	326	03
314	01	293	04
328	04	301	01
333	03	324	07
358	01	309	06
355	01	308	02
336	02	306	03
352	03	314	07
292	02	311	05
354	03	313	04
349	01	325	03
344	02	329	02
346	04	335	01
352	08	328	02
350	07	319	01
336	01	338	08
325	01	327	09
312	02	040	10
312	03	275	11

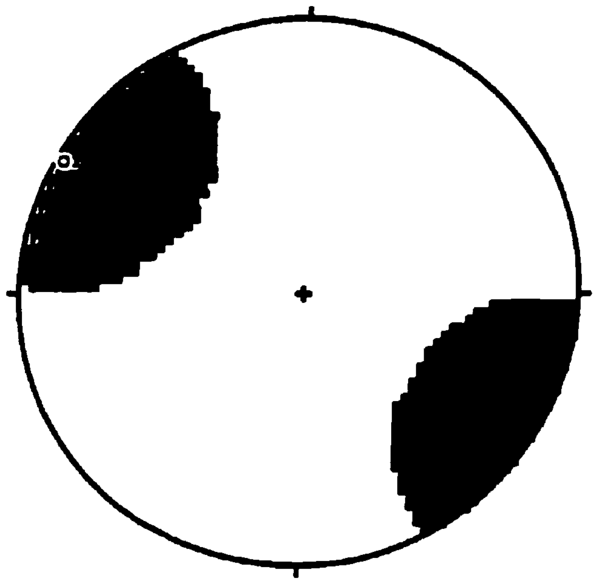
294	01	292	01
309	03	284	02
312	01	272	03
323	02	302	04
311	05	286	05



Data	Schmidt Equal Area Projection	Statistics
SS-1b Unit 3 1.0-3.0sd 3.0-5.0sd 5.0-7.3sd	N = 49	○ Mean Lineation Vector 320.7 3.6 E1 = 0.817 E2 = 0.181 E3 = 0.002 r1 = 1.51 r2 = 4.32 K = 0.35 s. var. = 0.126 Rbar = 0.874

Table of trend and plunges of flow noses for Site SS-1c Unit 4.

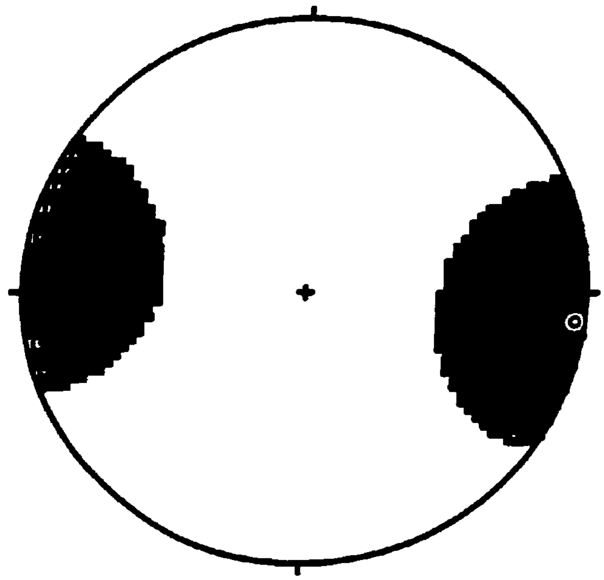
Trend	Plunge	Trend	Plunge
343	02	298	02
324	01	329	01
315	04	304	01
325	05	287	03
292	01	310	04
301	01	277	05
302	02	306	02
294	03	304	02
292	02	268	02
305	01	252	01
300	03	234	03
304	01	255	01



Data	Schmidt Equal Area Projection	Statistics
SS-1c Unit 4 □ 1.0-3.0sd ■ 3.0-5.0sd ■ 5.0-7.8sd	N = 24	o Mean Lineation Vector 299.1 2.4 E1 = 0.850 E2 = 0.149 E3 = 0.001 r1 = 1.74 r2 = 5.68 K = 0.31 s. var. = 0.088 Rbar = 0.912

Table of clast fabric measurements for Site SS-18a Unit 2 upper.

Trend	Plunge	Trend	Plunge
091	02	100	04
095	22	105	05
090	01	092	01
092	03	092	02
095	02	102	03
090	02	094	04
098	04	100	03
098	01	092	03
092	03	105	01
105	02	097	02
102	03	105	03
095	02	100	04
090	01		



Data	Schmidt Equal Area Projection	Statistics
SS-18a Unit 2 □ 1.0-3.0sd ■ 3.0-5.0sd ■ 5.0-9.8sd N = 25		○ Mean Lineation Vector 96.7 3.3 E1 = 0.987 E2 = 0.008 E3 = 0.005 r1 = 4.81 r2 = 0.55 K = 8.72 s. var. = 0.006 Rbar = 0.994

Table of clast fabric measurements for Site SS-19a Unit 2 lower.

Trend	Plunge	Trend	Plunge
260	32	268	18
351	18	004	18
350	14	312	24
360	18	218	3
359	8	204	5
010	24	192	5
334	14	294	12
238	8	344	10
154	2	088	18
024	3	080	16
152	3	024	32
264	62	120	34
58	22		

Table of clast fabric measurements for Site SS-19b Unit 2 middle.

Trend	Plunge	Trend	Plunge
148	16	252	18
326	21	324	18
220	33	218	18
204	23	271	24
302	16	198	11
270	26	166	16
268	12	342	12
360	8	108	39
298	28	358	15
228	9	194	22
316	38	204	11
308	12	238	28
290	69		

Table of trend and plunges of flow noses for Site SS-19c Unit 2 upper.

Trend	Plunge	Trend	Plunge
098	4	348	10
006	42	274	18
298	21	264	12
280	16	256	9
210	10	258	26
128	12	216	9
312	24	002	2
300	38	288	26
222	38	258	6
298	36	308	12
286	22	252	24
290	18	161	8
294	44		

APPENDIX 2: GRAINSIZE SIEVE DATA.

Appendix 2: Sieve Data											
sample #	sample wt	8mm	4mm	2mm	1mm	1Ø	2Ø	3Ø	4Ø	pan1	pan2
90 90001	207.45			0.06	0.15	0.07	3.99	102	74.6	7.44	14.2
90 90004	135.47				0.11	0.06	0.3	1.53	11.3	8.72	115
90 90005	139.09				0.02	0.05	1.26	39.6	40.2	9.7	43.7
90 90006	132.99			0.05	0.07	0.02	0.15	1.06	14.8	4.53	110
90 90007	137.81			0.14	0.11	0.07	0.26	0.48	5.8	1.74	127
90 90008	137.53			0.03	0.01	0.03	0.36	2.53	49.6	21	61
90 90009	137.97					0.02	0.06	1.41	5.17	6.47	120
90 90010	51.04					0.03	0.18	2	15.4	6.34	30.3
90 90012	137.62				0.04	0.03	0.87	1.98	10.2	4.01	120
90 90013	135.01						0.03	0.05	0.4	0.28	132
90 90017	139.52		4.24	2.07	2.35	2.62	2.47	2.01	7.66	1.95	112
90 90019	139.84					0.01	0.02	0.11	1.2	1.01	136
90 90020	139.65				0.07	0.02	0.03	0.2	9.82	3.08	125
90 90021	139.7		0.33	2.46	3.18	1.07	0.37	0.67	6.04	2.22	121
90 90022	134.35				0.04	0.07	0.18	0.63	4.53	0.81	127
90 90025	138.17		6.74	5.59	9.22	8.85	7.71	4.36	6.31	9.46	77
90 90027	139.66			0.06	0.12	0.2	0.72	2.85	21.3	11.3	100
90 90028	137.54			0.09	0.08	0.08	0.15	0.18	0.54	0.38	134
90 90032	138.22		1.29	0.04	0.28	0.29	0.54	0.91	2.49	0.31	131
90 90033	136.17		0.93	0.14	0.1	0.22	0.5	0.62	2.26	0.4	129
90 90037	139.7			0.05	0.01	0.03	0.14	1.12	2.73	0.87	133
90 90039	137.59			0.08	0.03	0.05	0.07	2.82	24	1.81	115
90 90040	138.94			0.49	0.5	2.79	17.4	17.9	8.09	2.38	86.3

Appendix 2: Sieve Data											
sample #	sample wt	8mm	4mm	2mm	1mm	1Ø	2Ø	3Ø	4Ø	pan1	pan2
90 90041	139.69					0.02	0.04	0.2	4.12	0.23	133
90 90042	134.18			0.08	0.03	0.13	2.24	17	23.5	1.05	88.5
90 90043	139.5			0.01	0.03	0.02	0.08	0.98	2.11	0.09	134
90 90047	138.41			0.35	0.3	0.52	0.78	2.01	4.56	0.28	128
90 90048	137.56			0.42	1.49	8.01	22.9	12.7	8.19	0.37	80.6
90 90049	139.27				0.09	0.05	0.19	18.9	60.5	3.45	54.2
90 90050	137.34			0.19	0.23	0.28	0.38	0.76	2.32	0.32	131
90 90053	138.91		1.52	0.2	0.23	0.42	6.05	23.6	14.3	0.61	89.5
90 90054	135.44				0.06	0.08	0.21	3.98	3.68	1.52	124
90 90055	138.86				0.12	7.67	87.5	32.1	0.78	1.44	4.82
90 90056	138.43		1.46	0.13	0.04	0.11	0.21	1.14	6.32	0.4	125
90 90057	139.88				0.1	0.2	3.13	71.5	31.5	1.4	24.1
90 90061	136.05		20	8.47	15.79	40	36.8	3.87	0.31	0.77	6.22
90 90062	139.98		76.1	2.89	2.96	4.35	15.4	10.7	2.83	0.45	18
90 90063	135.1		1.93	1.54	1.3	1.44	1.24	3.34	9.2	1.12	113
90 90067	139.93			0.09	0.02	0.06	0.18	0.31	1.21	0.32	137
90 1m	136.31		61	31.2	19.95	9.25	5.52	2.57	0.96	0.85	3.11
90 2m	138.47		8.78	2.3	1.85	2.43	2.02	1.49	9.75	4.2	104
90 2.5m	116.11		1.33	0.2	0.18	0.16	0.29	0.31	0.56	0.73	107
90 22m	105.96			0.07	0.46	7.52	11.8	18.6	23.8	2.56	38.9
90 23m	106.9		0.25	0.65	0.22	0.14	0.54	4.96	17.4	3.57	77.5
90 27m	137.86		58.4	17	14.08	18.2	15.2	6.86	2.54	0.34	2.83
90 90'+	123.05		73.1	29.7	13.05	3.47	0.62	0.11	0.1		0.73

Appendix 2: Sieve Data											
sample #	sample wt	8mm	4mm	2mm	1mm	1Ø	2Ø	3Ø	4Ø	pan1	pan2
90003	114.41	0	0	0.01	0.01	0	0.09	1.22	13.6	3.18	95.6
90014	137.65	0	0	0	0.03	0.01	0.07	0.24	6.48	2.99	127
90024	117.51	0	0	0.02	0.08	0.04	0.06	0.21	1.68	0.4	115
90031	112.1	0	0	0	0.05	0.04	0.1	0.19	1.78	0.83	109
90036	115.44	0	0.26	0.13	0.07	0.12	0.25	0.36	1.07	0.18	113
90045	132.42	0	0	0.16	0.1	0.11	0.18	1.22	9.48	0.95	120
90052	114.45	0	0	0.07	0.25	0.66	1.32	1.8	4.83	0.22	105
90059	121.82	0	0.2	0.34	0.29	0.37	0.76	8	14.3	0.93	95.9
90069	138.61	0	0.12	0	0.03	0.09	0.1	0.24	1.13	0.16	136

Appendix 2: Sieve Data

sample #	sample wt	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø
90 90001	207.45	100	100	99.971	99.8988	99.865	97.9417	48.5948
90 90004	135.47	100	100	100	99.9188	99.8745	99.6531	98.5237
90 90005	139.09	100	100	100	99.9856	99.9497	99.0438	70.6018
90 90006	132.99	100	100	99.962	99.9098	99.8947	99.7819	98.9849
90 90007	137.81	100	100	99.898	99.8186	99.7678	99.5791	99.2308
90 90008	137.53	100	100	99.978	99.9709	99.9491	99.6873	97.8477
90 90009	137.97	100	100	100	100	99.9855	99.942	98.9201
90 90010	51.04	100	100	100	100	99.9412	99.5886	95.6701
90 90012	137.62	100	100	100	99.9709	99.9491	99.317	97.8782
90 90013	135.01	100	100	100	100	100	99.9778	99.9407
90 90017	139.52	100	96.961	95.477	93.793	91.9151	90.1448	88.7041
90 90019	139.84	100	100	100	100	99.9928	99.9785	99.8999
90 90020	139.65	100	100	100	99.9499	99.9356	99.9141	99.7709
90 90021	139.7	100	99.7638	98.003	95.7266	94.9606	94.6958	94.2162
90 90022	134.35	100	100	100	99.9702	99.9181	99.7841	99.3152
90 90025	138.17	100	95.122	91.076	84.4033	77.9981	72.418	69.2625
90 90027	139.66	100	100	99.957	99.8711	99.7279	99.2124	97.1717
90 90028	137.54	100	100	99.935	99.8764	99.8182	99.7092	99.5783
90 90032	138.22	100	99.0667	99.038	98.8352	98.6254	98.2347	97.5763
90 90033	136.17	100	99.317	99.214	99.1408	98.9792	98.612	98.1567
90 90037	139.7	100	100	99.964	99.9571	99.9356	99.8354	99.0336
90 90039	137.59	100	100	99.942	99.9201	99.8837	99.8328	97.7833
90 90040	138.94	100	100	99.647	99.2875	97.2794	84.7848	71.8728

Appendix 2: Sieve Data								
sample #	sample wt	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø
90 90041	139.69	100	100	100	100	99.9857	99.957	99.8139
90 90042	134.18	100	100	99.94	99.918	99.8211	98.1517	85.5045
90 90043	139.5	100	100	99.993	99.9713	99.957	99.8996	99.1971
90 90047	138.41	100	100	99.747	99.5304	99.1547	98.5911	97.1389
90 90048	137.56	100	100	99.695	98.6115	92.7886	76.1195	66.9163
90 90049	139.27	100	100	100	99.9354	99.8995	99.7631	86.221
90 90050	137.34	100	100	99.862	99.6942	99.4903	99.2136	98.6603
90 90053	138.91	100	98.9058	98.762	98.5962	98.2939	93.9385	76.9347
90 90054	135.44	100	100	100	99.9557	99.8966	99.7416	96.803
90 90055	138.86	100	100	100	99.9136	94.39	31.3913	8.31053
90 90056	138.43	100	98.9453	98.851	98.8225	98.743	98.5913	97.7678
90 90057	139.88	100	100	100	99.9285	99.7855	97.5479	46.4684
90 90061	136.05	100	85.3069	79.081	67.4752	38.0448	10.9886	8.14406
90 90062	139.98	100	45.6279	43.563	41.4488	38.3412	27.311	19.6671
90 90063	135.1	100	98.5714	97.432	96.4693	95.4034	94.4856	92.0133
90 90067	139.93	100	100	99.936	99.9214	99.8785	99.7499	99.5283
90 1m	136.31	100	55.2637	32.382	17.7463	10.9603	6.91072	5.02531
90 2m	138.47	100	93.6593	91.998	90.6622	88.9073	87.4485	86.3725
90 2.5m	116.11	100	98.8545	98.682	98.5273	98.3895	98.1397	97.8727
90 22m	105.96	100	100	99.934	99.4998	92.4028	81.2948	63.7222
90 23m	106.9	100	99.7661	99.158	98.9523	98.8213	98.3162	93.6763
90 27m	137.86	100	57.6092	45.292	35.0791	21.8773	10.8588	5.88278
90 90'+	123.05	100	40.6095	16.514	5.90817	3.08818	2.58432	2.49492

Appendix 2: Sieve Data

sample #	sample wt	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø
90003	114.41	100	100	99.991	99.9825	99.9825	99.9039	98.8375
90014	137.65	100	100	100	99.9782	99.9709	99.9201	99.7457
90024	117.51	100	100	99.983	99.9149	99.8809	99.8298	99.6511
90031	112.1	100	100	100	99.9554	99.9197	99.8305	99.661
90036	115.44	100	99.7748	99.662	99.6015	99.4976	99.281	98.9692
90045	132.42	100	100	99.879	99.8037	99.7206	99.5847	98.6633
90052	114.45	100	100	99.939	99.7204	99.1437	97.9904	96.4176
90059	121.82	100	99.8358	99.557	99.3187	99.0149	98.3911	91.824
90069	138.61	100	99.9134	99.913	99.8918	99.8269	99.7547	99.5816

Appendix 2: Sieve Data			
sample #	sample wt	%f 4Ø	sum sieves
90 90001	207.45	12.63437	202.83
90 90004	135.47	90.16018	137.38
90 90005	139.09	41.714	134.49
90 90006	132.99	87.87879	130.83
90 90007	137.81	95.02213	135.53
90 90008	137.53	61.81924	134.47
90 90009	137.97	95.17286	132.66
90 90010	51.04	65.41928	54.29
90 90012	137.62	90.4883	137.59
90 90013	135.01	99.64447	132.85
90 90017	139.52	83.21388	137.6
90 90019	139.84	99.04176	138.5
90 90020	139.65	92.73899	138.51
90 90021	139.7	89.89263	137.68
90 90022	134.35	95.94343	132.97
90 90025	138.17	64.69566	135.28
90 90027	139.66	81.89174	136.92
90 90028	137.54	99.18569	135.79
90 90032	138.22	95.77485	136.8
90 90033	136.17	96.49703	134.42
90 90037	139.7	97.07946	138
90 90039	137.59	80.31107	143.47
90 90040	138.94	66.05009	135.81

Appendix 2: Sieve Data			
sample #	sample wt	%f 4Ø	sum sieves
90 90041	139.69	96.86449	137.8
90 90042	134.18	67.99076	132.5
90 90043	139.5	97.68459	137.8
90 90047	138.41	93.84438	136.69
90 90048	137.56	60.96249	134.63
90 90049	139.27	42.81611	137.26
90 90050	137.34	96.97102	135.45
90 90053	138.91	66.64747	136.45
90 90054	135.44	94.08594	133.84
90 90055	138.86	7.748812	134.36
90 90056	138.43	93.20234	135.07
90 90057	139.88	23.92765	131.94
90 90061	136.05	7.916207	132.27
90 90062	139.98	17.64538	133.68
90 90063	135.1	85.20355	133.8
90 90067	139.93	98.66362	138.84
90 1m	136.31	4.321033	134.38
90 2m	138.47	79.33126	137.03
90 2.5m	116.11	97.39041	110.85
90 22m	105.96	41.2231	103.75
90 23m	106.9	77.41815	105.18
90 27m	137.86	4.040331	135.46
90 90'+	123.05	2.413653	120.81

Appendix 2: Sieve Data			
sample #	sample wt	%f 4Ø	sum sieves
90003	114.41	86.95044	113.75
90014	137.65	95.03814	136.76
90024	117.51	98.22143	117.45
90031	112.1	98.07315	111.89
90036	115.44	98.04227	115.56
90045	132.42	91.5043	132.07
90052	114.45	92.19747	114.12
90059	121.82	80.06075	121.14
90069	138.61	98.76632	138.36

APPENDIX 3: GRAINSIZE COULTER DATA.

Appendix 3: Coulter Data

sample #	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø	%f 4Ø	%f4.29Ø
90 90001	100.00	100.00	99.97	99.90	99.87	97.94	48.59	12.63	12.21
90 90004	100.00	100.00	100.00	99.92	99.87	99.65	98.52	90.16	88.82
90 90005	100.00	100.00	100.00	99.99	99.95	99.04	70.60	41.71	40.43
90 90006	100.00	100.00	99.96	99.91	99.89	99.78	98.98	87.88	86.84
90 90007	100.00	100.00	99.90	99.82	99.77	99.58	99.23	95.02	88.72
90 90008	100.00	100.00	99.98	99.97	99.95	99.69	97.85	61.82	55.50
90 90009	100.00	100.00	100.00	100.00	99.99	99.94	98.92	95.17	91.88
90 90010	100.00	100.00	100.00	100.00	99.94	99.59	95.67	65.42	59.73
90 90012	100.00	100.00	100.00	99.97	99.95	99.32	97.88	90.49	90.01
90 90013	100.00	100.00	100.00	100.00	100.00	99.98	99.94	99.64	98.63
90 90017	100.00	96.96	95.48	93.79	91.92	90.14	88.70	83.21	81.74
90 90019	100.00	100.00	100.00	100.00	99.99	99.98	99.90	99.04	96.93
90 90020	100.00	100.00	100.00	99.95	99.94	99.91	99.77	92.74	91.92
90 90021	100.00	99.76	98.00	95.73	94.96	94.70	94.22	89.89	88.84
90 90022	100.00	100.00	100.00	99.97	99.92	99.78	99.32	95.94	94.38
90 90025	100.00	95.12	91.08	84.40	78.00	72.42	69.26	64.70	63.67
90 90027	100.00	100.00	99.96	99.87	99.73	99.21	97.17	81.89	78.35
90 90028	100.00	100.00	99.93	99.88	99.82	99.71	99.58	99.19	97.04
90 90032	100.00	99.07	99.04	98.84	98.63	98.23	97.58	95.77	95.08
90 90033	100.00	99.32	99.21	99.14	98.98	98.61	98.16	96.50	96.15
90 90037	100.00	100.00	99.96	99.96	99.94	99.84	99.03	97.08	96.45
90 90039	100.00	100.00	99.94	99.92	99.88	99.83	97.78	80.31	80.06

Appendix 3: Coulter Data

sample #	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø	%f 4Ø	%f4.29Ø
90 90040	100.00	100.00	99.65	99.29	97.28	84.78	71.87	66.05	65.94
90 90041	100.00	100.00	100.00	100.00	99.99	99.96	99.81	96.86	95.72
90 90042	100.00	100.00	99.94	99.92	99.82	98.15	85.50	67.99	67.83
90 90043	100.00	100.00	99.99	99.97	99.96	99.90	99.20	97.68	96.70
90 90047	100.00	100.00	99.75	99.53	99.15	98.59	97.14	93.84	93.64
90 90048	100.00	100.00	99.69	98.61	92.79	76.12	66.92	60.96	60.37
90 90049	100.00	100.00	100.00	99.94	99.90	99.76	86.22	42.82	41.08
90 90050	100.00	100.00	99.86	99.69	99.49	99.21	98.66	96.97	96.11
90 90053	100.00	98.91	98.76	98.60	98.29	93.94	76.93	66.65	66.38
90 90054	100.00	100.00	100.00	99.96	99.90	99.74	96.80	94.09	93.81
90 90055	100.00	100.00	100.00	99.91	94.39	31.39	8.31	7.75	7.69
90 90056	100.00	98.95	98.85	98.82	98.74	98.59	97.77	93.20	91.72
90 90057	100.00	100.00	100.00	99.93	99.79	97.55	46.47	23.93	23.58
90 90061	100.00	85.31	79.08	67.48	38.04	10.99	8.14	7.92	7.87
90 90062	100.00	45.63	43.56	41.45	38.34	27.31	19.67	17.65	17.30
90 90063	100.00	98.57	97.43	96.47	95.40	94.49	92.01	85.20	83.71
90 90067	100.00	100.00	99.94	99.92	99.88	99.75	99.53	98.66	97.32
90 90'+	100.00	40.61	16.51	5.91	3.09	2.58	2.49	2.41	2.39
90 27m	100.00	57.61	45.29	35.08	21.88	10.86	5.88	4.04	3.83
90 23m	100.00	99.77	99.16	98.95	98.82	98.32	93.68	77.42	75.55
90 22m	100.00	100.00	99.93	99.50	92.40	81.29	63.72	41.22	39.69
90 2.5m	100.00	98.85	98.68	98.53	98.39	98.14	97.87	97.39	96.76

Appendix 3: Coulter Data

sample #	%F -3Ø	%F -2Ø	%F -1Ø	%f 0Ø	%f 1Ø	%f 2Ø	%f 3Ø	%f 4Ø	%f4.29Ø
90 2m	100.00	93.66	92.00	90.66	88.91	87.45	86.37	79.33	78.03
90 1m	100.00	55.26	32.38	17.75	10.96	6.91	5.03	4.32	4.26

Appendix 3: Coulter Data									
sample #	%f4.63Ø	%f4.96Ø	%f5.3Ø	%f5.6Ø	%f5.96Ø	%f6.3Ø	%f6.6Ø	%f6.96Ø	%f7.3Ø
90 90001	11.58	10.65	9.51	8.30	7.17	6.20	5.32	4.50	3.73
90 90004	86.60	82.71	77.34	70.97	64.39	58.42	52.52	46.61	40.74
90 90005	36.91	33.28	28.73	24.73	21.10	18.09	15.53	13.10	11.06
90 90006	84.46	82.14	76.89	71.57	66.26	60.89	55.27	49.41	43.59
90 90007	80.30	70.08	59.36	46.67	36.97	29.99	24.63	20.45	16.51
90 90008	44.55	34.48	25.65	19.27	14.93	12.07	10.02	8.38	6.86
90 90009	86.81	78.29	68.73	59.72	51.45	44.05	37.62	31.75	26.11
90 90010	49.27	39.96	32.16	26.17	21.33	17.64	14.74	12.26	10.07
90 90012	87.27	83.15	76.98	70.81	64.44	57.99	51.48	44.69	38.58
90 90013	96.54	92.56	85.12	77.03	68.43	60.05	52.68	46.11	39.70
90 90017	78.26	74.25	66.82	58.93	51.64	44.55	38.06	32.37	27.16
90 90019	94.90	91.70	82.32	73.76	66.42	60.44	54.86	49.97	44.60
90 90020	86.88	82.09	74.46	67.47	61.67	56.13	51.15	46.42	40.84
90 90021	86.52	80.97	70.93	62.16	53.84	46.65	40.50	34.73	29.02
90 90022	92.82	89.77	80.93	72.25	64.59	57.09	49.74	42.46	35.73
90 90025	61.09	57.92	50.49	44.20	39.25	34.24	29.35	24.83	20.69
90 90027	71.78	65.28	53.44	43.90	36.61	31.63	27.37	23.61	20.08
90 90028	92.49	87.12	76.29	66.12	58.60	51.99	45.54	39.59	33.86
90 90032	93.05	90.32	83.46	75.83	68.06	61.13	54.62	48.39	42.02
90 90033	95.44	93.90	85.88	76.95	68.52	61.55	54.59	47.99	41.16
90 90037	95.41	93.30	90.51	87.36	84.07	80.74	77.00	73.00	68.32
90 90039	79.28	77.08	74.59	71.90	68.88	65.64	62.33	58.60	54.60

Appendix 3: Coulter Data

sample #	%f4.63Ø	%f4.96Ø	%f5.3Ø	%f5.6Ø	%f5.96Ø	%f6.3Ø	%f6.6Ø	%f6.96Ø	%f7.3Ø
90 90040	65.62	65.24	64.43	63.50	62.51	61.36	59.92	57.77	55.16
90 90041	95.22	93.49	91.42	89.34	87.19	84.78	82.35	79.59	75.59
90 90042	67.44	67.06	66.51	65.86	65.22	64.55	63.67	62.82	60.16
90 90043	96.17	95.64	93.41	91.27	89.27	87.62	85.17	81.43	76.76
90 90047	93.12	92.59	90.37	87.78	85.16	82.09	78.85	74.65	69.45
90 90048	59.64	58.28	56.76	55.15	53.52	51.68	49.62	47.08	44.24
90 90049	39.34	37.54	34.53	32.05	29.81	28.07	26.07	23.89	21.67
90 90050	95.43	94.41	92.90	91.17	89.21	86.81	84.05	81.14	77.31
90 90053	65.69	65.18	63.54	61.92	60.01	58.00	55.73	53.25	50.17
90 90054	93.58	92.67	90.99	88.59	86.08	83.10	79.68	75.99	71.77
90 90055	7.59	7.46	7.23	6.96	6.67	6.36	6.02	5.65	5.27
90 90056	90.14	88.53	86.85	85.17	83.19	81.05	78.51	75.75	71.55
90 90057	23.20	22.80	22.38	21.91	21.33	20.75	20.10	19.43	18.67
90 90061	7.70	7.46	7.07	6.57	6.08	5.60	5.11	4.56	3.98
90 90062	16.97	16.37	15.53	14.69	13.79	12.88	11.95	11.00	10.02
90 90063	81.64	78.36	70.58	61.81	53.90	46.84	40.27	34.07	28.50
90 90067	94.64	90.23	80.06	69.89	60.82	53.10	46.16	39.77	33.85
90 90'+	2.34	2.24	2.05	1.84	1.65	1.46	1.30	1.13	0.95
90 27m	3.31	2.87	2.39	2.00	1.67	1.41	1.20	1.01	0.84
90 23m	71.75	65.76	58.10	51.55	44.95	39.34	34.29	29.61	24.98
90 22m	37.73	35.30	31.12	27.56	24.31	21.60	18.92	16.21	13.91
90 2.5m	93.99	88.69	79.82	70.41	61.39	53.71	46.51	39.71	32.96

Appendix 3: Coulter Data									
sample #	%f4.63Ø	%f4.96Ø	%f5.3Ø	%f5.6Ø	%f5.96Ø	%f6,3Ø	%f6.6Ø	%f6.96Ø	%f7.3Ø
90 2m	75.50	68.87	59.09	50.00	42.06	35.98	30.71	25.93	21.41
90 1m	4.10	3.88	3.49	3.08	2.65	2.25	1.89	1.55	1.24

Appendix 3: Coulter Data

sample #	%f7.6Ø	%f7.96Ø	%f8.3Ø	%f8.63	%f8.96Ø	%f9.3Ø	%f9.6Ø	%f10Ø
90_90001	3.08	2.53	2.02	1.54	1.11	0.69	0.32	0.00
90_90004	35.02	29.44	24.10	18.83	13.55	8.51	3.92	0.00
90_90005	9.24	7.72	6.23	4.83	3.51	2.19	1.02	0.00
90_90006	37.78	31.89	26.01	19.97	14.16	8.72	3.95	0.00
90_90007	13.31	10.74	8.46	6.46	4.63	2.97	1.43	0.00
90_90008	5.60	4.52	3.62	2.77	2.07	1.34	0.67	0.00
90_90009	21.33	17.05	13.21	9.80	6.82	4.16	1.86	0.00
90_90010	8.31	6.71	5.29	3.98	2.87	1.76	0.82	0.00
90_90012	32.71	27.41	22.35	17.36	12.78	8.20	3.94	0.00
90_90013	33.62	27.94	22.41	16.89	11.93	7.28	3.28	0.00
90_90017	22.73	18.76	14.92	11.33	8.08	5.02	2.28	0.00
90_90019	38.93	33.26	27.44	21.61	15.86	10.27	4.90	0.00
90_90020	35.19	29.92	24.78	19.71	14.70	9.70	4.75	0.00
90_90021	24.52	20.15	16.19	12.43	9.14	5.71	2.62	0.00
90_90022	29.85	24.84	20.06	15.51	11.36	7.29	3.45	0.00
90_90025	17.17	14.02	11.02	8.28	5.90	3.57	1.60	0.00
90_90027	16.94	13.93	11.14	8.39	5.98	3.66	1.63	0.00
90_90028	28.65	23.69	19.12	14.48	10.49	6.37	2.90	0.00
90_90032	35.86	29.92	24.27	19.05	13.77	8.91	4.20	0.00
90_90033	34.95	29.13	23.92	18.78	14.10	9.20	4.52	0.00
90_90037	62.14	55.08	46.87	37.60	28.07	18.01	8.56	0.00
90_90039	49.56	43.93	37.49	30.00	22.22	14.22	6.67	0.00

Appendix 3: Coulter Data								
sample #	%f7.6Ø	%f7.96Ø	%f8.3Ø	%f8.63	%f8.96Ø	%f9.3Ø	%f9.6Ø	%f10Ø
90 90040	51.46	46.17	39.60	31.56	23.34	14.99	7.08	0.00
90 90041	70.78	64.20	55.58	44.91	33.70	21.70	10.32	0.00
90 90042	56.10	50.50	43.17	34.24	25.12	15.66	7.00	0.00
90 90043	71.75	64.75	55.76	45.04	33.28	21.53	10.29	0.00
90 90047	62.65	54.71	45.71	35.56	25.33	15.71	7.06	0.00
90 90048	40.26	35.45	29.50	22.50	15.84	9.50	4.21	0.00
90 90049	19.32	16.76	14.31	11.82	9.20	6.37	3.27	0.00
90 90050	72.30	65.47	57.10	46.62	35.06	23.04	11.02	0.00
90 90053	46.23	41.31	35.33	28.19	20.68	12.99	5.54	0.00
90 90054	65.93	58.05	48.55	38.08	27.69	17.70	8.20	0.00
90 90055	4.79	4.27	3.64	2.92	2.16	1.40	0.66	0.00
90 90056	64.93	56.37	46.64	36.41	26.34	16.11	6.88	0.00
90 90057	17.61	16.24	14.44	12.04	9.31	6.26	2.92	0.00
90 90061	3.38	2.80	2.24	1.68	1.18	0.72	0.33	0.00
90 90062	8.94	7.81	6.27	4.96	3.67	2.43	1.14	0.00
90 90063	23.54	19.43	15.61	11.98	8.71	5.57	2.72	0.00
90 90067	28.12	23.10	18.60	14.29	10.30	6.50	3.02	0.00
90 90'+	0.80	0.64	0.48	0.34	0.21	0.10	0.00	0.00
90 27m	0.69	0.55	0.41	0.29	0.18	0.09	0.00	0.00
90 23m	20.71	16.79	12.94	9.32	5.93	2.79	0.00	0.00
90 22m	11.83	9.80	7.78	5.80	3.83	1.92	0.00	0.00
90 2.5m	27.31	22.13	17.03	12.24	7.69	3.53	0.00	0.00

Appendix 3: Coulter Data

sample #	%f7.6Ø	%f7.96Ø	%f8.3Ø	%f8.63	%f8.96Ø	%f9.3Ø	%f9.6Ø	%f10Ø
90 2m	17.61	14.14	10.80	7.86	4.91	2.29	0.00	0.00
90 1m	0.98	0.74	0.53	0.36	0.20	0.09	0.00	0.00

APPENDIX 4: GRAINSIZE STATISTICS.

Appendix 4: Grainsize Statistics

Sample #	Site/Unit	gravel	sand	silt	clay	p95	p84	p75	p50	p25	p16	p5	mean
90 90001	SS-1 unit 1	0	86	11	3	2.10	2.40	2.60	2.90	3.20	4.00	6.30	3.10
90 90004	SS-1 unit 1	0	18	52	30	3.50	5.00	5.50	6.80	8.30	8.90	9.70	6.90
90 90005	SS-1 unit 1	0	60	32	8	2.40	2.80	2.90	3.80	5.70	6.50	8.60	4.37
90 90006	SS-1 unit 1	0	19	49	32	3.40	4.70	5.40	7.00	8.20	8.70	9.70	6.80
90 90007	SS-1 unit 1	0	30	60	10	4	4.4	4.8	5.5	6.4	7.3	8.9	5.73
90 90008	SS-1 unit 1	0	62	33	5	3.3	3.7	4	4.3	5.3	5.9	8.1	4.63
90 90009	SS-1 unit 1	0	19	64	17	4	4.7	5.2	6.1	7.3	8.1	9.2	6.30
90 90010	SS-1 unit 1	0	54	38	8	3	3.4	3.8	4.5	5.7	6.4	8.7	4.77
90 90012	SS-1 unit 1	0	17	54	29	3.6	5	5.6	6.7	8.3	8.9	9.7	6.87
90 90013	SS-1 unit 1	0	8	63	29	4.9	5.5	5.7	6.7	8.2	8.7	9.6	6.97
90 90017	SS-1 unit 2	5	26	50	19	-1	4.1	5	6	7.5	8.2	9.4	6.10
90 90019	SS-1 unit 3	0	8	58	34	4.8	5.2	5.6	7	8.6	9	9.8	7.07
90 90020	SS-1 unit 3	0	19	51	30	3.8	4.8	5.2	6.5	8.3	8.8	9.6	6.70
90 90021	SS-1 unit 3	2	18	60	20	2.3	4.9	5.2	6.1	7.5	8.2	9.7	6.40
90 90022	SS-1 unit 3	0	9	67	24	4.4	5.3	5.7	6.5	8	8.6	9.8	6.80
90 90025	SS-1 unit 4	9	42	35	14	-2	0.2	1.8	5.4	7.2	8.2	9.3	4.60
90 90027	SS-1 unit 5	0	35	49	16	3.2	4.1	4.4	5.4	6.9	8	9.3	5.83
90 90028	SS-1 unit 5	0	12	64	24	4.4	5.1	5.3	6.3	8	8.6	9.6	6.67
90 90032	SS-1 unit 5	0	9	61	30	4.2	5.3	5.7	6.6	8.2	8.9	9.7	6.93
90 90033	SS-1 unit 5	2	7	61	30	4.8	5.7	5.9	6.9	8.4	8.9	9.7	7.17
90 90037	SS-18 unit 1	0	6	39	55	4.8	6.2	7	8.3	9.2	9.6	9.9	8.03
90 90039	SS-18 unit 1	0	14	41	45	3.2	3.9	5.1	7.6	9	9.4	9.7	6.97
90 90040	SS-18 unit 1	0	35	18	47	1.1	2.2	2.8	7.7	8.9	9.3	9.8	6.40

Appendix 4: Grainsize Statistics continued

sample #	Site/unit	gravel	sand	silt	clay	p95	p84	p75	p50	p25	p16	p5	mean
90 90041	SS-18 unit 1	0	7	27	66	4.7	6.4	7.5	8.8	9.5	9.7	9.9	8.30
90 90042	SS-18 unit 1	0	33	17	50	2.5	3.2	3.7	8	9	9.5	9.9	6.90
90 90043	SS-18 unit 1	0	4	31	65	5.1	6.9	7.6	8.4	9.3	9.4	9.8	8.23
90 90047	SS-18 unit 1	0	8	37	55	4.2	6.2	7.1	8.2	8.8	9.4	9.8	7.93
90 90048	SS-18 unit 1	2	42	21	35	0.6	1.6	2.2	6.3	8.5	9	9.8	5.63
90 90049	SS-18 unit 1	0	44	38	18	2.7	3.1	3.2	3.9	6.7	8.2	9.7	5.07
90 90050	SS-18 unit 1	0	5	29	66	4.8	6.5	7.4	8.6	9.3	9.7	9.9	8.27
90 90053	SS-18 unit 2	2	35	21	42	1.7	2.7	3.2	7.4	8.7	9.3	9.8	6.47
90 90054	SS-18 unit 2	0	8	33	59	3.8	6.2	7.2	8.3	9	9.4	9.9	7.97
90 90055	SS-18 unit 2	0	88	7	5	0.9	1.2	1.4	1.7	2.1	2.4	8	1.77
90 90056	SS-18 unit 3	0	12	31	57	3.9	6.1	7.2	8.2	9	9.4	9.8	7.90
90 90057	SS-18 unit 3	0	59	23	18	2.2	2.7	2.9	3	3.9	8.2	9.6	4.63
90 90061	SS-19 unit 2	20	70	6	4	-3	-1.8	-0.7	0.7	1.3	1.8	7.6	0.23
90 90062	SS-19 unit 1	58	17	16	9	-3	-2.8	-2.7	-2.2	2.3	5	8.9	0.00
90 90063	SS-19 unit 1	2	22	57	19	2.4	4.4	5.2	6.2	7.6	8.2	9.5	6.27
90 90067	SS-19 unit 1	0	10	67	23	4.4	5.2	5.4	6.4	7.9	8.5	9.7	6.70
90 90'+	SS-2	84	14	2	0	-3	-2.7	-2.6	-2.2	-1.4	-0.9	0.3	-1.93
90 27m	SS-2	57	40	3	0	-3	-2.8	-2.7	-1.8	0.7	1.6	3.2	-1.00
90 23m	SS-2	0	35	47	18	3	3.8	4.4	5.7	7.3	8.2	9.4	5.90
90 22m	SS-2	0	55	35	10	0.8	1.8	2.5	3.7	6.1	7.3	8.9	4.27
90 2.5m	SS-2	2	10	66	22	4.6	5.3	5.5	6.5	7.9	8.4	9.5	6.73
90 2m	SS-2	8	30	47	15	-2	3.6	4.7	5.7	7.2	8	9.2	5.77
90 1m	SS-2	68	24	6	2	-3	-2.8	-2.6	-1.9	-0.8	0.2	4.7	-1.50

Appendix 4: Grainsize Statistics continued				
Sample #	Site/Unit	sorting	total	
90 90001	SS-1 unit 1	1.04	100	
90 90004	SS-1 unit 1	1.91	100	
90 90005	SS-1 unit 1	1.86	100	
90 90006	SS-1 unit 1	1.95	100	
90 90007	SS-1 unit 1	1.47	100	
90 90008	SS-1 unit 1	1.28	100	
90 90009	SS-1 unit 1	1.64	100	
90 90010	SS-1 unit 1	1.61	100	
90 90012	SS-1 unit 1	1.90	100	
90 90013	SS-1 unit 1	1.51	100	
90 90017	SS-1 unit 2	2.53	100	
90 90019	SS-1 unit 3	1.71	100	
90 90020	SS-1 unit 3	1.88	100	
90 90021	SS-1 unit 3	1.95	100	
90 90022	SS-1 unit 3	1.64	100	
90 90025	SS-1 unit 4	3.70	100	
90 90027	SS-1 unit 5	1.90	100	
90 90028	SS-1 unit 5	1.66	100	
90 90032	SS-1 unit 5	1.73	100	
90 90033	SS-1 unit 5	1.54	100	
90 90037	SS-18 unit 1	1.62	100	
9C 90039	SS-18 unit 1	2.36	100	
90 90040	SS-18 unit 1	3.09	100	

Appendix 4: Grainsize Statistics continued				
sample #	Site/unit	sorting	total	
90 90041	SS-18 unit 1	1.61	100	
90 90042	SS-18 unit 1	2.70	100	
90 90043	SS-18 unit 1	1.34	100	
90 90047	SS-18 unit 1	1.65	100	
90 90048	SS-18 unit 1	3.24	100	
90 90049	SS-18 unit 1	2.34	100	
90 90050	SS-18 unit 1	1.57	100	
90 90053	SS-18 unit 2	2.88	100	
90 90054	SS-18 unit 2	1.72	100	
90 90055	SS-18 unit 2	1.38	100	
90 90056	SS-18 unit 3	1.72	100	
90 90057	SS-18 unit 3	2.50	100	
90 90061	SS-19 unit 2	2.46	100	
90 90062	SS-19 unit 1	3.74	100	
90 90063	SS-19 unit 1	2.03	100	
90 90067	SS-19 unit 1	1.63	100	
90 90'+	SS-2	0.93	100	
90 27m	SS-2	2.02	100	
90 23m	SS-2	2.07	100	
90 22m	SS-2	2.60	100	
90 2.5m	SS-2	1.52	100	
90 2m	SS-2	2.84	100	
90 1m	SS-2	1.90	100	

APPENDIX 5: GEOCHEMICAL DATA.

Appendix 5: Geochemical Data

LAB NUMBER	Field #	Location	boron	boron 2	V	Ga	Nb	Th	Y	Sr
5031916	90003	springdale	31	17	99	21	8	2	30	207
5031917	90014	springdale	104	16	95	22	8	2	30	198
5031918	90024	springdale	28	21	109	23	7	2	29	200
5031919	90031	springdale	29	20	109	25	7	3	32	205
5031920	c		109							
5031921	90036	springdale	32	17	106	23	8	2	31	209
5031922	90045	springdale	63	22	92	25	11	2	33	171
5031923	90052	springdale	131	21	84	23	11	2	33	162
5031924	90059	springdale	34	20	103	25	11	4	34	160
5031925	90069	springdale	30	19	106	23	8	2	34	205

LAB NUMBER	Field #	Location	La	Ce	Fe %	Ba	Li	Sc	Dy	Mn%
5031916	90003	springdale	26	59	3.84	355	10.2	17	5.5	0.1
5031917	90014	springdale	26	61	3.76	349	10.9	17	5.5	0.1
5031918	90024	springdale	25	57	4.16	322	12.3	19	5.1	0.1
5031919	90031	springdale	27	60	4.27	341	14.1	21	5.7	0.1
5031920	c									
5031921	90036	springdale	28	61	4.17	350	14	19	5.8	0.1
5031922	90045	springdale	35	79	4.12	464	20.2	18	6.3	0.1
5031923	90052	springdale	34	71	3.94	458	19.3	17	6.1	0.1
5031924	90059	springdale	35	78	4.53	463	20.5	19	6.4	0.1
5031925	90069	springdale	28	66	4.22	339	16.9	20	6.2	0.1

Appendix 5: Geochemical Data continued

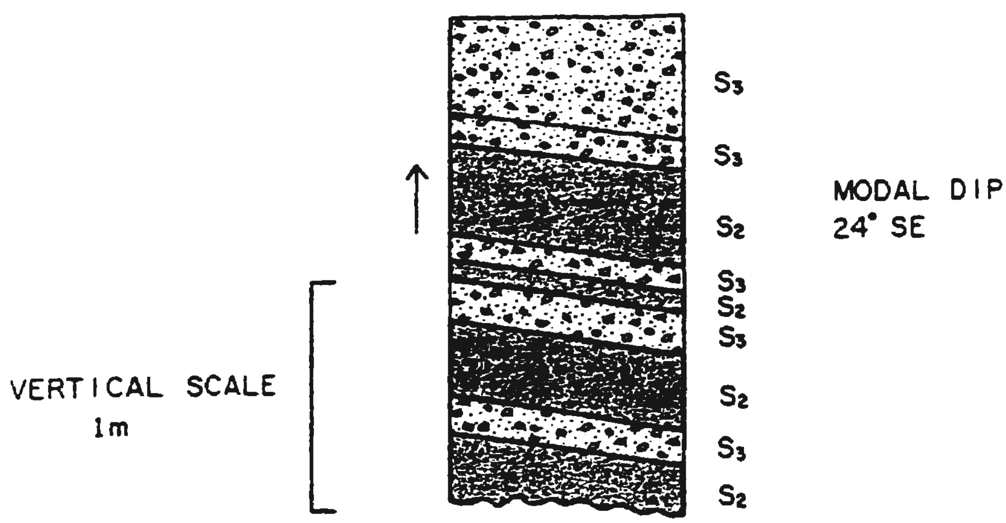
LAB NUMBER	Field #	Location	Cu	Zn	Pb	Ni	Rb	Cr	Be	Mo
5031916	90003	springdale	23	64	10	24	39	45	2.2	3
5031917	90014	springdale	23	66	10	30	42	46	2.3	4
5031918	90024	springdale	30	81	12	29	41	56	2.3	4
5031919	90031	springdale	32	83	11	27	42	49	2.2	3
5031920	c									
5031921	90036	springdale	27	76	11	28	46	51	2.3	4
5031922	90045	springdale	27	92	25	139	77	84	2.9	4
5031923	90052	springdale	25	87	17	172	69	101	2.9	3
5031924	90059	springdale	30	101	19	171	75	102	3	3
5031925	90069	springdale	26	82	11	30	46	62	2.4	3

Appendix 5: Geochemical Data continued

LAB NUMBER	Field #	Location	Co	Cd	gravel	sand	slt/cly
5031916	90003	springdale	11	-0.1	0.0176	13.11	86.88
5031917	90014	springdale	12	-0.1	0.0219	4.972	95.01
5031918	90024	springdale	14	-0.1	0.0851	1.694	98.22
5031919	90031	springdale	15	-0.1	0.0447	1.886	98.07
5031920	c						
5031921	90036	springdale	14	-0.1	0.3981	1.558	98.04
5031922	90045	springdale	19	-0.1	0.1969	8.321	91.48
5031923	90052	springdale	20	-0.1	0.2804	7.545	92.18
5031924	90059	springdale	21	-0.1	0.6852	19.37	79.95
5031925	90069	springdale	14	-0.1	0.1084	1.128	98.76

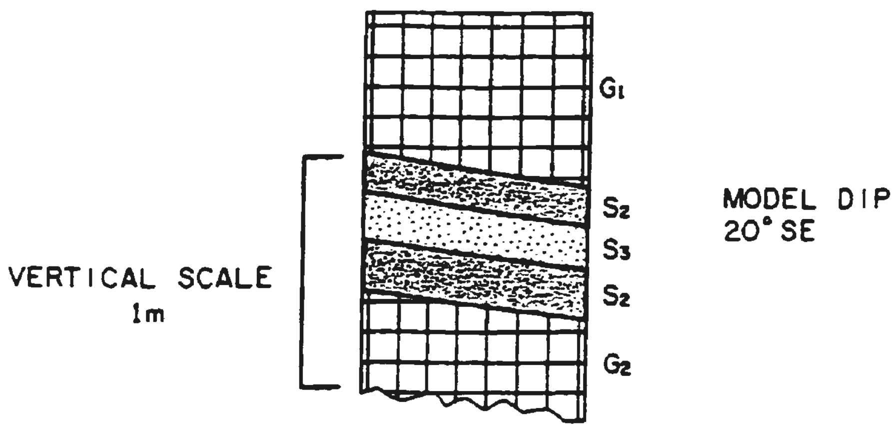
APPENDIX 6: SEDIMENTARY COLUMNS OF SAND AND GRAVEL DEPOSITS NOT DISCUSSED IN THE TEXT.

SITE SS-2 "PROXIMAL" SITE
68±3m a.s.l.
2.5m THICK



BASAL 2m COVERED TO FLOOR OF PIT

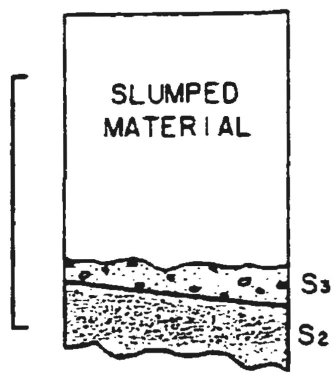
SITE SS-8 "PROXIMAL" SITE
72 ± 3m a.s.l.
1.7m THICK



BASAL 2m COVERED TO FLOOR OF PIT

SITE SS-9 "PROXIMAL" SITE
20±3m a.s.l.
1.4m THICK

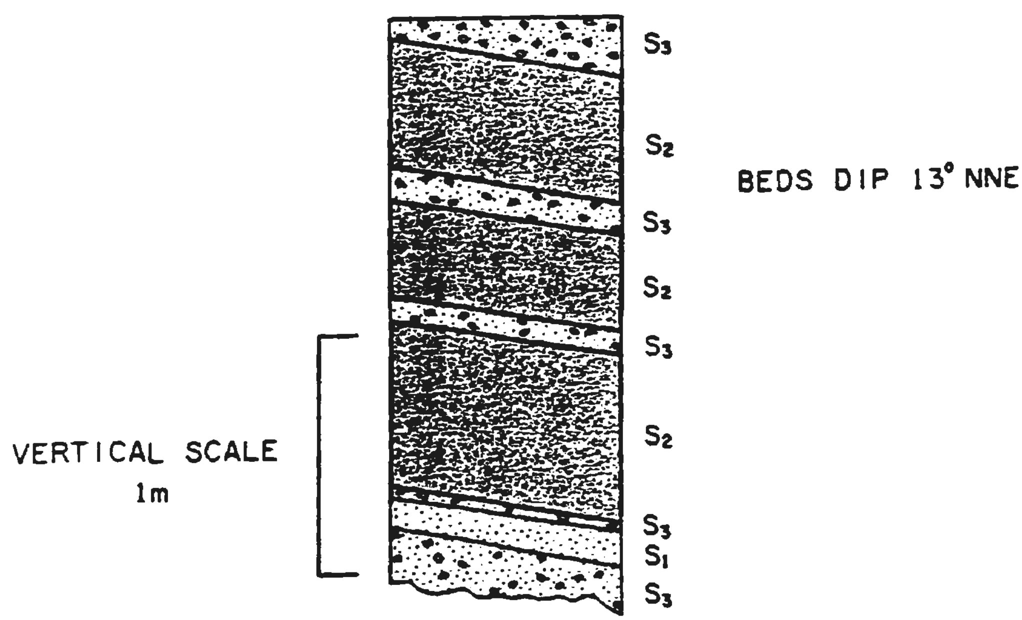
VERTICAL SCALE
1m



MODAL DIP
15° ESE

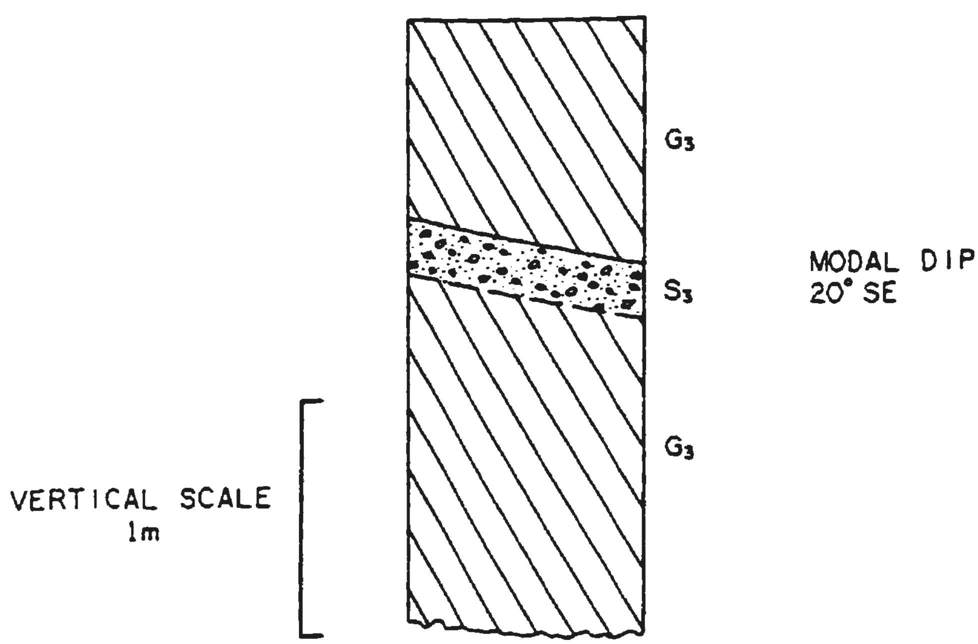
BASAL 3.5m COVERED TO FLOOR OF PIT

SITE SS-10 "PROXIMAL SITE"
50±3m a.s.l.
2.4m THICK



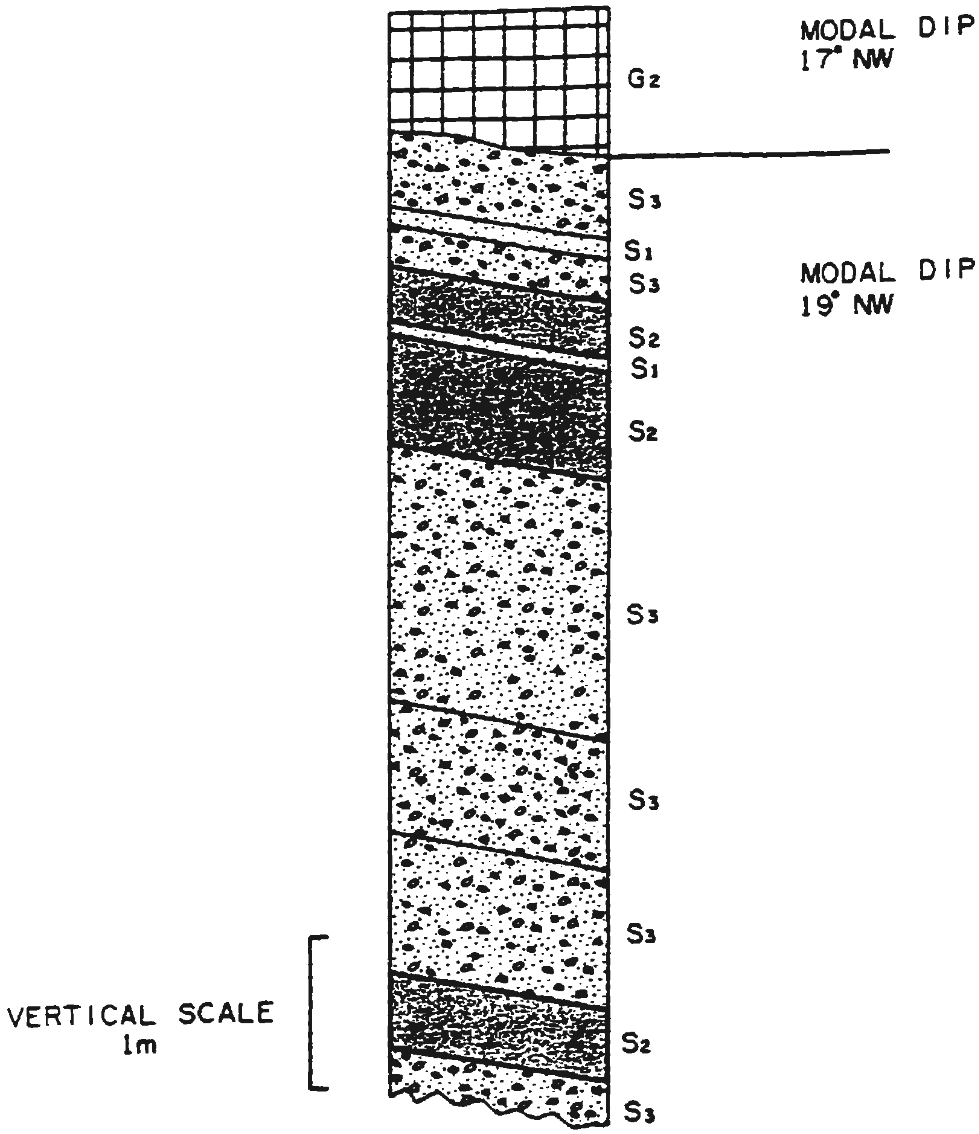
BASAL 2m COVERED TO FLOOR OF PIT

SITE SS-11 "PROXIMAL" SITE
64±3m a.s.l.
2.7m THICK

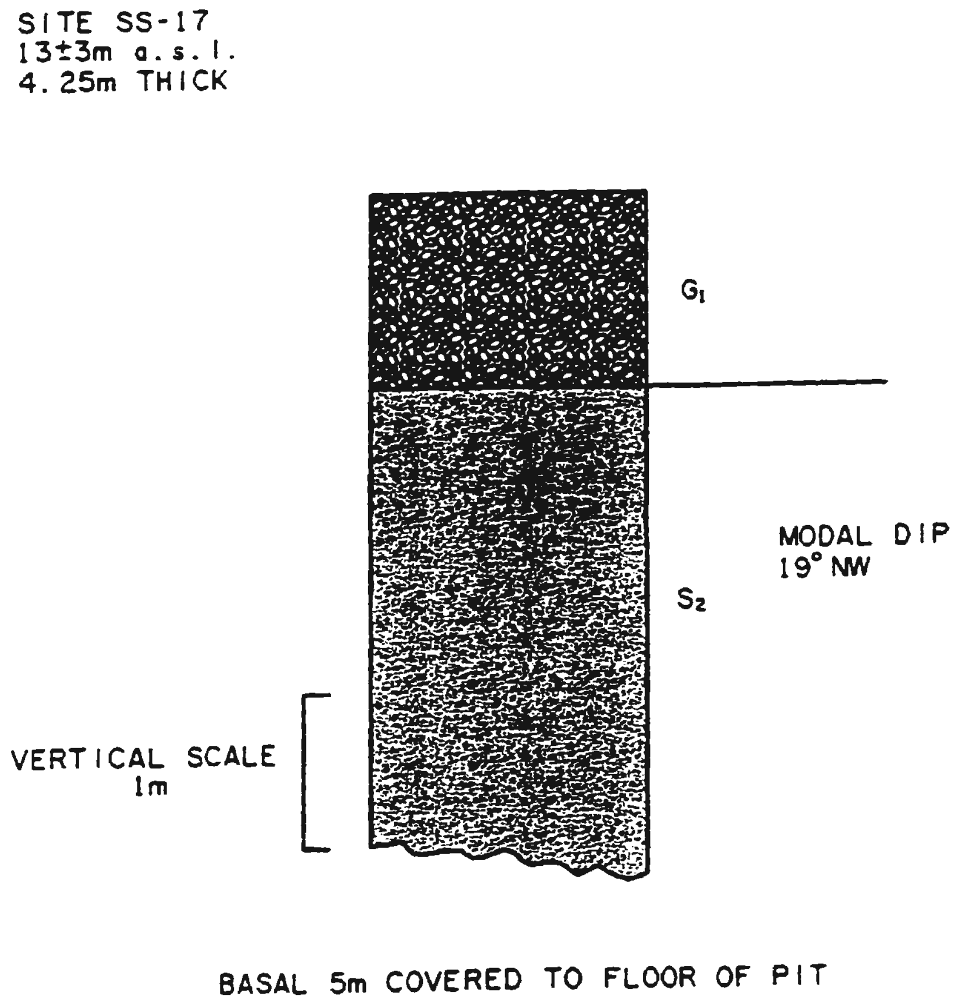


BASAL 3m COVERED TO FLOOR OF PIT

SITE SS-14 "DISTAL" SITE
72±3m a.s.l.
6.8m THICK



BASAL 5m COVERED TO FLOOR OF PIT


SITE SS-17
13±3m a.s.l.
4.25m THICK
G1
MODAL DIP
19° NW
S2
VERTICAL SCALE
1m
BASAL 5m COVERED TO FLOOR OF PIT