LATE QUATERNARY AND SURFICIAL MARINE GEOLOGY OF SOUTHEASTERN HUDSON BAY

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Science

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DALHOUSIE UNIVERSITY
DEPARTMENT OF GEOLOGY

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ABSTRACT

During the Late Quaternary both the Hudson and New Quebec Ice Domes that covered the southeastern Hudson Bay region began to recede, the region was flooded by glacial Lake Ojibway, water level dropped by up to 200m and the area was invaded by the Tyrrell Sea. This was followed by glacio-isostatic rebound. The onshore and offshore sediments have preserved the evidence of these events.

There are four distinct morphological zones of the till/ ice contact (Unit 2) sediments. The oldest zone is marked by a fluted discontinuous till and is associated with the initial division of the Labradorean Ice Dome into the Hudson and New Quebec Domes. Next an offshore moraine parallels the coastline from the southern border of the survey area to Duck Island and is interpreted to be the marine equivalent of the onshore Sakami Re-Equilibration Moraine. Catastrophic drainage and the initial outflow appears to have been south of the Belcher Islands then through Winisk Trough into Hudson Bay. This formed a calving bay extending into the southern portions of the survey area leaving the northern areas ice covered. Re-adjustment of the remaining ice sheet to this position formed the shallow water northern 8.0 ka moraine. Within the nearshore areas, complex ice contact sediments appear to coincide with glacial outflow from the last stages and could represent glaciofluvial deposits such as observed east of the Sakami Re-Equilibration Moraine.

Glaciolacustrine/marine is present throughout most of the study area as a conformable drape over the bedrock and till/ice contact sediments, these sediments do not interfinger with the till. An ice margin position is observed at an isolated location near the northern moraine. Similar well banded rhythmite sequences are present throughout Hudson Bay and into western Hudson Strait. The one condition that all these widely spaced occurrences have in common is that where micropaleontological analysis has been completed the zone is virtually barren.

This unit contains intervals of what appears to be previously frozen, disaggregated sediments. It is envisioned that small scale pore water chemistry and temperature changes induced by the influx of large volumes of cold and saline Tyrrell Sea water and the subsequent touchdown of the ice mass caused changes necessary for the temporary freezing of this unit.

The postglacial/recent sediments conformably overlie and grade into glaciolacustrine/marine sediment unit. Sediments of this unit display considerable horizontal and vertical variability. Deposition of this unit is influenced by tidal currents, wave base reworking and sediment failure.

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Technically I would like to foremost thank Robert Beiko for persevering in helping with the reduction of a very large, cumbersome and querky data set to a series of excellent illustrations and small graphic files. Along the way Phil Moir and Shawn Pecore have provided the essential GIS support.

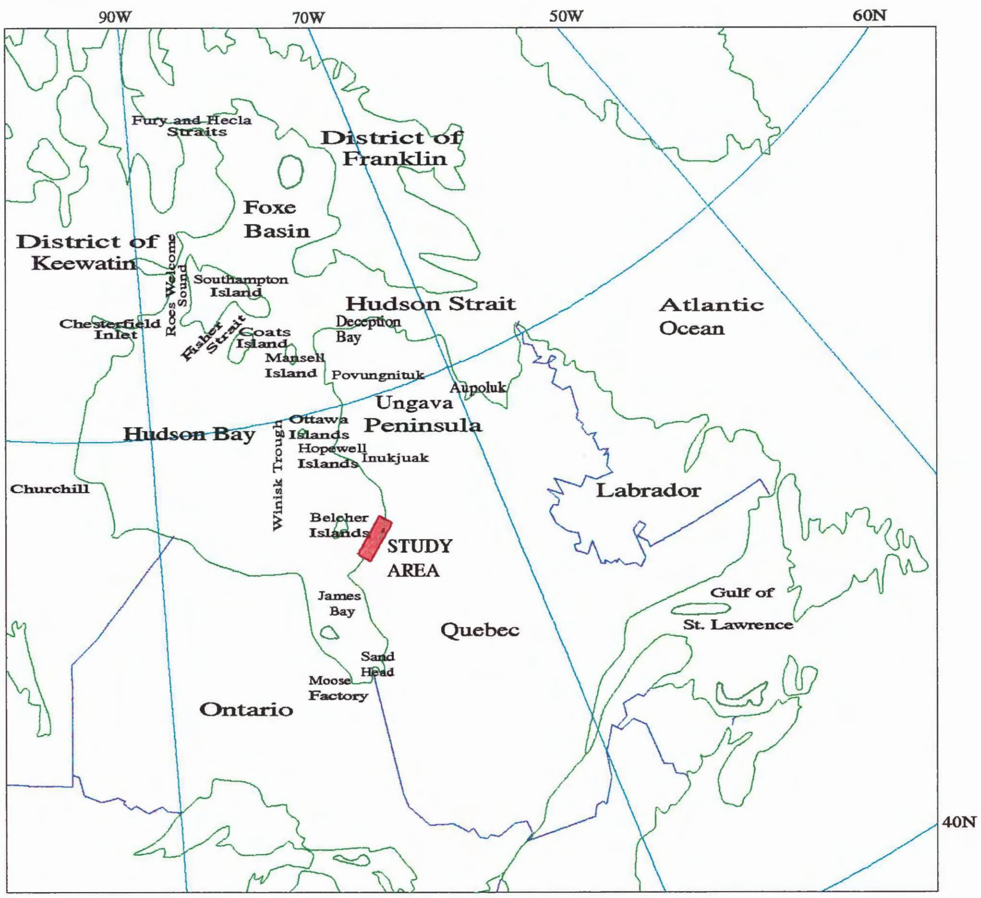
CHAPTER 1: INTRODUCTION

It is generally accepted that Hudson Bay was the geographic centre of the Laurentide Ice Sheet. With good air photo and satellite data available for the region, coupled with excellent exposure of stratigraphic sections in the many rivers that flow into Hudson Bay (Figure 1) the coastal regions in this area have been studied in detail. Due to the limited reconnaissance nature of the marine geological and geophysical data available in Hudson Bay, the large expanse of the bay has provided a convenient area to draw ice domes, divides and saddles as well as the mapping of the receding ice margin for the final disintegration chronology. The controversy of a single dome Laurentide Ice Sheet concept as proposed by Flint (1943) and Denton and Hughes (1981) versus multiple dome Laurentide Ice Sheet as proposed by Tyrrell (1898), Shilts (1980) and Dyke *et al.* (1982) is a classic example. Marine evidence of erratic dispersal (Henderson, 1989) and ice margin fluctuations (Josenhans and Zevenhuizen, 1990) support the multiple dome concept.

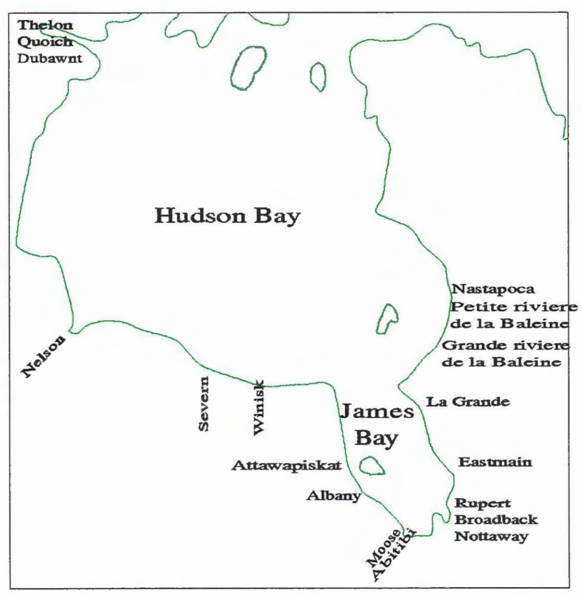
The surficial sediments and landforms occurring in and around James Bay preserve evidence of the late stages and disintegration of the Laurentide Ice Sheet. These features range from large scale regional landforms such as the Harricana Interlobate Moraine and the Sakami Re-equilibration moraine to paleo beach ridges, drumlins, fluted terrains and striae. Sediments preserved include remnants of basal tills, glaciolacustrine/glaciomarine, Tyrrell Sea, post glacial marine and estuarine sediments.

Figure 1:

Geographic location of the study area and terrestrial as well as oceanographic place names used in the text. The lower map inset shows the location of the major rivers which are a major source of freshwater input into Hudson Bay and James Bay.



Regional location map



Major rivers flowing into Hudson Bay and James Bay

Figure 1

The bulk of the data used for this thesis project is the result of surveys completed for hydroelectric development at the James Bay II Site, or more specifically the proposed damming of the Grande Rivière de la Baleine, Petite Rivière de la Baleine and Nastapoca Rivers.

The two lines of thought on acquiring baseline data for these projects are to 1.) either treat the entire region as one entity and focus all research on an all encompassing basis ie. cumulative effect or 2.) to initially treat each project on a stand alone basis, to understand the smaller system and then apply these findings to the more global perspective.

This thesis is essentially based on the second premise ie. the disintegration of the Laurentide Ice Sheet is a complex process and Hudson Bay proper has only been surveyed in a reconnaissance nature. There is a large volume of data available in the marine environment in Grande Rivière de la Baleine region. Onshore Quaternary studies for the period 10-7 ka in this area document the rapid disintegration and final stages of the Laurentide Ice Sheet. One major event is the division of the Labradorean Ice Dome into the Hudson and New Quebec Ice Domes and subsequent formation of the Harricana Interlobate Moraine. Another is the catastrophic drainage of Lake Ojibway and the incursion of the Tyrrell Sea. The resultant drop in water level provided the mechanism for the formation of the Sakami Re-equilibration Moraine. The seaward extent of these events is always marked by question marks.

The primary objective of this thesis is to extent the terrestrial surficial geological mapping into the offshore (marine survey area over 3500 km^2) by providing a regional seismostratigraphic framework of the marine and nearshore environments of the southeastern Hudson Bay region (Figure 2). The other objectives are to identify and map the glacial landforms in the marine environment and the seaward extent and positions of the ice margins. This will further develop the model for the Late Quaternary geological history for the region and discuss how this has influenced the present day surficial marine geology and depositional environment of Manitounuk Sound region. It is the intent to focus on the southeastern Hudson Bay region and not to digress by encompassing the entire Hudson Bay and Hudson Strait region.

The Quaternary marine geology of southeastern Hudson Bay is presented over ten chapters. The first 4 chapters introduce the thesis topic, provide a general overview of the oceanographic and climatic conditions of the region, set the stage with a discussion of previous work and discuss the methods used. The geology is determined primarily using seismostratigraphy (Chapter 5) and using the bottom sample lithostratigraphy to ground truth the seismic data and determine the depositional environment (Chapters 6). Results are presented in the form of a discussion and as a series of geological maps. Rapid and large vertical glacio-isostatic recovery is the most dramatic process observed in the region. The emergence and its effect upon the coastal zone is discussed separately in Chapter 8. Findings are discussed in Chapter 9 and conclusions in Chapter 10.

Figure 2:

Detailed survey area place names and geographic locations mentioned in text. This diagram provides a reference map for all the study area interpretive maps.

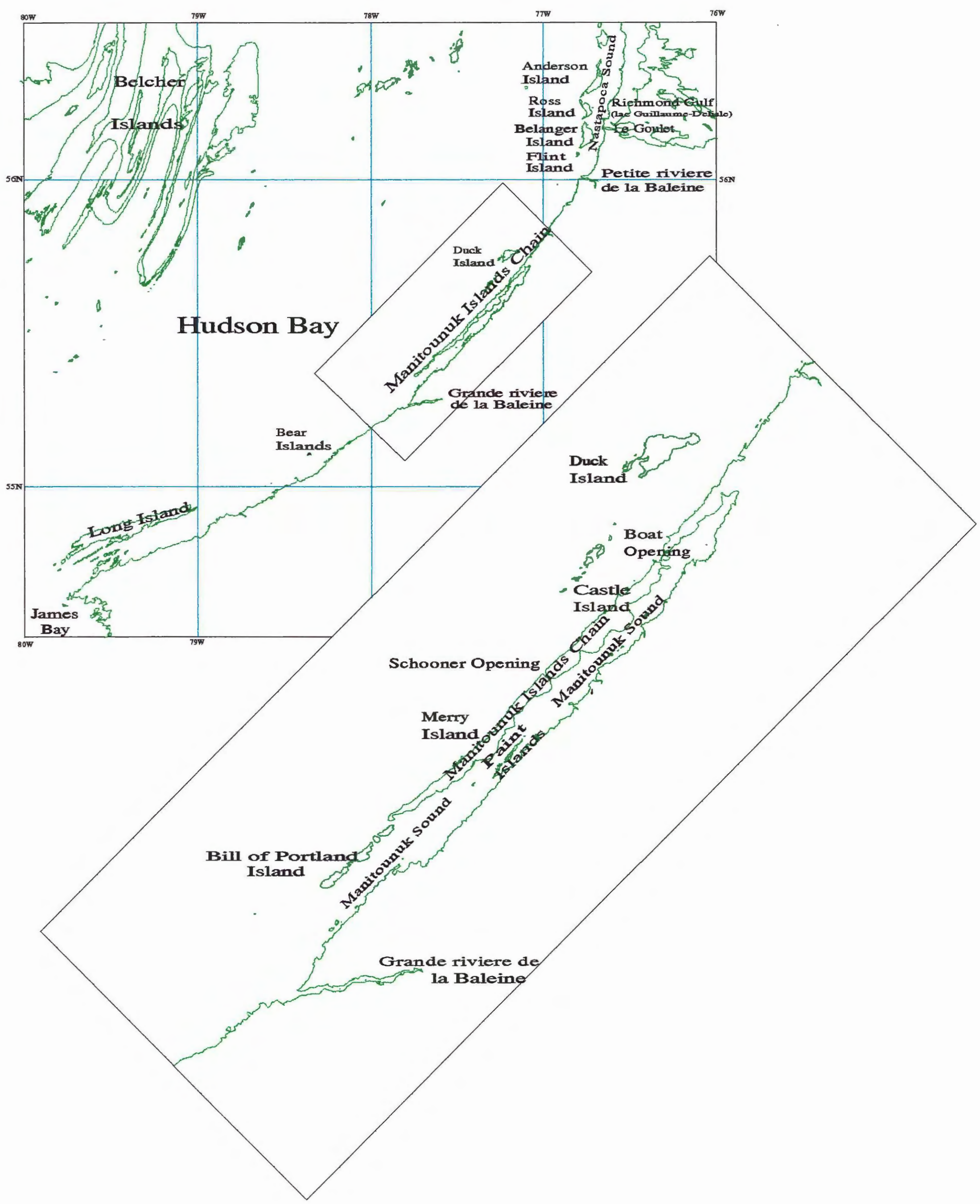

80W
79W
78W
77W
76W
56N
55N
Belcher
Islands
Hudson Bay
Anderson
Island
Ross
Island
Belanger
Island
Flint
Island
Nastapoca Sound
Richmond Gulf
(lac Guillaume-Delisle)
Le Goulet
Petite riviere
de la Baleine
Duck
Island
Manitounuk Islands Chain
Grande riviere
de la Baleine
Bear
Islands
Long Island
James
Bay
Duck
Island
Boat
Opening
Castle
Island
Schooner Opening
Manitounuk Islands Chain
Manitounuk Sound
Merry
Island
Paint
Islands
Bill of Portland
Island
Manitounuk Sound
Grande riviere de
la Baleine

Figure 2

CHAPTER 2: PHYSICAL AND CHEMICAL OCEANOGRAPHY

Hudson Bay is a large, inland sea open to the Atlantic Ocean only through Hudson Strait (Figure 1). Hudson Bay covers a total area of 637 000km^2 and has a maximum length and width of 1500 km and 830 km respectively. Hudson Bay is ice covered for up to 9 months of the year; open water conditions occur from August to October. For this reason the bulk of the Hudson Bay data base has been collected during the late summer, with some limited data collected by helicopter through the ice in winter. A year round current meter string mooring was deployed approximately 150km northeast of Churchill from September 1981 to August 1982 (Prinsenberg, 1986a). It is important to note that only limited oceanographic data have been collected during the periods of ice decay or freeze up, the times of greatest variability.

2.1 - BATHYMETRY

The bathymetry of Hudson Bay can be described as a generally shallow, saucer shaped basin; most of the depths range between 100-230 m with an average depth of 125m (Prinsenberg, 1986a). A maximum depth of 550m is reached at the northeastern margin off the Ungava Peninsula where the bay joins Hudson Strait. Winisk Trough, an enclosed bathymetric deep in the central part of the bay reaches a maximum depth of 370m (Josenhans and Zevenhuizen, 1990). Seabed relief is subdued but variable with slopes generally less than 2^0. Regionally, the topography is bedrock controlled with some limited glacial overdeepening of pre-existing drainage channels (Josenhans and Zevenhuizen, 1990). Quaternary deposits impart micro-relief with till ridges up to 15 m high and 300 m wide, hummocky subglacial topography, and ice-keel scour marks. Some of the relief is subdued by a thin blanket of postglacial - recent sediments. Water depths at the approaches to Hudson Bay are restricted to a maximum depth of 195m between Mansell and Coat's Islands. The bathymetry of the area east of the Belcher Islands, extending from Long Island to the northwestern tip of Ungava Peninsula, including the study area, is very complex; consisting of numerous shoals, islands, troughs and basins. This complex morphology coincides with the distribution of Precambrian terrains (Dyke *et al.*,1989) which ring Hudson Bay.

In the study area (Figure 2) detailed bathymetric data are available to approximately 30km offshore. Between Petite Rivière de la Baleine and Grande Rivière de la Baleine and seaward to the data limit the bathymetry reflects the underlying bedrock morphology, essentially mimicking the relief and orientation (strike southwest-northeast) of the cuesta ridge and basin morphology developed on Proterozoic interbedded volcanic and carbonate rocks. These impart a distinct northeast-southwest trend to the seabed morphology, with the basins increasing in depth seaward to local maximums of 200 m. The cuesta ridge - basin morphology forms Manitounuk Sound (basin) and the Manitounuk Islands (ridge) which constitute the seaward margin of the Manitounuk Sound and the Nastapoca Island chain north of the Petite Rivière de la Baleine estuary

In Manitounuk Sound water depths progressively increase westward to 85-100m adjacent to the Manitounuk Islands. Northeastward along the sound maximum depths of 50-60m extend to near the Paint Islands, 45m from there to the vicinity of Schooner Opening, shallowing to 25-30m near Boat Opening where 30m depths occur, and then progressively shallowing to the head of the sound.

West of the Manitounuk Island chain there is a marginal depression some 2.4km wide with depths >80m. This narrow basin is bounded seaward by a submerged cuesta ridge with water depths shallowing to <5m. The ridge is breached locally by small channels containing water depths to 50-60m; one of the most notable of these is adjacent to Schooner Opening which links the inner basin with a larger one to seaward where depths exceed 200 m. The connecting channel is steeply flanked on the south by a westerly extending zone of shallows <5m in depth.

Northward from Duck Island the bathymetry on the inner part of the shelf is generally deeper, ranging from 40-120m. In the southern part of the region, water depths of 50-100m commonly occur in the approaches to Manitounuk Sound which widens to 8 km offshore from the Grand Rivière de la Baleine estuary.

2.1 - CLIMATE (subarctic)

Atmospheric Environment Service is responsible for weather reporting as well as the archiving and interpretation of historical data. Summaries of the climatic conditions and extremes are published in the Hudson Bay Sailing Directions (Canadian Hydrographic Service, 1988) (Climatic conditions for the thesis survey area are reproduced in Appendix 1). Maxwell (1986) provides an overview of the meteorological conditions which persist over Hudson Bay and the effect of climate on the oceanography of the bay. A catalogue of severe storms and summary data was compiled by Lewis (1986). Sources for the meteorological data are land stations, ship observations and synoptic analysis for determining the geostrophic winds.

The ice free summer season weather of the eastern shore of Hudson Bay extends from August to October. During the ice free season the winds are primarily westerlies The following wind conditions were summarized from Bélanger and Filion (1991).

Wind direction	Wind speed (km h^{-1})	Frequency (%)
N	19.4	8.4
NNE	17.8	4.6
NE	13.1	1.6
ENE	13.1	1.1
E	18.6	5.8
ESE	17.9	10.2
SE	18.2	7.6
SSE	20.9	5.6
S	20.5	7.6
SSW	20.6	4.6
SW	22.4	4.5
WSW	23.2	7.3
W	21.6	9.7
WNW	20.2	5.6
NW	19.0	5.0
NNW	18.6	4.6

Table 1: Average wind velocity and frequency at Kuujjuarapik

The surface heat budget was described in detail by Danielson (1969) and further analyzed by Maxwell (1986). Solar radiation dominates from May through August with net radiation lowest in January (Maxwell, 1986). The net radiation from April to June is high even though the area is ice covered.

2.2 - WATER ORIGIN

2.3.1 - SALT WATER INPUT

Seafloor bathymetry influences the incursion of dense, saline water masses. Inflow of cold, dense, saline Atlantic water, through Hudson Strait, and Arctic bottom water, through Fury and Hecla Strait, into Hudson Bay, is restricted by sills at the approaches. Maximum water depths are: 135m Ungava Peninsula to Mansell Island, 195m Mansell Island to Coat's Island, 125m in Fisher Strait separating Coat's Island and Southampton Island, and 50m in Roes Welcome Sound separating Southampton Island and Keewatin. These shallow restrictions limit the exchange of bottom water and much of the formation of denser saline waters occurs in situ by salt rejection during the formation of the winter ice cover (Prinsenberg, 1986a).

2.3.2 - FRESHWATER INPUT

Freshwater input consists of two approximately equal volume components of terrestrial runoff and salt rejection during the winter ice cover formation (Prinsenberg, 1986a). Large volumes of freshwater enter Hudson Bay; the bulk of the freshwater input occurs from June to November from both major sources.

During the ice accretion which occurs during winter freeze up salt is rejected from the surface layer. This represents up to 50% of the annual freshwater input to Hudson Bay (Prinsenberg, 1982). The fluvial freshwater input is derived from the very large drainage area (3.1 million square kilometres) with an annual mean discharge rate of 22000 m^3/sec (Prinsenberg,1986a), nearly 30% of the national total. The distribution of the terrestrial component and variability is monitored by a network of streamflow gauging stations

(Fisheries and Environment, 1978). The bulk of the runoff comes from snow meltwater. The water derived from the continental divide is generally turbid, hard and more likely to release heavy metals like mercury from major water storage developments together with agricultural fertilizers and pesticides. Runoff from the Precambrian Shield to the north and east is more pristine (Pearse *et al.*,1985).

Many rivers discharge into Hudson Bay (Figure 1) and the largest of these is the Nelson River. On the eastern shore the major rivers are the Nastapoca, Petite Rivière de la Baleine, and Grande Rivière de Baleine. In James Bay, the major rivers are the La Grande Rivière, Eastmain, Nottaway, Broadback , Rupert, Moose, Abitibi, Albany, Attawapiskat Rivers. The Winisk and Severn Rivers empty in southwest Hudson Bay while the Hayes, Nelson, Churchill enter on the western side. The Thelon, Quoich and Dubawnt Rivers empty into Chesterfield Inlet then into Hudson Bay (Laycock, 1987). Meltwater runoff maxima occurs in June, when the snowpack which accumulated over winter is released. Low flow period around the Hudson Bay occurs in late winter when the rivers are ice covered and in some cases frozen to the bottom. The cumulative effect of the almost simultaneous melting of the Hudson Bay ice cover and the snow meltwater runoff cause the low surface water salinities in the bay during spring and summer.

2.4 - SALINITY AND TEMPERATURE

Prinsenberg (1986a) provides an overview of the temperature and salinity distribution and variability of Hudson Bay and James Bay. The bulk of the data was collected during the summer open water season and, to a limited extent, the through ice winter programs of southeastern Hudson Bay and James Bay. A current mooring 150km northeast of Churchill provides virtually the only year round data.

Temperature and salinity data indicate that the properties of the bottom waters of Hudson Bay remain relatively constant. The surface layer is highly variable and is separated from the bottom water by a distinct pycnocline. Vertical diffusion is limited and restricted to a layer 20-30 m below the pycnocline (Prinsenberg, 1986a). The surface layer is well defined and marked by its lower salinity and higher temperatures, which can be attributed to the large freshwater input during the warm open water season. The depth of the surface layer increases from June to November but rapidly equalizes with the bottom water during freeze up and total ice cover (Prinsenberg, 1986a).

2.5 - CIRCULATION

Circulation of Hudson Bay was first studied by Hachey (1935) and Barber (1967) using drift bottle techniques; much of the later work has been completed by Murty and Yeun (1973) and Prinsenberg (1986b).

Bottle drift data (Hachey, 1935, Barber, 1967) indicates a southeasterly flow along the south coast. Salinity and temperature data show a cyclonic surface circulation of 0.05

m/sec (Prinsenberg,1986a). No northwesterly return flow completing the loop has been observed; instead there exists a surface eastward outflow into Hudson Strait. The mean circulation of Hudson Bay is interpreted to be a combination of wind driven and estuarine components, with the estuarine components being density driven currents as a result of dilution by runoff (Prinsenberg, 1988). Limited yearlong current data collected 150 km northeast of Churchill indicates that the circulation pattern varies with the seasons (Prinsenberg, 1986b).

The bottom topography of Hudson Bay consists of low gradient slopes with the exception of the rugged topography of the eastern side. Water depths at the approaches to Hudson Bay are restricted, a maximum water depth of 195 m occur between Coat's and Mansell Islands. Due to the restricted water depths, incursion of the cold, dense, saline Atlantic and Arctic waters is limited. The limited volumes that enter the bay sink due to its density and do not show up as a surface flow. Sedimentary current wedges indicating strong bottom current activity are observed off the southeast corner of Coat's Island and in the northern Hudson Basin. Localized bottom current effects (Josenhans and Moir, 1991) have also been observed at the mouth of James Bay and along the channels separating islands along the southeastern coast of Hudson Bay. The shallowness and its distance from the Atlantic Ocean cause the marine environment of Hudson Bay to depend predominantly on local wind stress, runoff, radiation heat flux and annual ice cover (Prinsenberg, 1986b).

2.6 - TIDAL

Tidal patterns are described by Dohler (1989), Prinsenberg and Freeman (1986) and in the Sailing Directions for Labrador and Hudson Bay (Canadian Hydrographic Service, 1988). Tide tables for the region are published annually by Department of Fisheries and Oceans. Reference tide gauges for Hudson Bay are Churchill and Sand Head, James Bay. A series of secondary stations are situated around the perimeter of the bay (Fisheries and Oceans, 1990).

Tides in the Hudson Bay area are semi-diurnal, with the exception of the triangle formed by the Ottawa Islands, Povungnituk and Inukjuak where the low amplitude semi-diurnal rhythm is affected by diurnal variations. Tidal amplitudes are greater in summer and dampened in the winter months by ice cover (Prinsenberg and Freeman, 1986).

The tide flowing into Hudson Bay radiates in a roughly counter-clockwise circular movement around the bay following the contour of the shoreline. It starts from the entrance in the northwestern bay at about 2m amplitude, with tidal currents in the approaches up to 0.9m/sec (Prinsenberg and Freeman, 1986), increasing in amplitude along the low relief southwestern shore to 4m at Churchill and diminishing to about 0.3m along the eastern shore at Inukjuak. At the head of James Bay tides are occasionally obscured by weather (pressure) effects (Dohler,1989).

2.7 - ICE COVER

Hudson Bay is the largest body of water that freezes over completely in winter and becomes totally ice free in summer (Markham, 1986). Aerial reconnaissance and remote sensing data of the ice cover has been obtained since the opening of the Port of Churchill in 1931. Ice cover maps are available in the Sailing Instructions (Canadian Hydrographic Service, 1988) and in more detail in Markham (1988).

Most of the ice cover of Hudson Bay is locally formed as new ice (a general term which includes frazil, grease, slush and shuga ice). All are forms of weakly bonded ice crystals. New ice develops later in the season into first-year ice (sea ice of not more than one winters growth). Multi-year ice occasionally intrudes the northeastern Hudson Bay from Foxe Basin but usually occurs only as a late summer / early fall phenomenon.

Hudson Bay is relatively shallow and experiences the extreme continental meteorological influences due to its inland position; it is therefore only ice free for 3 months of the year, compared to 4.5-5 months on the Labrador Shelf which is closer to the more temperate influence of the Atlantic Ocean. The intrusion of icebergs into Hudson Bay has been reported but this is an extremely rare occurrence and would relate to unusual wind conditions.

Ice development in Hudson Bay starts with a rim of shorefast ice. Shorefast ice develops in a 10-20km rim along most of the coast. The area south and east of the Belcher Islands frequently becomes totally consolidated. Ice thickness in level shorefast ice average 0.8-1.0m by January 1 and 1.6-2.2m by May 1. Beyond the shorefast ice the bay is nearly filled with drifting pack ice which moves about in response to the wind. A variable pack is built up in response to the changing winds and ice ridges are built up giving the ice pack a rough and hummocky surface.

As temperatures rise in May and June leads develop in the northern and eastern portions of the bay. The pack ice generally clears towards the west from the Quebec shore and southward from Southampton Island. During late August the last of the ice cover has melted completely.

2.8 - WAVES

Due to the short navigation season and limited shipping activity only a few observations are available. Observations during early summer ice breakup and freeze up in late fall are even fewer. Maxwell (1986) summarizes the data available from 1951-1980 establishing a range of mean wave heights 0.7-2.0m with a period of 5-6 seconds and a maximum observed swell height of 4.0m and period of 8 seconds. The Environmental Application Group (1983) presented a summary of wave and swell data based on marine observations from 1895-1977 that is on file with Environment Canada. Maximum recorded wave height during this period was 8.2m.

2.9 - GENERAL PRODUCTIVITY

The physical-chemical and biological oceanography of Hudson Bay is summarized and discussed by Roff and Legendre (1986) and Environmental Applications Group (1983). Much of the analysis is based on data collected during the extensive oceanographic sampling program in 1975 when over 200 stations were occupied.

Hudson Bay is an oligotrophic body of water of low productivity, heavily influenced by freshwater runoff (Environmental Application Group, 1983). During the summer, lack of vertical mixing (Prinsenberg, 1986a) appears to restrict the regeneration of nutrients, particularly nitrate, in the surface waters. Also in summer distinct differences are noted between the inshore-offshore water chemical, physical and biological properties (Anderson and Roff, 1980). Hudson Bay waters are generally well oxygenated. Pett and Roff (1988) attribute the low productivity to the incomplete mixing and resultant low generation rates of nitrogen. They calculate that nitrate and nitrogen contribution from deep water mixing and freshwater runoff are of the same magnitude but that the atmospheric contribution is low. They also suggest that the vertical stability attributed to the large freshwater runoff affects primary production in a negative way. The summer surface chlorophyll distribution is generally low with high concentrations just west of the Belcher Islands and at the approaches of Hudson Bay and in Hudson Strait (Anderson and Roff, 1980). Data regarding baseline concentrations of heavy metals or hydrocarbons could not be found.

CHAPTER 3: PREVIOUS WORK

Initial exploration of Hudson Bay started with the European desire to locate a north-west passage to the Pacific Ocean (or South Sea). As a result of these explorations an active fur trade was established in the region. The details of early mapping surveys can be found in the Hudson's Bay Company records from posts in the survey area. These posts were located at the mouth of the Eastmain River (established 1719), Richmond Gulf (established 1749) (Francis and Morantz, 1983, Graburn, 1969) as well as intermittently operated posts at the mouths of the Grande Rivière de la Baleine, Petite Rivière de la Baleine and La Grande River (Figures 1 and 2)(Graburn, 1969).

After the establishment of the Hudson's Bay Post at Eastmain in either 1719 (Francis and Morantz , 1983) or 1724 (Neatby , 1969) the eastern shore of Hudson Bay was surveyed in detail by Hudson's Bay officers Mitchell and Longland. Mitchell and Longland in 1744 mapped from the mouth of the La Grande River to Grande Rivière de la Baleine, Petite Rivière de la Baleine and Richmond Gulf. They extended the survey to Digges Island in Hudson Strait in 1749 (Neatby, 1969).

The Geological Survey of Canada carried out a number of early surveys in the region. Bell (1879) surveyed the coast from Moose Factory at the head of James Bay to the Hopewell Islands by jolly-boat. During this survey the posts at the mouths of the Grande Rivière de la Baleine, Petite Rivière de la Baleine and La Grande River were all in operation. He was followed by Low (1888, 1902, 1903), who completed numerous coastal surveys as well as river traverses. Both researchers were struck with the rapid sea-level fall of the eastern shore of Hudson Bay and variations in glacial flow directions.

3.1 - GEOLOGY

3.1.1 - ONSHORE BEDROCK GEOLOGY

The Hudson Bay Paleozoic intercratonic basin (Sanford and Grant, 1990) is completely encircled by Precambrian terrain. Donaldson (1986) discussed the Precambrian geology of the Hudson Bay region and the Paleozoic platform was described by Norris (1986). Hudson Bay proper is floored by Paleozoic carbonates and outliers of Cretaceous sands and shales (Sanford and Grant, 1990). The bathymetry of Hudson Bay is largely controlled by the bedrock character and structure. The bathymetry of the area east of the Belcher Islands, extending from Long Island to the northwestern tip of Ungava Peninsula, is very complex consisting of numerous shoals, islands, troughs and basins. This complex morphology coincides with the Precambrian terrains (Dyke *et al.*,1989).

The mainland coastal bedrock in the study area consists of a series of cuesta ridges of Proterozoic volcanic and metamorphosed sedimentary rocks (Chandler, 1988, Sequin and Allard, 1984, Allard and Tremblay, 1983a,b). These cuesta ridges are characterized by a low angle dip on the western side and steep slopes on the eastern side. The Belcher and adjacent islands are primarily greywacke (Dimroth *et al.*, 1970).

3.2.1 - ONSHORE SURFICIAL GEOLOGY

During the Early Holocene the Laurentian Ice Sheet that formerly covered this area began to wane, the region was inundated by glacial lake Ojibway, and later by the Tyrrell Sea as marine waters entered the region (Dyke *et al.*, 1989)(Figure 3). This was followed by isostatic rebound, which continues in the present day (Figure 4), causing withdrawal of the sea to the present shoreline (Figure 5), and the development of normal low/sub Arctic subaerial, fluvial and marine processes. The offshore sediments are products of these glacial, transitional, and postglacial events.

Recent interpretations of the Laurentide Ice Sheet disintegration (Dyke and Prest,1987) suggest a very rapid breakup of thick (1000-2000m) ice which formed the multiple domes of the late Wisconsinan ice sheet over and around Hudson Bay. These studies from terrains flanking the bay, suggest that glacial ice covered Hudson Bay as recently as 8.4 ka, but that it had almost completely disappeared by 8.0 ka (Josenhans and Zevenhuizen,1990). Stratigraphic analysis of piston cores (Leslie, 1965) recorded a transition from glacially dominated to present marine conditions. Recent radiocarbon dates at this transition obtained by Vilks *et al.* (1989) from Hudson Strait, De Vernal (pers comm, 1991) off northeast Coats Island, and Bilodeau *et al.* (1990a) from the Grande Rivière de la Baleine estuary support the rapid 8.4-8.0 ka deglaciation.

Figure 3:

Deglaciation of the southeastern Hudson Bay region. The series of six maps span from 9 ka to 7 ka and show the inferred ice margin positions for this time period. Maps 9000,8400,8000 and 7000 were digitized from Dyke and Prest (1987). Maps 8300 and 8025 were digitized from Vincent and Hardy (1979) with modifications to the chronology added by Vincent (1989) applied. Dome, saddle and ice divides (Dyke and Prest, 1987) are marked by “D”, “S” and solid black lines respectively.

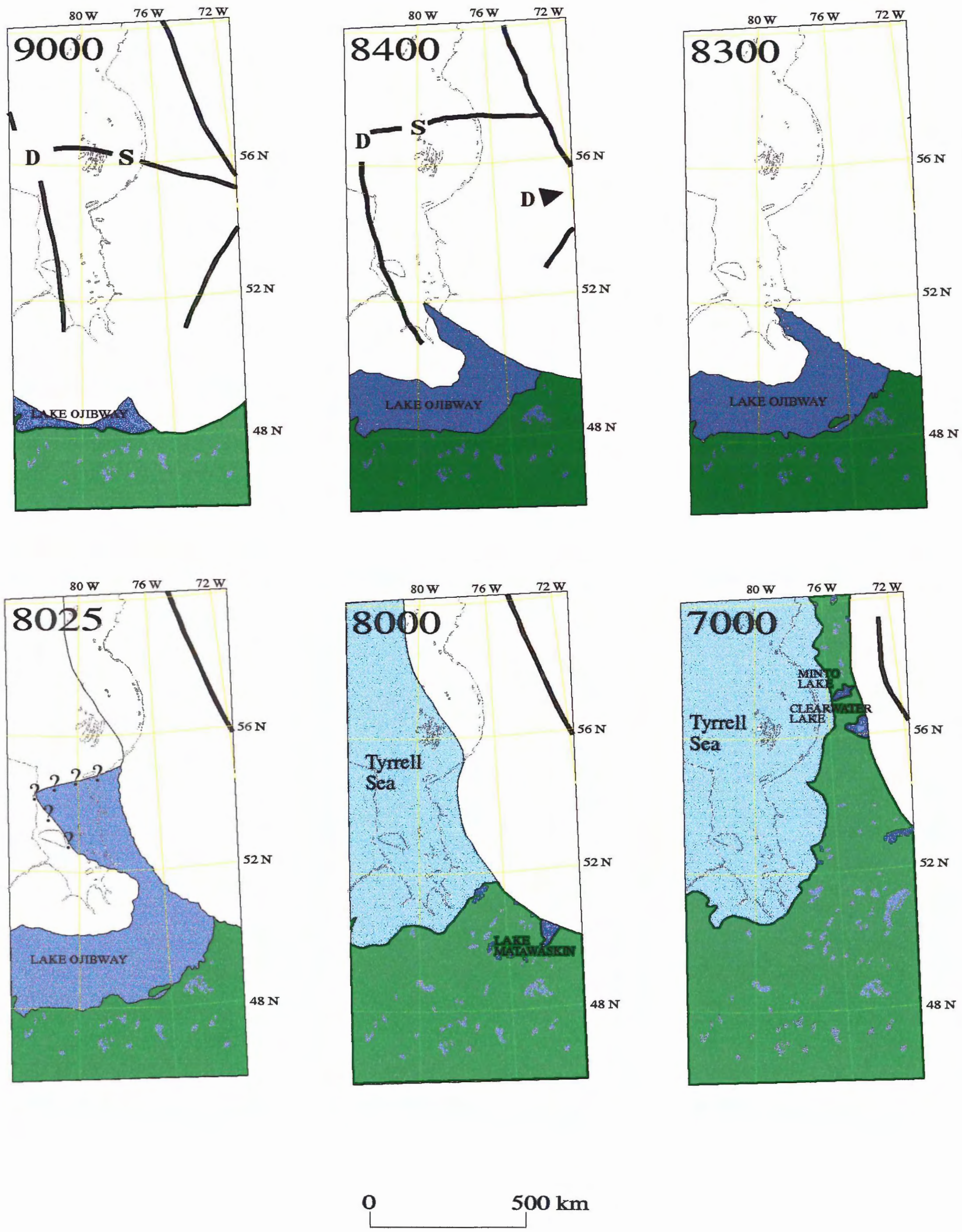

9000
8400
8300
8025
8000
7000
80 W
76 W
72 W
56 N
52 N
48 N
D
S
LAKE OJIBWAY
Tyrrell Sea
LAKE MATAWASKIN
MINTO LAKE
CLEARWATER LAKE
0
500 km

Figure 3

Figure 4:

Glacio isostatic emergence curves from various sources for the eastern shore of Hudson Bay and James Bay. The locations of study sites are shown in Figures 1 and 2. Diagram digitized from Vincent (1989).

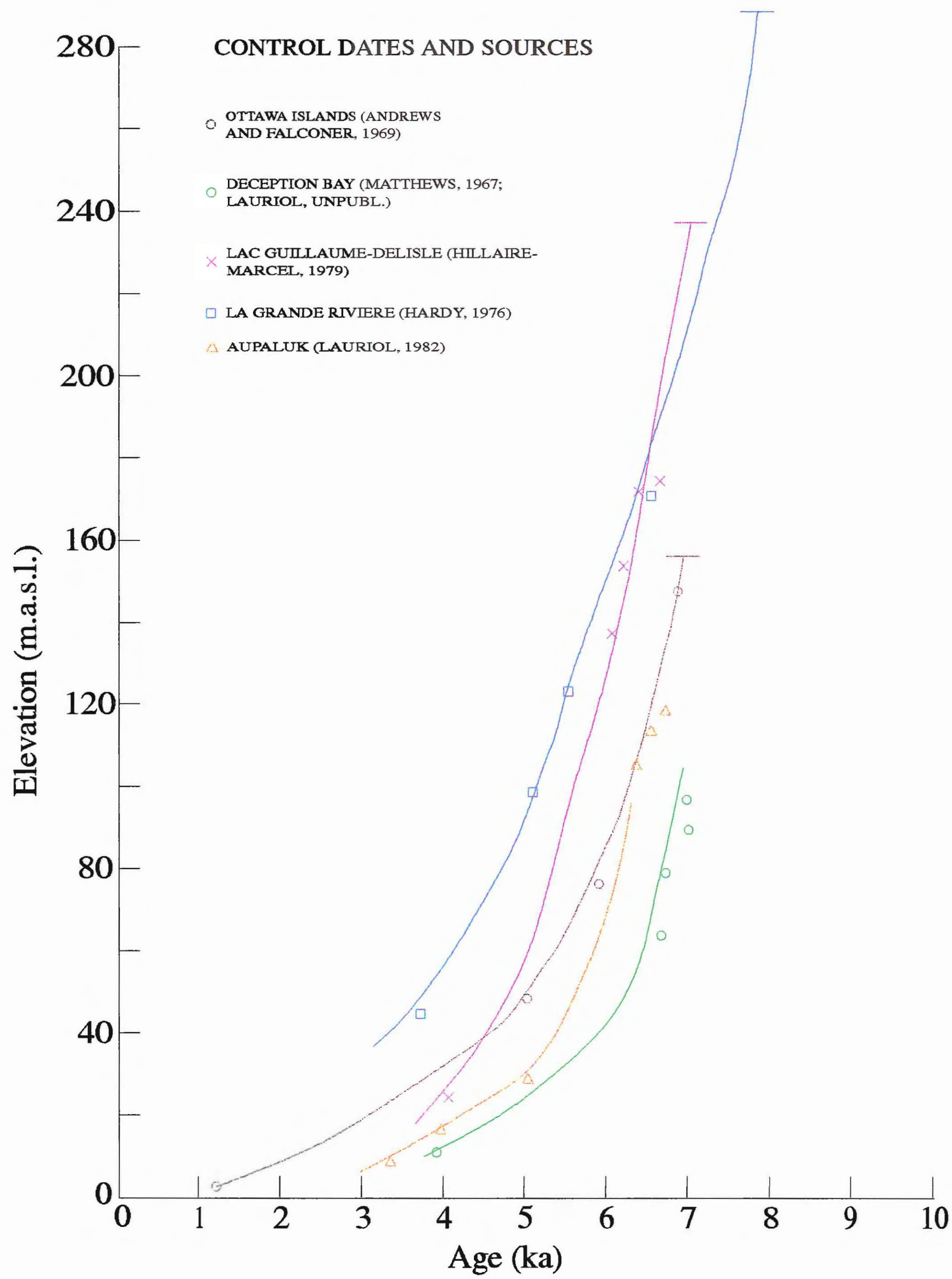

CONTROL DATES AND SOURCES
OTTAWA ISLANDS (ANDREWS AND FALCONER, 1969)
DECEPTION BAY (MATTHEWS, 1967; LAURIOL, UNPUBL.)
LAC GUILLAUME-DELISLE (HILLAIRE-MARCEL, 1979)
LA GRANDE RIVIERE (HARDY, 1976)
AUPALUK (LAURIOL, 1982)
Elevation (m.a.s.l.)
280
240
200
160
120
80
40
0
0
1
2
3
4
5
6
7
8
9
10
Age (ka)

Figure 4

Figure 5:

Coastline changes over time based on minimum emergence curve for Richmond Gulf (after Hillaire-Marcel, 1979). Richmond Gulf emergence curve (Hillaire-Marcel, 1979) is displayed on Figure 4.

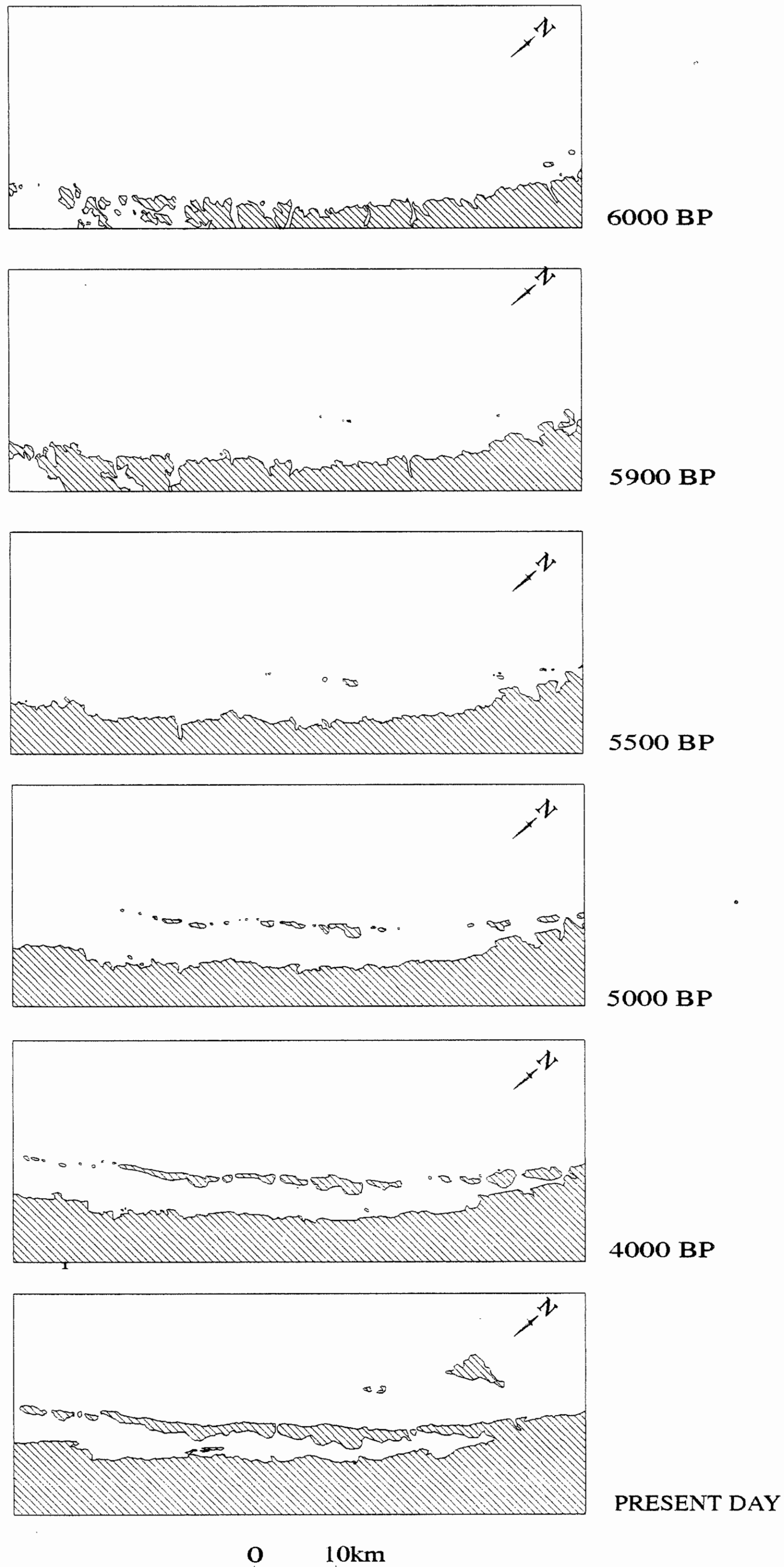


Figure 5

3.2 - MARINE GEOLOGY

3.2.1 - OFFSHORE BEDROCK GEOLOGY

Marine geophysical data indicate that in the study area submerged cuesta ridges , with a similar southwest - northeast orientation to those that form the bedrock of the coastal areas, extend offshore for up to 40 km west of Grande Rivière de la Baleine and approximately 20 km west of Petite Rivière de la Baleine. The sequential ridges and intervening valleys produce a pronounced northeast - southwest trend to the seabed morphology and surficial geology. However, the apparent alignment of several coastal physiographic features on the mainland and Manitounuk Islands and bathymetric contours suggest the presence of some regional east - west structural trends diagonal to and in part offsetting the dominant northeast - southwest orientation of the cuesta ridges (Chandler, 1988, Guilmont and Laverdière, 1980). The northwest dip associated with the cuesta ridges appears to reverse and change to a southeasterly dip approximately 35 km west of Bill of Portland Island (Figure 2) just before the contact of the bedrock associated with the Belcher Islands (Zevenhuizen, 1993).

3.2.2 - SURFICIAL MARINE GEOLOGY

The first marine geological and geophysical investigations of Hudson Bay were undertaken in 1961 (Leslie,1964, 1965, Leslie and Pelletier,1965, Hood,1966, Pelletier,

1966) and were followed in 1965 by a more extensive program. The results, summarized in Pelletier (1969, 1986), showed the surficial sediments to be thin, averaging 3 metres, but varying from zero on bathymetric highs and tidal flats to 30 metres in troughs. Recent surveys and mapping of the Quaternary and marine geology of Hudson Bay (Josenhans and Zevenhuizen, 1990, Zevenhuizen and Josenhans, 1989) indicated the sub/proglacial morphology is well preserved and that much of the bay is blanketed by a thin veneer of recent sediments. A synthesis of the marine geology of Hudson Bay in relationship to the adjoining marine areas of Hudson Strait and Foxe Basin as well as the Atlantic Ocean can be found in Piper *et al.* (1990).

With the exception of the complex and shoal areas east of the Belcher Islands, the surficial geology and surficial features have been mapped by Josenhans and Zevenhuizen (Josenhans et at., 1988, Josenhans and Zevenhuizen, 1990, Zevenhuizen and Josenhans, 1989). Interpretation and mapping are based on recently collected sidescan sonar and high resolution sub-bottom seismic data from Hudson Bay. In central Hudson Bay the generally thin veneer of Quaternary deposits has been interpreted to be composed primarily of glacial till. It appears that only the last glacial / deglacial cycle is recorded in the Hudson Bay sediments in the central area, with subsequent erosion to the bedrock with each readvance. Towards the south, thicker sections, which have been interpreted to represent multiple tills, are preserved within paleochannels.

Stratified silty glaciomarine sediments overlying the tills are generally less than 5m thick.

The postglacial sediments in Hudson Bay generally are thin (<5m) and selectively deposited near river estuaries and in localized depressions. On the basis of sedimentary patterns, modern (erosive) seafloor currents appear to be localized and seafloor disturbance by grounded ice has been restricted to the nearshore areas (approximately 20m depth) since deglaciation.

Surficial features were identified based primarily on sidescan sonar data (Josenhans and Zevenhuizen, 1990, Zevenhuizen and Josenhans, 1989). Detailed analysis of the well preserved geomorphic features observed on the floor of Hudson Bay indicated that these are similar to subaerially exposed glaciogenic features observed around the perimeter of Hudson Bay. Subglacial features observed include fluted terrains with superimposed rogen moraines, relief attributed to ice surging, eskers, subglacial channels and dead ice topography. Distinctive glaciogenic and stratigraphic indicators are well preserved in the floor of Hudson Bay and indicate minimal postglacial deposition. This supports the interpretation of extremely rapid deglaciation of Hudson Bay and implies low deposition rates in the present day.

In the study region (Figure 2) the unconsolidated surficial sediments are primarily the product of glacial and postglacial processes. Vincent (1989) presented a regional perspective of the late glacial history of the region while Allard and Sequin (1985), Allard and Tremblay (1983a,b), and Hillaire-Marcel (1976) provided more site specific information. Unconsolidated sediments in the Grande Rivière de la Baleine, Petite Rivière de la Baleine, and Manitounuk Sound region are interpreted to represent from base to top: glacial till deposited as the ice sheet retreated to the Sakami Moraine ice margin (Figure 6) position, glaciolacustrine sediments related to the glacial Lake Ojibway phase (Figure 3), ice proximal glaciomarine sediments associated with the invasion of the Tyrrell Sea (Figure 3), ice distal glaciomarine Tyrrell Sea sediments, postglacial marine sediments, and deltaic-estuarine sediments. This stratigraphic succession is well preserved in cross-section in both the Grande Rivière de la Baleine (Figure 3) and Petite Rivière de la Baleine valleys, although the entire sequence is preserved only in the Grande Rivière de la Baleine valley (Bilodeau *et al.*, 1990b). The eastern limit of Lake Ojibway sediments is marked by the Sakami Moraine which terminates onshore just southwest of Kuujjuaraapik (Figures 2 and 6). In all the previous literature, the seaward extent of Lake Ojibway appears to be speculative and inconsistant. This inconsistency is shown by comparing the limit of regional inundation by Lake Ojibway of Dredge and Cowan (1989, Figure 3.23) to the limit mapped by Vincent (1989, Figure 3.47). These two maps occur in the same chapter describing the Quaternary geology of the Canadian Shield (Dyke *et al*, 1989). Dredge and Cowan (1989) show that Long Island and most of James Bay (Figures 1,2) were not inundated by glacial Lake Ojibway, while Vincent (1989) shows that all of Long Island and the entire Quebec portion of James bay were inundated by the glacial lake.

Marine waters from Hudson Strait penetrated Hudson and James bays when glacial Lake Ojibway drained (Hardy, 1976). As the ice margin retreated, sea levels were substantially

Figure 6:

Main glacial landforms of the southeastern Hudson Bay region. Note the position of Harricana Interlobate and Sakami Re-equilibation Moraines. Map was primarily digitized from Vincent (1989). The detailed distribution of the Sakami Moraine was digitized from Hardy (1982).

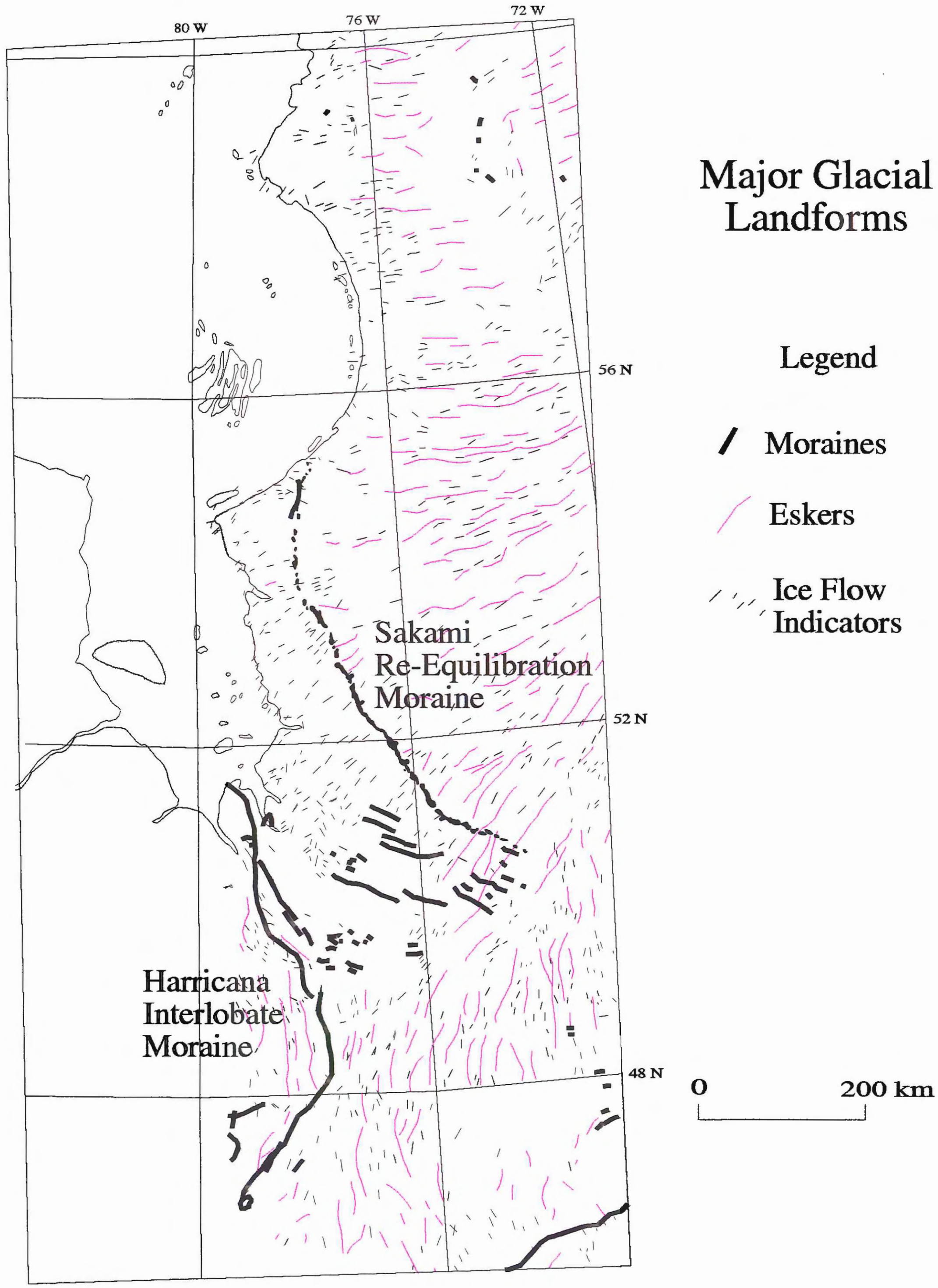

80 W
76 W
72 W
56 N
52 N
48 N
Major Glacial Landforms
Legend
Moraines
Eskers
Ice Flow Indicators
Sakami Re-Equilibration Moraine
Harricana Interlobate Moraine
0
200 km

Figure 6

higher than present due to isostatic depression of the region. Maximum recorded marine limit in the area is 315 m above present day sea level (Vincent, 1989). The area is rapidly emerging (Figures 4 and 5); a minimum emergence curve for Richmond Gulf (Vincent, 1989, Figure 3.58) (Hillaire-Marcel, 1976,1979) indicates that at the time of deglaciation uplift was rapid (10.0-6.5m/century) decreasing to 1.1m/century for the present day. Deglaciation for the area west of the Sakami Moraine (Vincent, 1989, Figure 2) is estimated at 8.1 ka (Hillaire-Marcel, 1976). In the Nastapoca River region a date of 6.7 ka obtained 45m below the marine limit indicates that isostatic rebound was well underway by that time (Allard and Sequin, 1985). These onshore sections are fairly analogous to the offshore sediment packages found in both Manitounuk Sound and farther offshore. Bilodeau *et al.* (1990a) compare a core collected approximately 24 km northwest of the mouth of the Grande Rivière de la Baleine to the stratigraphic sequence found along the river banks. Along the river sections the basal unit consists of till and proglacial sands overlain by glaciolacustrine, overlain by Tyrrell Sea marine muds which in turn is overlain by deltaic and estuarine sands (Bilodeau *et al.*, 1990b, Hillaire-Marcel, 1979, Vincent, 1989). In the offshore the interpreted sequence consists of till, overlain by glaciolacustrine/marine, overlain by Tyrrell Sea and the recent marine muds (Bilodeau 1990a,b, Zevenhuizen, 1991,1993, Zevenhuizen *et al.*, 1994, Gonthier *et al.*, 1993). A strong correlation exists between the visual observations of the onshore stratigraphic sections and the offshore seismostratigraphy.

The surficial marine geology of the Grande Rivière de la Baleine - Petite Rivière de la

Baleine offshore study area has been surveyed by the Atlantic Geoscience Centre for a variety of applications since 1987. This has been primarily through the collection and study of geophysical and sample data.

The data and preliminary analysis for the study area were catalogued in the format of cruise reports (Zevenhuizen and Josenhans, 1988; Josenhans and Johnston, 1990; Smith and Zevenhuizen, 1991; Amos *et al.*, 1992; Zevenhuizen *et al*, 1992) and technical reports (Marsters, 1988; Henderson, 1989; Bilodeau *et al.* ,1989; Zevenhuizen, 1991, 1993; Hardy and Zevenhuizen, 1993) which provide raw data with limited interpretation. Small scale mapping was completed within Manitounuk Sound (CSSA, 1991a-j) and the Grande Rivière de la Baleine estuary (Gonthier *et al*, 1993). Data collected up to 1990 was high-graded and published in the form of highlights by Josenhans *et al.* (1991). Paleo-environmental description of the marine sediments based on the micropaleontological and palynological analysis of the type section core 87-028-069 was completed by Bilodeau *et al.* (1990a). The 1992 data set was collected primarily for toxic flux and baseline studies prior to the James Bay II hydro-electric development. Present day sediment mobility (Amos *et al.*, 1993), sediment geochemistry (Buckley et al, 1993) and the sediment budget (Zevenhuizen *et al.*, 1994) were determined from this data.

The contributions made by this thesis are integration and synthesis of the above data and the comprehensive mapping of the surficial marine geology of the region (over 600 km^2). Due to the rapid and continuous emergence of this coast a strong correlation exists between the visual observations of the onshore stratigraphic sections and the offshore seismostratigraphy. Also based on detailed sidescan sonar and bathymetric data it is possible to extend terrestrial glacial terrain morphology and landforms into the marine region. Therefore another major component of this thesis is onshore-offshore correlation of the surficial sediments. From these data a model for the late Quaternary -early Holocene deglacial history of the marine region are presented and discussed.

CHAPTER 4: METHODS

Marine field data collected for this project span from 1987-1992 and include seven surveys. Primary methodology used for this project was established by King (1976) and Gunleiksrud and Rokoengen (1976). Their marine mapping methodology for regional reconnaissance surveys consists of a very simple but effective three step process which can be successfully applied in a cost effective manner to any marine geophysical and bottom sampling program. The steps are: 1.) generate as detailed a bathymetric chart for the survey region as possible (Figure 7); 2.) complete an archival data search and prepare these data in a similar format as the bathymetry (Figures 8,9); and 3.) incorporate the bathymetry and archival data to plan and complete a detailed geophysical and sampling survey. This simple method reduces redundance and facilitates survey planning and logistics. This method provides a good foundation which can then be systematically updated.

4.1 - DATA COMPILATION

All seismic reflection, sidescan sonar and bottom sample data collected by the Atlantic Geoscience Centre and Hydro- Quebec in the Grande Rivière de la Baleine region were compiled and integrated. Data were collected on seven cruises; *CSS Hudson* 92-028H, *MV Septentrion* 92-028S, CSSA 1990, *CSS Baffin* 90-017, *CSS Baffin* 90-024, *CCGS Narwhal* 1988 and *CSS Hudson* 87-028 (Figures 8,9).

Figure 7:

Colour shaded bathymetry map with a forty metre contour interval for the study area. Data was derived from various sources. Field sheet and digital data was supplied by Hydrographer in charge Ed Thompson from the Inland Waters Division of the Canadian Hydrographic Service and Pierre Desrouche of Hydro Quebec.

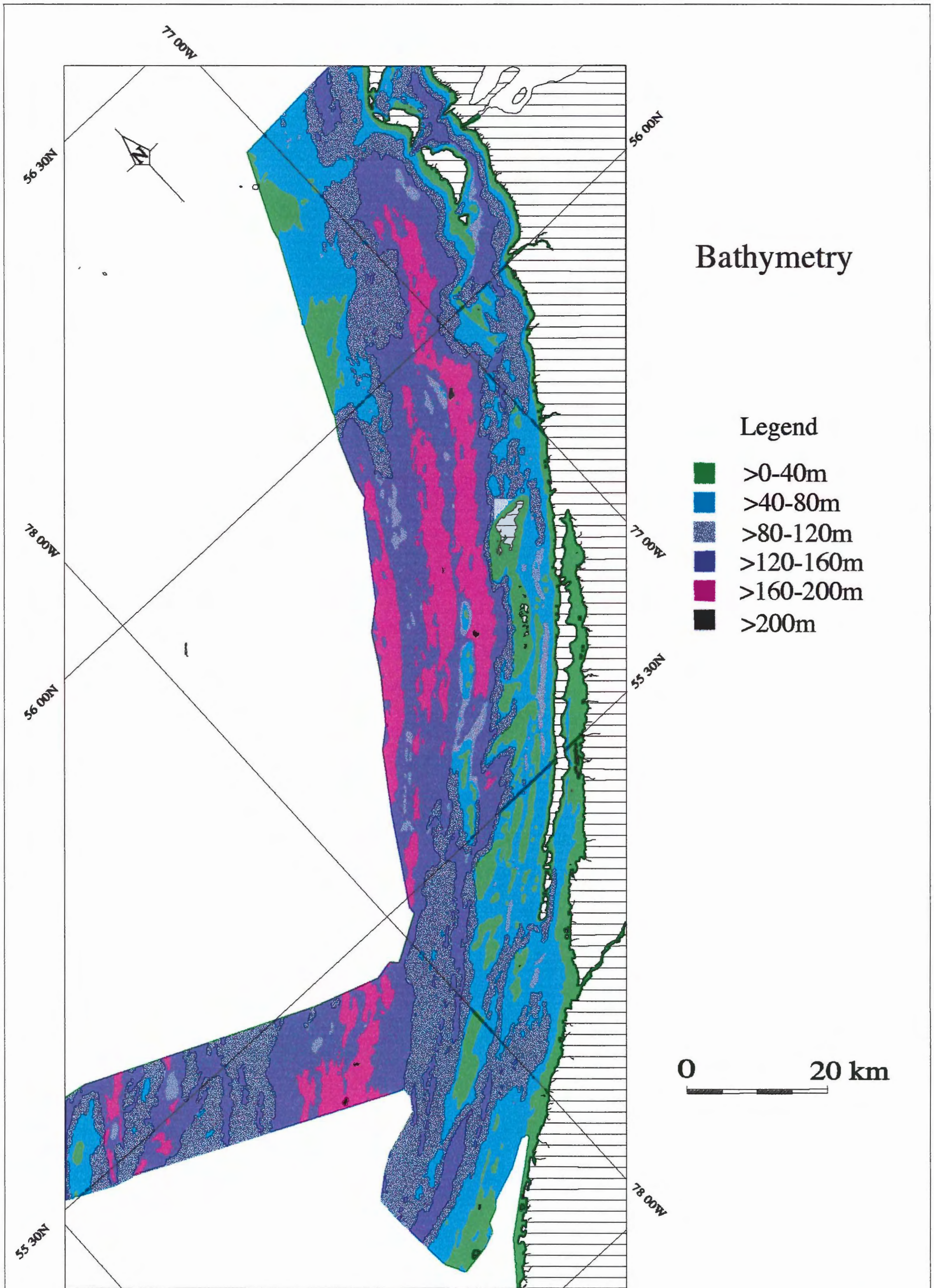

77 00W
56 30N
56 00N
77 00W
78 00W
56 00N
55 30N
55 30N
79 00W
55 00N
78 00W
Bathymetry
Legend
>0-40m
>40-80m
>80-120m
>120-160m
>160-200m
>200m
0
20 km

Figure 7

Figure 8:

Seismic control map showing all the available seismic reflection and sidescan data for the region. Surveys are differentiated by line type and colour.

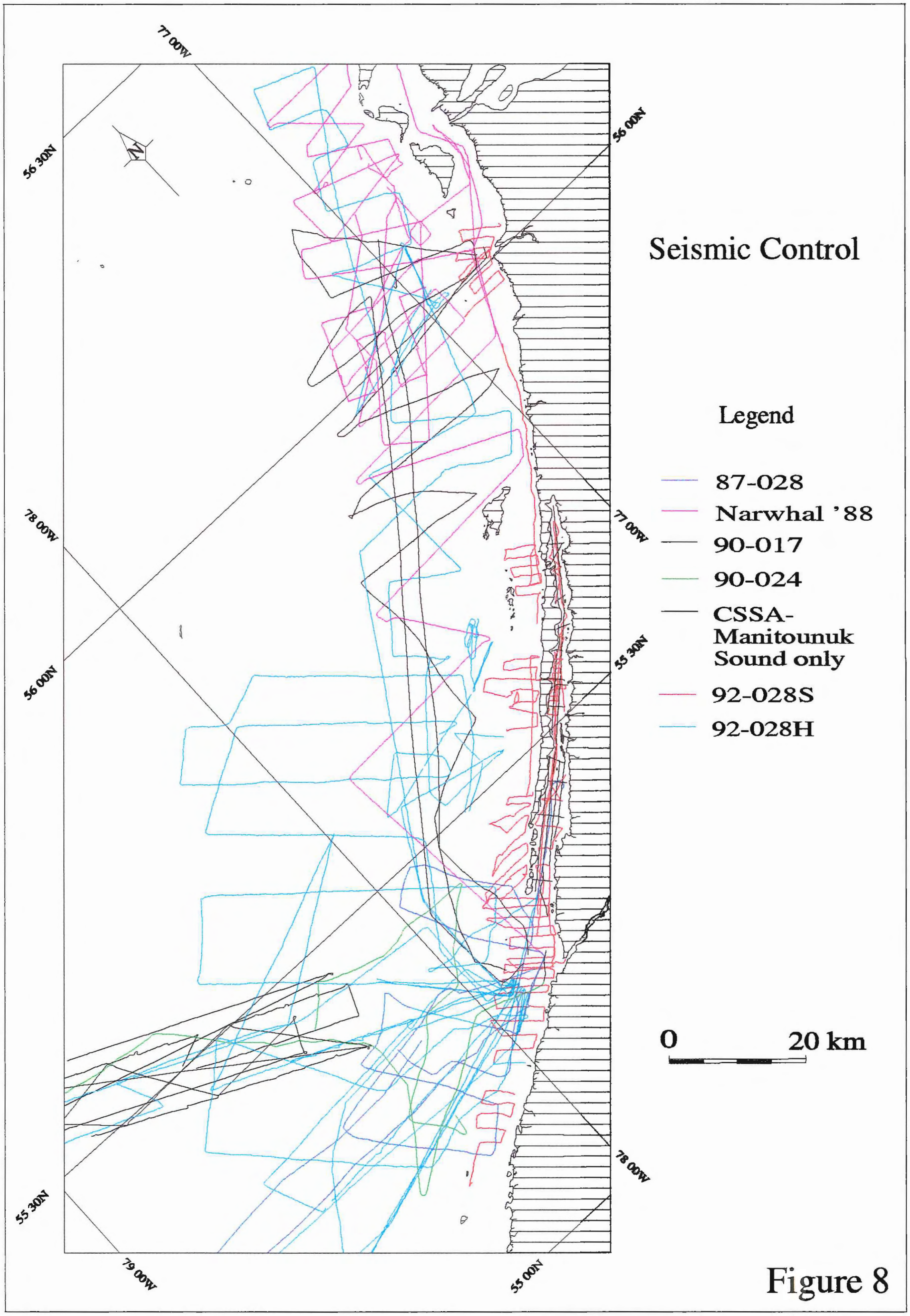

77 00W
56 30N
56 00N
Seismic Control
Legend
87-028
Narwhal '88
90-017
90-024
CSSA-
Manitounuk
Sound only
92-028S
92-028H
78 00W
77 00W
55 30N
56 00N
0
20 km
55 30N
78 00W
79 00W
55 00N

Figure 8

Figure 9:

Sample location map shows all the available bottom sample data. Samples are differentiated as core, grab and camera stations. The core stations could be one or a combination of AGC Long core, LeHigh gravity, Benthos Gravity or box core while the grab samples were all collected with various volume Van Veen grab samplers.

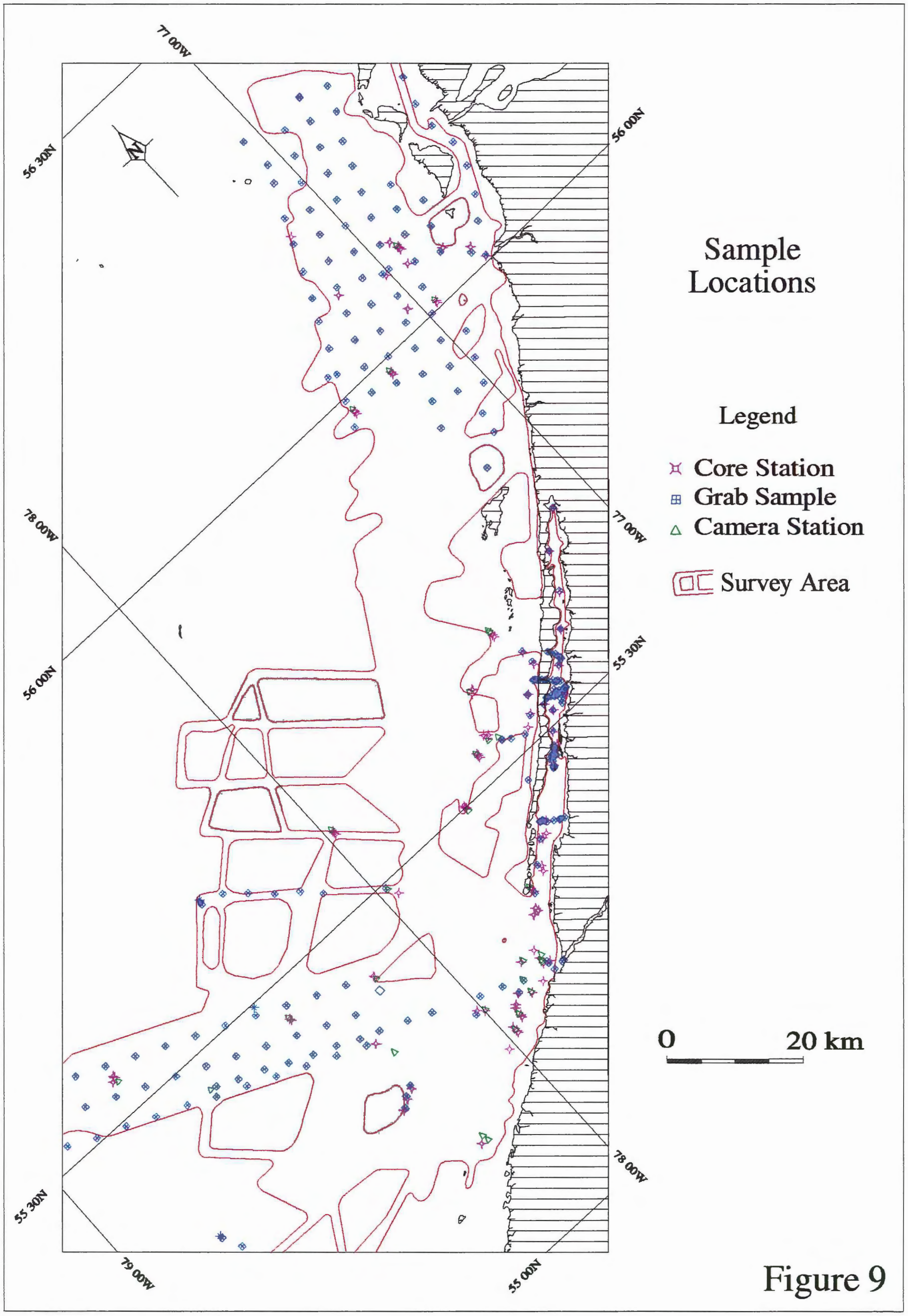

77 00W
56 30N
56 00N
78 00W
56 00N
77 00W
55 30N
55 30N
79 00W
55 00N
78 00W
Sample Locations
Legend
Core Station
Grab Sample
Camera Station
Survey Area
0
20 km

Figure 9

For this project more than 4000 line km of airgun or Huntec Sea-Otter Boomer data, more than 5000 line km of sub-bottom profiler data, 1500 line km of sidescan sonar and nearly 500 bottom samples were compiled and integrated.

4.1.1 - CSS HUDSON 87-028

During the 1987 field season, Atlantic Geoscience Centre *CSS Hudson* Cruise 87-028 obtained 560 line km of seismic reflection and Huntec Deep Tow System profiles, 350 line km of 3.5 kHz profiles, 260 line km of 70 kHz sidescan sonograms, together with sediment samples from 16 stations (including piston cores, gravity cores, VanVeen grabs, box corer). Data were also obtained from a 25 km BRUTIV camera sled transect and from 25 other stations (bottom camera, CTD, NISKIN water sampler S-4 and Amatek current profiler data). Navigation was by Satnav and radar (Josenhans,1988). Data was collected for Dr. Bruno D'Anglegan of McGill University and was primarily restricted to region of the Grand Rivière de la Baleine estuary extending to approximately 25km offshore with one reconnaissance line completed up to the Paint Islands in Manitounuk Sound (Gonthier *et al.*, 1993)(Figures 8,9).

4.1.2 - CCGS NARWHAL

In 1988 on an opportunity basis Atlantic Geoscience Centre staff collected 580 line km of sparker and Sea-Otter boomer seismic refection data, 800 line km of 3.5 kHz sub-bottom profiler data, 330 line km of 100 kHz sidescan sonograms, and 59 Shipek grab samples during a Canadian Hydrographic Service *CCGS Narwhal* cruise. Navigational positioning was by Canadian Hydrographic Service's Seylidis System with 1 m accuracy (Zevenhuizen and Josenhans, 1988). This survey was focussed around the Nastapoca Islands and Petite Rivière de la Baleine region with a few regional shore normal seismic survey lines completed from Duck Island to the southern extent of the Manitounuk Island chain (Figure 8,9).

4.1.3 - CSS BAFFIN 90-017

In 1990 Atlantic Geoscience Centre staff, on an opportunity basis, collected 450 line km of 3.5 kHz sub-bottom profiler data and 95 Van Veen grab samples during Canadian Hydrographic Service *CSS Baffin* Cruise 90-017. Navigational positioning was by Canadian Hydrographic Service's Seylidis System with 1 m accuracy (Smith and Zevenhuizen, 1990). This survey was restricted to an offshore corridor extending from approximately 30km west of the Grande Rivière de la Baleine estuary to the southern edge of the Belcher Islands (Figures 8,9).

4.1.4 - CSS BAFFIN 90-024

Atlantic Geoscience Centre *CSS Baffin* Cruise 90-024 collected 501 line km of Huntec Sea-Otter Boomer seismic reflection data, 856 line km of 3.5 kHz sub-bottom profiles, 367 line km of 100 kHz sidescan sonar data, and 27 bottom samples (LeHigh and Benthos gravity cores, VanVeen grab samples). Navigational positioning was by Canadian Hydrographic Service's Seylidis System with 1 m accuracy (Josenhans and Johnston, 1990). Seismic data was collected off the mouth of the Grande Rivière de la Baleine and extending to the Belcher Islands (Figure 8). Core and grab samples were collected off the mouths of the Grande Rivière de la Baleine and the Petite Rivière de la Baleine (Figure 9). These samples are catalogued and described by Zevenhuizen (1991).

4.1.5 - CSSA CONSUL

Hydro-Quebec through CSSA Consul completed a detailed survey of Manitounuk Sound. For this geological compilation project, data from 175 line km of Sea-Otter Boomer, 175 line-kilometres of 7 kHz sub-bottom profiles and 175 line-kilometres of 100 kHz sidescan sonar were used (CSSA, 1991a-d)(Figure 8). Due to the regional nature of this thesis, the high density of data collected at the outfall site in the central Manitounuk Sound was not used (CSSA, 1991j).

4.1.6 - CSS HUDSON 92-028H

In the 1992 field season, Atlantic Geoscience Centre in conjunction with Centre Geoscientific de Quebec and Hydro Quebec completed a two vessel (*CSS Hudson* and *MV Septentrion*), launch, zodiac and helicopter survey. For geophysical data, *CSS Hudson*

Cruise 92-028H obtained 1400 line km of seismic reflection and Huntec Deep Tow System profiles, an additional 1660 line km of 3.5 kHz profiles as well as 600 line km of 100 kHz sidescan sonograms. The bottom sampling program consisted of sediment samples collected from 119 stations (including piston cores, gravity cores, VanVeen grabs, box corer) and from 26 process related stations (sediment traps, Niskin water samples, camera stations as well as Sea-Carousel, RALPH, SOBS and Excalibur deployments for in-situ measurements). Navigation was GPS/BIONAV (Amos *et al.*, 1992). The entire offshore area from Bear Islands to Belanger Island was surveyed and sampled with the major effort concentrated at the mouth of Manitounuk Sound and the Grande Rivière de la Baleine estuary (Figures 8,9). Geophysical and sidescan sonar data was interpreted and mapped by Zevenhuizen (1993) and Zevenhuizen *et al.* (1994). The analysis of the bottom sample data is currently ongoing, with the preliminary results released by Hardy and Zevenhuizen (1993).

4.1.7 - MV SEPTENTRION 92-028S

The *MV Septentrion* and ship's crew were provided by Hydro Quebec. A geophysical and sampling survey was completed from Moosonee, Ontario to Richmond Gulf, Quebec. Efforts were concentrated at: 1.) Nottaway, Broadback and Rupert Rivers (NBR) proposed Hydro-electric development site; 2.) the La Grand River estuary; and 3.) the Grande Rivière de la Baleine, Petite Rivière de la Baleine and Nastapoca River proposed James Bay II (GWR) hydro-electric site (Zevenhuizen *et al.*, 1992). A regional tie line extending from the NBR site to the GWR site was only partially completed (Amos et al, 1992, Zevenhuizen *et al.*, 1992).

For geophysical data, *MV Septentrion* 92-028S obtained 600 line km Huntec Sea-Otter Boomer System and 3.5 kHz profiles as well as 400 line km of 100 kHz sidescan sonograms (Figure 8). The bottom sampling program consisted of sediment samples collected from 119 stations (including piston cores, gravity cores, VanVeen grabs, box corer) The entire nearshore area from Bear Islands to Belanger Island was surveyed (Figure 9). The sampling effort was concentrated in the Grande Rivière de la Baleine, Manitounuk Sound and the first Manitounuk Island chain parallel trough with the major effort in the trough concentrated at the mouth of Schooner and Boat Openings (Figures 1,2). Geophysical and sidescan sonar data was interpreted and mapped by Zevenhuizen (1993) and Zevenhuizen *et al.* (1994). The analysis of the bottom sample data and is currently ongoing, with the preliminary results released by Hardy and Zevenhuizen (1993) and Gray (1994).

4.2 - INTEGRATION

As the data were collected during seven different cruises using different vessels, navigation systems, equipment and technical staff some problems with consistency were encountered. Integration difficulties resulted from a range of equipment types, differences in system resolution, varying layback corrections, navigational system variability, and data quality variations. To compensate for these problems all data were corrected to the sub-bottom profiler data. On all vessels the sub-bottom profiler data were collected in close proximity to the vessel and navigation receivers and thus were the most precisely positioned, layback was therefore referenced and calculated from the sub-bottom profiles. Profile navigational positions were corrected at line cross-overs to agree with those from cruises navigated using the most accurate Canadian Hydrographic Service Seylidis system which were deemed to be the most precise. The majority of the navigation problems were encountered with the *CSS Hudson* Cruise 87-028 where >200 m offset occurred 15-20 km offshore due to the more limited accuracy of the shipboard navigational systems.

The seismic reflection data consisted of profiles obtained from a 655 cm^3 acoustic source and Nova Scotia Research Foundation hydrophone, Huntec DES high resolution profiles (with internal and external hydrophone data)(2 cruises), Huntec Sea-Otter Boomer profiles (from five cruises), multi-tipped sparker profiles (1 cruise), and 3.5 kHz and 7 kHz (hull mounted and towed) sub-bottom profiler systems (from seven different cruises). Sidescan sonar data were collected using both hand and winch deployed towed instruments of different frequencies (70-100 kHz) and depth capabilities.

Sample analytical results were compiled, integrated and correlated with the seismic data.

4.3 - INTERPRETATION AND DIGITIZATION

The first task completed for this project was a series of 1:50 000 hand contoured bathymetry base maps for the seismic and sample data. The seismic data were interpreted on the basis of reflection character, and information on sediment distribution, sediment thickness and seabed features were digitized and mapped. Sediment thicknesses are computed in metres based on an assumed seismic velocity of 1500 m/sec in unconsolidated sediments. The bathymetry was digitized using the Atlantic Geoscience Centre CARIS GIS and the geological mapping was completed using AutoCAD 11, based on a UTM grid (zone 18).

A series of 1:50,000 maps were produced for bathymetry, seismic and sample control, surficial geology, total unconsolidated sediment isopach, postglacial sediment isopach, and surficial features. A series of 1:250 000 overview maps of the above as well as glaciolacustrine/marine and till/ice contact sediment isopach maps and digital files for further analysis were prepared. Cross-sections were generated and interpreted, and representative seismic sections are included (Figure 10).

4.4 - MAPS

Many of the maps used in this thesis were originally digitized at a 1:50 000 map scale and reproduced at 1:50 000 and 1:250 000 by Zevenhuizen (1993). The approximate

Figure 10:

The figure locations map shows the positions of the seismic sections illustrated in the text. The bold lines refer to approximate figure extent and orientation while the numbers indicate appropriate figure reference.

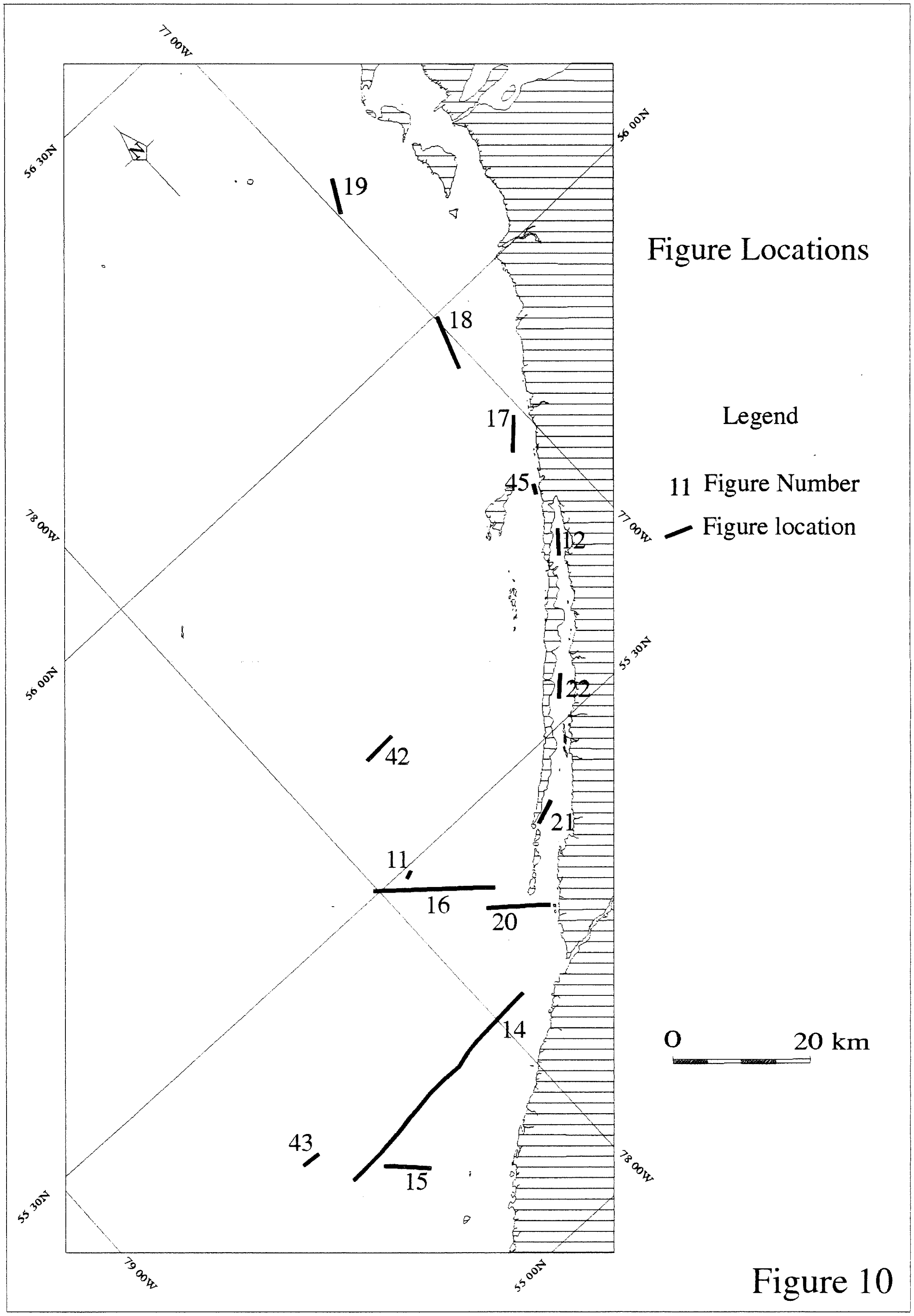

77 00W
56 30N
56 00N
N
19
Figure Locations
18
17
Legend
45
11 Figure Number
Figure location
77 00W
12
78 00W
55 30N
56 00N
22
42
21
11
16
20
14
0
20 km
43
15
78 00W
55 30N
79 00W
55 00N

Figure 10

scale of the page size maps is 1: 750 000 (UTM Zone 18, NAD27). With the exception of the bathymetry map all the colour maps accurately reproduce the data as originally displayed on the 1:50 000 map sheets.

4.4.1 -BATHYMETRY MAP

This map (Figure 7) was digitized from two sources. The regional data was digitized from a series of 1:50 000 field sheets supplied by Ed Thompson of the Inland Waters Division, Canadian Hydrographic Service in Burlington Ontario using AutoCAD. Survey line density in this region is generally less than 500m spacing. Original field sheet contour intervals ranged from 1m in the Grand Rivière de la Baleine estuary to 20m along the steep slopes of the cuesta ridges. In general the contour interval was a 5m contour interval from the shoreline to approximately 5km offshore and a 10m contour interval from 5km offshore to the western margin of the survey area. A slight error is present towards the western extreme of this corridor (west of $79^0 50'$W) as the field sheet for this area was generated in a different UTM zone (UTM Zone 17, NAD27) and visually spliced into the present map. This introduces a rotational error and position shift of less than 100m in this area. The second bathymetric data source was for Manitounuk Sound which was not surveyed by the Canadian Hydrographic Service but by CSSA Consul of Montreal for Hydro Quebec (CSSA, 1990). These maps were digitized from a 1:50 000 map sheet with 5m contour interval. In areas of limited data within the sound the contours were corrected using the *MV Septentrion* 92-028 bathymetry data (Figure 8).

Larger scale versions of these bathymetry maps are available at both 1:50 000 and 1:250 000 scales in Zevenhuizen (1993). The bathymetry map (Figure 7) was simplified to a 40m contour interval due to the sheer size of the original data file. The map was redigitized and partially generalized from the 1:250 000 scale map (Zevenhuizen, 1993).

4.4.2 - SEISMIC CONTROL

This map (Figure 8) indicates the large volume of high resolution geophysical data collected in the region. Between 1987 and 1992 seven geophysical and sampling survey cruises were completed in the area. Ship's tracks along which high resolution reflection seismic and sidescan sonar data were collected are shown with the individual surveys differentiated by colour. With the exception of the CSSA Consul - Manitounuk Sound survey this data was initially compiled at the Atlantic Geoscience Centre and reproduced at both Mercator and Lambert Conformal projections. The data were then corrected to UTM Zone 18, NAD27 for mapping and digitizing purposes. In total over 4000 line kilometres of data were collected in the survey area.

4.4.3 - SAMPLE LOCATIONS

A large suite of representative bottom sample data was collected primarily on *CSS Hudson* 87-028 and the two 92-028 cruises, *CSS Hudson* and *MV Septentrion*. The remainder of the grab sample data was collected by the Canadian Hydrographic Service for substrate characterization. Many different sampling devices were used during these surveys: only the substrate sampling devices are mapped. Differentiated on the map (Figure 9) are core, grab and bottom camera station locations. The core stations include a variety of coring devices including AGC Longcore, Benthos piston, LeHigh gravity and various size box cores. Grab samples included various size Van Veen and IKU large volume samplers. The 1987 results are described in detail in Henderson (1989), Marsters (1988), Bilodeau *et al.* (1990a), Zevenhuizen (1991) and Gonthier *et al.* (1993) while the 1992 results are described in detail in Zevenhuizen (1993), Zevenhuizen *et al.* (1994), Amos *et al.* (1992, 1994), Hardy and Zevenhuizen (1993), Gray (1994) and Buckley *et al.* (1993). Canadian Hydrographic Service data was catalogued by Zevenhuizen and Josenhans (1988), Josenhans and Johnston (1990) and Smith and Zevenhuizen (1990).

4.4.4 - INTERPRETIVE MAPS

In the following sections the methodology used to generate the interpretive maps is discussed. The actual maps are not referenced in the text until the discussion section of the thesis.

4.4.4.1 - SURFICIAL GEOLOGY

Huntec DTS and Huntec Sea Otter boomer reflection seismic data coupled with sidescan sonar data were used to map the regional extent of the various surficial geological units.

Where possible the seismostratigraphic data was correlated with the lithostratigraphy derived from the bottom sample core analysis. The regional extent of the units was extrapolated from line to line (Figure 8). Basically, the three surficial unconsolidated sediment units and bedrock outcrop are mapped. Both the postglacial sediments and the till/ice contact are subdivided into two distinct units. The postglacial is subdivided into marine and postglacial estuarine muds and the till/ice contact sediments are subdivided into continuous till/ice contact and discontinuous till over bedrock. Sediment failure/slump deposits are shown as individual outcrops as the composition of these sediments is variable, although it appears that the failure has occurred primarily in the glaciolacustrine/marine unit.

4.4.4.2 - POSTGLACIAL SEDIMENT ISOPACH

Based upon a detailed seismostratigraphic analysis the thickness and distribution of this unit was mapped. Primarily Huntec DTS and Huntec Sea Otter boomer reflection seismic data coupled with sidescan sonar data were used and groundtruthed using the lithostratigraphy where available (Figures 8,9). Thicknesses determined from the sub-bottom profiler and Huntec data are based on an assumed velocity of 1500m/sec. The regional extend of the units was extrapolated from line to line (Figure 8).

4.4.4.3 - GLACIOLACUSTRINE/GLACIOMARINE SEDIMENT ISOPACH

Based upon a detailed seismostratigraphic analysis the thickness and distribution of this unit was mapped. Primarily Huntec DTS and Huntec Sea Otter boomer reflection seismic data coupled with sidescan sonar data were used for groundtruthing using the lithostratigraphy where available (Figure 9). Thicknesses determined from the sub-bottom profiler and Huntec data are based on an assumed velocity of 1500m/sec. The regional extend of the units was extrapolated from line to line (Figure 8).

4.4.4.4 - TILL/ICE CONTACT SEDIMENT ISOPACH

Primarily Huntec DTS and Huntec Sea Otter boomer reflection seismic data coupled with lower frequency airgun data were used to map this unit. Thicknesses determined from the airgun, sub-bottom profiler and Huntec data are based on an assumed velocity of 1500m/sec. Lithostratigraphy for this unit is restricted to limited surface grab and small base of core samples. In isolated areas of thick accumulations a few continuous internal reflectors were observed indicating possible multiple tills or older sediments of which the source can only be speculated. Thickness of these sediments is undetermined and incorporated with the till/ice contact sediment thickness.

4.4.4.5 - TOTAL QUATERNARY SEDIMENT ISOPACH

All available seismic reflection data but primarily the Huntec DTS, Huntec Sea Otter boomer and airgun reflection seismic data were used to map total Quaternary sediment thickness. Thicknesses determined from the airgun, sub-bottom profiler and Huntec data are based on an assumed velocity of 1500m/sec.

4.5 - SAMPLE ANALYSES

The core analyses from the *CSS Hudson* 87-028 cruise were compiled from Geological Survey of Canada Open File Data Reports prepared by Marsters (1988), Bilodeau *et al.* (1989) and Henderson (1989). All the preliminary core analyses completed on the *CSS Hudson* 92-028H and *MV Septentrion* 92-028S were compiled by Hardy and Zevenhuizen (1993). These cores were collected using the Atlantic Geoscience Centre wide-diameter piston corer, LeHigh gravity corer and box corer.. The cores were split onboard, subsequently the cores were subsampled and x-rayed at Atlantic Geoscience Centre, physical property analysis was completed at the onboard. Foraminiferal and palynological analysis of the 1987 data was completed at GEOTOP located at the University of Quebec at Montreal. The foraminiferal analysis is based on the greater than 63 micron fraction.

Onboard the cores were split, photographed, logged and in situ shear vane and velocity measurements were obtained; the cores were subsampled for micropaleoentology, palynology, sediment texture.

4.6 - ADDITIONAL STUDIES

Due to the rapid and extensive glacio-isostatic recovery of the region much of the present day onshore was previously marine (Figure 5). Within sheltered areas morphological features and stratigraphic section have been preserved.

4.6.1 - ONSHORE STRATIGRAPHIC SECTIONS

Participation in all the regional surveys with the exception of the CSSA 1990 field program allowed the author to extensively review the onshore section. The 1987 survey fortunately was in the area just prior to the 1987 INQUA Field Trip (Vincent *et al.*, 1987). The Grande Rivière de la Baleine section was traversed from the first falls to the estuary reviewing all the sites in the area discussed by Vincent *et al.* (1987) with group leaders Dr. Claude Hillaire-Marcel and Dr. Michel Allard. In 1988 the opportunity presented itself to traverse Ross Island of the Nastapoca Island chain (Figure 2) and the Petite Rivière de la Baleine from the first falls to the estuary with Dr. Bruno D'Anglegan. In 1990 helicopter support provided the chance to travel with Dr. Jean Veillette to: 1.) the southeastern portions of the Belcher Islands; 2.) the shoreline from Petite Rivière de la Baleine to the mouth of Richmond Gulf; and 3.) the spectacular raised beaches of Richmond Gulf. Due to crew and vessel size restrictions the 1992 *MV Septentrion* survey was a daytime operation, anchoring every evening. This allowed an opportunity to complete various shore transects at the rate of one every 2 or 3 days. Shore transects were completed at the La Grande River estuary, Long Island, Grande Rivière de la Baleine estuary, Bill of Portland Island, Castle Island, Petite Rivière de la Baleine estuary and at Le Goulet the narrow channel which connects the Richmond Gulf to Hudson Bay. The excellent preservation of some of the onshore sections provided the unique opportunity to mentally compare the observed and accessible exposed lithostratigraphy to the marine seismostratigraphy and core lithostratigraphy.

4.6.2 - COASTAL VIDEO

In 1992 a series of coastal videos were collected from the southern Nastapoca Islands to Long Island (Figure 2)(Michaud and Frobel, 1993). During the opportunity to critically review these tapes (both video and audio), the regional coastal morphology as well as large scale glacial landforms were observed and correlated with the offshore features.

CHAPTER 5: SEISMOSTRATIGRAPHY

This section discusses and illustrates by examples the character and distribution of the regional seismostratigraphic units. Based on reflection seismic data seismostratigraphic sequences were determined and mapped. The seismic character, stratigraphic order, nature of contacts and geometry of the sediments are used to define the bedrock (Unit 1) surface and to subdivide the overlying unconsolidated sediment sequence into three units (Units 2-4, Figure 11) with two subunits in the uppermost unit (Units 4 and 4E, Figures 11,12). Along the seismic lines where a combination of either airgun, sleevegun or boomer and sub-bottom profiler data were collected, good penetration through the unconsolidated sediment package to bedrock was achieved to depths in excess of 80 m below seafloor. Where only sub-bottom profiler data are available, depth to bedrock could not be defined but the upper two unconsolidated sediment units (Units 3 and 4) could be differentiated. Due to the regional consistency of the acoustic character of the seismic units there is good correlation to the more limited lithostratigraphic and paleo-environmental core data (Chapter 6). Due to the rapid emergence of this coast the Quaternary sediments onshore are frequently preserved in the river valleys and isolated depressions. In the deeper basins of the marine environment the Quaternary sediments are well preserved. The marine section appears to be analogous to the onshore river sections.

5.1 - BEDROCK (UNIT 1)

The bedrock surface is marked by an initial high amplitude reflector (Figures 11,12,14-22). Beneath this surface, penetration of seismic energy is restricted to the upper part of the sequence where some evidence of parallel, evenly spaced, seaward dipping reflectors is observed. This unit has limited outcrop distribution at the seafloor but can be readily observed in terrestrial exposures on the coast. The bedrock exposed in the coastal outcrops is composed of interbedded Proterozoic volcanic and carbonate rocks that form a series of cuesta ridges. These are characterized by low relief on the western side with steep slopes on the eastern side. Airgun, sleevegun, Huntec DTS and Sea-Otter boomer data indicate that in the study area submerged cuesta ridges , with a similar southwest - northeast orientation to those that form the bedrock of the coastal areas, extend offshore for up to 40 km west of Grande Rivière de la Baleine and approximately 20 km west of Petite Rivière de la Baleine. The sequential ridges and intervening valleys produce a pronounced northeast - southwest grain to the seabed morphology and surficial geology (Figure 7). However, the apparent alignment of several coastal physiographic features on the mainland and Manitounuk Islands and bathymetric contours suggest the presence of some regional east - west structural trends diagonal to and in part offsetting the dominant northeast - southwest orientation of the cuesta ridges (Figure 7). The northwest dip associated with the cuesta ridges appears to reverse and change to a southeasterly dip approximately 35 km west of Bill of Portland Island and is marked by a strong synclinal axis. Just west (~5km) of the synclinal axis there is a very pronounced contact and a

Figure 11:

Huntec DTS boomer profile of the offshore type section. The profile shows typical offshore sediment sequences which consists of till/ice contact (Unit 2) (locally discontinuous) overlying bedrock (Unit 1), overlain by glaciolacustrine/marine (Unit 3) sediment which in turn is overlain by postglacial sediment (Unit 4). The type section core 87-028-069 (shown as dashed line on seismic section) was collected at this location. See Figure 10 for section location.

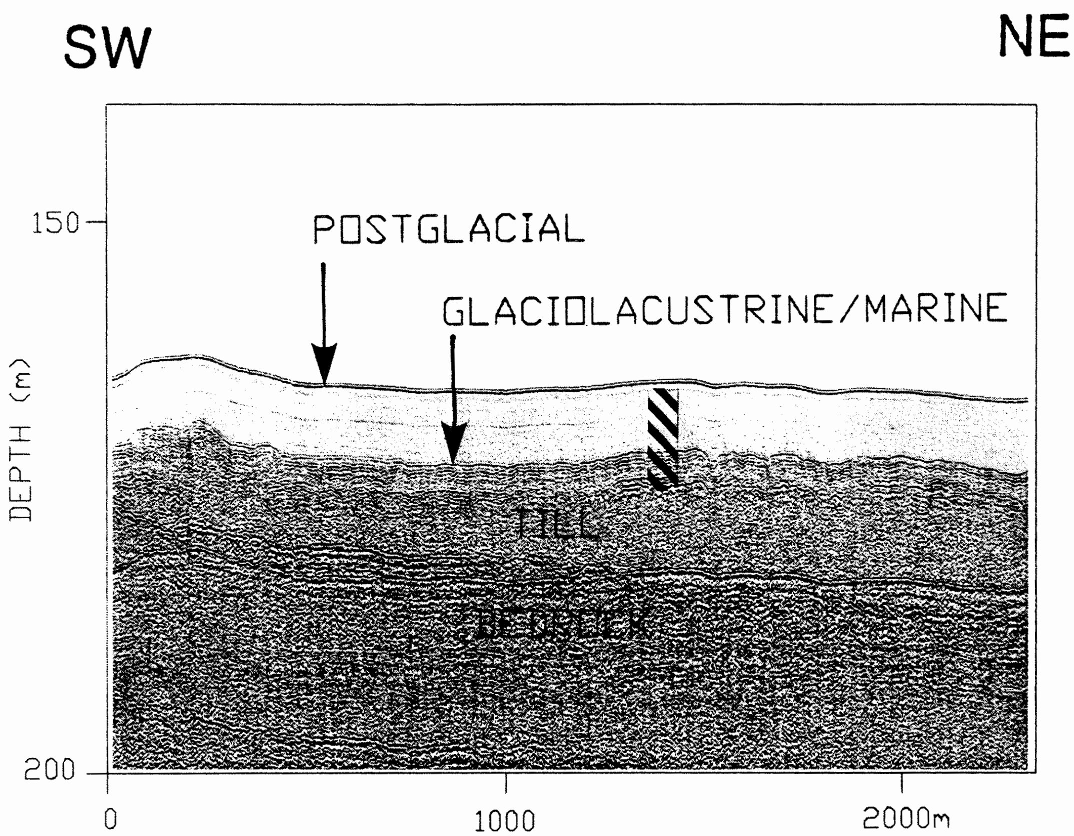

SW
NE
150
200
DEPTH (m)
POSTGLACIAL
GLACIOLACUSTRINE/MARINE
TILL
BEDROCK
0
1000
2000m

Figure 11

Figure 12:

Huntec Sea-Otter boomer profile displays the nearshore, estuarine, type section of thick undisturbed pro/postglacial sediments in Inner Manitounuk Sound (Figure 2). Note localized gas masking associated with decomposition of organic material within the sediments. Cores within Inner Manitounuk Sound have a high organic carbon content (Buckley, personal communication, 1993). See Figure 10 for section location.

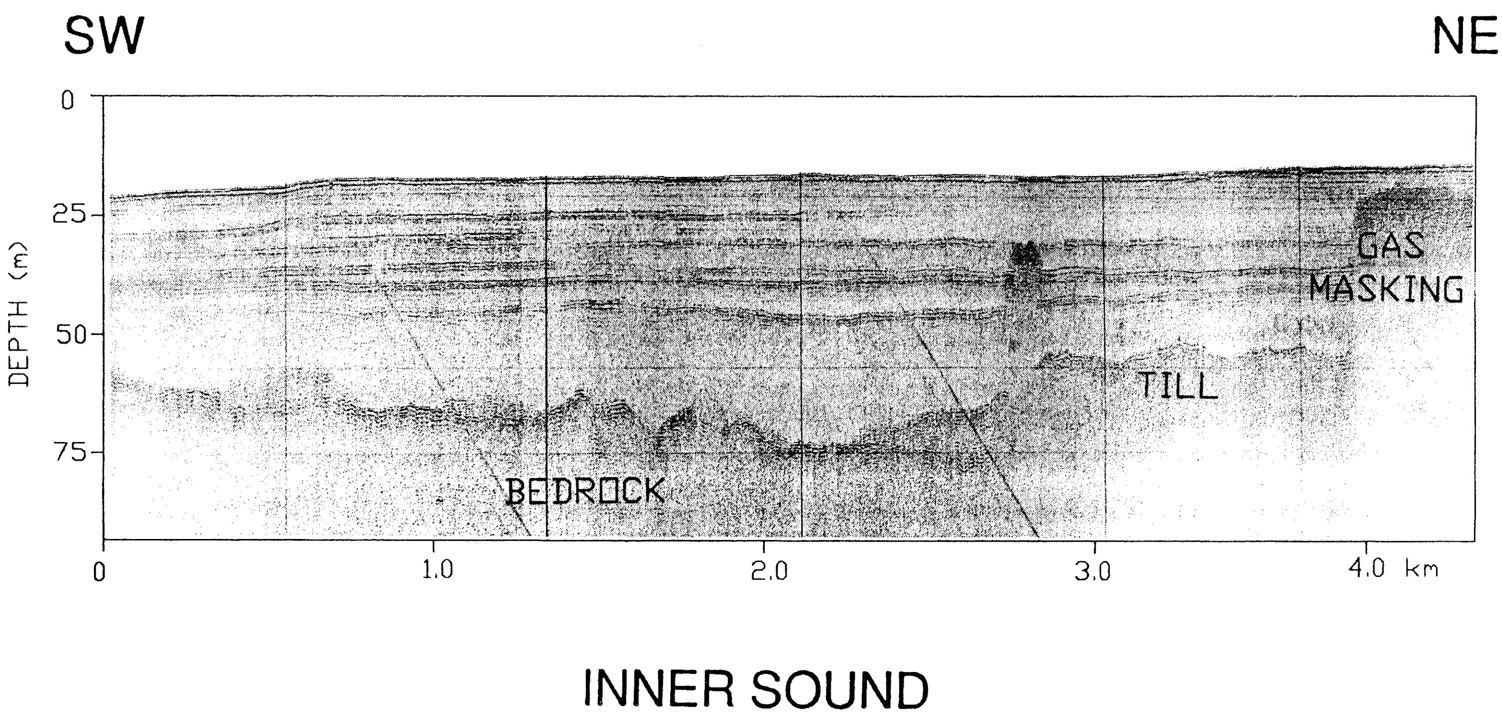

SW
NE
DEPTH (m)
0
25
50
75
GAS
MASKING
TILL
BEDROCK
0
1.0
2.0
3.0
4.0 km
INNER SOUND

Figure 12

Figure 13:

Legend for surficial geological units shown on the interpreted airgun profiles, Figure 14-19. These interpreted six 40 $inch^3$ sleevegun reflection seismic profiles show the variable till/ice contact (Unit 2) distribution throughout the study area.

Legend for Sleeve-gun Seismic Sections

- Bedrock (Unit 1)
- Till / Ice contact (Unit 2)
- Glaciolacustrine / marine (Unit 3)
- Postglacial muds (Unit 4)

Figure 13

Figure 14:

West to east sleeve gun profile extending from the Grande Rivière de la Baleine estuary seaward. Note that the bathymetric high consists of till/ice contact (Unit 2) deposits and does not appear to be bedrock controlled. The combined glaciolacustrine/marine (Unit 3) and postglacial sediments (Unit 4) are substantially reduced in thickness seaward of this morainal ridge. Seaward of the morainal ridge the postglacial sediments are postglacial marine muds while the inner basin sediments are postglacial estuarine muds. Sidescan sonar data between 3-4 km displays a fluted surface. Flute orientation is to the southwest. Sidescan sonar data from 18-20 km displays a hummocky surface with frequent point source reflectors interpreted to represent boulders. The surface of this section from 18-20 km appears to display a dead ice topography. For section location see figure 10.

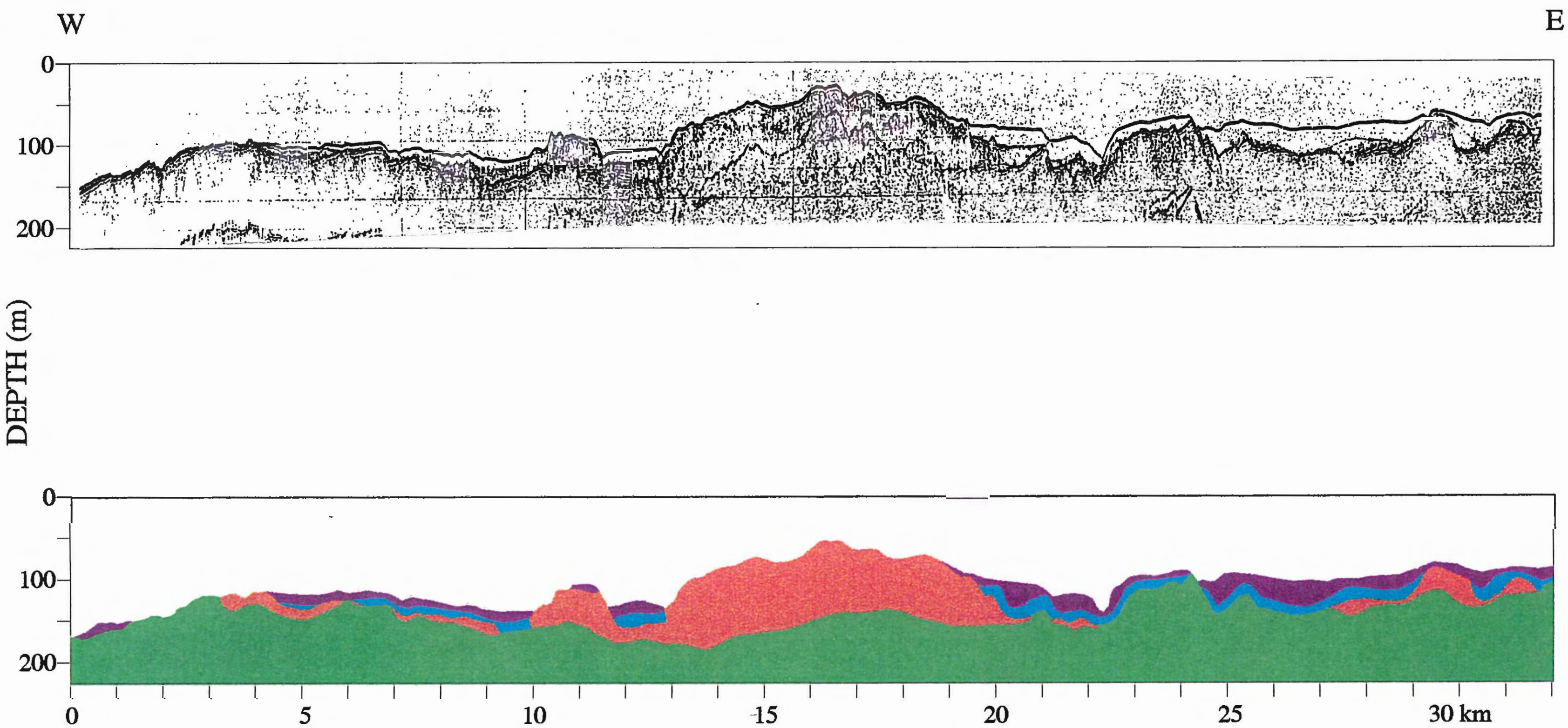


Figure 14

Figure 15:

Shore normal sleeve gun profile collected southwest of the Grande Rivière de la Baleine estuary. Note the thick accumulation of till/ice contact (Unit 2) deposits and the non-deposition/erosion of the glaciolacustrine/marine sediments (Unit 3) over the moraine. The moraine location does not appear to be bedrock controlled. See figure 10 for section location.

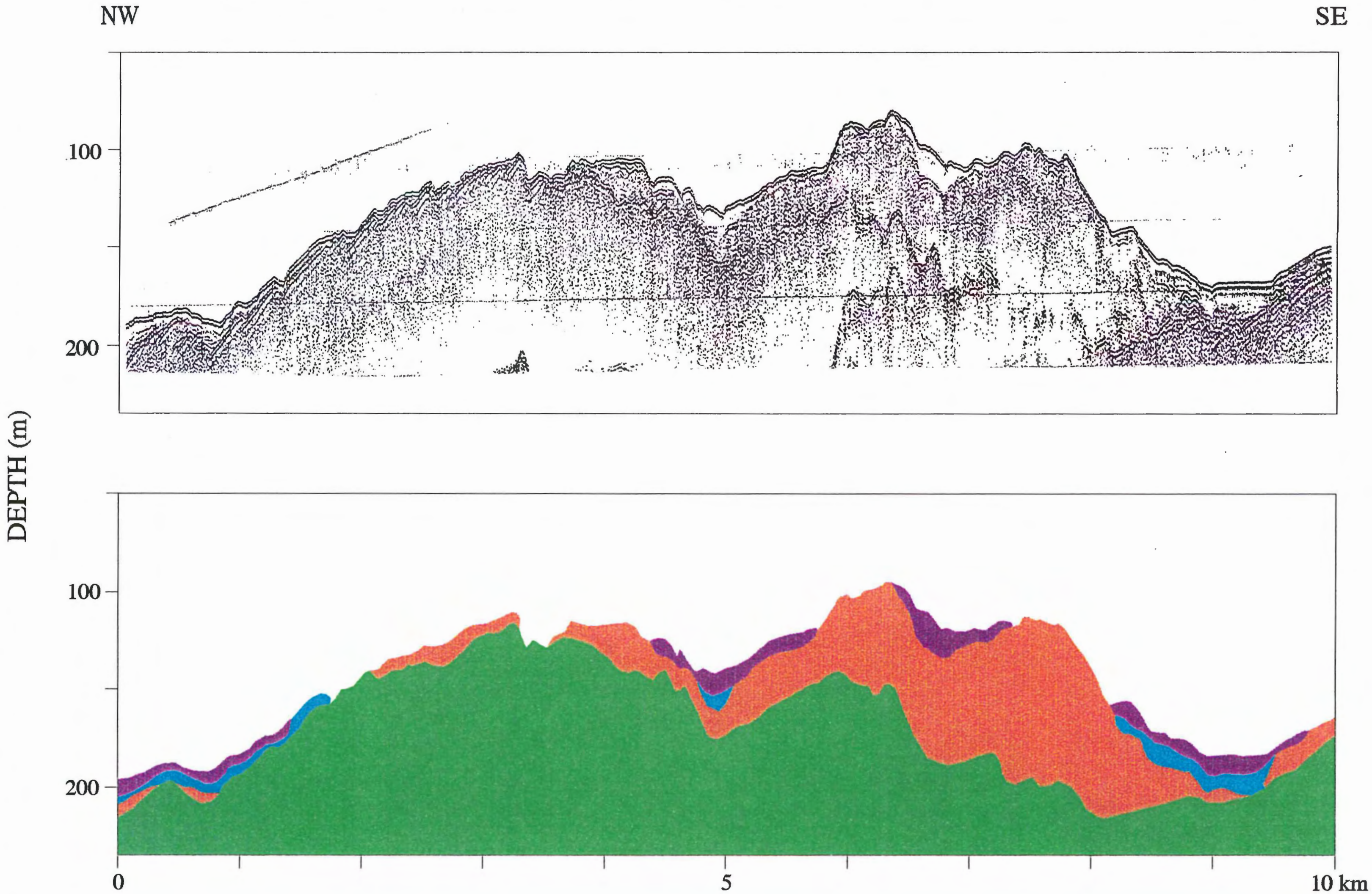


Figure 15

Figure 16:

Shore normal sleeve gun profile extending seaward from the crest of the first offshore cuesta ridge (Figure 7). Note the thick deposit of till/ice contact (Unit 2) sediments on the low angle seaward slope of the cuesta ridge. These till/ice contact (Unit 2) sediments become substantially thinner and discontinuous seaward of this moraine. Till/ice contact (Unit 2) sediments within the first seaward basin, west of the Manitounuk Island chain have a very irregular surface morphology and complex internal geometry (See figure 17). For section location see figure 10.

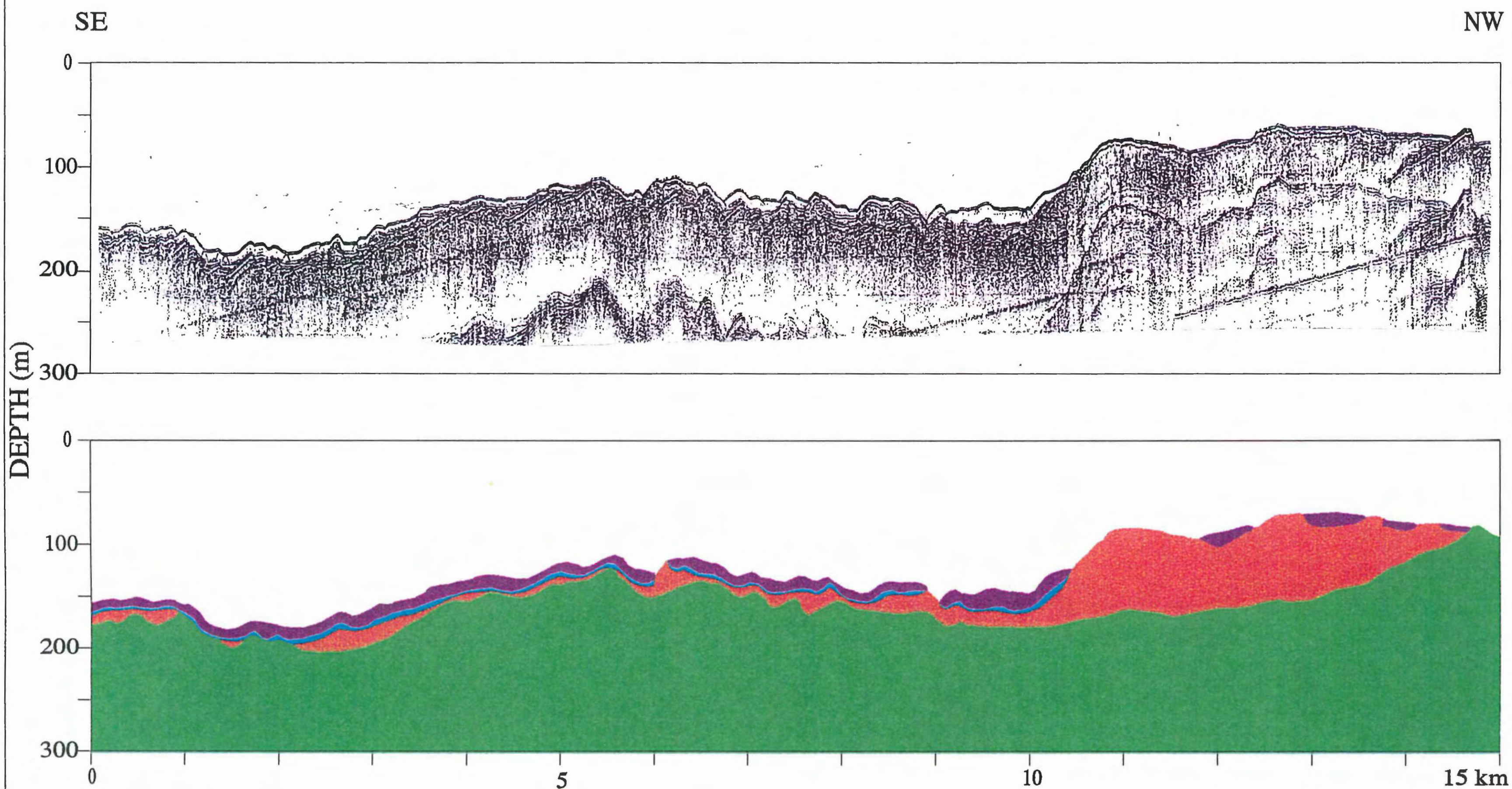


Figure 16

Figure 17:

Shore parallel sleeve gun profile collected across the estuary of a small river 30 km southwest of Petite Rivière de la Baleine. Note the complex morphology of the till/ice contact (Unit 2) sediments overlain by a conformable drape of glaciolacustrine/marine (Unit 3) sediments. Postglacial sediments display both a ponded and disturbed character. The disturbed postglacial sediments towards the southwest appear to be slump deposits. For section location see figure 10.

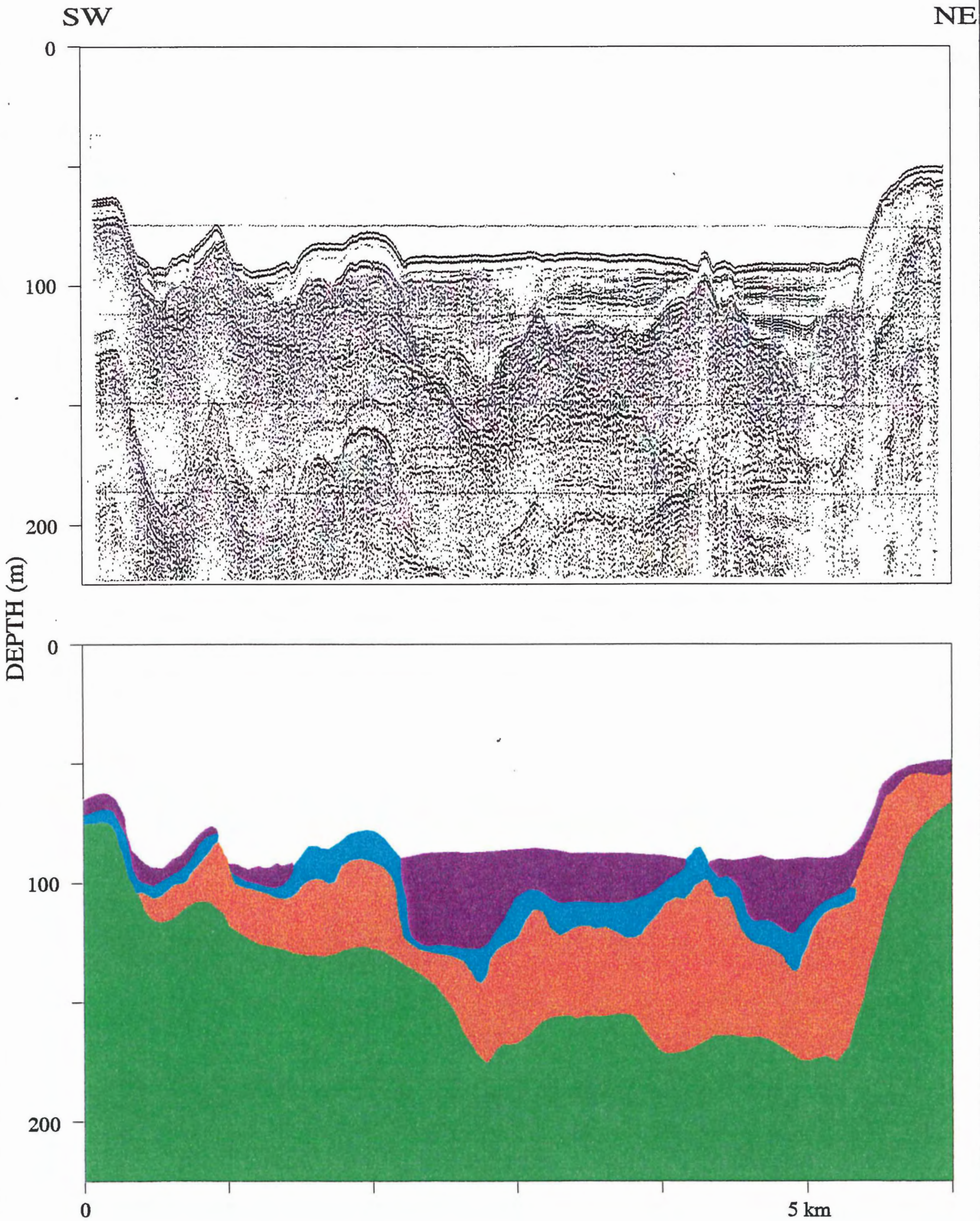


Figure 17

Figure 18:

Shore parallel sleeve gun profile along the crest of the first cuesta ridge, southwest of the Petite Rivière de la Baleine estuary. Profile is located approximately 12 km offshore. Note thick accumulation of till/ice contact (Unit 2) sediments along the ridge without any apparent bedrock control. See figure 10 for section location.

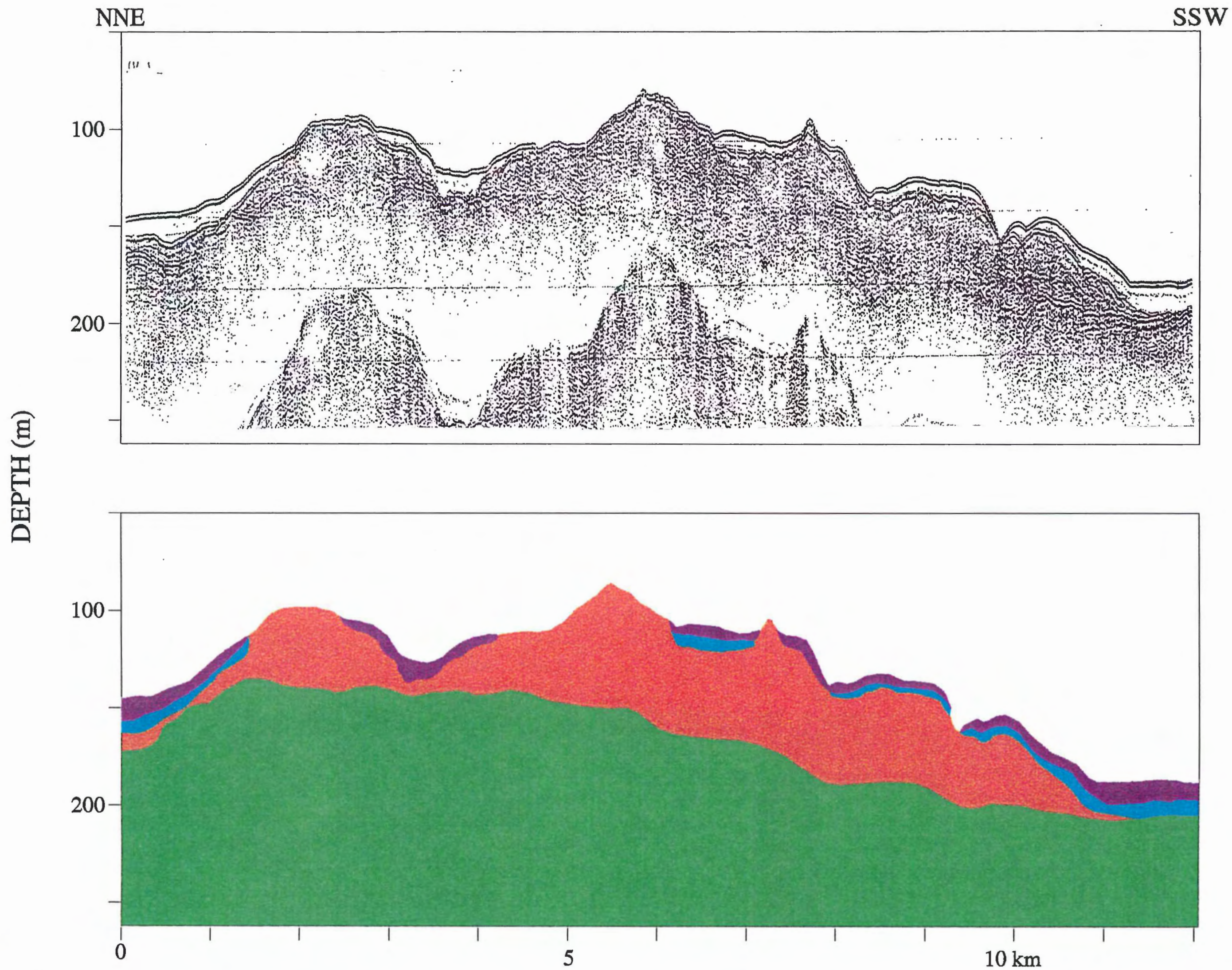


Figure 18

Figure 19:

Shore parallel sleeve gun profile collected 15 km west of Ross Island (Figure 2). Till/ice contact (Unit 2) morainal deposit is blanketed by glaciolacustrine/marine (Unit 3) and postglacial (Unit 4) sediments in deeper water (>120 m). These sediments are not observed to interfinger with the till/ice contact (Unit 2) deposits. Instead the glaciolacustrine/marine (Unit 3) sediments are truncated while the postglacial (Unit 4) sediments are ponded with deposition appearing to be bathymetrically controlled.

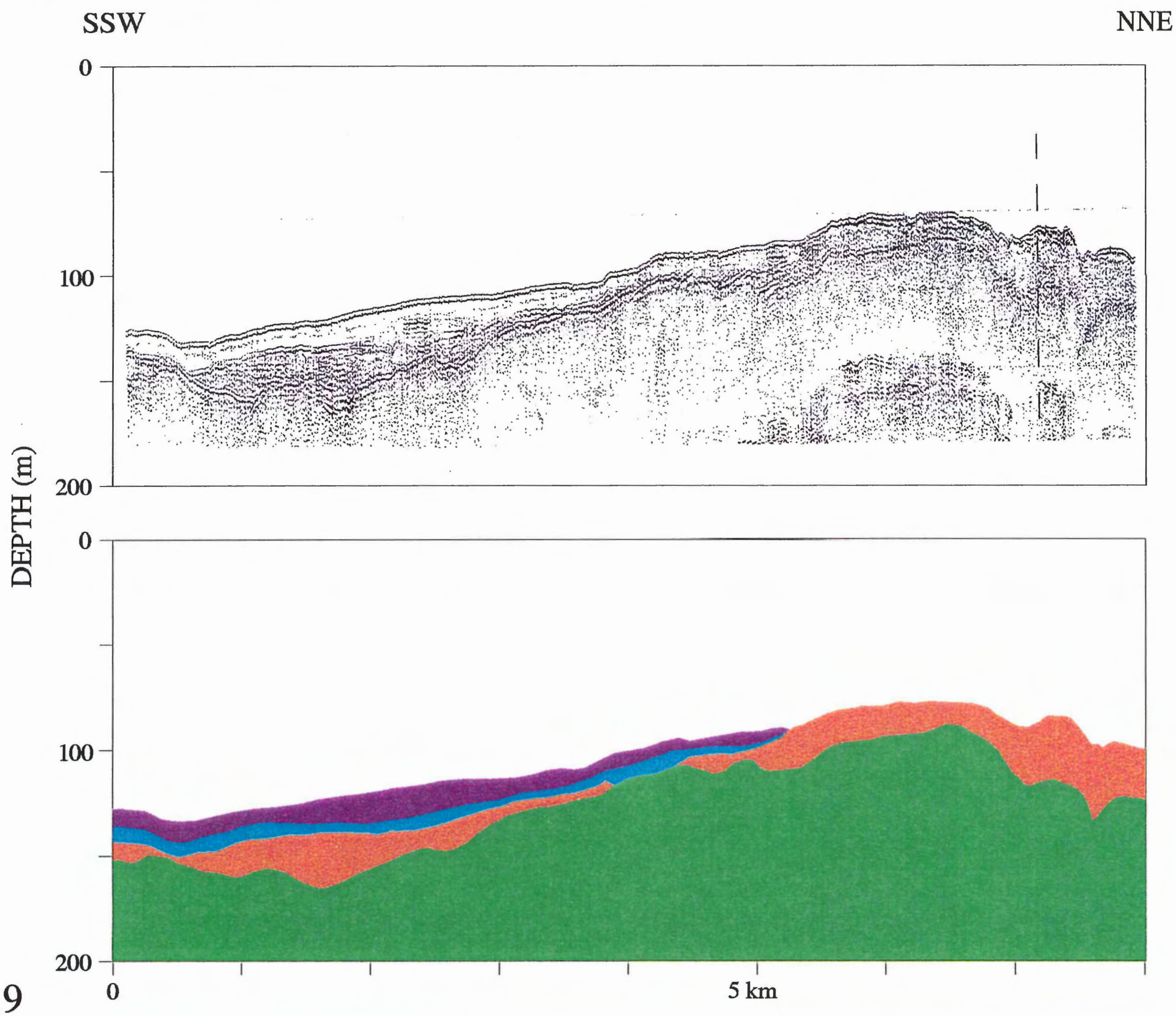


Figure 19

Figures 20, 21 and 22:

These Huntec Sea-Otter boomer profiles show the nearshore variability within the Quaternary section when compared to the undisturbed estuarine section of the Manitounuk Sound environment. Note the areas of non-deposition, asymmetric depositional style and disturbances of the postglacial unit. See Figure 10 for section locations.

Figure 20:

Shore normal Huntec Sea-Otter boomer profile extending from approximately 10 km offshore to nearshore just seaward of the mouth of Manitounuk Sound (Figure 2). Note thin delta front deposits in the southeast and thick glacial deposits in the northwest. See Figure 10 for section location.

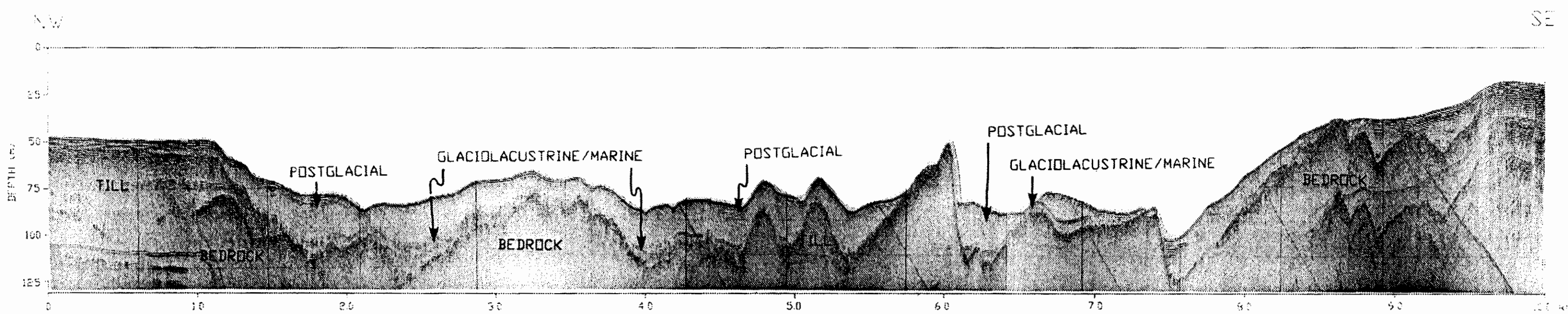

SE
POSTGLACIAL
GLACIOLACUSTRINE/MARINE
POSTGLACIAL
POSTGLACIAL
GLACIOLACUSTRINE/MARINE
TILL
BEDROCK
BEDROCK
BEDROCK
50
75
100
125
0
10
20
30
40
50
60
70

Figure 20

Figure 21:

Huntec Sea-Otter boomer profile illustrating sediments in outer Manitounuk Sound (Figure 2). This section displays the asymmetric depositional pattern of pro/postglacial sediments. Note possible failure scarp in the southwest and associated disturbed sediments. Sediment failure occurred at base of the cuesta ridge southeast Merry Island. See Figure 10 for section location.

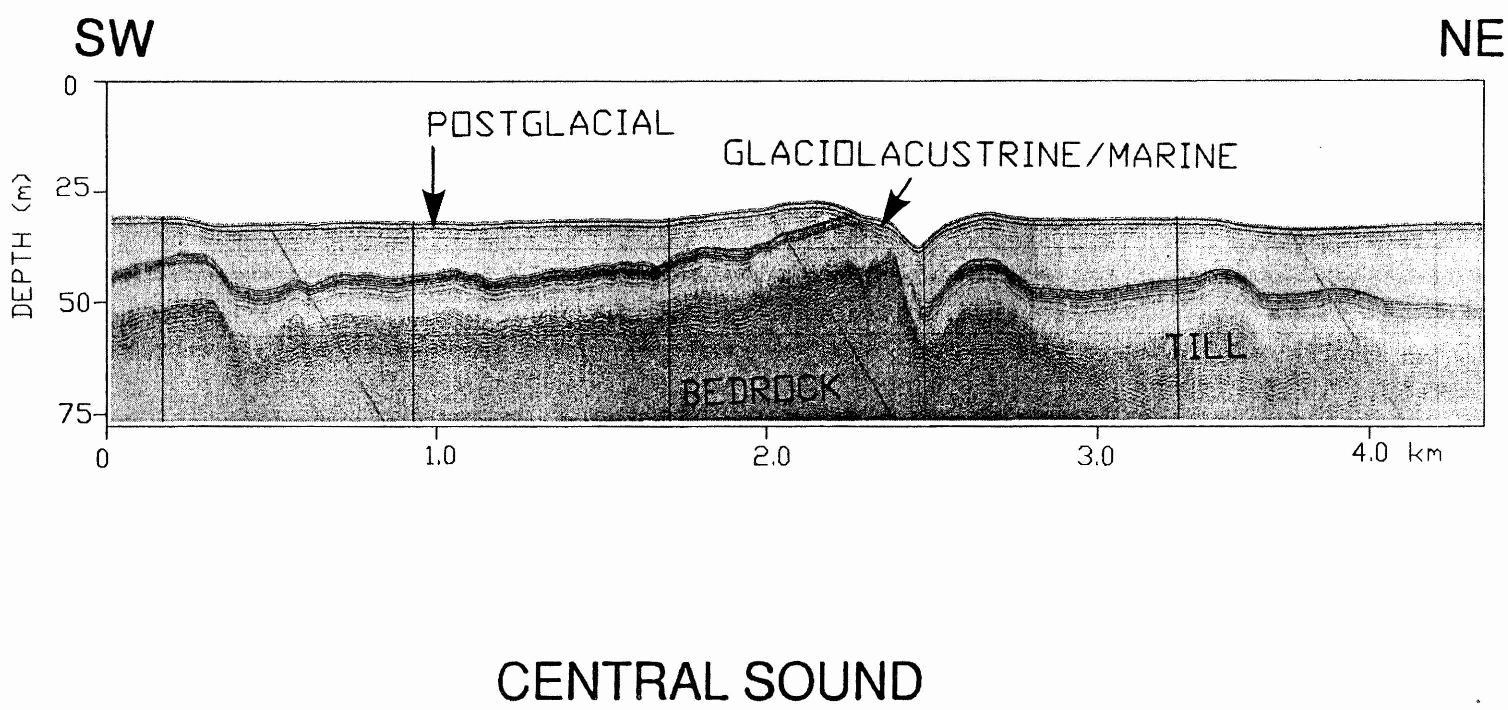
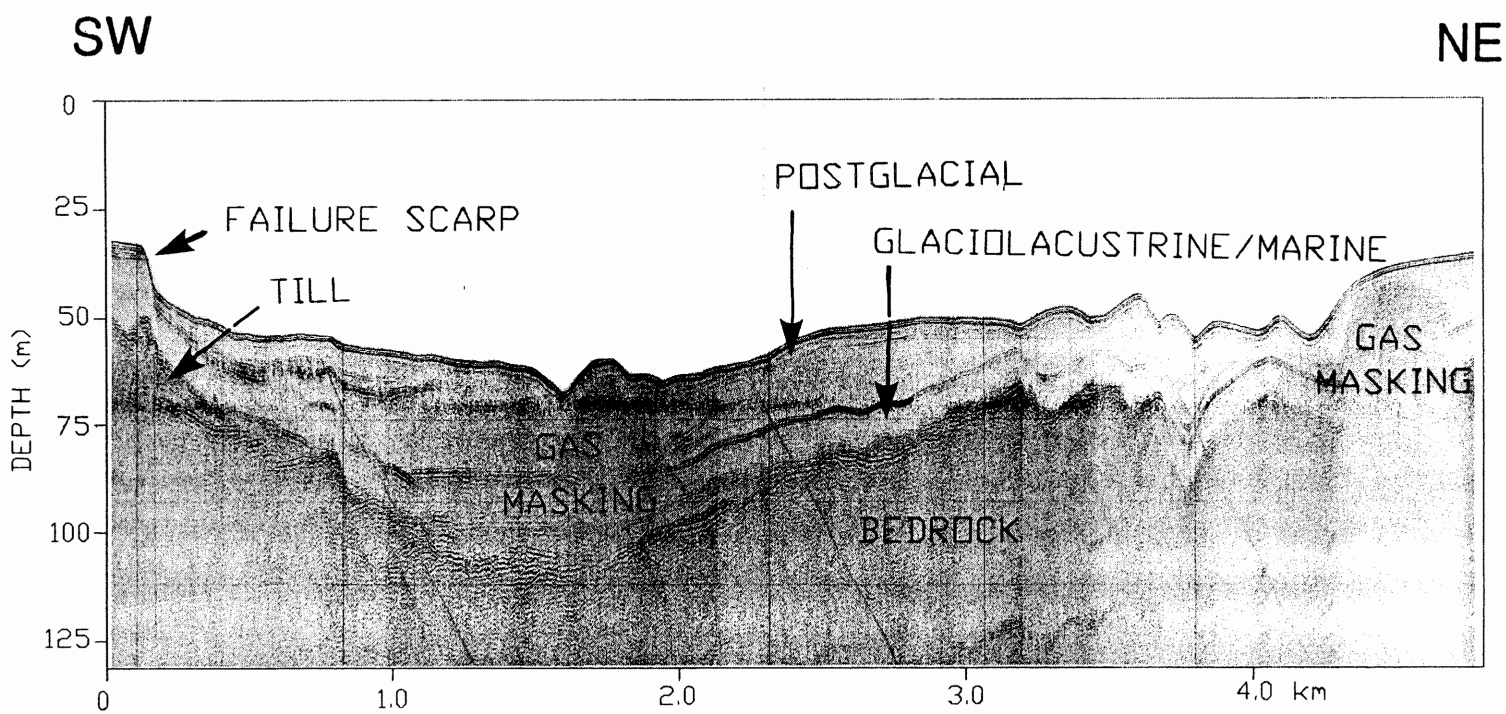

SW
NE
POSTGLACIAL
GLACIOLACUSTRINE/MARINE
BEDROCK
TILL
DEPTH (m)
0
25
50
75
0
1.0
2.0
3.0
4.0 km
CENTRAL SOUND

Figure 21

Figure 22:

Huntec Sea-Otter boomer profile displaying longitudinal section of central Manitounuk Sound (Figure 2). Note ponded depositional style of postglacial/recent sediments. See Figure 10 for section location.



OUTER SOUND

Figure 22

marked change in bedrock character. Both within the centre of the syncline and at the contact the bedrock seismic character is very chaotic. West of the contact, the morphology of the bedrock consists of a series of rounded bedrock highs separated by deep basins. These bedrock highs are not sharp crested cuesta ridges and the sleevegun data does not display any continuous, coherent, internal reflectors. Similar bedrock morphology continues to within 30km of the Belcher Islands (the extent of sleevegun seismic coverage).

5.2 - GLACIAL TILL / ICE CONTACT DEPOSITS (UNIT 2)

This unit is predominantly acoustically massive when viewed along east-west transects. In this orientation Unit 2 displays no continuous, coherent internal reflectors. The unit basal surface is marked by an angular, high amplitude reflector, which separates Unit 2 from the underlying bedrock. When viewed in a north-south oriented transects the seismic character of Unit 2 is locally complex. Complexity is especially evident in the first offshore trough west of Schooner Opening and just seaward of the coastline from Boat Opening to Petite Rivière de la Baleine (Figure 2). Although reflections are discontinuous there appears to be a complex internal structure.

Where the upper surface of Unit 2 underlies Units 3 and 4 it is marked by a high amplitude, irregular, hummocky reflector. Unit 2 lies directly on bedrock and is interpreted to be glacial till (Figures 11,12,14-19). The Unit 2 thickness and distribution are variable in occurrence ranging from discontinuous deposits a few metres in thickness to deposits >80m thick (Figures 14,15,16). This unit is exposed at the seabed in the nearshore, on the crests of the submerged cuesta ridges and as a massive deposit in the northwestern portion of the study area . Where exposed the upper surface of Unit 2 characteristically is irregular to undulating. Sidescan sonograms in the nearshore and on the crests of large accumulations show abundant point source reflectors indicative of boulders. In the offshore the sidescan sonograms over this unit display elongated ridges trending west-southwest. These ridges are interpreted to represent fluted tills formed by late glacial ice flow (Josenhans *et al.*, 1991).

The till deposits in the southern portions of the study area do not appear to be greatly influenced by the bedrock structure (Figures 14-16). It is deposited in the base of the first offshore trough (Figures 14,15), then over and on the crest of the first major cuesta ridge and deposited on the seaward side of this major cuesta ridge (Figure 16). Fluting of the exposed till surface in the marine environment can be well discerned in the deeper portions of Hudson Bay (Josenhans and Zevenhuizen, 1990). Possible fluting of the till surface in the study area was observed on sidescan sonar data along a till outcrop 30 km west-northwest of the Grande Rivière de la Baleine estuary (Figure 6 in Josenhans *et al.*, 1991) and at the 3-4 km interval along Figure 14. Trend of the fluting for the first example was west-southwest ($\sim 225^0$) in water depths of 120m and in the second example the trend of the fluting is southwest, these also occur in 120m of water.

5.3 - GLACIOLACUSTRINE/MARINE SEDIMENTS (UNIT 3)

This unit is an acoustically well stratified, conformably draped unit with a fairly uniform thickness in the offshore (Figure 11). In the inner basin of Manitounuk Sound this unit thickens substantially (Figure 12). Unit 3 directly overlies the bedrock (Unit 1) and the till (Unit 2) where present, and mimics the surface morphology of these units. It is overlain in basinal areas by postglacial sediments of Unit 4 . Outcrop of this unit is associated with upper basin flanks and areas of non-deposition of postglacial sediments such as the bedrock high that extends in a linear fashion along the axis of Manitounuk Sound, west of the Richmond Gulf outlet, and in the offshore basins in areas where erosional furrows are documented (Josenhans *et al.*,1991). Based on the conformable draped character of this unit it is interpreted to have been deposited in less dynamic, deep water conditions. In Manitounuk Sound this unit is present everywhere with the exception of Schooner Passage and near Paint Islands. The sediments assigned to Unit 3 within Manitounuk Sound, and especially the inner basin, are an order of magnitude thicker than those found in the basins seaward of the islands. Though acoustically resembling the sediments of Unit 3 in other parts of the region, it is possible that the acoustically stratified sequences in Manitounuk Sound also contain near-shore facies equivalents of the postglacial / recent sediments. Elsewhere in the Grande Rivière de la Baleine - Petite Rivière de la Baleine offshore region this unit is restricted to the deeper basins below present day water depths of at least 50 m.

5.4 - POSTGLACIAL SEDIMENTS (UNITS 4 and 4E)

This unit conformably overlies and grades into Unit 3 (Figures 11,12). Sediments of this unit display considerable horizontal and vertical variability (Figure 20-22). In the nearshore, especially in the vicinity of the estuaries of the Grande Rivière de la Baleine and Petite Rivière de la Baleine, the unit (mapped as Unit 4E) (Figure 12) is well stratified, but seaward changes from draped to ponded character, and there occasionally is cut by channel or debris flow events. In the estuaries this unit represents a constructional wedge of well stratified material and three to four episodic (?) sets/pulses of high amplitude reflectors are observed within Unit 4E. A transition occurs approximately 8km offshore where the Unit 4E grades laterally into the ponded, seismically transparent to weakly stratified sediment that is characteristic of Unit 4 throughout basinal areas of the offshore region. Thickness of the units also decrease dramatically from Unit 4E (Figure 12) to Unit 4 (Figure 11). In the offshore basins the boundary between Units 4 and 4E is marked by a change from high amplitude acoustic reflectors (Unit 4E) to weakly stratified or transparent seismic character (Unit 4). Locally this contact is diffuse and appears to have been disturbed. Isolated ponded sediment deposits also occur locally in depressions on glacial till with no evidence of Unit 3 being present at those locations. The ponded style of sediment deposition in the basins and general absence of these sediments over topographic highs reflects the increased hydro-dynamic conditions of the present day.

5.5 - SEISMOSTRATIGRAPHY SUMMARY

Seismostratigraphic interpretation of the section offshore at the mouth of the Grande Rivière de la Baleine indicates three seismically defined units overlying bedrock. Seismic Unit 2 is massive and unstratified, seismic Unit 3 is a series of conformably draped, evenly spaced, fairly high amplitude reflectors, and seismic Unit 4 offshore is transparent to weakly stratified with low amplitude reflectors.

CHAPTER 6: LITHOSTRATIGRAPHY

Onshore surficial materials can be observed and sampled in exposed river and coastal sections. In these sections small scale local variability assists in the determination of the detailed environmental and depositional history of the units. Morphological aspects associated with the emplacement of the surficial units can be viewed on a regional scale with flyovers, aerial photography and satellite observations. Some problems encountered onshore are vegetation cover and surface lag deposits which were caused by the sea-level fall. These mask the areal extent, deposit thickness and internal structure of the unconsolidated material. In the offshore one of the most important data acquisition techniques is seismic reflection profiling. This and more recently the ability to accurately position the vessel and equipment is a definite advantage in marine Quaternary studies over Quaternary studies on land (Piper *et al*, 1990). Seismic reflection profiling consists of various sound sources and frequencies and provide the ability to continuously profile a section and determine the internal structure and unit relationships. Problems with marine bottom sampling are primarily associated with equipment limitation especially as these pertain to previously glaciated terrains.

The seismostratigraphic Units 1-4 have been identified on high resolution seismic reflection profiles, and in this chapter are correlated to cores, grab samples and bottom photographs. The lowermost unit (Unit 1) identified as bedrock was not sampled. This unit forms coast parallel cuestas, with a distinct northeast-southwest morphological trend.

Immediately overlying the bedrock, a discontinuous, acoustically massive and unstratified unit of variable thickness (Unit 2) is thought to represent glacial till/ice contact sediments. This unit was only penetrated by two cores during this project. The surface of this unit was sampled by grab samples and photographed. The overlying acoustically stratified glaciolacustrine/marine (Unit 3) sequence, appears to be relatively uniform and can be traced acoustically over large distances. It was sampled by coring nearshore south of Schooner Opening, and as far as 40 km west-northwest offshore from the Grande Rivière de la Baleine estuary. The overlying postglacial muds (Units 4 and 4E), were found to be highly bioturbated and mottled, with occasional shells, pebbles and stringers of very fine sand.

The locations of the core, grab and camera station data used in this section are shown on Figures 10 and 23. The type section of the offshore Quaternary sediment package is presented as the profile and description of core 87-028-069 by Bilodeau *et al.* (1990a)(Figure 24). The proposed onshore equivalent section is shown in Figure 25 (Hillaire-Marcel, 1979).

6.1 - BEDROCK (UNIT 1)

Bedrock discussion although not a part of this predominantly Quaternary paper should be described. The Proterozoic cuesta ridge and basin terrain extends from the offshore islands of the Manitounuk Island Chain to 40 km offshore. The overall trend is

Figure 23:

The figure locations map shows the positions of the bottom samples and photographs referenced in the text. Sample positions are labelled with reference to cruise and sample number (eg 7-69, where 7 designates cruise 87-028 and 69 designates core 87-028-069).

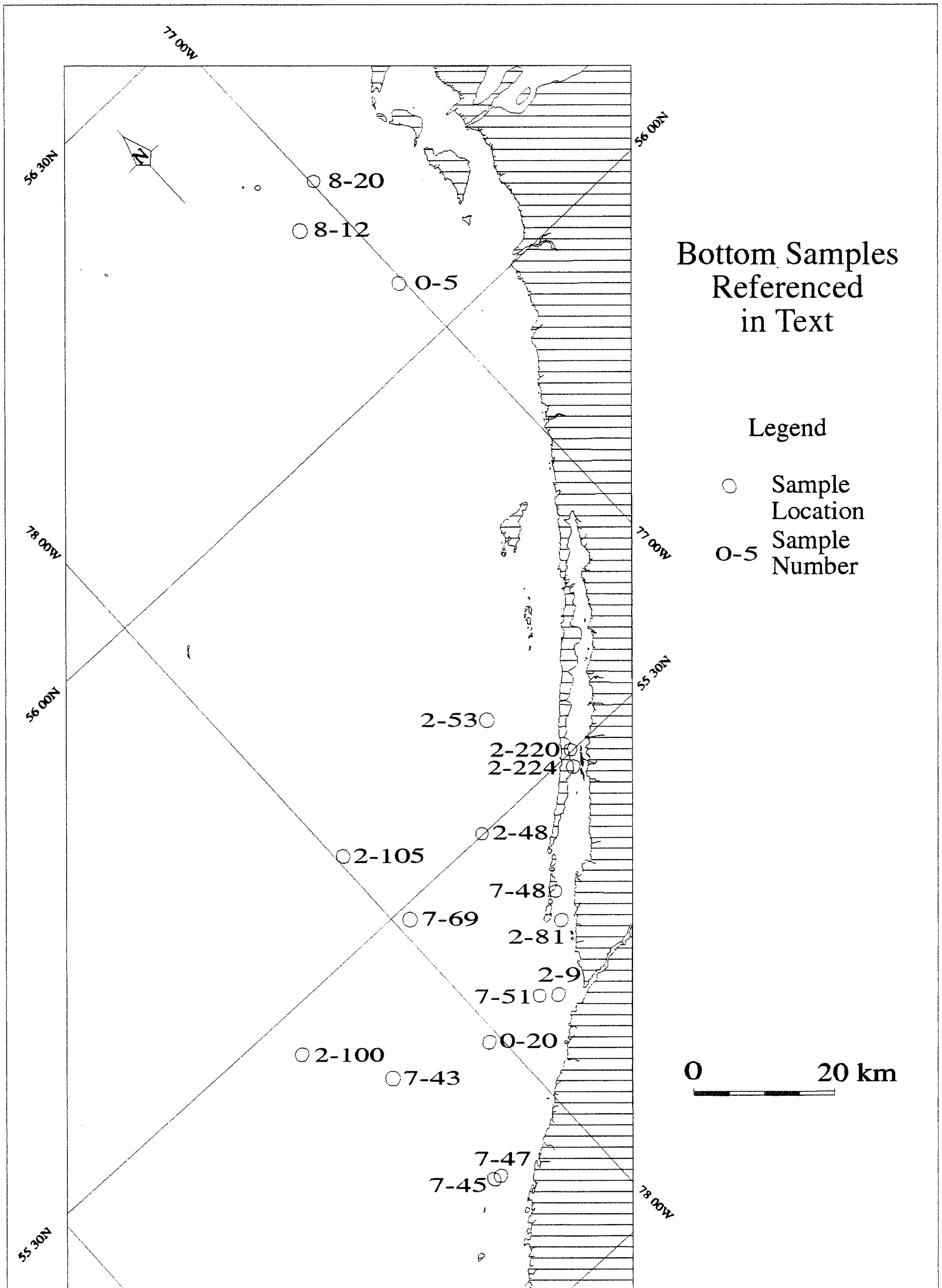

Bottom Samples Referenced in Text
Legend
Sample Location
o-5 Sample Number
0 20 km
77 00W
56 30N
56 00N
78 00W
55 30N
79 00W
55 00N
8-20
8-12
0-5
2-53
2-220
2-224
2-48
2-105
7-48
7-69
2-81
2-9
7-51
0-20
2-100
7-43
7-47
7-45

Figure 23

Figure 24:

Core 87-028-069 represents the offshore type section. The detailed biostratigraphy and environmental data completed by Bilodeau et al. (1990a) is correlated to the lithostratigraphy.

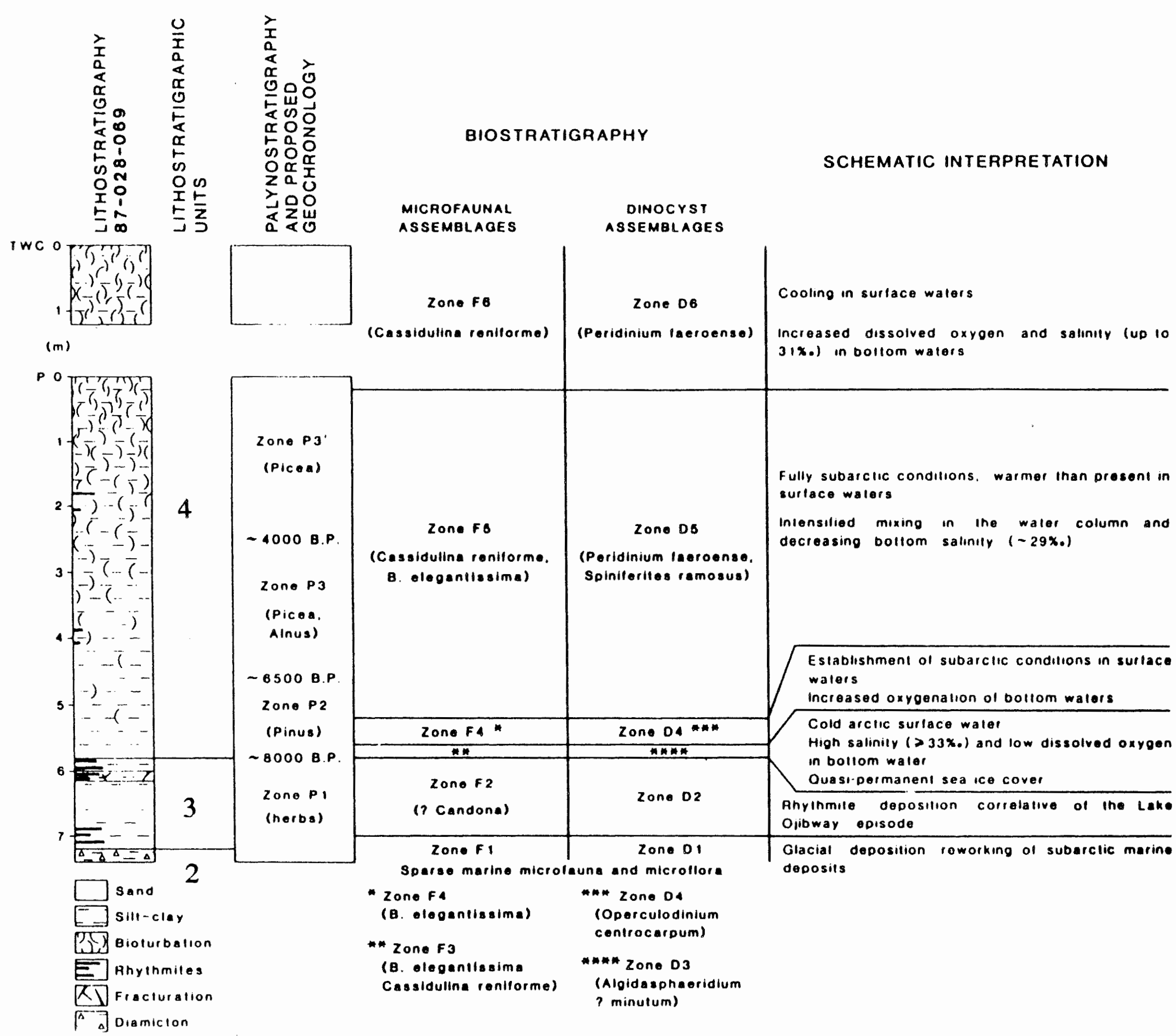

LITHOSTRATIGRAPHY 87-028-069
LITHOSTRATIGRAPHIC UNITS
PALYNOSTRATIGRAPHY AND PROPOSED GEOCHRONOLOGY
BIOSTRATIGRAPHY
MICROFAUNAL ASSEMBLAGES
DINOCYST ASSEMBLAGES
SCHEMATIC INTERPRETATION
TWC 0
1
(m)
P 0
1
2
3
4
5
6
7
4
3
2
Zone F6
(Cassidulina reniforme)
Zone D6
(Peridinium faeroense)
Cooling in surface waters
Increased dissolved oxygen and salinity (up to 31‰) in bottom waters
Zone P3'
(Picea)
~4000 B.P.
Zone P3
(Picea, Alnus)
~6500 B.P.
Zone P2
(Pinus)
~8000 B.P.
Zone P1
(herbs)
Zone F5
(Cassidulina reniforme, B. elegantissima)
Zone D5
(Peridinium faeroense, Spiniferites ramosus)
Fully subarctic conditions, warmer than present in surface waters
Intensified mixing in the water column and decreasing bottom salinity (~29‰)
Establishment of subarctic conditions in surface waters
Increased oxygenation of bottom waters
Zone F4 *
**
Zone D4 ***
****
Cold arctic surface water
High salinity (≥33‰) and low dissolved oxygen in bottom water
Quasi-permanent sea ice cover
Zone F2
(? Candona)
Zone D2
Rhythmite deposition correlative of the Lake Ojibway episode
Zone F1
Zone D1
Sparse marine microfauna and microflora
Glacial deposition reworking of subarctic marine deposits
* Zone F4
(B. elegantissima)
** Zone F3
(B. elegantissima Cassidulina reniforme)
*** Zone D4
(Operculodinium centrocarpum)
**** Zone D3
(Algidasphaeridium ? minutum)
Sand
Silt-clay
Bioturbation
Rhythmites
Fracturation
Diamicton

Figure 24

Figure 25:

Section in the upper terrace of the Grande Rivière de la Baleine; 600 rhythmites are overlain by 14 m of compact marine clay. The C^{14} ages of calcareous concretions in the rhythmites and that of the first fossil-bearing bed of the Tyrrell Sea at the base of the clays are in agreement and give the approximate date of the marine invasion (from Hillaire-Marcel, 1979).

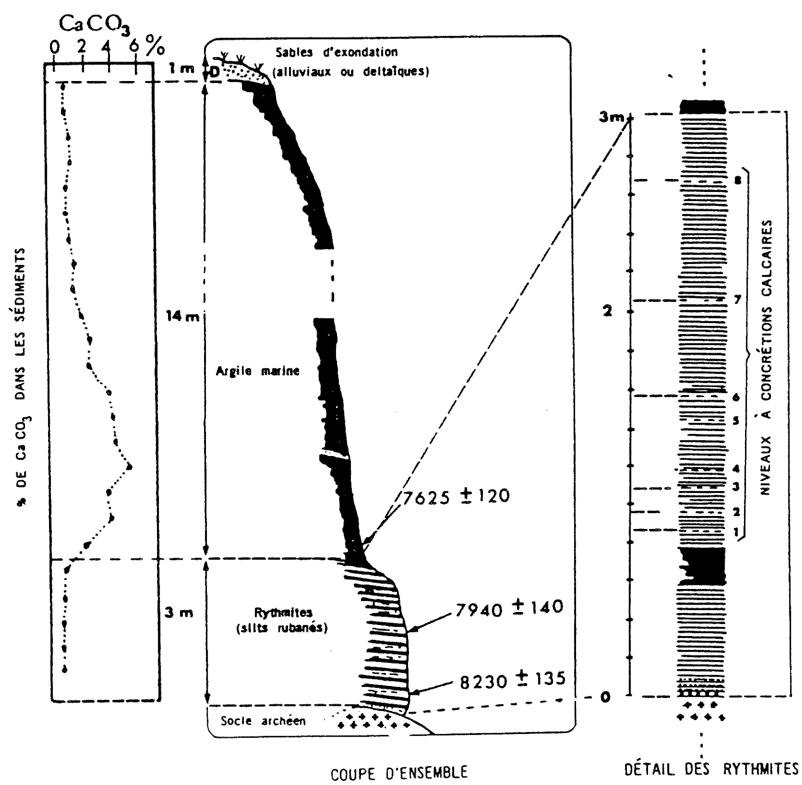


Figure 25

Onshore section Grande Riviere-de-la-Baleine
(from Hillaire-Marcel, 1979)

Figure 26A,B:

Photographs taken from the eastern shore of Manitounuk Sound opposite Schooner Opening (Figure 2). Note steep bedrock cliffs along the western shore of Manitounuk Sound and low angle slope of cuesta ridge facing Hudson Bay (A). Bottom photograph (B) taken from mud flat opposite Schooner Opening. Seismic data collected by Hydro Quebec (CSSA, 1991d) show that this material is currently being eroded.

A

B

Figure 26

predominantly southwest to northeast. The trend does not change but the gentle dip to the northwest is reversed on the other side of an anticlinal axis which occurs 35 km offshore. The reversal of the dip appears to indicate that these meta-sedimentary and volcanic rocks could overlie the Belcher Island rocks (Chandler, 1988).

The bathymetry of the area east of the Belcher Islands, extending from Long Island to the northwestern tip of Ungava Peninsula, is very complex consisting of numerous shoals, islands, troughs and basins. This complex morphology coincides with the Precambrian terrains (Dyke *et al.*,1989). The Belcher and adjacent islands are primarily greywacke (Dimroth *et al.*, 1970). The mainland coastal bedrock in the study area consists of a series of cuesta ridges of Proterozoic volcanic and metamorphosed sedimentary rocks (Chandler, 1988, Sequin and Allard, 1984, Allard and Tremblay, 1983a,b). These cuesta ridges are characterized by a low angle dip on the western side and steep slopes on the eastern side.

The bedrock was not sampled in the study area, but the surface morphology and acoustic character suggest that immediately off the coast the bedrock strata are analogues of the Proterozoic interbedded volcanics and carbonates which form the Manitounuk Islands (Figure 26).

6.2 - GLACIAL TILL/ICE CONTACT DEPOSITS (UNIT 2)

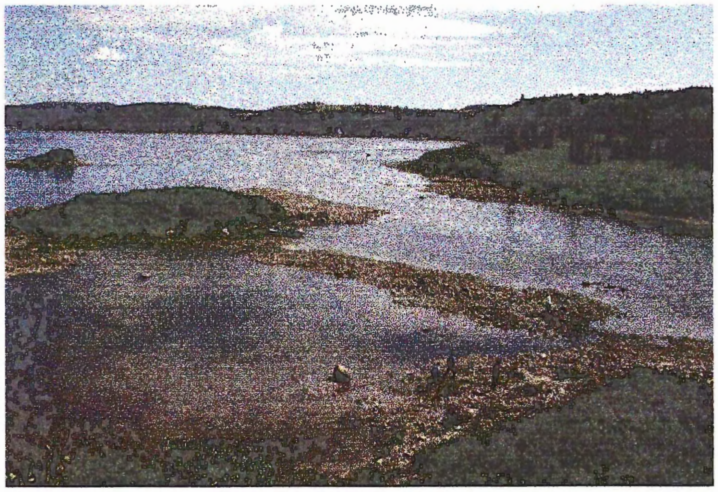
Onshore the till in the southeastern Hudson Bay region has a variable texture, composition and morphology. Material is derived from metamorphic and igneous rock and is non-calcareous sandy and stony. Distribution of this material is as a thin <2 m basal or lodgement till with local accumulations exceeding 10 m (Vincent *et al.*, 1987).

Two large scale regional moraines are associated with the region. These are the Harricana Interlobate Moraine (Vincent, 1989, Vincent and Hardy, 1987) and the Sakami Re-equilibration Moraine (Hillaire-Marcel, 1976, 1979). Both of these moraines are interpreted to be ice contact / glaciofluvial features (Vincent, 1989). The Sakami Moraine extends from Kuujjuarapik (Figure 27) to Mistassini Lake (Figure 6) a distance of 630 km (Vincent, 1989). It consists of asymmetric ridges of ice contact and proglacial sediments. The Harricana Moraine (Figure 6) extends for more than 1000 km (Vincent, 1989). It extends from Lake Simcoe in Ontario to the islands of eastern James Bay. It may extend considerably further to the north towards the mouth of James Bay and possibly further (Zevenhuizen *et al.*, 1992) but the seismic data collected at the mouth of James Bay has yet to be processed in detail. The ridges present on the seabed along the eastern shore of James Bay (Zevenhuizen *et al.*, 1992) and islands seaward of the eastern coast of James Bay (Meagher *et al.*, 1976) all appear to be composed entirely of unconsolidated material, probably till. The moraine is composed of a series of ridges pocked with kettles. These ridges are up to 10km long and 100m thick and consist of glaciofluvial

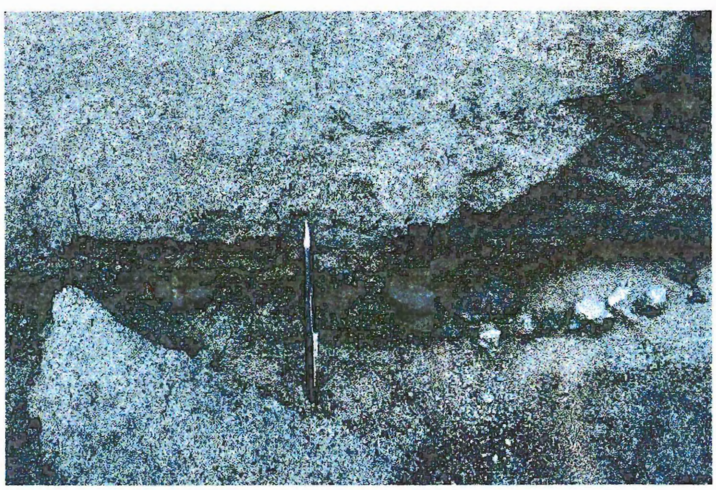
Figure 27A,B:

The top photograph (A) was taken approximately 7 km up river from the Grande Rivière de la Baleine estuary (Figure 2). The small island in the middle of the river consists of till and large boulders. This island is interpreted to represent the northern end of the Sakami Moraine (Vincent *et al.*, 1987).

The bottom photograph (B) was taken along the south shore of the Grande Rivière de la Baleine (Figure 2) approximately 4 km up river from the estuary. The gravelly layer marks the horizon associated with the drainage of Lake Ojibway. The underlying unit is interpreted as glaciolacustrine while the overlying unit consists of clays associated with the Tyrrell Sea (Vincent *et al.*, 1987).



A

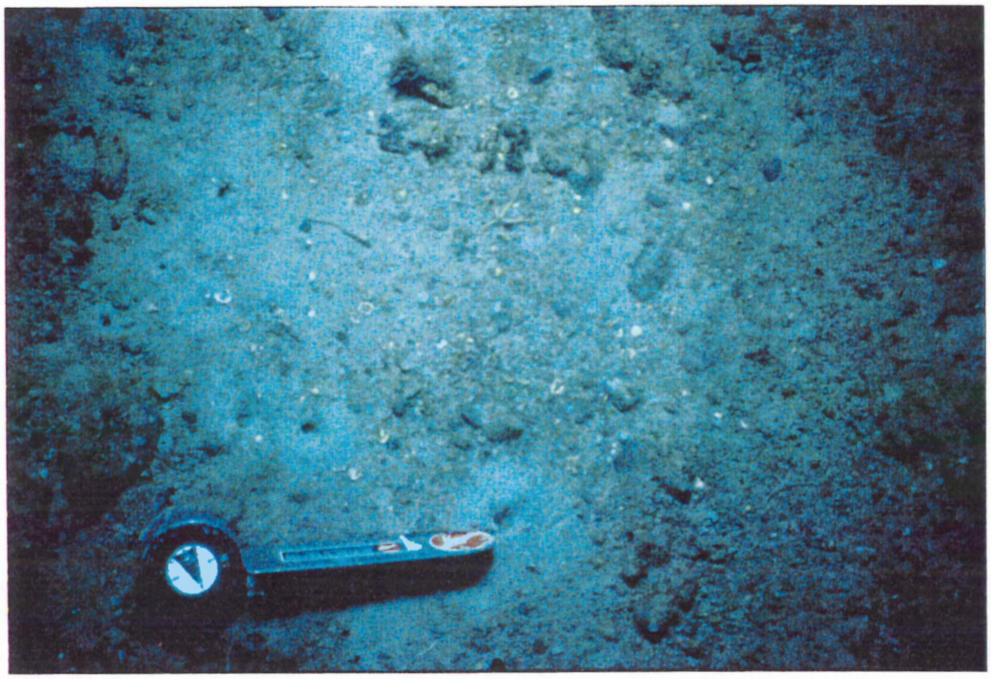


B

Figure 27

Figure 28:

Bottom photographs at station 87-028-045 collected over till (unit 2) outcrop in a water depth of 51 m. For scale reference, the trigger vane length is 0.4 m. See Figure 23 for sample location.



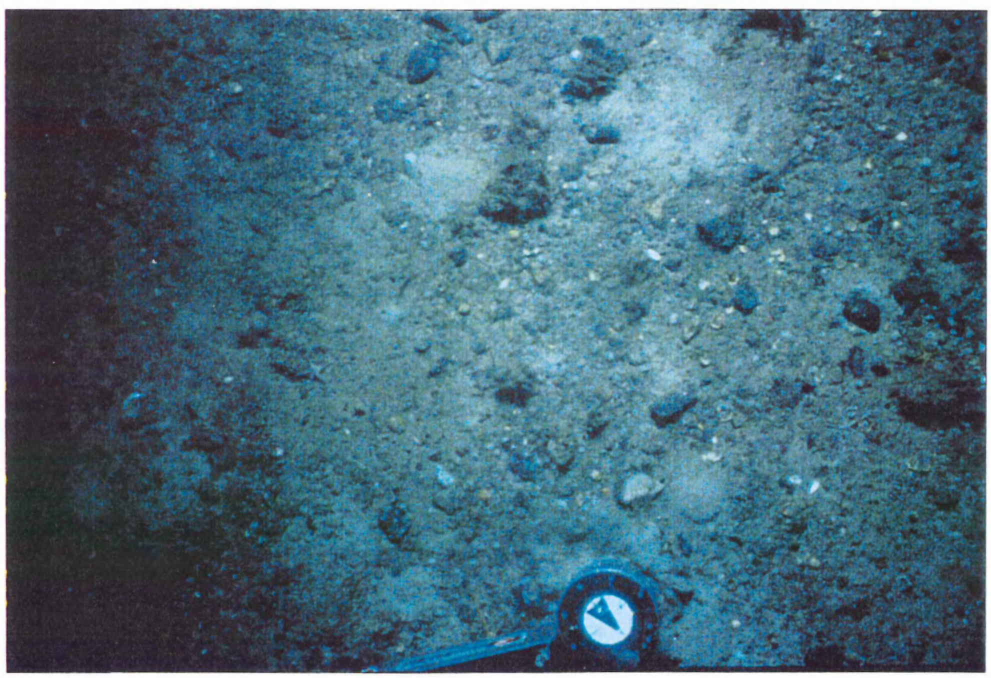


Figure 28

CAMERA STATION 87-028-045

Figure 29:

These core photographs from core 87-028-047 show all three units. This core is the only core to have sampled till (unit 2). The base of the core (2.76-2.96 m) shows a dark gray diamicton, fairly sandy with many angular pebbles. Glaciolacustrine/marine (Unit 2) laminated unit occurs from 2.29-2.76 m and contains a disturbed "cottage cheese" layer common to this unit from 2.50-2.62 m. Tyrrell Sea, bioturbated fine grained sediments occur from the top of the core to 2.29 m. Core was collected in a water depth of 46 m. See Figure 23 for sample location.

Piston Core 87-028-047

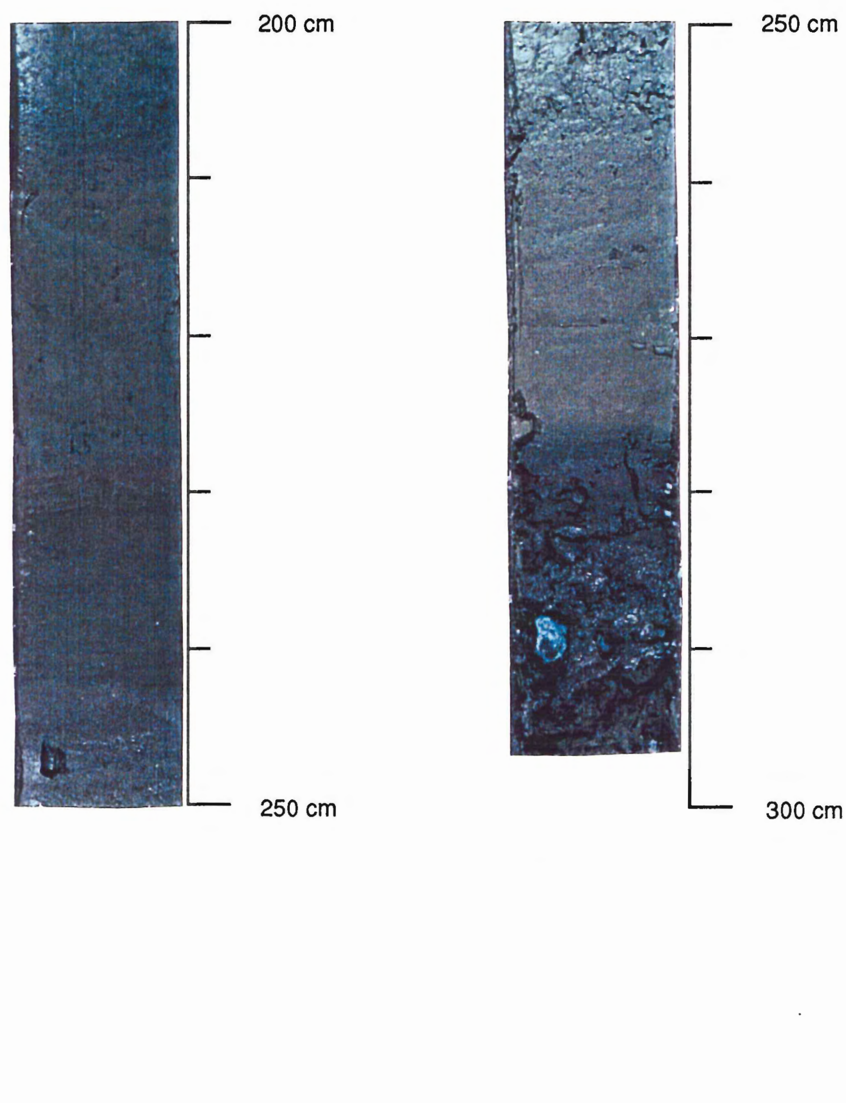
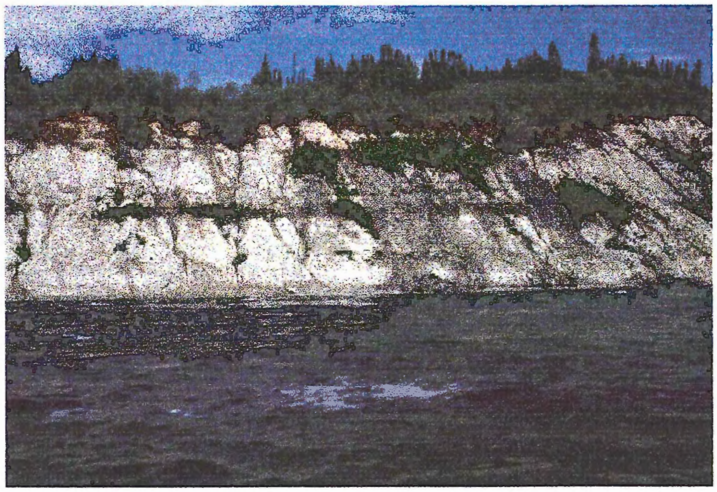


Figure 29

Figure 30A,B:

These photographs were taken along the northern shore of the Grande Rivière de la Baleine (Figure 2), just below the first falls approximately 15 km from the estuary. The upper photo (A) shows a 14 m thick section of fine grained sediments of the Tyrrell Sea overlying 600 rhythmites (Vincent *et al.*, 1987). Associated stratigraphic section as well as radiocarbon dates are shown in Figure 25. The bottom photograph (B) was taken at the base of the section and shows an example rhythmites.



A

B

Figure 30

sediments (Vincent, 1989).

Till was sampled in only two cores (87-028-047,069 Figure 23) but the till surface was observed on sidescan sonar, by diver observations, photographed and sampled with a grab sampler. The micropaleontological analysis showed that this unit contained marine forams (Figure 24)(Bilodeau *et al.*, 1990). Age of these forams was not established and they could have possibly been derived from the reworking of earlier deposits. Foraminiferal analysis completed by Bilodeau *et al.* (1990) on *CSS Hudson* core 87-028-69 designate the foraminiferal assemblage for Unit 2 as Zone F1. Zone F1 is marked by low diversity and abundance. The dominant species are *Elphidium clavatum* forma *clavata* and *Cassidulina reniforme* associated with till/ice contact to ice proximal glaciomarine sediments (Unit 2 and the base of Unit 3).

The sidescan sonograms and diver observations (CSSA, 1991b,c) indicate the presence of large boulders at the seabed in the areas of interpreted till outcrop (Figure 28). Grab samples (Narwhal 1988-012,020, 90-024-005,020, Figure 23) indicate that the sediments of Unit 2 are poorly sorted (gravel 2-45%, sand 10-57%, silt 10-31% and clay 16-54%). Henderson (1989) described the possible till at the base of core 87-028-047 (Figure 29) as a dark gray sandy diamicton with many angular crystalline (95.4%) pebbles. Due to the nature of this unit core sample recovery is limited and no geotechnical measurements are available.

6.3 - GLACIOLACUSTRINE/MARINE SEDIMENTS (UNIT 3)

Onshore the glaciolacustrine sediments represent accumulations of deep water, Lake Ojibway sediments. These are in the form of varved silty clay beds, averaging 12-15m thickness, which directly overly bedrock or till/ice contact deposits where present (Vincent *et al.*, 1987) (Figures 26,30).

All cores of sufficient length to penetrate the seismically defined glaciolacustrine/marine unit consist of rhythmically banded, possibly varved sediments (Figures 29,31). Piston cores 87-028-043, 047, 048 and 069, 92-028H-009, 048, 053, 081, 100, and 105 and 92-028S-220 and 221 are interpreted to have sampled this unit (Figure 23).

Where this unit directly overlies the glacial till / ice contact sediments (Unit 2) the basal contact is well defined by colour but appears to be transitional in texture (Figure 29). The upper contact of this unit as observed on all the cores listed in Table 2he erosion and lag deposit noted onshore (Figure 27B) has not been documented in the offshore. The contact of the Unit 3 and overlying Unit 4 varies from conformable to a sharply defined erosional surface in the marine environment.

Micropaleontological analysis completed by Bilodeau *et al.* (1990a) on *CSS Hudson* core 87-028-69 designate the foraminiferal assemblage for the glaciolacustrine/marine (Unit 3) as Zone 2 (Figure 24). Zone F2 contains a sparse microfauna, there are no foraminifera and only a small number of badly preserved ostracods. Based on the presence of the freshwater ostracod genus *Candona* (Figure 24), Bilodeau *et al.* (1990a) interpreted this sequence as glaciolacustrine.

Sediments of this unit are rhythmically banded alternating gray to grayish brown silty clays with a minor pebble component (gravel 0-20%, sand 0-24%, silt 21-38% and clay 42-76% (Henderson, 1989)). Detailed grain size analysis completed by Gonthier *et al* (1993) indicated that the darker laminae were slightly coarser than the lighter laminae. In all cores zones of deformed rhythmically banded sediments are present. These deformed zones are composed of subrounded clay clasts with a lumpy texture ("cottage cheese" texture) (Figures 29,31). In places the original bedding is preserved. Microfaulting with offsets ranging from a 0.1cm to 1.0 cm is common within this unit (Figure 31). The geotechnical parameters of the entire unit are best summarized from cores 87-028-043 and 069; peak shear strengths of 4.7-15.0 kPa were measured in core 87-028-069 and 4.4-10.0 kPa in core 87-028-043; water content ranged from 43- 97% in core 87-028-069 and from 25-99% in core 87-028-043; bulk density ranged from 1.54-1.86 g cm^{-3} in core 87-028-069 and from 1.53-2.07 g cm^{-3} in core 87-028-043; velocities ranged from 1443-1648m s^{-1} in core 87-028-069 and from 1438-1708 m s^{-1} in core 87-028-043 (Marsters, 1988).

Geochemical analysis completed by Gonthier *et al.* (1993) in Unit 3 indicates a sulphate content of approximately 5% as SO_3 which has a greater affinity to sea water. Freshwater

Figure 31:

Photographs of a one metre section of core 87-028-069 displaying glaciolacustrine/marine varved sequence. This well laminated unit has three "cottage cheese" texture sections (6.20-6.38m, 6.48-6.55m, 6.65-6.97m). Throughout these zones the laminations are disturbed but can be easily recognized. Also note microfaulting which offsets the varves at 6.06-6.12m. Core was collected in a water depth of 165 m. See Figure 23 for sample location.

Piston Core 87-028-069

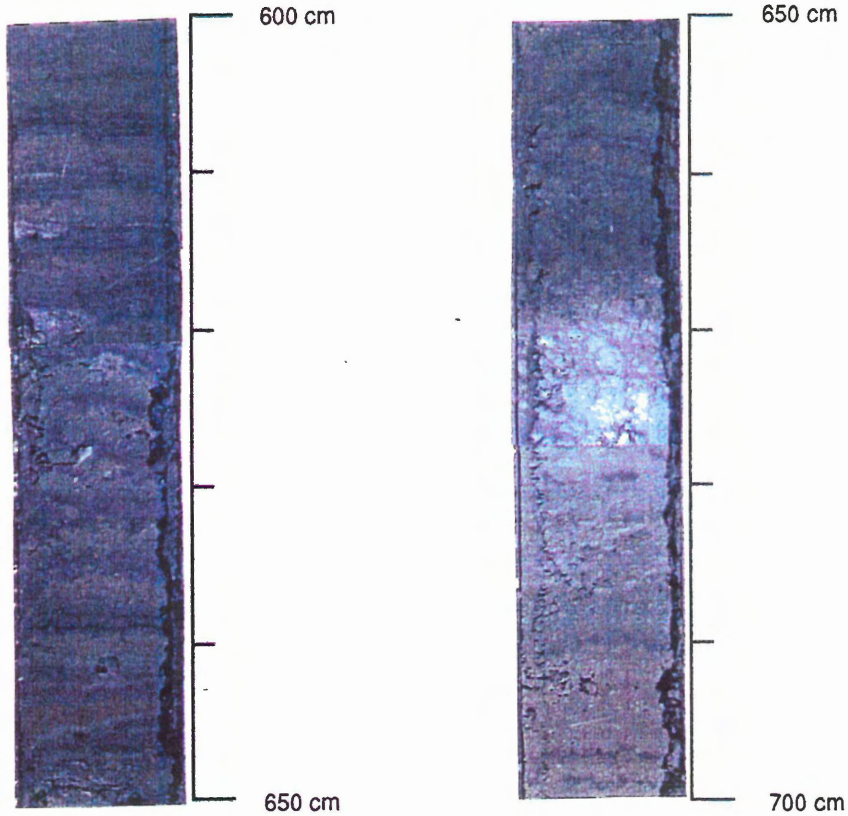


Figure 31

sulphate content on average is <1% of average values associated with seawater (Berner and Raiswell, 1984). Pore water salinities within and throughout this entire unit are all greater than 29.5 ‰ (Marsters, 1988, Gray, 1994) and usually higher averaging 31‰. Organic carbon contents within this unit range from 0.0-0.4% (Henderson, 1989).

Comparison with the onshore section suggests that the rhythmically bedded sediments represent glaciolacustrine deposits of pro-glacial Lake Objiway (Hillaire-Marcel, 1979, Hillaire-Marcel and Vincent, 1980). Hillaire-Marcel (1979) documents the presence of ~600 rhythmites in a section approximately 15 km inland from the Grande Rivière de la Baleine estuary (Figures 25,33). In the marine setting the rhythmites were counted from core photographs on the above cores. The problem which arises with this counting is that only core 87-028-047 and probably core 87-028-069 (Figure 23) sampled this entire section. The other cores bottomed out in Unit 3 and did not penetrate to Unit 2. The following table indicates the core identification number (Figure 23) and the number of observed rhythmites in brackets.

87-027-47(>100)	
87-028-069 (>130)	
92-028H-009 (33)	
92-028H-081 (35)	(0.5m sampled, seismic data shows 6-8m of Unit 3)
92-028H-053(54)	
92-028H-048(92)	
92-028H-100(116)	
92-028H-105(49)	
92-028S-220(105)	
92-028H-221(33)	

Table 2: Cores sampling the glaciolacustrine/marine (Unit 3) and number of rhythmites as observed on core photographs.

The only mechanism proposed to date which could have caused the disaggregation of the clay laminae is the freezing of the pore waters within this unit is by the introduction of super-cooled seawater during the Tyrrell Sea incursion (Josenhans *et al.*, 1988, Bilodeau, 1990a, Gonthier *et al.*, 1993). The laminae within this unit, although disturbed, are well preserved. These conclusions were all based upon a comparison of the observed sediment texture (Figure 29, 2.47-2.57m and Figure 31, 6.20-6.38m, 6.48-6.55m, 6.65-6.97m) to the textures observed in the laboratory experiments completed by Chamberlain and Gow (1979) and the observations based on boreholes collected in 12m water depth in the Alaskan sector of the Beaufort Sea (Chamberlain *et al.*, 1978). These Beaufort Sea samples would have been subaerially exposed within the last 8000 years and could therefore have been previously frozen. Discussion with various geotechnical engineers (Christian, Moran, Marsters personal communications) confirms the conclusion based on the appearance of these sediments that they had to have been previously frozen. Problems arise though with the mechanism causing the freezing. These sediments were deposited in water depths ranging from 500->700m and have therefore never been subaerially exposed. Organic carbon content of these sediments is too low to generate gas and gas hydrates. Also the Proterozoic bedrock is not considered a source of petrogenic gas. The rapid cooling then freezing by an influx of super-cooled seawater as an underflow should affect the upper portion of this unit. None of the observed disturbed zones occur at the top of the unit and deformation appears to increase with depth in all the cores.

As these sediments were deposited in very cold conditions near or at the ice margin, the conditions required for freezing were probably easy to attain. Favourable conditions for freezing could be triggered by only small scale temperature and salinity changes. Touchdown of the ice sheet during re-equilibration required by the catastrophic draining of Lake Ojibway, and associated greater than 150m water level drop, probably provided the mechanism whereby increased groundwater flow associated with loading changed conditions enough to induce freezing. It is difficult to imagine the large volumes of freshwater released and the effect that this would have.

6.4 - POSTGLACIAL SEDIMENTS (UNIT 4)

Onshore, a variety of the postglacial marine sediments associated with the Tyrrell Sea episode occur. Sediment type and depositional environment depend largely on the glacioisostatic emergence of the area. Sediments consist of a basal deep water facies (Figure 30) progressively changing higher up in the section to littoral as water depths decrease (Vincent *et al.*, 1987). It is interesting to note that the carbonate content of the basal sediments west of the Sakami Moraine is 10-20% while east of the Sakami Moraine the carbonate values are only 5-7% (Vincent *et al.*, 1987).

The postglacial sediments have a highly variable style/geometry of deposition which preserves evidence of both present day and past oceanographic conditions and amounts of terrestrial input/timing /fluctuation. The variability is best displayed in Manitounuk

Sound (Figures 12,20-22) and in transects extending from the mouths of the Grande Rivière de la Baleine and the Petite Rivière de la Baleine. Within Manitounuk Sound the Inner Sound best represents an entire undisturbed sediment package (Figure 12).

Foraminiferal analysis completed by Bilodeau *et al.* (1990a) on *CSS Hudson* core 87-028-69 designate the foraminiferal assemblage for postglacial muds (Unit 4) as Zone F3. Zone F3 is marked by higher concentrations and increased diversity; dominant species are still *Elphidium clavatum* and *Cassidulina reniforme*. *Nonionellina labradorica* and *Buccella frigida* as well as *Buliminella sp.* and *Islandiella sp.* increase substantially but *Fursenkoina fusiformis* virtually disappears. Zone F3 occurs in Unit 4, the postglacial hemipelagic mud (Figure 24).

Piston cores 87-028 - 69 and 043 are interpreted to have sampled sediments of unit 4 (Bilodeau *et al.*, 1990a, Bilodeau, 1990). This unit is bioturbated olive gray mud with black reduction spots (Figure 32). Upper portions of this unit sampled in cores consist of gray silty clay with active worm burrowing underlain by postglacial olive gray bioturbated clays with occasional shells, pebbles, relict burrows and occasional thin stringers of very fine sand. Texturally the sediment components include : gravel 0 - 31%, sand 1 - 78%, silt 12 - 81 %, clay 6 - 87% (Henderson, 1989). Geotechnical property measurements included: peak shear strengths in core 87-028-069 6.2-14.0 kPa, and in core 87-028-043 3.7-10.9 kPa; water content in core 87-028-069 60- 97%, and in core 87-028-043 64-104%; bulk density in core 69 1.52-1.74 g cm^{-3} and in core 87-028-043 1.53-1.70 g cm^{-3};

and velocities in Core 69 of 1443-1648m s^{-1} and in core 87-028-047 of 1448-1551m s^{-1}.

Throughout the survey area, where present day deposition occurs, all samples of the postglacial mud and postglacial estuarine sediments contain a heavily bioturbated veneer of soupy oxidized mud overlying gray bioturbated muds of Unit 4 and 4E (Figures 32,33). This unit is too thin to be defined on seismic data. Where this unit was sampled by a piston or gravity corer the recent thin (0.01-0.12m) oxidized surface veneer was often blown away through the action of coring. Active bioturbation has often incorporated some of this veneer into this underlying bioturbated gray muds of Unit 4. The transition from the postglacial muds to this surface veneer is transitional and is not interpreted to represent a major environmental change (Zevenhuizen *et al*, 1994) but rather as the equivalent of the postglacial muds prior to burial.

Figure 32:

Photographs of a one metre section of core 87-028-069 displaying the postglacial sequence (unit 4). The sediment is fine-grained and heavily bioturbated (black mottling). Core was collected in a water depth of 165 m. See Figure 23 for sample location.

Piston Core 87-028-069

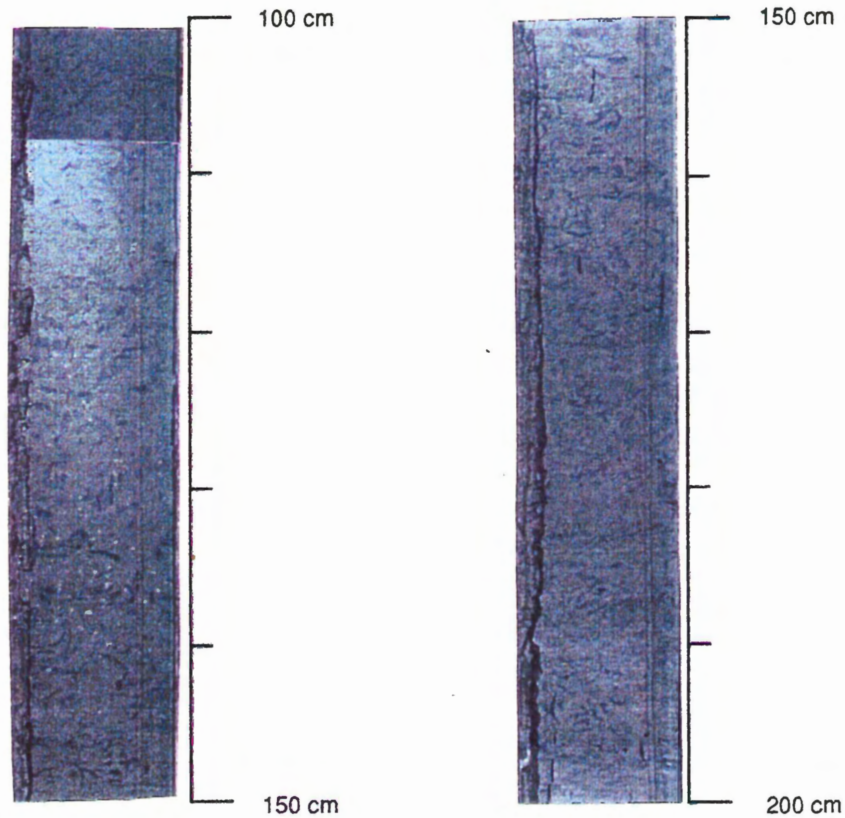
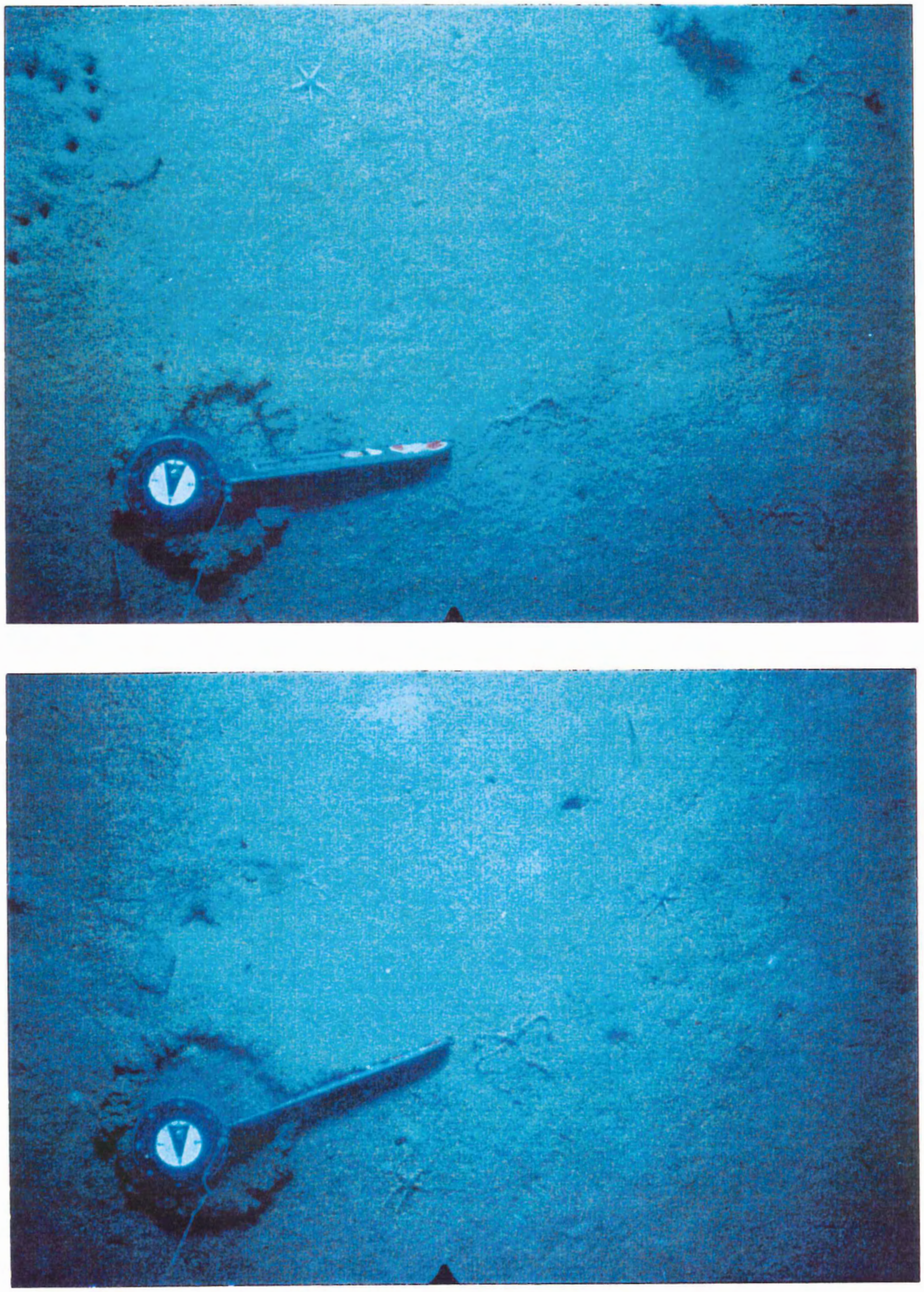


Figure 32

Figure 33:

Representative bottom photographs at station 87-028-051 collected over postglacial muds (unit 4) at a water depth of 73 m. Note high intensity of colonization and bioturbation. See Figure 23 for sample location.



CAMERA STATION 87-028-051

Figure 33

CHAPTER 7: SURFICIAL GEOLOGY AND SEABED FEATURES

One of the unique aspects of this study for someone who has worked throughout the marine environment in Canada is that Hudson Bay represents an emergent coast during a time when most other coastlines in eastern Canada are being influenced by a relative sealevel rise. The rapid emergence of this coast provides the unique opportunity to complete an excellent onshore-offshore correlation.

The entire Hudson Bay region displays well preserved glaciogenic features. By the use of seismostratigraphic and sidescan sonar techniques, Josenhans and Zevenhuizen (1990) were able to profile these features and compare them to air photos and stratigraphic sections exposed along the shores of Hudson Bay. It has been the preservation of these features and the ability to compare them with the onshore that has opened up a complete new dialogue with terrestrial Quaternary geoscientists. The removal of a large amount of the skepticism which was prevalent has made for excellent joint participation in onshore-offshore correlation. As a result there has been better incorporation of marine data such as the surficial geology map of Zevenhuizen and Josenhans (1989) in Fulton's (1995) "Surficial Materials of Canada Map".

For this project the surficial geology and seabed feature mapping is based on detailed interpretation of more than 5000 line kilometres of seismic reflection data (Figure 8) groundtruthed with nearly 500 bottom samples (Figure 9). From these data a series of 8 interpretive maps were prepared. Approximate scale of the interpretive maps is 1:830 000 (UTM Projection, Zone 18, NAD27). The following chapter describes and discusses these maps.

7.1 - SURFICIAL GEOLOGY AND ISOPACH MAPS

The surficial geology interpretation presented with the following maps is primarily based on seismostratigraphy. The lithostratigraphic interpretation associated with these units was derived from bottom sample data and the comparison of these data to the onshore stratigraphic sections exposed in the valleys of the Grande Rivière de la Baleine and the Petite Rivière de la Baleine and those exposed in the coastal areas.

7.1.1 - SURFICIAL GEOLOGY

This surficial geology map (Figure 34) shows the distribution of the surficial units as determined from sub-bottom profiler and sidescan data (Figure 8). The coloured areas represent areas where sufficient data are available for mapping at this scale. On this map the seabed distribution of the surficial units (as described in Chapter 5 and 6) is shown. Extent of sediment failure/slump deposits is shown on this map as a unit as the composition of these deposits probably represents a fairly homogenous mixture of all the sediments. In some areas, especially where only 3.5kHz sub-bottom profiler data was available, such as the corridor to the Belcher Islands, it was not possible to differentiate sediment type exposed at the seabed. These zones are mapped as "undifferentiated sediments". The surface relief of most of these sediments suggests that within the resolution of the seismic system these areas consist predominantly of till.

The surficial geology map (Figure 34) indicates that within the survey area bedrock (Unit 1) and glaciolacustrine/marine (Unit 3) outcrop is limited. Bedrock (Unit 1) outcrop is primarily restricted to the crests of the cuesta ridges (Figures 7,16,20,26). The glaciolacustrine/marine (Unit 3) is also restricted to erosionally truncated outcrop along the low angle slope of the cuesta ridges and in some of the deeper basins where the postglacial sediments (Units 4 and 4E) are either in a non-depositional or erosional setting, exposing the glaciolacustrine/marine (Unit 3).

The postglacial muds (Unit 4) and estuarine muds (Unit 4E) blanket over 70% of the region. These units appear to be to some extent depth controlled although this depth varies between the coastal zone and the offshore. Offshore, that is beyond the first major cuesta ridge (Figure 7), the unit is only present in water depths greater than 80m. From the shoreline out to the first basin and along the Manitounuk Islands chain to Richmond Gulf the postglacial units (Units 4 and 4E) are present to at least 40m water depth. In areas sheltered from wave base reworking the unit extends to nearly the shoreline, such as in Manitounuk Sound.

Figure 34:

Surficial geology map is based primarily on seismostratigraphy and sidescan sonar data (Figure 8). This data is groundtruthed with available bottom sample data (Figure 9).

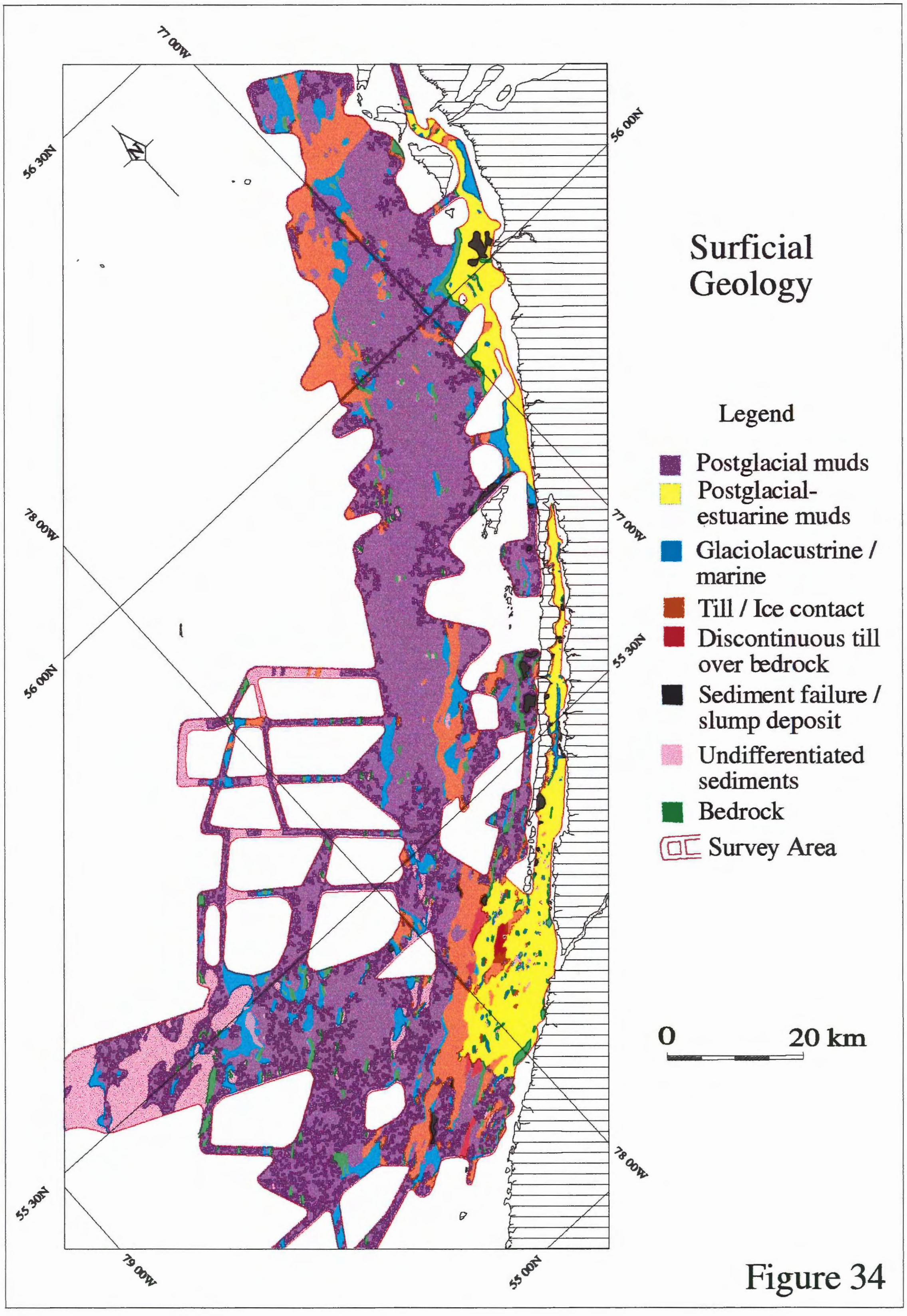

77 00W
56 30N
56 00N
78 00W
77 00W
56 00N
55 30N
55 30N
78 00W
79 00W
55 00N
Surficial Geology
Legend
Postglacial muds
Postglacial-estuarine muds
Glaciolacustrine / marine
Till / Ice contact
Discontinuous till over bedrock
Sediment failure / slump deposit
Undifferentiated sediments
Bedrock
Survey Area
0
20 km

Figure 34

The till/ice contact sediment (Unit 2) distribution is masked by the overlying sediment. On the seabed, outcrop of this unit is primarily restricted to water depths less than 80m. The linear outcrop of the till/ice contact (Unit 2) sediment, as shown on the map trending southwest-northeast in the southern portion of the map, coincides with a thick accumulation of this unit. In the northern section of this map the unit is more evenly distributed (Figure 35).

7.1.2 - TILL/ICE CONTACT SEDIMENT ISOPACH

The till/ice contact sediment isopach map (Figure 35) shows the areal distribution and thickness of the till/ice contact (Unit 2). Data for this unit was primarily determined from airgun, sleevegun, Huntec DTS and Huntec SeaOtter boomer data. Note that the survey area is reduced when compared to Figure 34,36 and 37: this is due the inability of the 3.5kHz subbottom profiler system to determine the bedrock contact which is a requirement to obtain the Unit 2 thichness.

Till/ice contact (Unit 2) sediment distribution can be subdivided into four individual zones. These are: the two large scale accumulations occurring in the southern and northern portions of the map; the western discontinuous deposit which is interspersed with southwest-northeast low relief ridges, and the localized accumulations in the first basin extending from Bear Islands along the shore to Boat Opening (Figure 2).

Note the distribution of thick accumulations of the unit from the southern section of the map and extending almost to Duck Island (Figure 2). Unit 2 thicknesses, along this linear accumulation, locally exceed 80m, is depth transgressive (Figure 7), and does not appear to be bedrock controlled (Figures 14-16).

The accumulation in the northern portion (Figures 18,19,34,35) occurs primarily in shallow water and appears to be distributed more evenly and in a more east-west trend. It is not known whether the islands between Richmond Gulf and the Belcher Islands (Figure 2) consist predominantly of bedrock or, as in James Bay, till/ice contact sediments. Based on the irregular shape of the coastlines of these islands, as shown on the navigation charts of the region, and the linear nature of both the mainland and Belcher Island coastlines (Figure 2), these islands could represent till accumulations. Bruce Sanford (personal communication, 1996) does not feel that these islands consist primarily of bedrock.

The western, seaward zone of discontinuous till, a few metres thick, occasionally interspersed with linear southwest-northeast low relief ridges, areally represent the largest region. Fluting, as determined from sidescan sonar data, appears to be restricted to the small scale linear ridges of this area (Figure 14 and Josenhans *et al.*, 1991). Where observed in plan view on the sidescan sonar data these features are parallel, linear and have the same orientation as the striae orientation observed onshore. Large scale distribution of the fluting is inferred from the till surface morphology, but surface expression of these is masked or obliterated by the presence of ponded postglacial muds (Unit 4, Figures 11,34).

The nearshore till/ice contact (Unit 2) deposit displays the most internal complexity. Along east-west seismic transects the thick accumulations of Unit 2 display no internal structure. When the line orientation is changed to northnortheast - southsouthwest frequent chaotic discontinuous reflectors and hints of stratification are observed. This pertains especially to those deposits extending from Schooner Opening to Petite Rivière de la Baleine. These deposits coincide with substantial pockets of unconsolidated material, especially at Boat Opening.

7.1.2 - GLACIOLACUSTRINE/MARINE SEDIMENT ISOPACH

Distribution and accumulations of the glaciolacustrine/marine (Unit 3) sediments are shown on Figure 36. This unit is present throughout most of the study area as a conformable drape over the bedrock and till/ice contact sediments (Unit 2) where present. Offshore the unit is truncated between 80-90m water depth and is not present over much of the corridor extending to the Belcher Islands. In the first offshore basin and extending to the shore the unit does not appear to be restricted by water depth. Within Manitounuk Sound, opposite Schooner Opening, geophysical data (Zevenhuizen *et al.*, 1992, CSSA, 1991j) suggests that the unit extends to the shore and makes up the bulk of the material of the tidal flats (Figure 26). In uninterrupted depositional settings, such as the inner

Manitounuk Sound (Figure 12), it is difficult to determine the position of the transition from glaciolacustrine/marine to the Tyrrell Sea sediments and/or postglacial estuarine muds.

7.1.3 - POSTGLACIAL SEDIMENT ISOPACH

This map (Figure 37) shows the distribution of the postglacial muds (Unit 4) and the postglacial estuarine muds. Thicknesses of these two sub-units are not differentiated. This unit substantially increases in thickness in the nearshore. This is the result of increased fluvial sediment input. Figure 5 shows the changes in the shoreline over time and the emergent coastal area. The emergent areas were blanketed by till/ice contact (Unit 2), glaciolacustrine/marine (Unit 3) and Tyrrell Sea (Unit 4) sediments. The bulk of the exposed fine grained material has since been deposited in the first nearshore trough accounting for the thick accumulations of Unit 4.

7.1.5 - TOTAL QUATERNARY SEDIMENT ISOPACH

The total Quaternary sediment isopach map (Figure 38) indicates the total unconsolidated sediment thickness over bedrock. This maps shows that with the exception of thinning over the cuesta ridges (Figure 7) and bedrock outcrop (Figure 34) the entire area is covered by unconsolidated sediments. Some of these sediments though consist only of an accumulation of boulders.

Figure 35:

Till/ice contact sediment (Unit 2) isopach map shows the distribution and thickness of the till/ice contact sediments (Unit 2) based primarily on seismostratigraphy (Figure 8). This unit was not frequently sampled (see lithostratigraphy chapter 6).

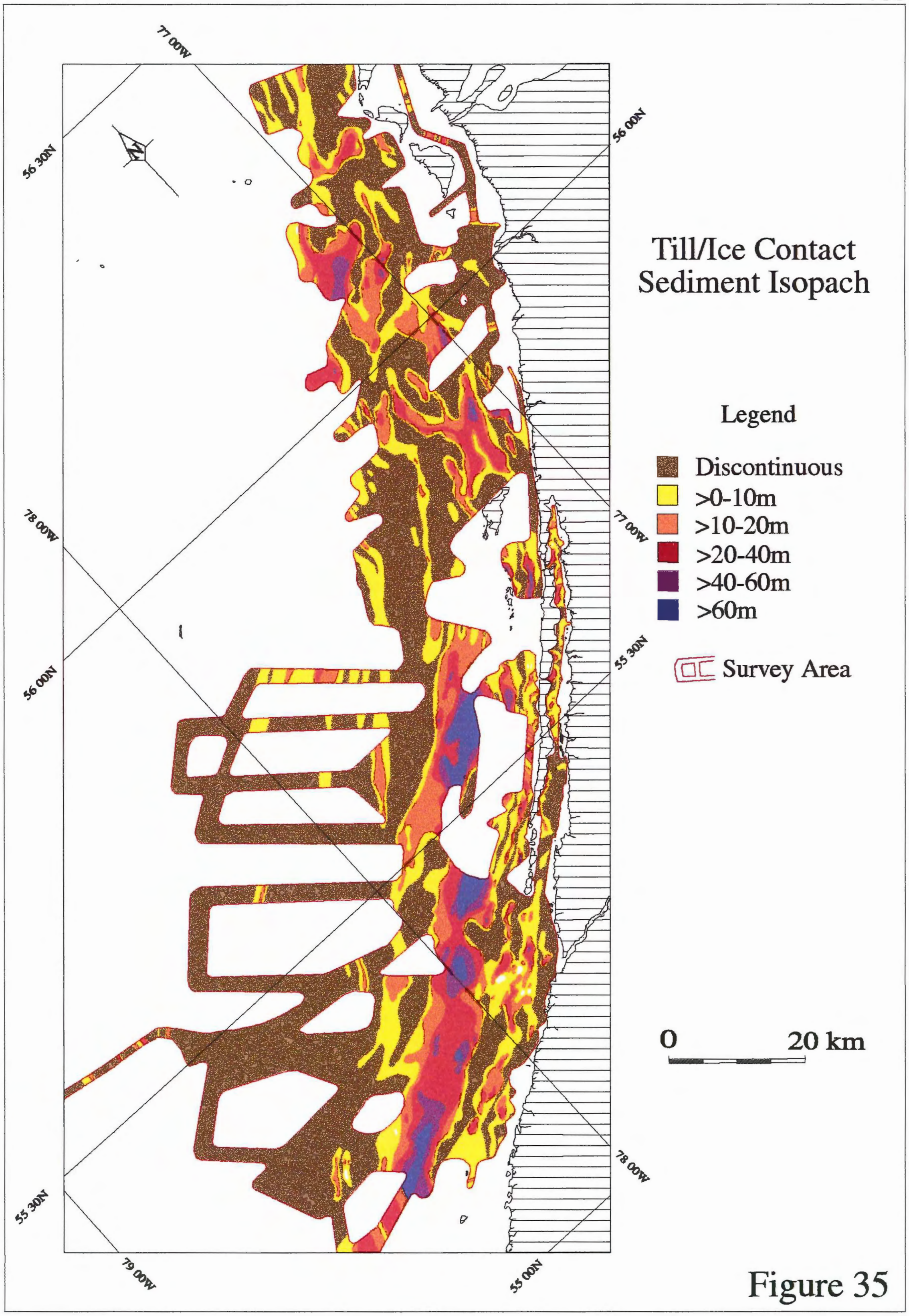

77 00W
56 00N
56 30N
78 00W
77 00W
55 30N
56 00N
55 30N
78 00W
79 00W
55 00N
Till/Ice Contact
Sediment Isopach
Legend
Discontinuous
>0-10m
>10-20m
>20-40m
>40-60m
>60m
Survey Area
0
20 km

Figure 35

Figure 36:

Glaciolacustrine/marine sediment (Unit 3) isopach map shows the distribution and thickness of the glaciolacustrine/marine sediment (Unit 3). Interpretation was based on seismostratigraphy (Figure 8) and core data (Figure 9). from glaciolacustrine/marine to Tyrrell Sea (Unit 4) sediments. Accumulations of this unit >10m appear to be restricted to the nearshore.

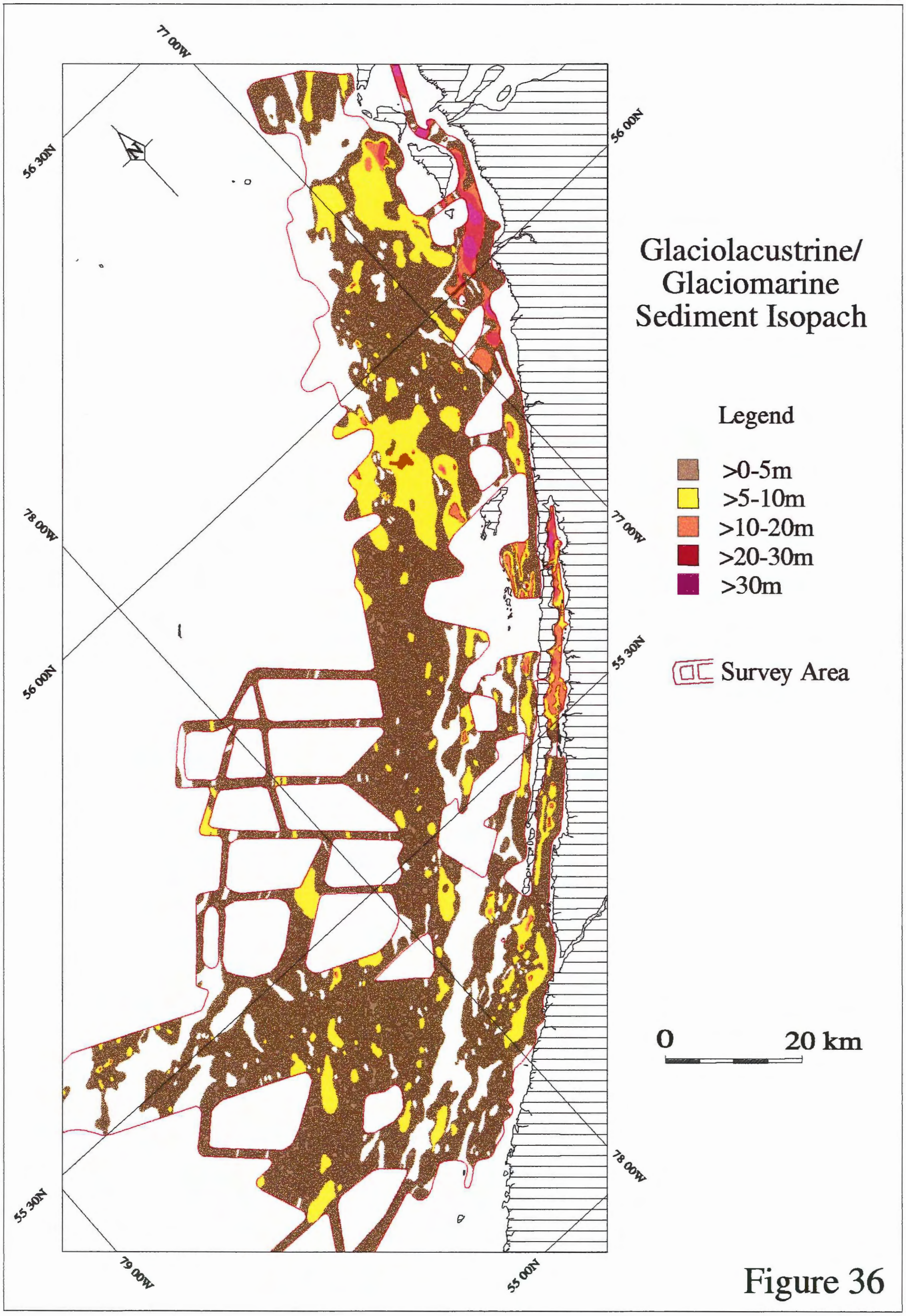

77 00W
56 30N
56 00N
78 00W
77 00W
56 00N
55 30N
55 30N
78 00W
79 00W
55 00N
Glaciolacustrine/
Glaciomarine
Sediment Isopach
Legend
>0-5m
>5-10m
>10-20m
>20-30m
>30m
Survey Area
0
20 km

Figure 36

Figure 37:

Postglacial sediment (Unit 4) isopach map shows the distribution and thickness of the Postglacial sediment (Unit 4). Interpretation was based on seismostratigraphy (Figure 8) and bottom sample data (Figure 9). This map does not differentiate postglacial muds from postglacial estuarine sediments (Figure 34).

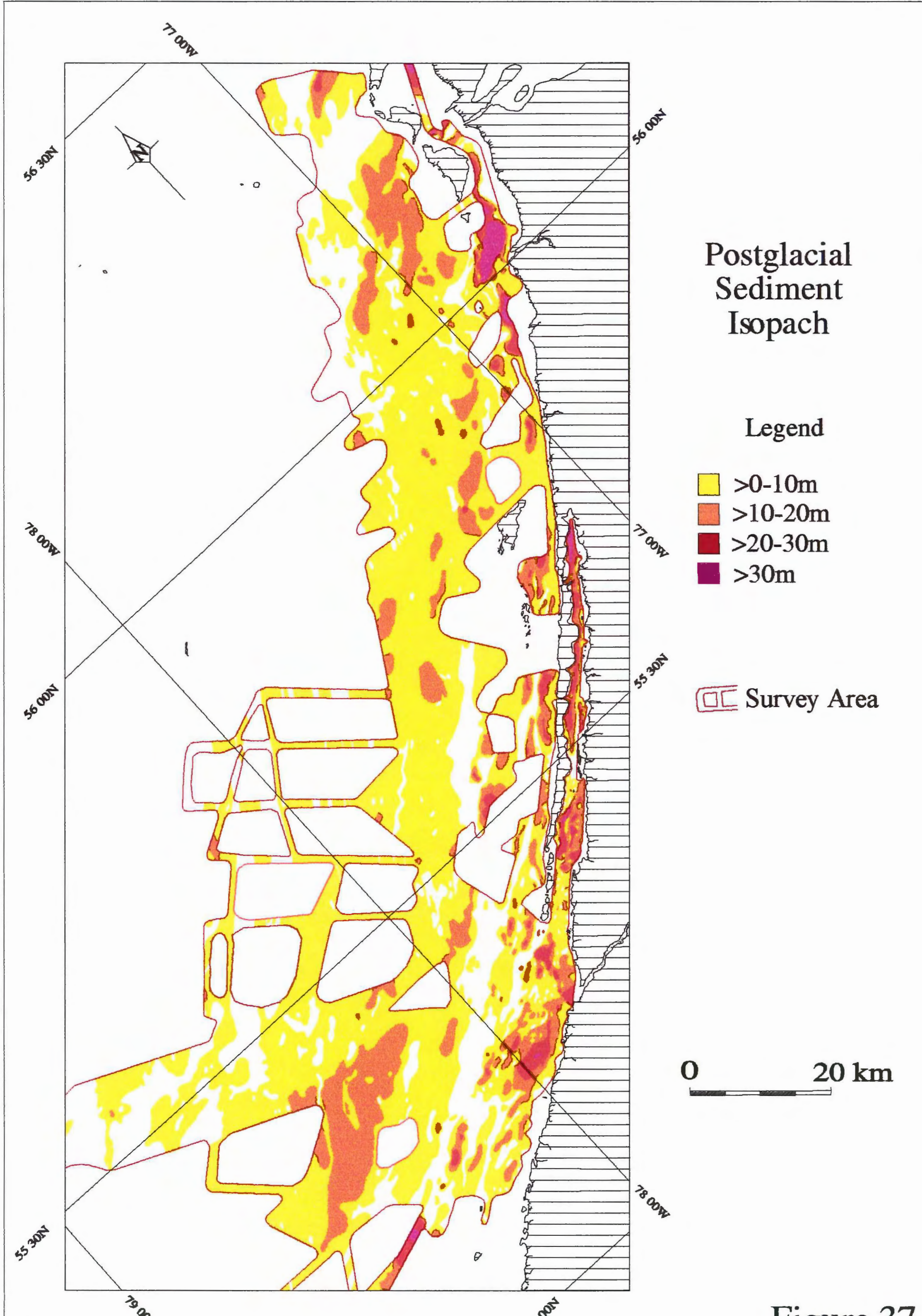

77 00W
56 00N
56 30N
Postglacial
Sediment
Isopach
Legend
>0-10m
>10-20m
>20-30m
>30m
78 00W
77 00W
55 30N
56 00N
Survey Area
0
20 km
55 30N
78 00W
79 00W
55 00N

Figure 37

Figure 38:

Total Quaternary sediment isopach map shows the distribution and thickness of the Quaternary sediments based primarily on seismostratigraphy (Figure 8).

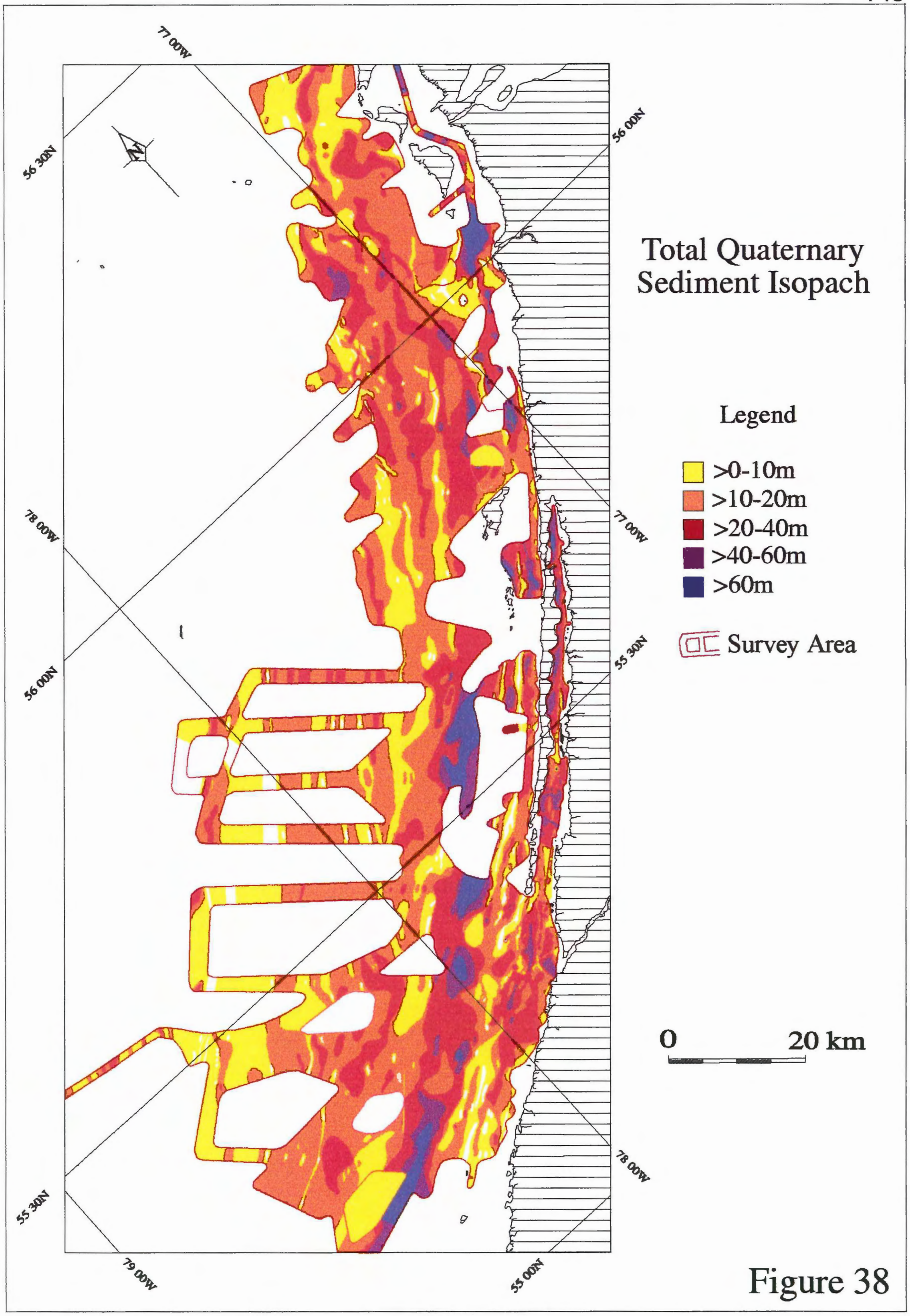

77 00W
56 30N
56 00N
78 00W
77 00W
56 00N
55 30N
78 00W
55 30N
79 00W
55 00N
Total Quaternary Sediment Isopach
Legend
>0-10m
>10-20m
>20-40m
>40-60m
>60m
Survey Area
0 20 km

Figure 38

7.2 - SEABED FEATURES

Distribution of seabed features as determined from sidescan sonar and sub-bottom profiler data have been mapped (Figures 39-41,44); these include glacial features such as moraines and ice marginal positions as well as features such as current features, sandwaves/megaripples, sediment failure/slump deposits and icekeel scouring.

7.2.1 - INFERRED OFFSHORE MORAINES

Based on the till/ice contact sediment isopach map (Figure 35) continuous accumulations of this unit exceeding >10m thickness were mapped as moraines. Also shown on this map are the cross-section location which best illustrates the depositional style of these till/ice contact sediment accumulations. This map shows a fairly continuous linear accumulation extending along the entire survey. This feature ranges from 5-10km wide with sediment accumulations ranging from 5 to >80m thickness. Where observed on sidescan sonar the upper surface of these features appears to be a dead ice topography with a hummocky surface, occasional rhombohedral patterns and frequent point source reflectors interpreted as boulders. No fluting was observed on sidescan sonar imagery over this feature. Fluting appeared to be restricted to areas seaward of this feature.

7.2.2 - INFERRED ICE MARGINS

Based upon the glaciolacustrine/marine sediment isopach map (Figure 36) continuous accumulations of this unit exceeding >10m thickness were displayed. Interfingering of the glaciolacustrine/marine (Unit 3) sediments with the till/ice contact sediments (Unit 2) was only definitely observed at location (A)(Figure 40) (Josenhans *et al.*, 1991). Along the first nearshore trough the till/ice contact (Unit 2) internal structure becomes more complex. Although not definitive this could represent a possible ice margin position especially near Boat Opening (B)(Figure 40).

7.2.3 - BOTTOM CURRENT SEABED FEATURES

Within the deeper basins, sedimentary furrows (Figure 42) and areas of non-deposition (Figure 43) occur while in the Manitounuk Sound outer basin (Figure 21) and seaward of Grande Rivière de la Baleine asymmetric deposition of the postglacial/recent sediments suggest the presence of strong tidal currents.

Bottle drift data (Hachey, 1935, Barber, 1967) indicates a southeasterly flow along the south coast veering to the north in the study area. The bottom topography of the region is complex with numerous shoals separated by deep northeast-southwest trending basins. Localized bottom current (Josenhans and Moir, 1991, Josenhans et al, 1991 and Zevenhuizen, 1993) effects have been observed at the mouth of James Bay and along the channels separating islands along the southeastern coast of Hudson Bay. These bottom currents are predominantly tidally induced.

Tides in the Manitounuk Sound area are semi-diurnal. The tide setting into Hudson Bay radiates in a roughly counter-clockwise circular movement around the bay, following the contour of the shoreline. Mean tidal range in Manitounuk Sound region is 1.5m. Tidal amplitudes are greater in summer, but dampened in the winter months by ice cover (Prinsenberg and Freeman, 1986).

These bottom currents influence the high variability which is best observed in the style of deposition of the postglacial/recent sediments in Manitounuk Sound. Variation can be primarily defined by the three basins with decreasing dynamic conditions from the mouth (Figure 21) to the head (Figure 12) of the sound.

The deposition of the postglacial/recent sediments in the outer Manitounuk Sound (Figure 21) is highly variable. These sediments display an asymmetric depositional style marked by areas of non-deposition/erosion attributed to scour by strong tidal currents. There is a bedrock sill that separates the central and outer sound: this area is interpreted as a zone of non-deposition/erosion. The postglacial/recent sediments in the central sound (Figure 22) shows an asymmetrical ponded deposition (Figure 41). The inner sound (Figure 12) displays a relatively undisturbed, continuous depositional pro/postglacial sediment section. There is little evidence of current scour and reworking with the exception of the basin just east of Boat Opening and the constriction which separates the inner and central sound.

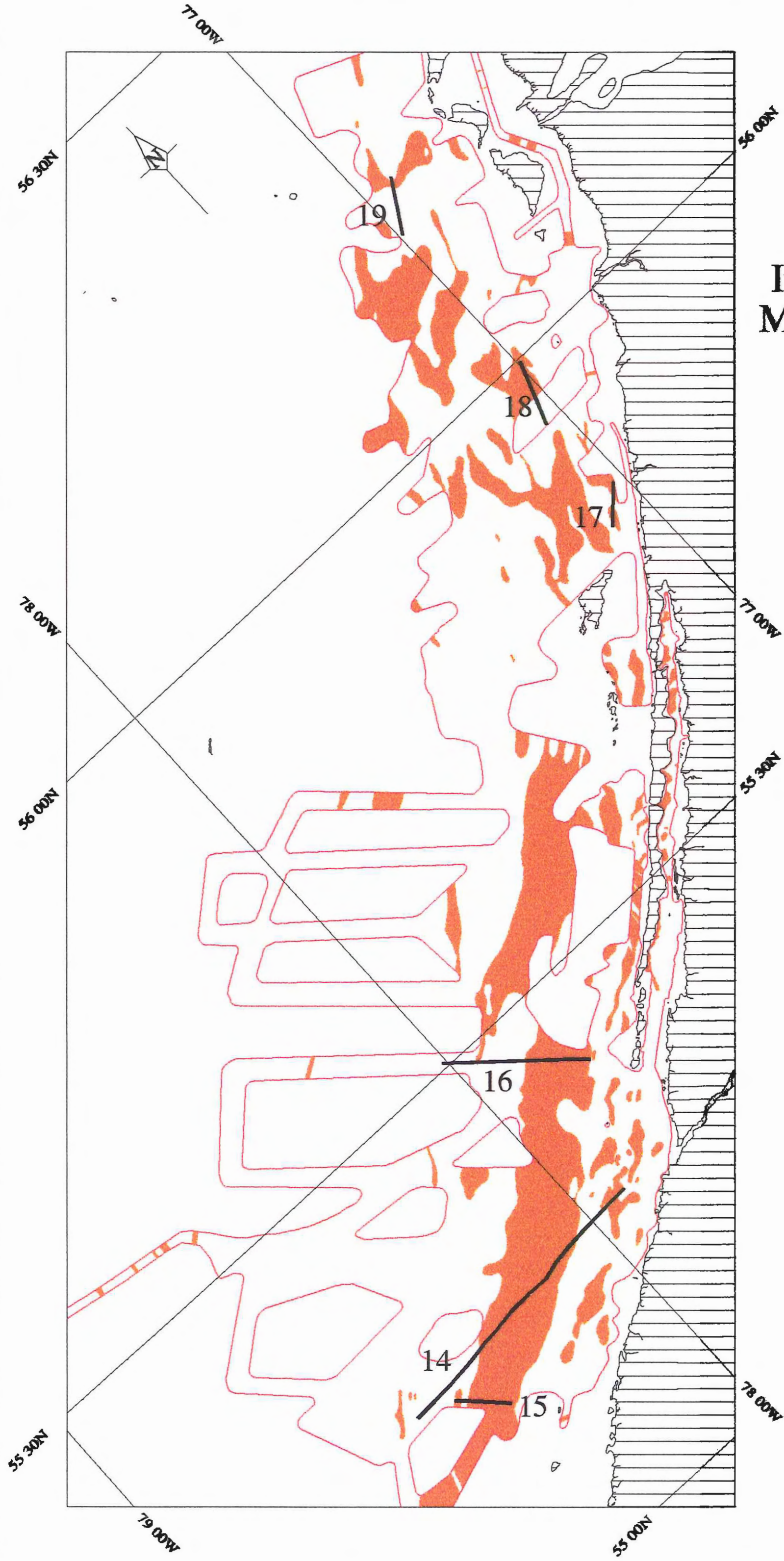
Sandwaves are observed within Manitounuk Sound at approximately 35 m water depth (Figure 41), north of the mouths of the Grande Rivière de la Baleine and in the Petite Rivière de la Baleine area.

7.2.4 - SEDIMENT FAILURE / SLUMP DEPOSITS

Slumping occurs throughout the study area in varying degrees of magnitude (Figure 44). Slumping is only observed within the well stratified glaciolacustrine/marine and postglacial sediments. Isolated regions of undulating and hummocky relief, seismically displaying discontinuous chaotic internal reflectors, associated with areas of steep seabed morphology are interpreted as slump deposits. Failure scarps can be observed on the sidescan sonograms (Figures 45). The majority of large scale slump deposits are concentrated at the base of the steep slopes associated with the coastal cliff sections of the islands and submerged cuesta ridges (Figure 44), and at the delta fronts of the Grande Rivière de la Baleine and Petite Rivière de la Baleine rivers. The largest sediment failure scarp was observed along the western shore of outer Manitounuk Sound.

Figure 39:

Inferred offshore moraine locations map represent till/ice contact (Unit 2) deposits with an accumulation greater than 10 m thick. Note the shore parallel trend from Bear Islands to the Petite Rivière de la Baleine estuary and then a seaward shift of this virtually continuous feature west of the Petite Rivière de la Baleine estuary. For style of deposition of the moraine see Figure 14-19.



Inferred Offshore Moraine Locations

Legend

Till sediment thickness greater than 10 m

11 Figure Number

Figure location

Survey Area

0 20 km

Figure 39

Figure 40:

Inferred ice margin position map represents glaciolacustrine/marine sediment (Unit 3) deposits with an accumulation greater than 10 m thick. These glaciolacustrine/marine sediment (Unit 3) deposits are only observed as interfingering with the till/ice contact (Unit 2) deposits at a location 30 km seaward of the Petite Rivière de la Baleine estuary (A) (Josenhans *et al.*, 1991). Accumulations are associated with large onshore glacial outwash deposits especially at Boat Opening (B).

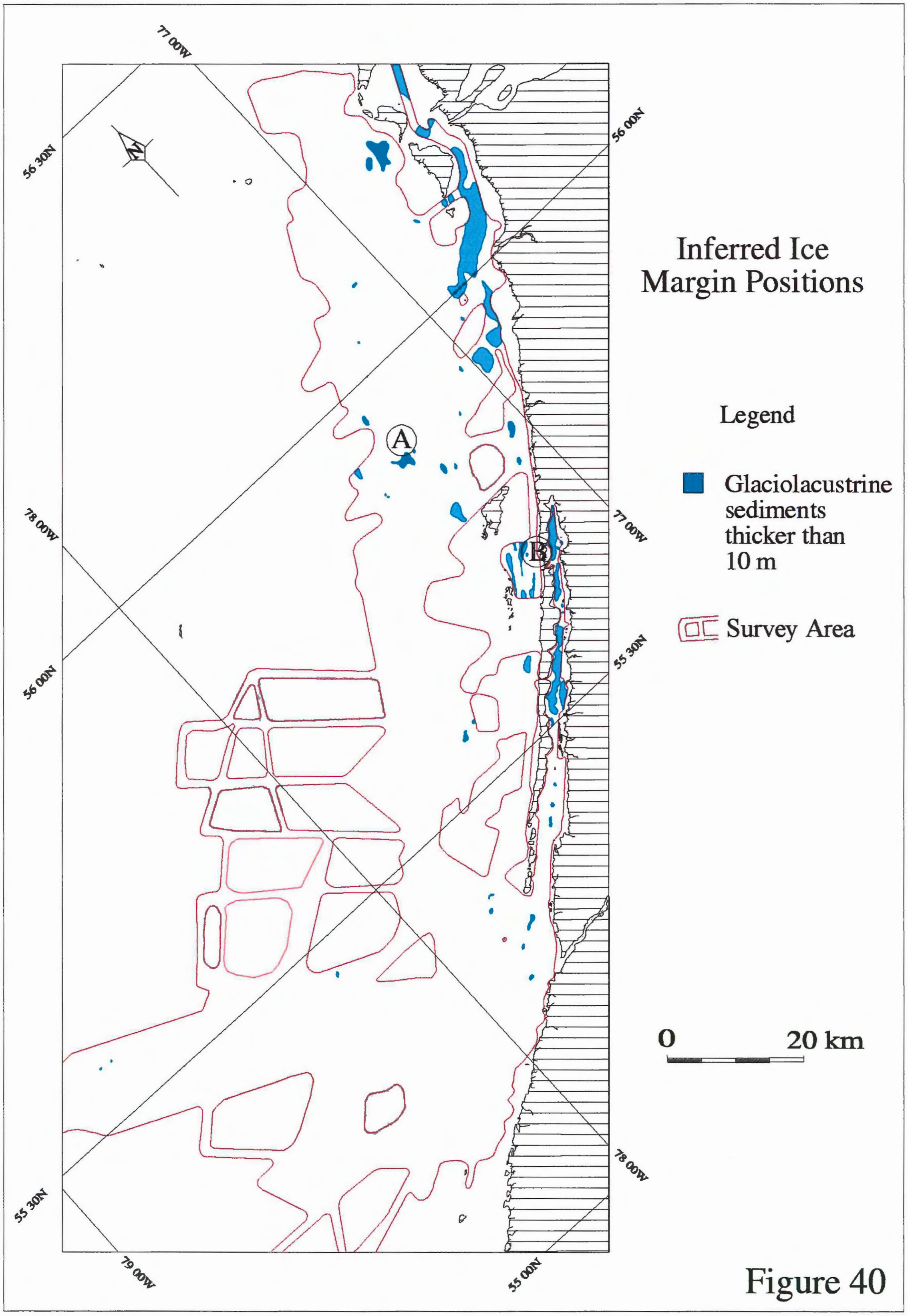

77 00W
56 30N
56 00N
77 00W
78 00W
A
B
55 30N
56 00N
55 30N
78 00W
79 00W
55 00N
Inferred Ice Margin Positions
Legend
Glaciolacustrine sediments thicker than 10 m
Survey Area
0
20 km

Figure 40

Figure 41:

Bottom current seabed feature map shows the location of prominent erosional scarps and areas of non-deposition usually associated with bedrock outcrop, sedimentary furrows and their orientation in the deeper portions of the offshore basins, and the location of both active and relict sandwave/megaripple fields.

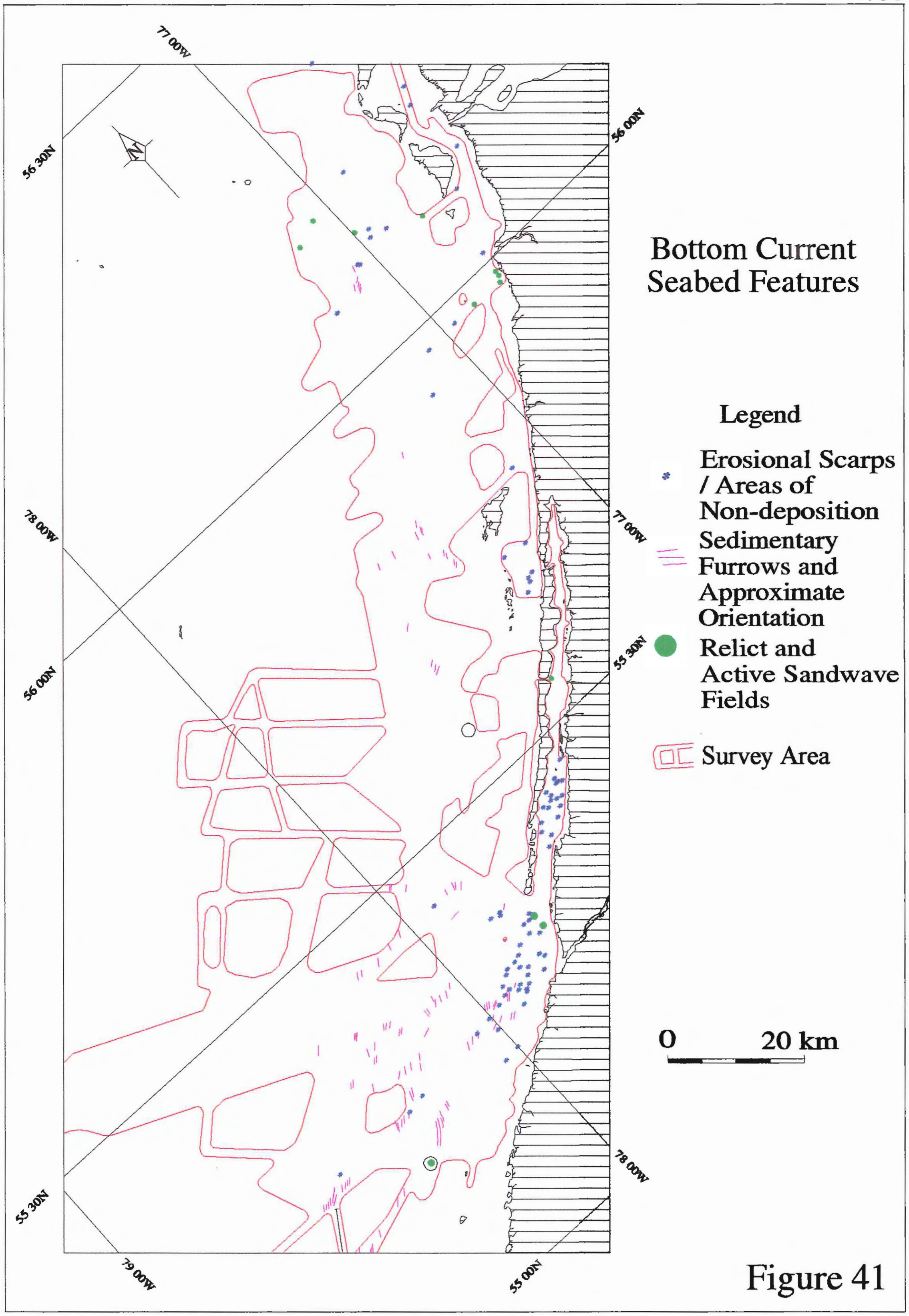

77 00W
56 30N
56 00N
78 00W
56 00N
77 00W
55 30N
55 30N
78 00W
79 00W
55 00N
Bottom Current
Seabed Features
Legend
Erosional Scarps
/ Areas of
Non-deposition
Sedimentary
Furrows and
Approximate
Orientation
Relict and
Active Sandwave
Fields
Survey Area
0
20 km

Figure 41

Figure 42:

Composite sidescan sonogram and Huntec Sea-Otter boomer profile of sedimentary furrows. These erosional furrows are formed in the modern muddy sediments by localized currents, usually along the axis of the deeper troughs. The arrow indicates the direction of current flow and resultant sediment transport in a southwesterly direction (Josenhans *et al*, 1991). See Figure 10 for section location.

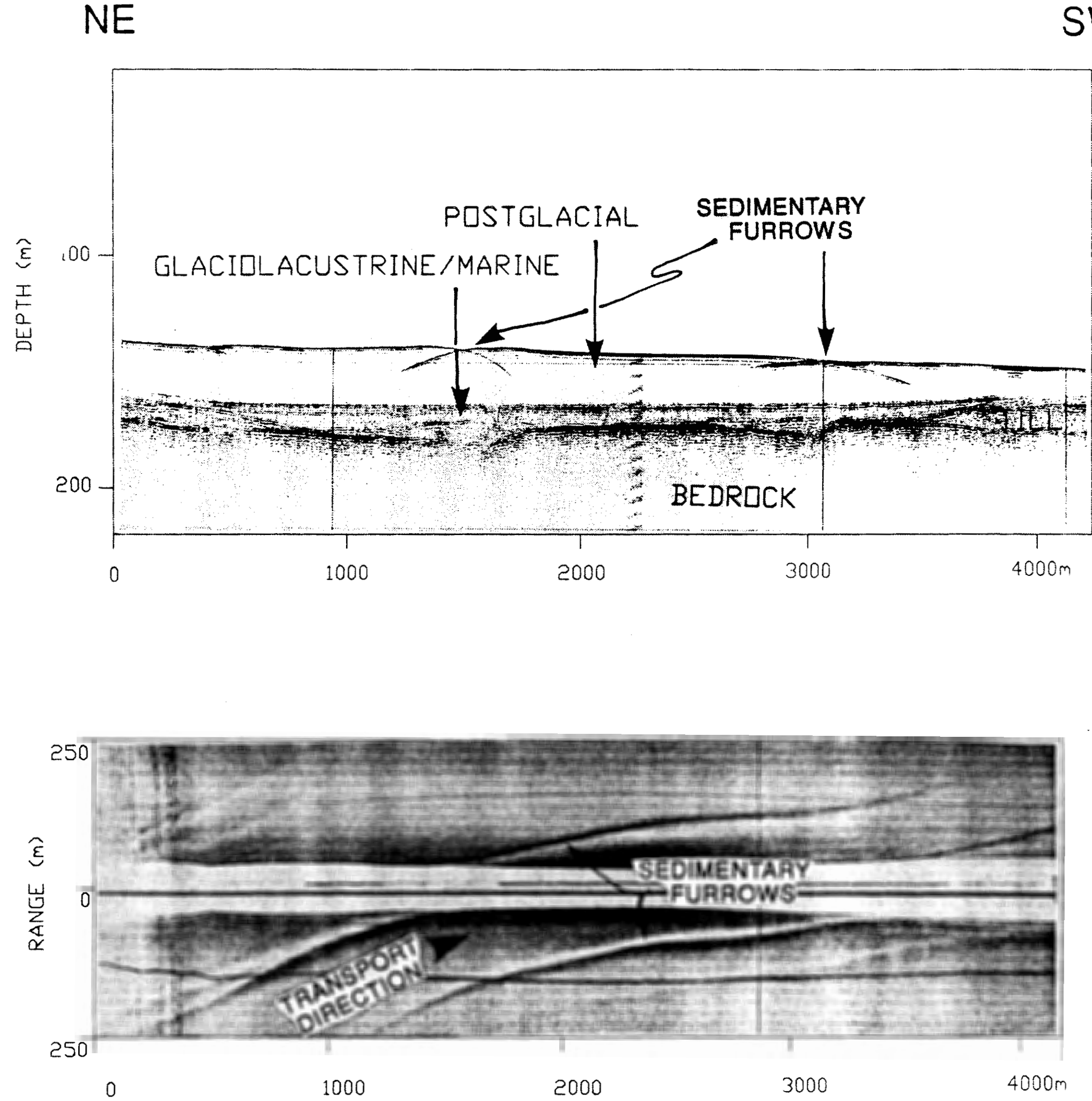

NE
SW
DEPTH (m)
100
200
POSTGLACIAL
SEDIMENTARY FURROWS
GLACIOLACUSTRINE/MARINE
BEDROCK
TILL
0
1000
2000
3000
4000m
RANGE (m)
250
0
250
SEDIMENTARY FURROWS
TRANSPORT DIRECTION
0
1000
2000
3000
4000m

Figure 42

Figure 43:

Huntec Sea-Otter boomer profile of a wedge of postglacial sediments preferentially deposited in a deep basin. The profile illustrates the irregular deposition pattern of modern sediments with an area of non-deposition in the present day within the deepest portions of the basin (Josenhans *et al*, 1991). See Figure 10 for section location.

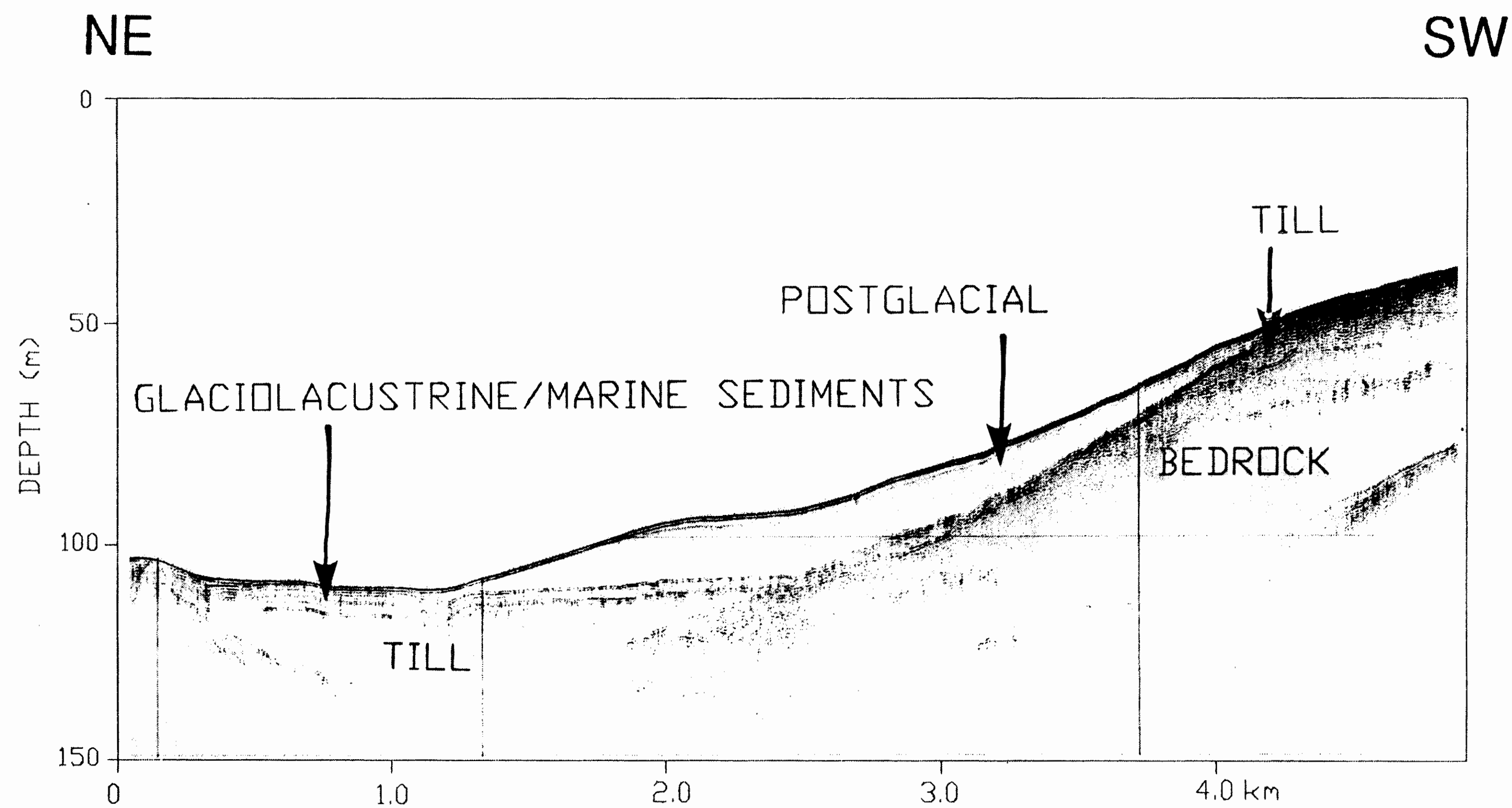
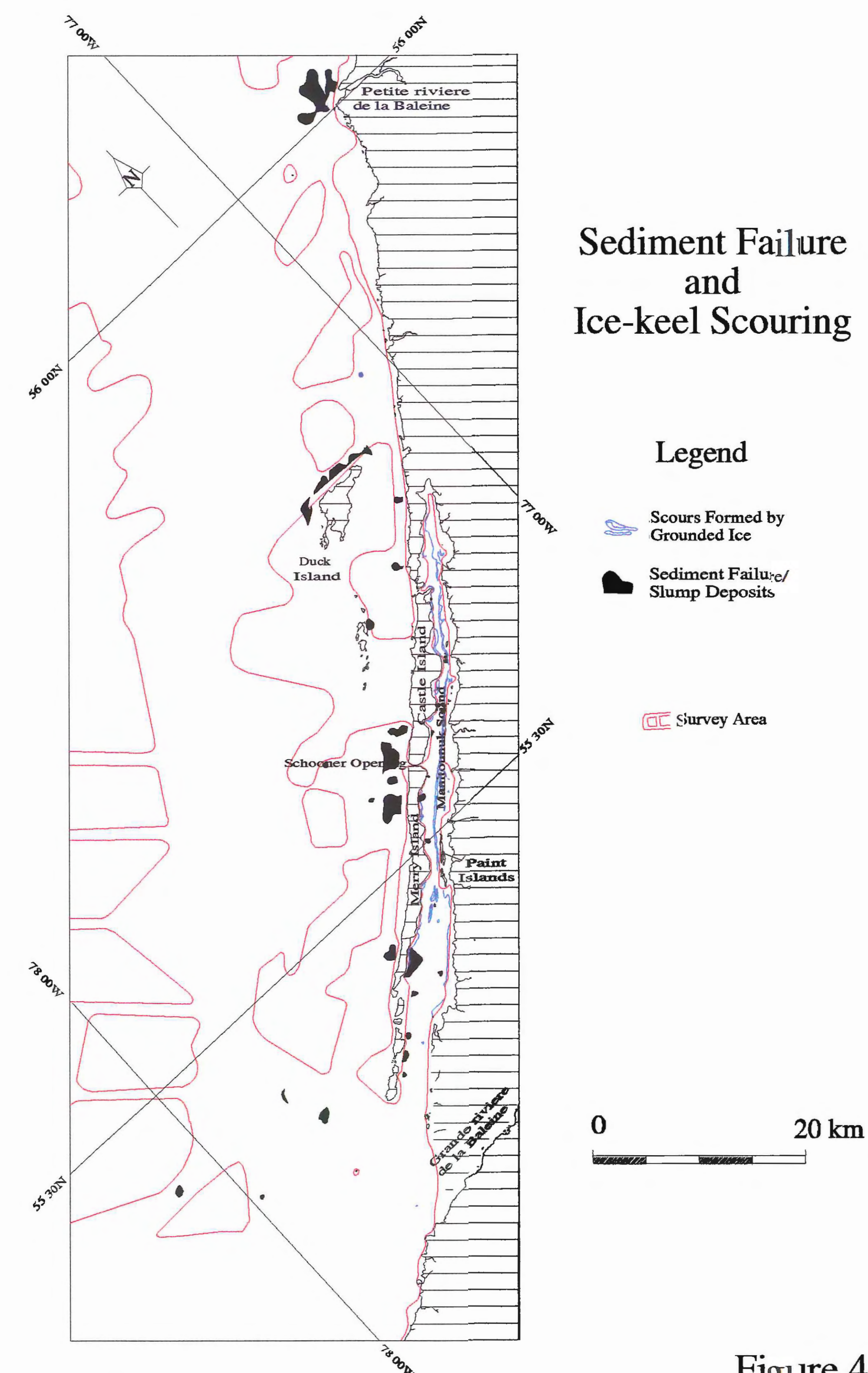

NE
SW
0
50
100
150
DEPTH (m)
TILL
POSTGLACIAL
GLACIOLACUSTRINE/MARINE SEDIMENTS
BEDROCK
TILL
0
1.0
2.0
3.0
4.0 km

Figure 43

Figure 44:

Sediment failure and ice-keel scouring map indicates the locations of observed slump/sediment failure deposits and nearshore ice-keel scouring. Note that slump deposits are not restricted to the high slope areas. Ice-keel scour mapping is very dependant upon preservation potential, scour appears to restricted to water depths less than 22 m (Zevenhuizen *et al.*, 1994).



Sediment Failure and Ice-keel Scouring
Legend
Scours Formed by Grounded Ice
Sediment Failure/ Slump Deposits
Survey Area
0
20 km
77 00W
56 00N
Petite riviere de la Baleine
N
56 00N
77 00W
Duck Island
Castle Island
Manitounuk Sound
55 30N
Merry Island
Paint Islands
78 00W
Grande riviere de la Baleine
55 30N
78 00W

Figure 44

Figure 45:

Composite Huntec Sea-Otter boomer profile and 100 kHz sidescan sonogram illustrating debris flow and channel which occurred in pro/postglacial sediments off a small river just north of Manitounuk Sound. Boomer profile illustrates sediment failure 400 metres wide and up to 15 metres deep. Note disturbed sediments at the base of the channel on the boomer profile, the surface morphology of these disturbed sediments are well defined on the accompanying sidescan sonogram. This sediment failure occurred on the low slope mainland shore. See Figure 10 for location.

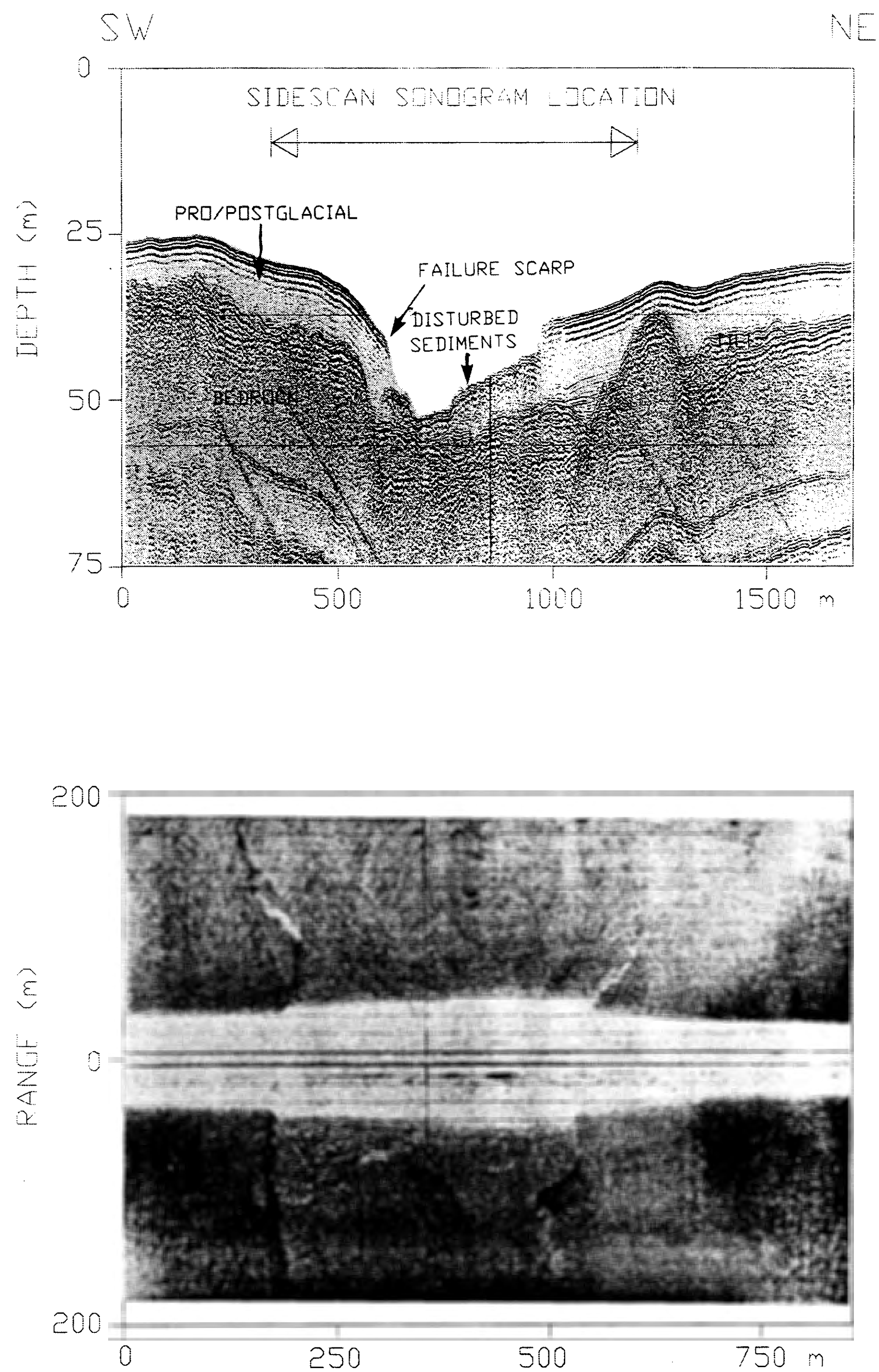

SW
NE
SIDESCAN SONOGRAM LOCATION
PRO/POSTGLACIAL
FAILURE SCARP
DISTURBED
SEDIMENTS
BEDROCK
DEPTH (m)
0
25
50
75
0
500
1000
1500 m
RANGE (m)
200
0
200
0
250
500
750 m

Figure 45

7.2.5 - ICEKEEL SCOURING

Icekeel scouring has been observed to present day water depths of greater than 22m. Icekeel scouring occurs predominantly along the low slope coastlines and is best preserved in the fine grained glaciolacustrine/marine and postglacial sediments. Scouring was observed south of the Grande Rivière de la Baleine, along the eastern shore of Manitounuk Sound and offshore the Manitounuk Island chain. No scours were observed along the coast from north of Grande Rivière de la Baleine to the mouth of Manitounuk Sound possibly due to wave base reworking during the ice-free period. Best documented icekeel scouring occurs along the eastern shore of the central Manitounuk Sound.

The ice cover of Manitounuk Sound reaches a thickness of 1.6-2.2m by May 1 (Markham, 1986). Beyond the shorefast ice the bay is nearly filled with drifting pack ice which moves about in response to the wind. A variable pack is built up in response to the changing winds and ice ridges are built up giving the ice pack a rough and hummocky surface. The keels of these ridges impact the shore to a depth of 22m.

CHAPTER 8: COASTLINE

8.1 COASTAL MORPHOLOGY

Hudson Bay has three basic coastal types determined in large part by bedrock type and structure. Western James Bay and southwest Hudson Bay form the Hudson Bay lowlands. This is an area of low lying coastal marshes, dissected and drained by a number of large rivers. These lowlands are associated with unmetamorphosed Paleozoic sedimentary formations (Sanford and Grant, 1990). Steep coastal cliffs and headlands characterize the northeast and northwest coastline and the north coasts of Southampton, Coat's and Mansell Islands, the Nastapoca Arc and Richmond Gulf. The eastern shoreline, with the exceptions of the cliff sections mentioned, is a complex area of numerous small bays, islands, inlets and headlands.

8.2 - COASTAL ELEMENTS

The coastal relief in this region decreases from north to south. Coastal elements in the northern Richmond Gulf section are primarily a scarp coast with a chain of barrier islands offshore. The east facing sides of the barrier islands are cliffed. Coarse sediments occur at some locations, otherwise the dominant substrate is rock. The Petite Riviere de la Baleine estuary is dominated by a scarp coast, but a mixture of rock outcrop and coarse sediment is prevalent in the river mouth.

In the Manitounuk Sound and Duck Island region, the mainland coast and the outer (western) side of the Manitounuk Islands form a scarp coast, whereas the east (Manitounuk Sound) side of the islands is cliffed.

The coastal elements of Manitounuk Sound are consistent along the western shore as a high cliff coast which is vertical or near vertical with heights greater then 30 m and an absent or narrow foreshore with the exception of Boat Opening where a substantial accumulation of unconsolidated material (moraine (?)) is present along the southern shore (Michaud and Frobel, 1993, Zevenhuizen, 1993). The eastern mainland shore from the head of the sound to the Paint Islands has broad tidal flats separated by rocky promotories. Fine sediment beaches are common along the mainland coast of Manitounuk Sound, and extensive mud flats are developed along the mainland side of the inner basin from the Paint Islands to the head of the sound. The outer sound has an irregular coast of low slope with small embayments in which small pocket beaches and narrow tidal flats are present (Michaud and Frobel, 1993, Zevenhuizen, 1993).

A fine sediment beach and narrow tidal flat are developed at the Grande Riviere de la Baleine estuary. The remainder of the coast in the study area consists mainly of a scarp coast with coarse sediments at some locations.

8.3 - COASTAL EMERGENCE DUE TO GLACIO-ISOSTATIC RECOVERY

Inuit and Cree occupation followed shortly after deglaciation. Francis and Morantz (1983) suggest that the earliest habitation of the James Bay area by the Cree could have been more than 5000 years ago while Inuit occupation north of James Bay extends back at least 4000 years (McGhee, 1976).

The Geological Survey of Canada carried out a number of early surveys in the region. Bell (1879) surveyed the coast from Moose Factory at the head of James Bay to the Hopewell Islands by jolly-boat. He was followed by Low (1888, 1902, 1903), who completed numerous coastal surveys as well as river traverses. Both researchers were struck with the rapid sea-level fall of the eastern shore of Hudson Bay and variations in glacial flow directions. They described the presence of marine clays, well above the present day shoreline, terraces, old beaches and glacial striae. Bell (1879) noted that "there is abundant evidence that the sea-level is falling at a comparatively rapid rate in Hudson's Bay. Since the Hudson's Bay posts have been established at the mouths of various rivers there has been an increasingly difficulty in approaching them with large craft". Bell (1879) makes sea-level history observations based upon an assumed rate of decay for spruce wood fragments. The presence of spruce driftwood was observed at the lower paleo beach ridges and was not observed on beach ridges above 15m, the wood fragments observed displayed an increasing level of decay from present sea level to the level 15m above present sea level. From these observations Bell postulated a lowering of sealevel of 1.53 - 3.05m per century. Vessel draft observations (Bell, 1879) were probably based on Hudson's Bay Company post records from Eastmain (established 1719), Richmond Gulf (established 1749) (Francis and Morantz, 1983, Graburn, 1969) as well as intermittently operated posts in Great Whale River, Little Whale River and Fort George (Graburn, 1969). The last three posts were all operating during Bell's survey.

Bell (1879) established two sea-level reference sites north of the study area in the Hopewell Island chain. To date it is not known whether these sites have been reoccupied. One is the narrow strait which separates the eastern side of the fifth Hopewell Island from the mainland, which was reported to be 18m wide and shallow but deep enough to allow a longboat with draft of 0.6m to pass freely at high tide but through a sinuous channel route at low tide. Therefore this strait should at present be totally exposed. At another nearby site, along Five-mile Inlet, there is a shallow narrow (5-6m wide) entrance to a lagoon through which the jolly boat had to be disembarked and poled through. During Bell's survey water from this lagoon was brackish and should at present be definitely fresh. At present tides at Inukjuak are 0.3m. In reference to this work it would also be interesting to review shipping records of the Hudson Bay Company.

Low (1888) documents glacio-isostatic recovery rates ranging from 115-220m based on observation of stratified marine sands and clays in the Grande riviere de la Baleine, Petite riviere de la Baleine and Clearwater River (this river flows into Richmond Gulf). Low

(1888) attributes the presence of terraces in these sediments as periods of quiet, or reduced recovery.

The Hudson's Bay post on the Belcher Islands was not established until 1928 (Usher, 1976). Recent observations at Eskimo Harbour on the Belcher Islands, based on the reoccupation of a tidal station (Sandilands, personel communication, 1992), indicated a rate of sea-level fall of approximately 0.01m/year.

Due to isostatic recovery (currently approximately 0.01m/year, Figure 4) the unconsolidated material from the tidal flats and shoreline is constantly exposed to erosion by tidal currents and wave action, and by episodic storm surges. Fine grained material is transported to the deeper basins and possibly out into Hudson Bay through the various openings. Figure 5 indicates the changing shoreline from 6 ka to present. Note that the recovery rates (Figure 4) were substantially higher in the past. Unfortunately as the basin becomes smaller by this process, coastal sediments are constantly being reworked. This makes radiocarbon dating of shell material problematic as can be seen on the three dates determined from shell material obtained from a core taken on the riviere Kuugapik tidal flat area. These dates are:

Depth of:	0.70m	83.6 mg wood fragments	3960±50
	0.99m	128.7 mg wood fragments	1310±50
	1.01m	51.3 mg shell fragments	2130±60

Table 3: Upper postglacial C^{14} dates, Manitounuk Sound

An attempt was made to correlate tide gauge data to determine present day isostatic recovery rates. The tide gauges established in the Manitounuk Sound region have only been temporary, the bench mark at a tide gauge at Kuujuaraapik proved unstable but the bench mark at Eskimo Harbour on the Belcher Islands which was installed in the 60's and re-occupied in the late 80's indicated a rate exceeding 0.01m/year (Sandilands, pers comm).

Shortly after ice retreat Hudson Bay covered approximately a 30% greater area (Dyke and Prest, 1987), with a significantly different coastal configuration (Figures 3,6). As the ice margins retreated to the perimeter of present day Hudson Bay sea levels in southeastern Hudson Bay were up to 315m higher than present (Vincent, 1989). Maximum recorded marine limit in the Keewatin District indicate paleosealevels up to 123m higher than present day (Shilts, 1986, Shilts et al., 1987) which occur at approximately 8.0 ka. In the southeastern area of Hudson Bay a sea level of up to 315 m above present day sea level (Vincent, 1989) has been observed. The area is rapidly emerging; a minimum emergence curve for Richmond Gulf (Vincent, 1989, Hillaire-Marcel, 1976,1979) indicates that at the time of deglaciation, 8.1 ka according to Hillaire-Marcel (1976), initial uplift was rapid

(10.0-6.5m/century) decreasing to 1.1m/century in the present day (Figure 4). Uplift was therefore rapid in the beginning although timing is a contentious issue with the start of emergence beginning sometime between 8.1ka (Hillaire-Marcel, 1976) and 6ka (Allard and Tremblay, 1983a,b). Emergence slowed and has remained constant at 0.01m/yr from about 2.8ka (Allard and Tremblay, 1983a,b). This present day rate is currently best observed at a permanent tide gauge at Eskimo Harbour on the Belcher Islands (Sandilands, personel communiction, 1992).

Pirazzoli (1991) provides an excellent quantitative and subjective overview of sea-level change occuring in Hudson Bay. These changes are factual based strictly on the C14 dates in the published literature and are presented in a global context.

CHAPTER 9: DISCUSSION

Hudson Bay was the geographic centre of the Laurentide Ice Sheet. Regional Quaternary studies have conveniently used the large expanse of Hudson Bay as an area to draw ice domes, divides, saddles and receding ice margin boundaries. Reconnaissance marine surveys and the lack of any transgressive surfaces found on land have shown that one of the unique features of Hudson Bay is that since deglaciation the coast has been constantly emerging. The rapid emergence of this coast provides the unique opportunity to complete an onshore-offshore correlation because, within the bay, all glaciogenic features are preserved up to the level of the present day wave base reworking. This is in contrast to other areas of eastern Canada such as the Scotian Shelf where up 100m of relative sea level rise has occurred.

The disintegration of the Laurentide Ice Sheet during the late Quaternary - Early Holocene has sculpted the morphology of the region. The surficial sediments and landforms occurring in and around James Bay preserve evidence of the late stages and disintegration of the Laurentide Ice Sheet. Onshore the Harricana Interlobate Moraine and the Sakami Re-Equilibration Moraine (Figure 5) (Vincent, 1989) are the most prominent regional glacial features. This thesis extends these features seaward to provide a Late Quaternary geological history for the region.

9.1 - DIVISION OF THE LABRADOREAN ICE DOME AND THE FORMATION OF THE HARRICANA MORAINE

Onshore Quaternary studies of Hudson Bay and surroundings for the period 10-7 ka document the rapid disintegration and final stages of the Laurentide Ice Sheet. The major glaciogenic landforms observed onshore are the product of the wasting of the Labradorean Ice Dome and subsequent division into the Hudson and New Quebec Ice Domes (Vincent, 1989). Within the southeastern Hudson Bay - James Bay region this formed the ice contact/glaciofluvial Harricana Interlobate Moraine (Vincent and Hardy, 1979).

Glacial lakes were formed along the southern glacial ice margins due to the wasting of both the Hudson and New Quebec Ice Domes. Glacial lakes Barlow-Ojibway initially drained to the south, through the Saint Lawrence River valley (Vincent and Hardy, 1979). The lake was later pinned between the Hudson Bay and St Lawrence River valley drainage divide and the ice front.

The initial formation of Lake Barlow-Ojibway was at about 11.5 ka with the incorporation of Lake Barlow by Lake Ojibway by about 10.0 ka. Lake Ojibway lasted until the catastrophic drainage at 8.0 ka (Vincent and Hardy, 1987). Along the southern margin of the lake total of 2110 varves were deposited in the varved sequence (Vincent, 1989). If these varves are considered as true annual indicators than the glacial lake was in existence for this time frame. Catastrophic drainage and the resultant drop in water levels formed the grounding line of Sakami Re-equilibration Moraine along the eastern shore of the lake.

9.2 - DRAINAGE OF LAKE OJIBWAY AND TYRRELL SEA INVASION

The catastrophic drainage of Lake Ojibway was initiated when the ice sheet separating Lake Ojibway and the Tyrrell Sea was breached. The resultant drop of at least 150m in water level provided the mechanism for the formation of the Sakami Re-equilibration Moraine (Figure 46). Tyrrell Sea waters from Hudson Strait penetrated Hudson and James Bays when glacial Lake Ojibway drained (Hardy, 1976). As the ice margin retreated, sea levels were substantially higher than present due to isostatic depression of the region.

In Chapters 5 and 6 of this thesis the comparison of the onshore and offshore stratigraphic section indicates that the onshore sections are analogous to the offshore sediment packages. The entire marine sequence (Figure 24) can be correlated to the sections preserved in the Grande Rivière de la Baleine (Figure 25) with the exception of the drainage horizon (Figure 27) associated with the catastrophic drainage of Lake Ojibway (Vincent, 1989). The occurrence of this horizon onshore also does not appear to be continuous as it does not appear at the onshore section site (Figure 25,30). Deltaic sediments (Figure 25) associated with the paleo Grande Rivière de la Baleine estuary (Figure 25) are interpreted to be present in the marine environment but were not sampled.

Figure 46

(46-A) Model for the formation of the Sakami Moraine during the catastrophic drainage of Lake Ojibway (level 1) to the level of the Tyrrell Sea (level 2) as shown by Hillaire-Marcel (1979). Glaciofluvial/ice contact sediment accumulation are deposited at the grounding line emplacing the moraine.

(46-B,C) Model proposed for the formation of the Sakami Moraine equivalent in the marine environment. Based on bathymetric and topographic data there appears to be no topographic barrier restricting ice flow or containment of the ice sheet. The ice sheet would therefore be more unstable and have a significantly reduced profile than proposed by Hillaire-Marcel (1979)(A).

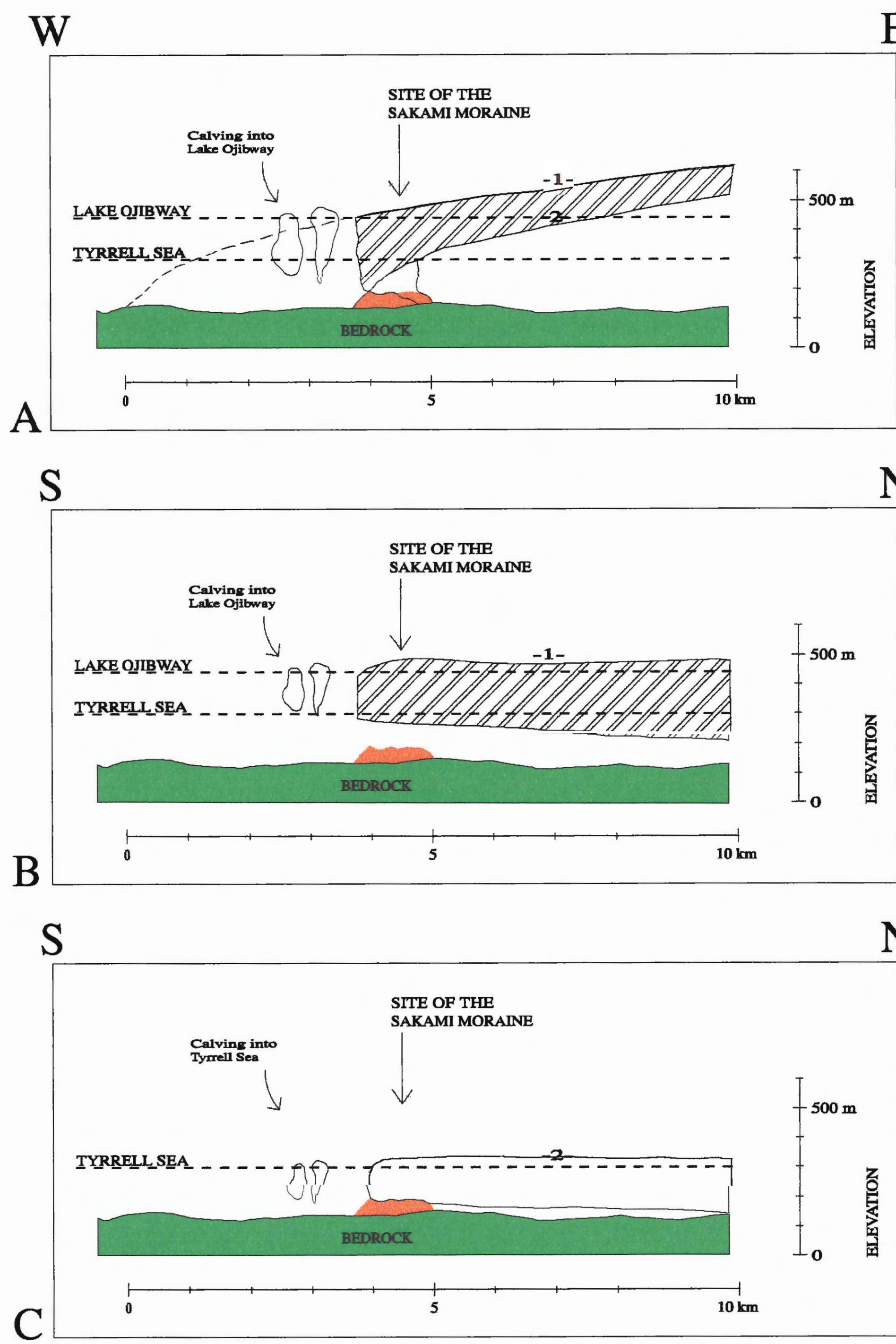

W
E
SITE OF THE
SAKAMI MORAINE
Calving into
Lake Ojibway
-1-
-2-
LAKE OJIBWAY
TYRRELL SEA
BEDROCK
500 m
0
ELEVATION
0
5
10 km
A
S
N
SITE OF THE
SAKAMI MORAINE
Calving into
Lake Ojibway
-1-
LAKE OJIBWAY
TYRRELL SEA
BEDROCK
500 m
0
ELEVATION
0
5
10 km
B
S
N
SITE OF THE
SAKAMI MORAINE
Calving into
Tyrrell Sea
-2-
TYRRELL SEA
BEDROCK
500 m
0
ELEVATION
0
5
10 km
C

Figure 46

9.3 - REGIONAL COMPARISONS AND INFLUENCES

The southeastern Hudson Bay section is very similar to the Champlain Sea section to the south and the Hudson Bay basin and Hudson Strait to the north.

The base of the Champlain Sea section consists of a Wisconsinan till overlain by rhythmites interstratified with gray diamicton (ice contact or tidewater glacier margin) then overlain by rhythmites which either represent ice proximal glaciomarine (Champlain Sea, Gadd, 1988) or glaciolacustrine sediments of Lake Frontenac; these are then overlain by blue green marine clays. Gadd (1988) states that the relationship of the Champlain Sea to the freshwater both preceding and following the marine incursion is very problematic and discussion always seems to centre on the rhythmite sequence.

Hudson Strait, due to its substantial depth (up to 900 metres deep) and width (90 - 340 kilometres), forms an important conduit for any glacial ice centred over Hudson Bay. A large volume of the Laurentide Ice Sheet covering Hudson Bay, Foxe Basin and Labrador-Ungava dispersed through Hudson Strait as either ice or meltwater (Andrews *et al.*, 1995). Hudson Strait, in comparison to the relatively shallow Hudson Bay and Foxe Basin, has a substantially greater water depth and opens to the east into the north Atlantic. The Hudson Strait depth and susceptibility to oceanic influences were probably a significant factor in initiating the draw-down of the continental ice sheets and starting outflow (Gray *et al.*,1993). Recent findings indicate that the last deglaciation cycle was rapid and up to 2000 metres of ice cover over Hudson Bay receded within 400 years (Dyke and Prest,1987). Detailed seismostratigraphic analysis (MacLean *et al.*, 1992) and detailed lithological and foraminiferal analysis (Vilks et al., 1989) indicate that although complex the stratigraphic section is similar to both the Champlain Sea section (Gadd, 1988) and the southeastern Hudson Bay section (Bilodeau *et al.*, 1990a, Zevenhuizen, 1991, 1993, Zevenhuizen et al., 1994, Gonthier *et al*, 1993)

Distinctive glaciogenic and stratigraphic indicators are well preserved in the floor of central Hudson Bay and indicates low rates of postglacial deposition in this region. Analysis of these geomorphic features observed on the floor of Hudson Bay indicated that these are similar to subaerially exposed glaciogenic features observed around the perimeter of Hudson Bay. Subglacial features observed include fluted terrains with superimposed rogen moraines, relief attributed to ice surging, eskers, subglacial channels and dead ice topography (Josenhans and Zevenhuizen, 1990).

9.4 - ENVIRONMENTAL DISCUSSION OF STRATIGRAPHIC UNITS

9.4.1 -BEDROCK (UNIT 1)

Within the survey area bedrock (Unit 1) outcrop is limited. Bedrock (Unit 1) outcrop is primarily restricted to the crests of the cuesta ridges (Figures 7,16,20,26). The question arises whether the coast parallel troughs and intervening crests are a product of glacial erosion or whether these are pre-existing structural features, possibly overdeepened by glacial activity. They appear to be orogenic type features locally offset by faults. During the pre-Lake Ojibway period the bedrock provided some control by subdued topographic steering of the ice mass as the position of the ice domes shifted. Two generations of striae are preserved on the coastal bedrock. The older striae have a distinct north-northwest trend while the younger striae in the Petite Rivière de la Baleine trend towards the west-northwest and further south at Grande Rivière de la Baleine are deflected to the west-southwest (Parent and Paradis, 1993). In the offshore fluted till ridges are observed.

Bedrock, although importand in the development and present day characteristics of the region, appears during the early Holocene to have only increased some of the basal stresses on the ice sheet. The ice sheet had thinned substantially by 8.4 ka to 1000m or less and with pre-drainage lake levels along the ice margin of 500-700m the ice sheet would have been fairly buoyant. After the catastrophic drainage to 300-500m during the initial Tyrrell Sea phase (Figure 46) the ice margin underwent substantial re-adjustment.

9.4.2 -TILL/ICE CONTACT SEDIMENTS (UNIT 2)

A morphological zonation of the till distribution indicates that the distribution in the offshore is marked by four distinct zones. These divisions are determined by surface morphology, unit distribution, thickness and orientation. These are: the two large scale accumulations occurring in the southern and northern portions of the map; the western discontinuous deposit which is interspersed with southwest-northeast low relief ridges; and the localized accumulations in the first basin extending from Bear Islands along the shore to Boat Opening (Figure 2).

The oldest zone is interpreted to be the discontinuous deposit along the western margin of the survey area. This zone of discontinuous till a few metres thick, occasionally interspersed with linear southwest-northeast low relief ridges, areally represents the largest region. Fluting, as determined from sidescan sonar data, appears to be restricted to the small scale linear ridges of this area (Figure 14 and Josenhans *et al.*, 1991). Large scale distribution of the fluting is inferred from the till surface morphology, but surface expression of these is masked or obliterated by the presence of ponded postglacial muds (Unit 4, Figures 11,34). Throughout all the sidescan sonar data collected in the region only ten, fairly restricted occurrences of fluting were observed (Zevenhuizen, 1993). These occurrences were all in areas of fairly thin till/ice contact sediment and were all seaward of and not on top of the moraine. This terrain appears to have preserved the west-southwest movement of the ice sheet and is associated with the initial division of the Labradorean Ice Dome into the Hudson and New Quebec Domes (Figure 3). This zone was mapped as the fluted zone (Figure 47).

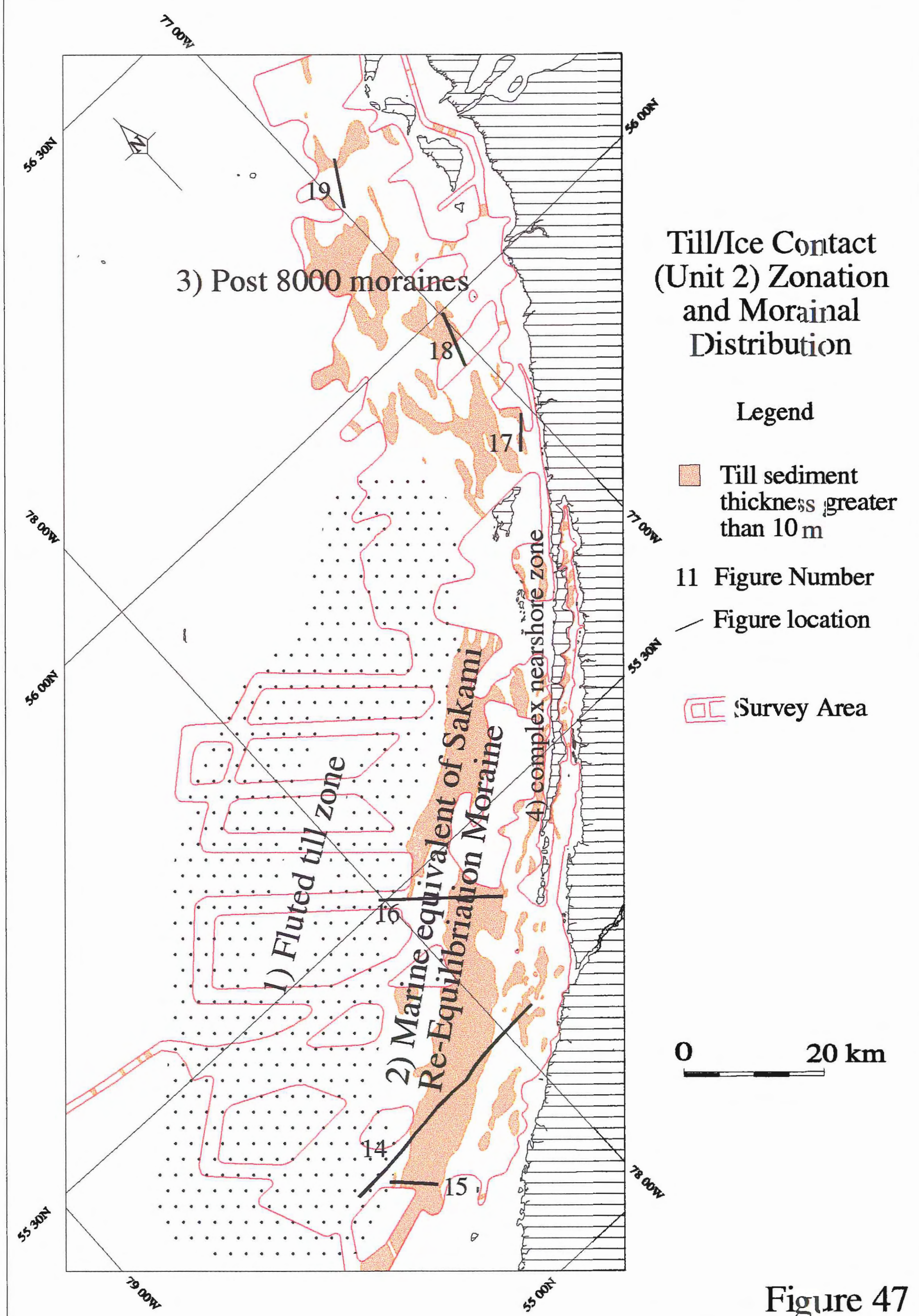
Note the distribution of thick accumulations of the unit from the southern section of the map and extending almost to Duck Island (Figure 2). Unit 2 thickness, along this linear accumulation, locally exceeds 80m. This feature is depth transgressive (Figure 7) and does not appear to be bedrock controlled (Figures 14-16) and displays no visible buoyancy line where it interfingers with the glaciolacustrine/marine. This feature ranges from 5-10km wide with sediment accumulations ranging from 5 to >80m thickness. Where observed on sidescan sonar the upper surface of these features appears to be a dead ice topography with a hummocky surface, occasional rhombohedral patterns and frequent point source reflectors interpreted as boulders. No fluting was observed on sidescan sonar imagery over this feature. Fluting appeared to be restricted to areas seaward of this feature. This feature is interpreted to represent the marine equivalent of the Sakami Re-Equilibration Moraine (Figure 47).

Based upon detailed analysis of all available bathymetric data and the later date for ice retreat from the Ottawa Islands at 7,430 $\pm$ 180 (Andrews and Falconer, 1969), 6,700 $\pm$ 100 for the Rivière Nastapoca region (Allard and Sequin, 1985) and the evidence for catastrophic flow through Winisk Trough (Josenhans and Zevenhuïzen, 1990), initial outflow appears to have been south of the Belcher Islands then into Hudson Bay. Outflow would have been through Winisk Trough with a calving bay extending into the southern portions of the study area (Figure 48).

It is not clear to the author the exact relationship of the Sakami Moraine to the varved Lake Ojibway sediments. By definition and estimated time of formation the Sakami

Figure 47

The till/ice contact (Unit 2) sediment distribution is divided into four zones. The chronological order of emplacement are: 1.) fluted till, 2.) marine equivalent of the Sakami Re-Equilibriation Moraine, 3.) post 8000 moraine and 4.) complex nearshore ice/contact sediments.

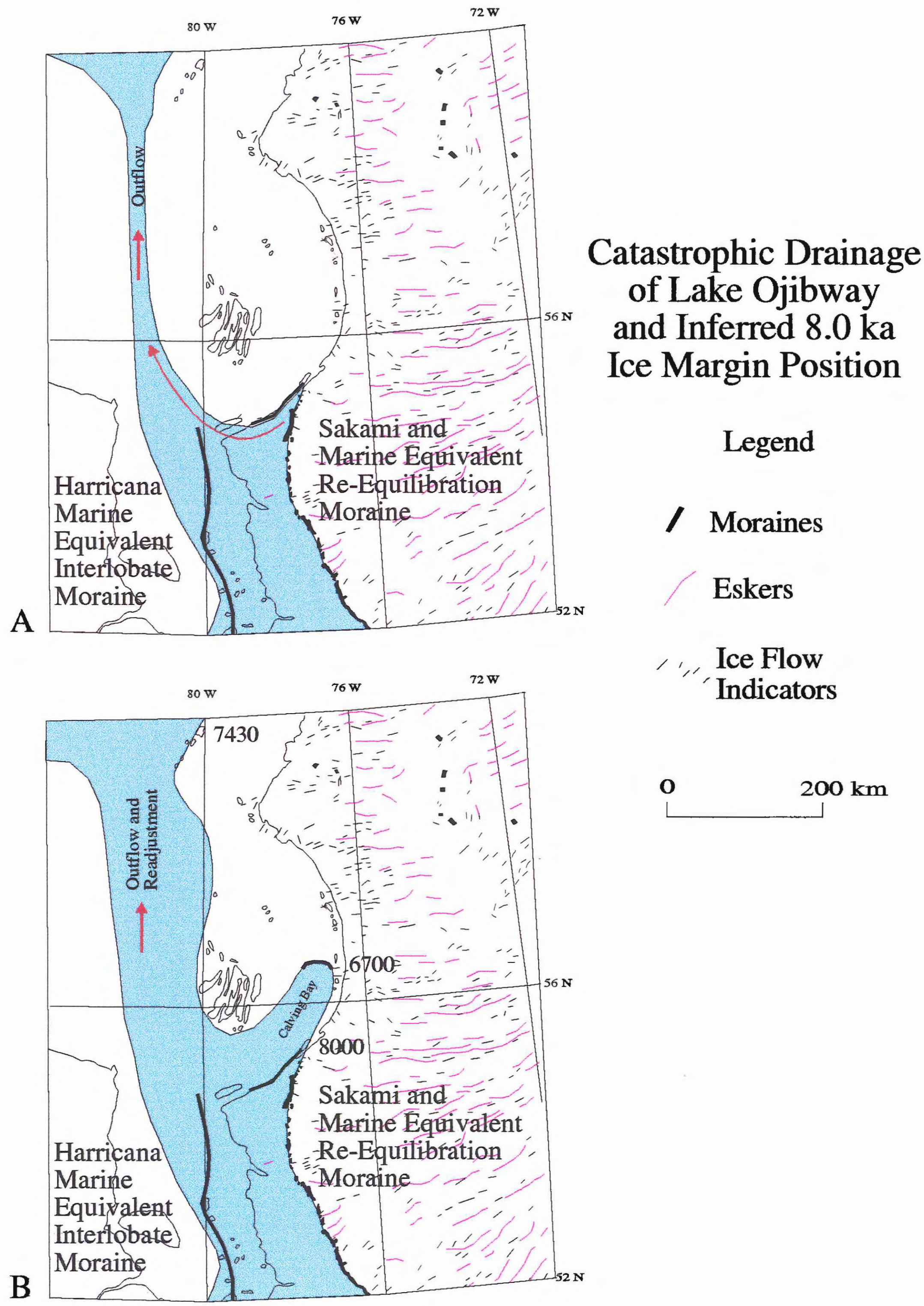


Till/Ice Contact (Unit 2) Zonation and Morainal Distribution
Legend
Till sediment thickness greater than 10 m
11 Figure Number
Figure location
Survey Area
3) Post 8000 moraines
1) Fluted till zone
2) Marine equivalent of Sakami Re-Equilibriation Moraine
4) complex nearshore zone
19
18
17
16
14
15
0
20 km
77 00W
56 30N
56 00N
78 00W
55 30N
79 00W
55 00N

Figure 47

Figure 48

Figure 48-A shows the inferred ice margin position during the catastrophic drainage of Lake Ojibway through Winisk Trough and Figure 48-B the formation of a calving bay just seaward of the Grand Rivière de la Baleine estuary and extending to the mouth of James Bay. Compare these figures to Figure 3 and note the differences in the proposed ice margin. The ice margin extends further out to the Belcher Islands based upon the later deglaciation dates at the Ottawa Islands (7.4ka, Andrews and Falconer, 1969) and the Nastapoca River (6.7ka, Allard and Sequin, 1985) when compared to the deglaciation of the Grande Rivière de la Baleine area at 8.0ka (Hillaire-Marcel, 1979)



Catastrophic Drainage of Lake Ojibway and Inferred 8.0 ka Ice Margin Position
80 W
76 W
72 W
56 N
52 N
Outflow
Sakami and Marine Equivalent Re-Equilibration Moraine
Harricana Marine Equivalent Interlobate Moraine
A
7430
Outflow and Readjustment
6700
Calving Bay
8000
B
Legend
Moraines
Eskers
Ice Flow Indicators
0
200 km

Figure 48

Moraine sediments should overlay or at least interfinger with the varved sequence. Bilodeau *et al.* (1990b) and Vincent *et al.* (1987) describe the section as pro-glacial sands of the Sakami Moraine overlain by the varved Lake Ojibway sediments then marked by an outwash deposit associated with the catastrophic drainage of Lake Ojibway (Hillaire-Marcel et al,1981).

The accumulation in the northern portion of Unit 2 (Figures 18,19,34,35) occurs primarily in shallow water and appears to be distributed more evenly and in a more east-west trend. It is not known whether the islands between Richmond Gulf and the Belcher Islands (Figure 2) consist of predominantly bedrock or, as in James Bay, till/ice contact sediments. Based on the irregular shape of the coastlines of these islands as shown on the navigation charts of the region and the linear nature of both the mainland and Belcher Island coastlines (Figure 2) these islands could represent till accumulations. Bruce Sanford (personal communication, 1996) does not feel that these islands consist primarily of bedrock. If the dates for ice retreat from the Ottawa Islands (Andrews and Falconer 1969) and the date for the Nastapoca region(Allard and Sequin, 1985) are in fact up to 600 years later than the drainage of the Grande Rivière de la Baleine region of ~8.0 ka (Figure 3) (Hillaire-Marcel, 1979) then the till/ice contact along the northern edge of the survey area could mark the initial northern divide. If the moraine indicates the ice grounding line , then a marginal bathymetric restriction exists from Richmond Gulf to the Belcher Islands (Figures 2,7). These moraines are named the post 8000 moraines (Figure 47). This high would not exert much influence on the remaining ice sheet, allowing it to waste rapidly.

The nearshore till/ice contact (Unit 2) deposit displays the most internal complexity. Along east-west seismic transects the thick accumulations of Unit 2 display no internal structure. When the line orientation is changed to north northeast - south southwest frequent chaotic discontinuous reflectors and hints of stratification are observed. This pertains especially to those deposits extending from Schooner Opening to Petite Rivière de la Baleine. These deposits coincide with substantial unconsolidated material deposits especially at Boat Opening. These complex nearshore ice contact sediments (Figure 47) appear to coincide with glacial outflow from the last stages and could represent glaciofluvial deposits such as those shown by Vincent (1989) east of the Sakami Re-Equilibration Moraine (Figure 6).

9.4.3 - GLACIOLACUSTRINE/MARINE (UNIT 3)

Glaciolacustrine/marine (Unit 3) distribution (Figure 36) indicates that this unit is widely distributed. The surficial geology map (Figure 34) indicates that within the survey area glaciolacustrine/marine (Unit 3) outcrop in the present day is limited. This unit is present throughout most of the study area as a conformable drape over the bedrock and till/ice contact sediments (Unit 2) where present. Offshore the unit is truncated between 80-90m water depth and is not present over much of the corridor extending to the Belcher Islands. In the first offshore basin and extending to the shore the unit does not appear to be restricted by water depth. There is a substantial difference in thickness of this unit on either side of the Sakami Moraine offshore equivalent (Figures 36,47) with thicker deposits south of this feature. Increased deposition is also observed along the southern margin of the northern post 8000 moraine features and interfingering with the till is observed here (Josenhans et al., 1991).

Onshore the glaciolacustrine sediments were deposited in Lake Ojibway. The Lake Ojibway varve chronology is based on a continuous 2110 varve sequence. Varve 1 is associated with the first evidence of lacustrine deposits in the Lake Témiscamingue region. Varve count starts at 1485 for James Bay lowlands (Vincent, 1989). According to this chronology, varve 1510 should be base of rhythmite deposit along the Grande Rivière de la Baleine dated at 8,230 $\pm$ 135 (Hillaire-Marcel, 1979)(Figures 25,30). Hillaire-Marcel (1979) dates the rhythmite - Tyrrell Sea sediment contact at 7,625 $\pm$ 120. Cochrane I surge is associated with varve year 1810 and the Cochrane II surge with varve year 2035 (Vincent, 1989). Maximum rhythmites counted in the marine cores in this study exceed 130. Core 87-028-047 (>100 rhythmites)(Figures 23,29) displays only 0.5m of rhythmite sequence, which in this core appears to be the entire section. Here a problem arises where core 92-028-081displays 35 rhythmites in 0.5m of section and bottoms out in the glaciolacustrine/marine (Unit 3) section which continues for at least another 5.5m and possibly 7.5m.

With the exception of the presence of the ostracod *Candona* (Bilodeau, 1990a) there is no definite evidence as to whether these sediments were deposited in freshwater or marine conditions. The interpretation of true varves deposited in lacustrine environment as stated by Gonthier *et al.*, (1993) appears to be tenuous. Hillaire-Marcel (1979) strongly states that these are rhythmites and should not be considered as annual events. The genesis of these sediments is widely argued but even in the well researched Champlain Sea setting evidence is not conclusive. Well banded rhythmite sequences are present throughout Hudson Bay and into Hudson Strait (Leslie, 1965, Josenhans et al., 1988, Zevenhuizen and Josenhans, 1989, Josenhans and Zevenhuizen, 1990, Vilks et al.,1989). The one condition that all these widely spaced occurrences appear to have in common is that where micropaleontological analysis (Leslie, 1965, Bilodeau et al., 1990a, Vilks et al.,1989) has been completed the zone is barren.

In the type section core 87-028-069 this unit occurs at 7.20-5.82m and consists of laminated clays, which are in part disaggregated. Comparison with the onshore section suggests that the rhythmically bedded sediments represent lacustrine deposits of pro-glacial Lake Ojibway (Hillaire-Marcel and Vincent, 1980). Bilodeau *et al.* (1990a,b) completed microfaunal analyses on the >63 micron fraction and reported absolute abundances in numbers per unit volume (individuals/cm^3). Based on the lack of foraminifera and dynocysts, and the presence of the freshwater ostracod genus *Candona* Bilodeau *et al.* (1990a) interpreted this sequence as glaciolacustrine. Based on textural and geochemical analysis Gonthier *et al.* (1993) interpret the rhythmically banded sediments as true varves. Gonthier *et al.* (1993) do use geochemical sulphate data to infer that the interstitial pore waters have to be marine. Detailed salinity observations (Marsters, 1988) show that the measured salinity never drops below 29.5 $^{0}/_{00}$. Onshore Hillaire-Marcel *et al.* (1981) present evidence that the transition from the rhythmically banded sediments to the heavily bioturbated overlying sediments represent the transition from lake levels up to 500m above present day sea level to the 315m maximum above sea level of the Tyrrell Sea. This is supported by evidence presented by Bilodeau *et al.* (1990a) who recognize a sequence of sparse foraminifera at the top of this unit which suggests that those sediments interpreted as initial Tyrrell Sea sediments are of glaciomarine origin.

Where the till and glaciolacustrine appear together the glaciolacustrine appears to overlie the till and not interfinger. The unit is not present over the possible marine equivalent of the Sakami Re-Equilibration Moraine. It does not appear to have ever interfingered with this feature and appears to have been removed over the crest of this feature by wave base reworking and subsequent redistribution in the Tyrrell Sea and later postglacial section. Interfingering of the glaciolacustrine/marine (Unit 3) sediments with the till/ice contact sediments (Unit 2) was only definitely observed at location (A)(Figure 40) (Josenhans *et al.*, 1991) at the post 8.0 ka moraine (Figure 47). Along the first nearshore trough the till/ice contact (Unit 2) internal structure becomes more complex. Although not definitive this could represent a possible ice margin position especially near Boat Opening (B)(Figure 40).

Disturbance of the unit probably occurred during the same time frame as postulated by other writers but probably by a different method. The presence of large volumes of meltwater and the subsequent touchdown of the ice mass during this time would have increased the groundwater pressures whereby small scale changes in temp/pressure/salinity could have caused temporary freezing of this unit. It is interesting to note that all observed sediment failure / slump deposits (Figures 44,45) appear to have failed within the glaciolacustrine/marine sediments.

9.4.4 -POSTGLACIAL MUDS (UNIT 4) AND POSTGLACIAL ESTUARINE SEDIMENT (UNIT 4E)

The postglacial muds (Unit 4) and estuarine muds (Unit 4E) blanket over 70% of the region. These units appear to be to some extent depth controlled although this depth varies between the coastal zone and the offshore. Offshore, that is beyond the first major cuesta ridge (Figure 7), the unit is only present in water depths greater than 80m. From the shoreline out to the first basin and along the Manitounuk Islands chain to Richmond Gulf the postglacial units (Units 4 and 4E) are present to at least 40m water depth. In areas sheltered from wave base reworking the unit extends to nearly the shoreline, such as in Manitounuk Sound. In the nearshore the postglacial estuarine muds are a sublittoral deposit which is marked by fairly widely spaced episodic pulses of coarser grained material (Figure 12). The unit grades from sandy silty sediments at the base to bioturbated mud in the upper part. Fauna at the base of Unit 4 suggest the presence of cold arctic surface waters, with subsequent warming to subarctic surface water conditions followed near the top of the core by a distinct cooling of the surface waters that prevails today (Bilodeau et al., 1990a). Throughout the study area postglacial basinal muds are overlain by a layer of brown, oxidized, soupy muds ranging in thickness from a thin veneer to 0.05m (Zevenhuizen et al., 1994, Hardy and Zevenhuizen, 1993).

Figure 5 indicates the changing shoreline from 6 ka to present. Note that the glacio-isostatic emergence rates (Figure 4) were substantially higher in the past. Offshore seismic data and onshore exposed river section mapping indicate that prior to isostatic recovery the entire area was blanketed by discontinuous till/ice contact deposit first overlain by draped glaciolacustrine/marine sediments then by ice distal Tyrrell Sea sediments grading into postglacial muds and/or estuarine deposits. During isostatic recovery this entire section would have been exposed to reworking and erosion. For this reason the postglacial estuarine sediment (Unit 4E) thickness increases substantially in the nearshore as the result of coastal erosion and fluvial sediment input.

Unfortunately as the basin becomes smaller by this process coastal sediments are constantly being reworked. This makes radiocarbon dating of shell material problematic as can be seen on the three dates determined from shell material obtained from a core taken on the Rivière Kuugapik tidal flat area (Section 8.3). The only C^{14} date obtained offshore is a date of 6 240 $\pm$ 130, obtained by Duplessi, at 3.9m in core 87-028-069. This date represents the offshore section and does not appear to be influenced by coastal erosion as was observed in Manitounuk Sound. The date also correlates well with the well dated onshore-offshore palynology as shown in Figure 24.

Within the deeper basins, sedimentary furrows (Figure 42) and areas of non-deposition (Figure 43) occur while in the Manitounuk Sound outer basin (Figure 21) and seaward of Grande Rivière de la Baleine asymmetric deposition of the postglacial/recent sediments suggest the presence of strong tidal currents.

CHAPTER 10: SUMMARY AND CONCLUSIONS

Reconnaissance marine surveys and the lack of any transgressive surfaces found on land have shown that since deglaciation the Hudson Bay coast has been constantly emerging. The rapid emergence of this coast provides the unique opportunity to complete an onshore-offshore correlation.

Onshore Quaternary studies of Hudson Bay and surroundings for the period 10-7 ka document the rapid disintegration and final stages of the Laurentide Ice Sheet. In the southeastern Hudson Bay region the major glaciogenic landforms observed onshore are the product of the wasting of the Labradorean Ice Dome and subsequent division into the Hudson and New Quebec Ice Domes forming the ice contact/glaciofluvial Harricana Interlobate Moraine.

During the Early Holocene the Laurentian Ice Sheet that formerly covered this area began to wane, the region was inundated by glacial lake Ojibway, and later by the Tyrrell Sea as marine waters entered the region (Figure 3). This was followed by glacio-isostatic rebound, which continues to the present day (figure 4), withdrawal of the sea to the present shoreline (Figure 5), and the development of normal low/sub Arctic subaerial, fluvial and marine processes (Figure 24). The offshore sediments are products of these glacial, transitional, and postglacial events (Figures 11,12).

The surficial sediments and landforms occurring in and around James Bay preserve evidence of the late stages and disintegration of the Laurentide Ice Sheet. Onshore the Harricana Interlobate Moraine and the Sakami Re-Equilibration Moraine (Figure 5) (Vincent, 1989) are the most prominent regional glacial features.

Glacial Lake Ojibway was formed along the southern glacial ice margins due to the wasting of both the Hudson and New Quebec Ice Domes, draining to the south (Vincent and Hardy, 1979)(Figure 3). In later stages Lake Ojibway was pinned between the Hudson Bay and St. Lawrence River valley drainage divide and the ice front. Catastrophic drainage and the resultant drop in water levels formed the grounding line of Sakami Re-equilibration Moraine and its marine equivalent (Figure 47) along the eastern and northern shores of the lake.

Sediments in the region are interpreted to represent from base to top; till (which consists of both a basal/lodgement glacial till deposited under the ice sheet and ice contact/glaciofluvial sediment associated with the Sakami Re-equilibration Moraine), glaciolacustrine sediments related to the glacial Lake Ojibway phase, ice proximal glaciomarine sediments associated with the invasion of the Tyrrell Sea, ice distal glaciomarine Tyrrell Sea sediments, postglacial marine sediments, and deltaic-estuarine sediments. Onshore the unconsolidated Quaternary sediments are generally represented by a thin veneer of sediments interpreted to be composed primarily of glacial till. Locally, within the river valleys complete sections recording the last glacial / deglacial cycle are recorded. This stratigraphic succession is preserved in cross-section in both the Grande Rivière de la Baleine (Figures 25,27,30) and Petite Rivière de la Baleine valleys, although the entire sequence is preserved only in the Grande Rivière de la Baleine valley (Bilodeau *et al.*, 1990b).

The above series of events is well preserved within both the onshore and offshore unconsolidated sediments of the region. Reconstruction of the late glacial history is based on the onshore and offshore observation.

Bedrock (Unit 1) provided some control by subdued topographic steering of the ice mass as the position of the ice domes shifted during the pre-Lake Ojibway period. The bedrock appears to have had little effect on the ice sheet after the onset of Lake Ojibway drainage and Tyrrell Sea invasion.

Evidence preserved within the sediments of the marine region of the study area provides four morphologically distinct zones of the till/ ice contact (Unit 2) sediments (Figure 47). The oldest zone is marked by a fluted discontinuous till. This terrain appears to have preserved the west-southwest movement of the ice sheet and is associated with the initial division of the Labradorean Ice Dome into the Hudson and New Quebec Domes.

A large linear accumulation of till/ice contact sediments, locally exceeding 80m thickness, parallels the coastline from the southern border of the survey area to Duck Island. This feature is interpreted as the marine equivalent of the Sakami Re-Equilibration Moraine. This feature is depth transgressive and does not appear to be bedrock controlled.

Catastrophic drainage of Lake Ojibway occurred at approximately 8.0 ka. Initial outflow appears to have been south of the Belcher Islands then through Winisk Trough into Hudson Bay (Figure 48). This formed a calving bay extending into the southern portions of the study area leaving the northern areas ice covered, north of the bathymetric high which extends east-west from the southern Nastapoca Islands to the Belcher Islands. This is supported by deglaciation dates of 7,430 $\pm$ 180 from the Ottawa Islands (Andrews and Falconer 1969) and the date of 6,700 $\pm$ 100 for the Nastapoca region (Allard and Sequin, 1985) which are up to 600 years younger than the corrected date ~8000 (Hillaire-Marcel, 1979) for the Grande Rivière de la Baleine region. Re-adjustment of the remaining ice sheet to this position formed the northern 8.0 ka moraine (Figures 47,48).

This moraine occurs primarily in shallow water and appears to be distributed in an east-west trend. Based on the irregular shape of the coastlines of the islands between the mainland and the Belcher Islands these islands could represent till accumulations. These moraines are named the post 8.0 ka moraines (Figure 47). As it is not well topographically constrained this grounding line along the bathymetric high would not exert much influence on the remaining ice sheet, allowing it to waste rapidly.

The latest events influencing till/ice contact sediment deposits occur along the nearshore trough, west of the Manitounuk Islands chain. The more complex internal structure of these nearshore deposits favours an ice contact/glaciofluvial genesis. These complex nearshore ice contact sediments (Figure 47) appear to coincide with glacial outflow from the last stages and could represent glaciofluvial deposits such as those shown by Vincent (1989) east of the Sakami Re-Equilibration Moraine (Figure 6).

Glaciolacustrine/marine (Unit 3) is present throughout most of the study area as a conformable drape over the bedrock and till/ice contact sediments (Unit 2) where present. There is a substantial difference in thickness of this unit on either side of the Sakami Moraine offshore equivalent (Figures 36,47) with thicker deposits south of this feature. Increased deposition is also observed along the southern margin of the northern post 8000 moraine feature.

Where the till and glaciolacustrine appear together the glaciolacustrine appears to overlie the till and not interfinger. The unit is not present over the possible marine equivalent of the Sakami Re-Equilibration Moraine. Glaciolacustrine/marine sediments appear to have been removed from the crest of this feature by wave base reworking and subsequent redistribution within the Tyrrell Sea and later postglacial sediments. Interfingering of the glaciolacustrine/marine (Unit 3) sediments with the till/ice contact sediments (Unit 2) was only definitely observed at location (A)(Figure 40) (Josenhans *et al.*, 1991) at the post 8000 moraine (Figure 47).

The genesis of these sediments is widely argued but even in the well researched Champlain Sea setting evidence is not conclusive (Gadd, 1988). Well banded rhythmite sequences are present throughout Hudson Bay and into Hudson Strait (Leslie, 1965, Josenhans et al., 1988, Zevenhuizen and Josenhans, 1989, Josenhans and Zevenhuizen, 1990, Vilks et al.,1989). The one feature that all these widely spaced occurrences appear to have in common is that where micropaleontological analysis (Leslie, 1965, Bilodeau et al., 1990a, Vilks et al.,1989) has been completed the zone is virtually barren.

Where observed offshore the unit contains intervals of what appears to be previously frozen, disaggregated sediments, this was not observed onshore (Bilodeau, 1990b, Hillaire-Marcel, 1979). Freezing sediments at water depths ranging from a present day 100m water depth to up to 700m water depth during the Lake Ojibway phase is a difficult process to envision. Small scale changes in temp/pressure/salinity induced by the influx of large volumes of cold and saline Tyrrell Sea water and the subsequent touchdown of the ice mass during this time would have increased the groundwater pressures which could have caused changes necessary for the temporary freezing of this unit. It is interesting to note that all observed sediment failure / slump deposits (Figures 44,45) appear to have failed within the glaciolacustrine/marine sediments.

The postglacial/recent sediments (Units 4 and 4E) conformably overlie and grade into glaciolacustrine/marine sediment unit. Sediments of this unit display considerable horizontal and vertical variability. In the nearshore, especially in the vicinity of the estuaries of the Grande Rivière de la Baleine, Petite Rivière de la Baleine and inner Manitounuk Sound, the unit is well stratified. Where sampled this unit consists of a heavily bioturbated olive gray mud with black reduction spots. Units 4 and 4E, the uppermost unit, comprising postglacial sediments blankets seventy per cent or more of the area (Figure 34). Sidescan sonogram and high resolution seismic reflection data indicate that the distribution of this unit is influenced by the outcrop of bedrock scarps, current controlled non-deposition at bathymetric highs (Figures 12,20-22,41) and sedimentary furrows (Figures 41,42) in the offshore basins. In the nearshore, sidescan sonogram and subbottom profiler data indicate partially eroded bedforms (Figure 41), and above 22m water depth intensive reworking by icekeel scouring (Figure 44).

In this thesis the integration and synthesis of the large southeastern Hudson Bay data set was used to complete the comprehensive mapping of the surficial marine geology of the region. Detailed mapping of the marine geology was completed for an area greater than 3500 km^2. Completed were the surficial geology (Figure 34), surficial units distribution and isopach (Figures 35-38) and surficial features (Figures 39-45).

Due to the rapid and continuous emergence of this coast good stratigraphic sections are preserved in the major river valleys providing an excellent onshore - offshore correlation. Based upon the detailed seismostratigraphic mapping in the offshore and the ability to correlate with the onshore glacial geology the Late Quaternary - Early Holocene a model for the geological evolution of the marine area is proposed. In the proposed model for the Late Quaternary -Early Holocene deglacial history of the marine region the northern shoreline of Lake Ojibway is defined and the initial pathway for the Tyrrell Sea invasion and subsequent catastrophic drainage of Lake Ojibway is inferred.

APPENDIX: CLIMATIC CONDITIONS SUMMARY AT KUUJJUARAPIK QUEBEC (Canadian Hydrographic Service, 1988)

KUUJJUARAPIK, QUÉBEC — 55°17'N., 77°46'W.

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Temperature															
Daily Maximum Temperature	°C		-18.0	-17.3	-11.2	-1.6	5.6	11.5	15.5	14.5	10.5	4.7	-2.0	-12.1	0.0
Daily Minimum Temperature	°C		-26.9	-27.9	-22.9	-12.0	-3.3	1.5	5.5	6.3	3.6	-0.8	-7.8	-19.1	-8.7
Daily Temperature	°C		-22.5	-22.6	-17.1	-6.8	1.2	6.5	10.5	10.4	7.1	2.0	-4.9	-15.9	-4.3
Extreme Maximum Temperature	°C		3.3	6.7	11.1	18.3	28.3	33.3	33.3	33.3	33.9	23.9	11.5	5.6	33.9
Extreme Minimum Temperature	°C		-49.4	-45.6	-45.0	-33.9	-25.0	-7.8	-2.2	-1.1	-6.1	-15.0	-28.9	-46.1	-49.4
Precipitation															
Rainfall	mm		0.1	0.3	1.9	5.2	23.5	51.7	82.0	94.0	85.2	46.3	10.1	1.0	401.3
Snowfall	cm		26.9	24.2	20.2	22.1	19.2	4.8	0.3	0.0	1.7	27.3	52.5	42.0	241.2
Total Precipitation	mm		25.8	23.5	21.0	26.9	42.4	56.8	82.4	94.0	87.3	73.5	61.1	42.2	636.9
Greatest Rainfall in 24 hours	mm		1.3	6.4	8.1	21.3	27.1	42.2	72.9	58.4	56.9	55.9	26.0	6.9	72.9
Greatest Snowfall in 24 hours	cm		17.8	19.1	21.3	38.1	20.3	11.8	4.8	0.0	16.5	25.4	29.2	36.8	38.1
Greatest Precipitation in 24 hours	mm		17.8	24.1	23.9	38.1	27.1	42.2	72.9	58.4	56.9	55.9	29.2	47.2	72.9
Days With															
Rain			*	*	1	2	7	11	15	17	16	11	3	*	83
Snow			12	10	10	10	8	3	*	0	1	10	19	17	100
Precipitation			12	10	10	11	13	12	15	17	17	19	20	17	173
Fog			1	1	2	3	6	9	11	9	2	1	*	*	45
Thunder			0	0	*	*	*	1	2	2	1	0	0	0	6
Mean Sea Level Pressure (kPa)			101.3	101.5	101.8	101.7	101.5	101.2	101.0	101.0	101.2	101.1	101.1	101.4	101.3
Relative Humidity (%)			73	71	73	77	78	79	81	83	80	81	82	76	78
Cloud Amount Scale 0–10			6	5	5	6	8	7	7	8	8	8	8	7	7
Wind															
Percentage Frequency	N		4.5	6.1	9.0	11.7	13.8	14.9	9.8	9.3	7.6	6.5	4.7	3.0	8.4
	NNE		3.7	3.5	5.8	6.5	6.1	6.3	5.1	3.8	4.3	4.1	3.0	2.6	4.6
	NE		1.3	0.9	1.0	1.6	1.3	1.5	1.5	1.4	2.5	3.0	2.3	1.0	1.6
	ENE		1.0	0.6	0.7	1.6	1.2	0.8	0.9	0.8	1.5	1.8	1.9	1.1	1.1
	E		7.3	3.7	4.6	7.3	6.1	3.7	4.3	3.7	5.3	6.1	8.2	8.9	5.8
	ESE		15.2	11.6	12.5	10.5	8.7	5.4	5.7	6.3	6.9	8.3	12.7	18.1	10.2
	SE		10.7	9.7	8.1	6.4	5.4	4.3	5.6	6.4	6.4	7.5	8.7	12.5	7.6
	SSE		7.8	6.1	4.6	4.5	3.1	3.7	4.8	4.7	6.0	7.0	7.6	7.8	5.6
	S		10.0	9.5	5.6	5.0	3.9	4.8	5.4	6.8	8.2	10.0	11.8	10.7	7.6
	SSW		6.4	5.5	3.2	2.6	2.4	2.8	2.9	3.8	4.3	5.6	8.5	7.3	4.6
	SW		4.8	7.3	4.7	3.2	3.9	4.2	5.1	5.5	4.2	4.1	3.3	3.3	4.5
	WSW		5.8	8.3	7.3	6.4	8.4	8.6	11.8	12.4	6.6	4.9	3.0	3.6	7.3
	W		6.8	8.8	8.4	8.5	10.2	10.7	14.0	13.4	12.3	8.8	7.5	6.6	9.7
	WNW		4.2	4.0	4.4	5.4	6.6	6.3	5.3	5.8	7.5	6.9	5.9	4.8	5.6
	NW		2.2	3.1	4.2	5.1	6.2	6.7	5.8	5.4	6.4	6.8	5.1	3.1	5.0
	NNW		1.9	2.6	4.4	5.1	6.4	8.3	4.9	5.1	5.4	5.4	3.8	1.9	4.6
	Calm		6.4	8.7	11.5	8.6	6.3	7.0	7.1	5.4	4.6	3.2	2.0	3.7	6.2
Mean Speed (Knots)	N		11.0	9.9	9.1	9.3	10.3	9.6	8.6	9.0	10.4	11.6	13.3	13.7	10.5
	NNE		9.2	8.7	9.5	9.9	9.8	9.3	9.4	8.5	9.6	10.4	10.4	10.1	9.6
	NE		6.5	5.7	6.7	7.7	7.4	7.3	7.3	6.5	8.1	7.6	7.6	6.4	7.1
	ENE		6.2	5.2	5.7	8.2	8.4	7.3	6.6	6.7	6.9	7.5	7.4	6.6	6.9
	E		10.7	10.5	11.2	10.8	10.5	9.6	9.4	8.2	8.8	9.9	10.3	10.6	10.0
	ESE		9.9	10.3	9.4	10.8	10.4	9.9	8.4	8.2	8.6	9.2	10.0	10.5	9.7
	SE		9.6	9.3	9.8	10.4	11.0	9.2	9.0	9.1	10.0	10.1	10.7	9.8	9.8
	SSE		10.6	10.1	10.4	12.3	11.8	11.7	11.0	10.8	11.8	12.5	11.8	10.8	11.3
	S		9.6	10.3	9.9	11.5	11.5	12.3	11.3	11.3	11.7	11.4	11.6	10.4	11.1
	SSW		10.0	9.4	9.4	11.1	11.4	12.2	11.1	11.6	11.6	11.5	12.3	11.4	11.1
	SW		11.3	11.0	10.6	11.4	12.6	13.4	11.9	13.1	12.4	12.3	12.4	12.6	12.1
	WSW		14.0	11.0	9.2	10.7	11.0	11.8	11.2	12.7	13.7	14.6	16.0	14.6	12.5
	W		12.6	10.3	8.4	9.7	9.6	8.9	9.3	11.1	13.9	14.7	16.5	14.7	11.7
	WNW		12.7	10.2	8.0	9.2	9.5	7.6	6.9	9.7	13.1	13.6	14.9	15.6	10.9
	NW		11.7	9.8	7.8	8.1	8.9	7.4	6.6	9.2	11.3	13.8	14.3	14.2	10.3
	NNW		11.2	8.8	8.6	8.4	8.9	8.4	6.7	8.1	10.9	13.1	14.1	12.9	10.0
	All Directions		9.9	9.1	8.2	9.2	9.6	9.0	8.6	9.7	10.8	11.4	11.9	11.0	9.9
Extremes	Maximum Hourly Speed		45	40	35	43	37	35	39	42	41	43	52	45	52
			WSW	S	N	S	WSW	SVL	SVL	SVL	WSW	NW	W	WNW	N
	Maximum Gust Speed		58	57	51	57	48	53	60	57	55	59	54	57	60
			SE	ESE	SSW	S	W	SW	SW	WSW	SW	NW	SVL	WNW	SW

Notes: SVL — more than one occurrence of the same speed
kPa — kilopascals = mb/10
* — less than one occurrence on average
Number of days with under precipitation, indicates days with falls of 0.2 mm or more of rain, 0.2 cm or more of snow, and 0.2 mm or more of water equivalent.

TABLE 1 - CLIMATE SUMMARY - KUUJUARAAAPIK

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