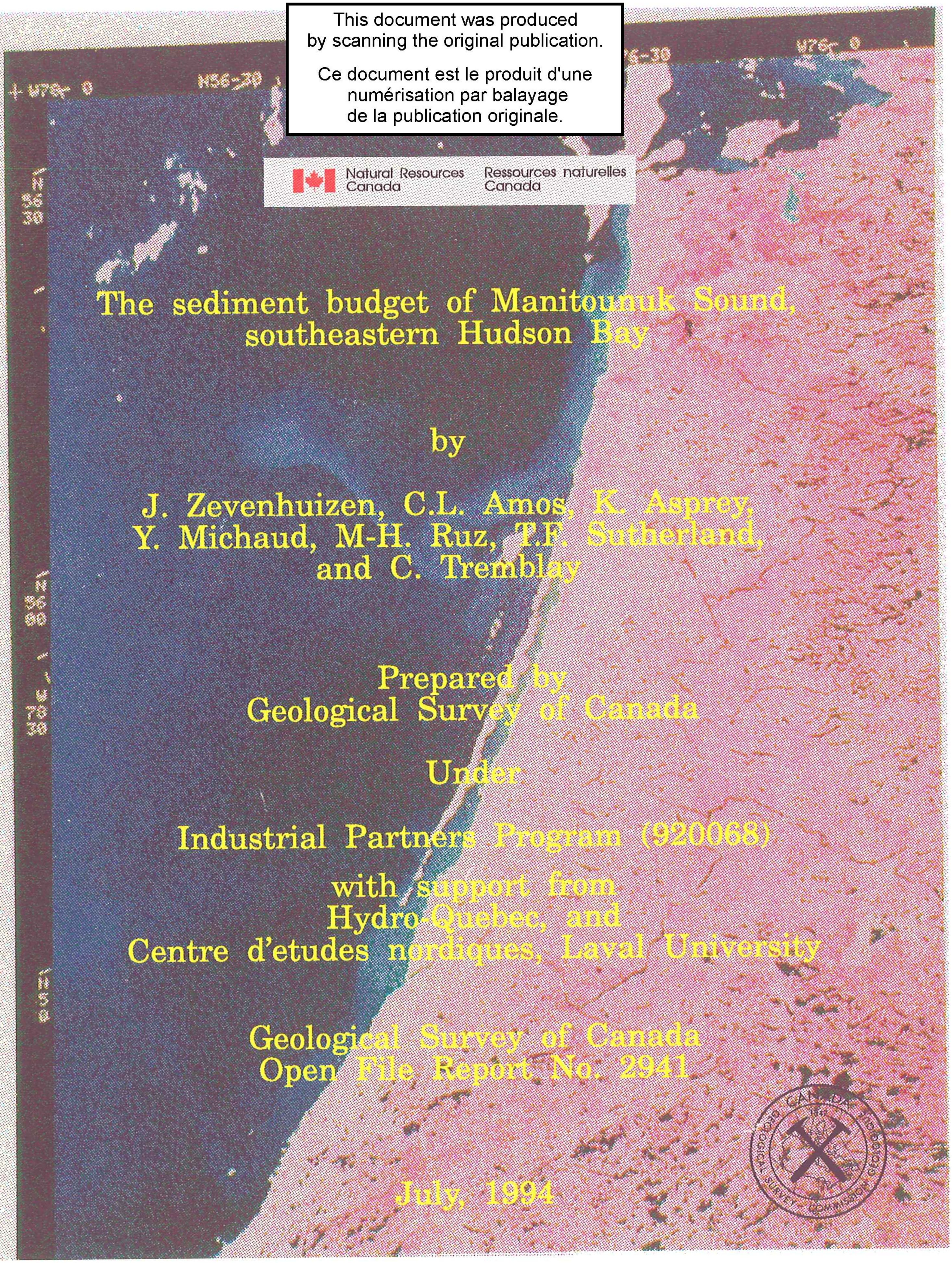

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The sediment budget of Manitounuk Sound, southeastern Hudson Bay

by

J. Zevenhuizen, C.L. Amos, K. Asprey, Y. Michaud, M-H. Ruz, T.F. Sutherland, and C. Tremblay

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THE SEDIMENT BUDGET OF MANITOUNUK SOUND, SOUTHEASTERN HUDSON BAY

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1 INTRODUCTION

Planned hydro-electric development in the Manitounuk Sound - Grande Riviere de la Baleine region (figure 1) involves partial diversion of Grande riviere de la Baleine, Petite riviere de la Baleine and riviere Domanchin waters to a new combined outfall into Manitounuk Sound. The proposed outfall location lies in central Manitounuk Sound opposite Schooner Opening. Schooner Opening separates Merry and Castle Islands of the Manitounuk Islands chain and opens up into Hudson Bay proper.

During the 1992 field season extensive bottom sample data were collected. The bulk of the grab and core samples collected displayed a highly oxidized brown surface layer ranging in thickness from a thin veneer to up to 0.07m thick. This unit was interpreted as representing an annual accumulation of sediment. The objectives of this report are to provide a sediment budget and preliminary mass balance calculation for the present day depositional environment of Manitounuk Sound. This was accomplished by the compilation, integration and interpretation of data available within the published literature and various data reports as well as including preliminary results obtained from researchers at the Atlantic Geoscience Centre, Laval University, Dalhousie University and Centre geoscientifique de Quebec.

The base maps for this report are primarily 1:100,000 reductions of the maps used to establish a regional geological framework for the marine environment (Zevenhuizen, 1993). These maps provide baseline information on the distribution, depositional environments and physical characteristics of the unconsolidated marine sediments within Manitounuk Sound. Volumetric and linear measurements of the various sediment sources and transport processes considered for this project were based on these maps.

Sediment sources considered for the sediment budget calculations are; 1. fluvial input from both rivers and streams within Manitounuk Sound and the possible contribution by the Grande riviere de la Baleine, 2. coastal emergence due to isostatic recovery and subsequent erosion of the tidal flats, 3. resuspension of sediment by wave-base reworking especially those sediments experiencing changes in geotechnical properties due to freeze-thaw processes on the tidal flats, 4. resuspension of coastal zone sediments by icekeel scouring and ice rafting, 5. coastal erosion especially thermal erosion and permafrost degradation along the microcliff associated with a low terrace along the eastern shoreline, 6. aeolian input from the sand dunes at the head of the sound, and 7. material associated with biological productivity. Within the outer and central sections of the sound there are frequent sediment failure/slump deposits, as these only rework the already inplace sediments and are not a source the calculated volumes are presented but not used in the overall sediment budget calculations.

2 PHYSICAL AND CHEMICAL OCEANOGRAPHY

- 2.1 BATHYMETRY

Hudson Bay is a large, inland sea open to the Atlantic Ocean only through Hudson Strait. Hudson Bay covers a total area of 637,000 square km 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 through the ice in winter. Limited oceanographic data have been collected during the periods of ice decay or freeze up, the times of greatest variability.

The bathymetry of Hudson Bay can be described as a generally shallow, saucer shaped basin, most of the depths range between 100-230m with an average depth of 125m (Prinsenberg, 1986b). Maximum depth of 550m is reached at the northeastern margin off the Ungava Peninsula where the bay joins Hudson Strait. In the central part of the bay, Winisk Trough, an enclosed bathymetric deep, reaches a maximum depth of 370m (Josenhans and Zevenhuizen, 1989). Seabed relief is subdued but variable with slopes generally less than 2 degrees. Regionally, the topography is bedrock controlled with some limited glacial overdeepening of pre-existing drainage channels (Josenhans and Zevenhuizen,1989). Quaternary deposits impart micro relief with till ridges up to 15 metres high and 300 metres 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 detailed bathymetric data are available to approximately 30 km offshore. Between Petite Riviere de la Baleine and Grande Riviere de la Baleine and seaward to the data limit the bathymetry reflects the underlying bedrock morphology, essentially mimicking in 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 grain to the seabed morphology, with the basins increasing in depth seaward to local maximums of 200m. The cuesta ridge - basin morphology forms Manitounuk Sound and the Manitounuk Islands (Bill of Portland, Neilsen, Merry, and Castle islands) which constitute the seaward margin of the Sound.

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

West of the Manitounuk Island chain there is a marginal depression some 2.4 km wide with depths >80 m. This narrow basin is bounded to seaward by a submerged cuesta ridge with water depths shallowing to <5 m. The ridge is breached locally by small channels containing water depths to 50 - 60 m; 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 <5 m in depth.

- 2.2 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) (Table 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 July to November. The following wind conditions were summarized from the Labrador and Hudson Bay Sailing Directions (DFO, 1988). All wind speeds were recalculated from knots to kilometres per hour.

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.

- 2.3 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 and Southampton Islands, and 50m in Roes Welcome Sound separating Southampton Island and Keewatin. These shallow restrictions therefore limit the exchange of bottom water. Much of the formation of denser saline waters occurs in situ during the formation of the winter ice cover by salt rejection (Prinsenberg, 1986).

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, 1986). Large volumes of freshwater enter Hudson Bay, the bulk of the freshwater input occurs from June to November.

During the ice accretion which occurs during winter freeze up salt is rejected from the surface layer. This represents up to

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 WSW	40 S	35 N	43 S	37 WSW	35 SVL	39 SVL	42 SVL	41 WSW	43 NW	52 W	45 WNW	52 N
	Maximum Gust Speed	58 SE	57 ESE	51 SSW	57 S	48 W	53 SW	60 SW	57 WSW	55 SW	59 NW	54 SVL	57 WNW	60 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 - KUUJJUARAAPIK5

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,1986), nearly 30% of the national total. The terrestrial component distribution and variability is monitored by a network of streamflow gauging stations (Canadian Hydrological Atlas, 1978). The bulk of the runoff comes from snow meltwater. This water derived from the continental divide is generally turbid and hard and is more likely to release heavy metals like mercury from major water storage developments as well as agricultural fertilizers and pesticides. Runoff from the Precambrian Shield to the north and east is more pristine (Pearse,1985).

Many rivers discharge into Hudson Bay. The largest of these is the Nelson River. On the eastern shore the major rivers are the Nastapoca, Petite Riviere de la Baleine, and Grande Riviere de Baleine. In the James Bay the major rivers are the La Grande Riviere, 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.

Salt rejection by ice accretion and runoff into Hudson Bay supply the bulk of the freshwater input. The cumulative freshwater input is responsible for the low surface water salinities observed in the bay.

- 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 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 20-30m below the pycnocline (Prinsenberg, 1986). The surface layer is well defined and marked by its lower salinity and higher temperatures, attributed to the large freshwater input during the warm open water season, the depth of this layer increases from June to November than rapidly equalizes with the bottom water during freeze up and total ice cover (Prinsenberg, 1986).

- 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 (1986).

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 0.05m/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, 1983). 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 with a maximum water depth of 195 m that occurs 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 does 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, 1986).

- 2.6 TIDAL

Tidal patterns are described by Dohler (1989), Prinsenberg and Freeman (1986) and in the Sailing Directions for Labrador and Hudson Bay (Fisheries and Oceans, 1988). Tide tables for the region are published annually by Department of Fisheries and Oceans (1990). 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 dampened in the winter months by ice cover (Prinsenberg and Freeman, 1986).

The tide setting 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). Ice formation can generally be expected in November and ice free conditions are present from August to October.

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 tempering influence of the Atlantic Ocean. The accompanying ice maps depict the percentage of time that sea ice is present based on a 20 year database of Ice Forecasting Central (Canadian Hydrographic Service, 1988). 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 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) present a summary of wave and swell data based on marine observations from 1895-1977 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, 1980a). Hudson Bay waters are generally well oxygenated. Pett and Roff (1982) 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 atmospheric contribution are low. They also suggest that the vertical stability attributed to the large freshwater runoff affect primary production in a negative way. Roff and Legendre (1986) also attribute the low phytoplankton biomass and productivity of the central Hudson Bay region to persistent vertical stratification. 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.

3 GEOLOGY

- 3.1 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 Cretaceaous 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, Seguin 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 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 (Figure 2) (Dyke et al, 1989). This was followed by isostatic rebound, which continue in the present day (Figure 3), withdrawal of the sea to the present shoreline, 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 (1-2000m) 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,1989). 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) off northeast Coats Island, and Bilodeau et al. (1990) from the Grande Riviere de la Baleine estuary support the rapid 8.4-8.0 ka deglaciation.

- 3.3 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 riviere de la Baleine and approximately 20 km west of Petite riviere de la Baleine. The sequential ridges and intervening valleys produce a pronounced northeast - southwest grain 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. 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 just before the contact of the bedrock associated with the Belcher Islands.

- 3.4 SURFICIAL MARINE GEOLOGY

The first marine geological and geophysical investigations of Hudson Bay were undertaken in 1961 (Leslie,1964,Leslie, 1965, Leslie and Pelletier,1965, Hood,1966, Pelletier, 1966) and were followed in 1965 by a more extensive program. The results, summarized in Pelletier et al (1969) and Pelletier (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, 1989, 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.

The surficial geology and surficial features have been mapped (Josenhans et at., 1988, Josenhans and Zevenhuizen, 1989, Zevenhuizen and Josenhans, 1989) 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 5 metres thick. The postglacial sediments in Hudson Bay generally are thin (<5 metres) 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, 1989, 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 successive depositional events. This supports the interpretation of extremely rapid deglaciation of Hudson Bay and implies low deposition rates in the present day.

In the study region the unconsolidated surficial sediments are primarily the product of glacial and postglacial processes (Figure 2). Vincent (1989) presented a regional perspective of the late glacial history of the region while Allard and Seguin (1985), Allard and Tremblay (1983a and b), and Hilliare-Marcel (1976) provided more site specific information. Unconsolidated sediments in the Grande Riviere de la Baleine, Petite Riviere 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 marginal position, glacio-lacustrine 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. This stratigraphic succession is well preserved in cross-section in both the Grande Riviere de la Baleine (Figure 3) and Petite Riviere de la Baleine valleys although the entire sequence is preserved only in the Grande Riviere de la Baleine valley (Bilodeau, in press). The eastern limit of Lake Ojibway sediments is marked by the Sakami Moraine which terminates onshore just southwest of Kuujjuaraapik.

Marine waters from Hudson Strait penetrated Hudson Bay and James Bay 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. There is some discussion as to the maximum recorded marine limit in the area ranging from 275 m (Parent and Paradis, 1994) and 315 m (Vincent, 1989) above present day sealevel . The area is rapidly emerging (Figure 4), a minimum emergence curve for Richmond Gulf (Vincent, 1989, Figure 3.58) (Hilliare-Marcel, 1976,1979) indicates that at the time of deglaciation uplift was 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 (Hilliare-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.

These onshore sections are fairly analogous to the offshore sediment packages found in both Manitounuk Sound and farther offshore. Bilodeau et al (in press) compared Core 87-028-069 collected approximately 24 km off the mouth of the Grande Riviere de la Baleine to the stratigraphic sequence found in the river valley providing an onshore/offshore stratigraphic correlation.

The geology and history of the Grande Riviere de la Baleine - Petite Riviere de la Baleine offshore region has been investigated by a number of researchers since 1987 through the collection and study of geophysical and sample data. These include: Josenhans et al, (1991), Josenhans and Moir, (1991), Zevenhuizen and Josenhans, (1988), Grant et al., (1989), CSSA, (1991), Josenhans and Johnson, (1990), Smith and Zevenhuizen, (1991), Marsters, (1988), Henderson, (1989), Bilodeau et al,(1989), Gauthier et al.(1993), Zevenhuizen (1992,1993), Amos et al (1992,1993). Hardy and Zevenhuizen (1993). Data catalogued and analyzed in the above reports have been drawn upon extensively in this report.

- 3.5 SEISMO AND LITHOSTRATIGRAPHY

This section discusses the character and distribution of the stratigraphic units. Based on reflection seismic data four seismic stratigraphic sequences were mapped (Zevenhuizen, 1993). The seismic character, stratigraphic order and geometry of the sediments are used to define the bedrock surface and to subdivide the overlying unconsolidated sediment sequence into three units. 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. The rapid emergence of this coast has also preserved analogous sections onshore.

Seismostratigraphic interpretation of the section offshore at the mouth of the Grande Riviere de la Baleine indicates three seismically defined units overlying bedrock. Detailed analysis of the lithological, micropaleoentological and palynological properties of a representative 7.58m long, wide diameter piston core reveals 6 distinct paleo-environments (Bilodeau et al., 1990). 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. Piston core 87-028-069 provides lithostratigraphic data on all three seismic units. Seismic unit 2 equivalent, (7.58-7.20m) consists of poorly sorted gravelly muds interpreted to represent glacial till / ice contact deposits. Seismic unit 3 equivalent (7.20-5.82m), consists of laminated clays, which are in part disaggregated. Seismic unit 4 equivalent (5.82-0m) grades from sandy silty sediments at the base to bioturbated mud in the upper part. Contained fauna at the base of Unit 4 suggest the presence of cold arctic surface waters, with subsequent warming to subarctic surface water conditions followed towards the top of the core by a distinct cooling of the surface waters that prevails to the present day.

The Grande Riviere de la Baleine onshore section shows glacial till/ice contact sediments at the base overlain by sediments dated at 8.0 ka (Hillaire-Marcel, 1979). The overlying sediments are varved(?) glacio-lacustrine sediments associated with glacial Lake Ojibway. Overlying the varved sediments are sediments associated with the Tyrrell Sea invasion, and the influx of cold bottom waters. In the offshore core a transition from glaciolacustrine/marine to present day sedimentation occurs in the upper (4.0-0m) section. Full subarctic conditions are recorded at 2.5m depth and dated around 4.0 ka, a general cooling of surface waters is observed from 2.5m upwards to the present day surface layer (Bilodeau et al, 1990).

- 3.5.1 BEDROCK

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. This unit has limited outcrop distribution at the seafloor, exposure is limited to areas of high relief. Reflection seismic and sidescan sonar data indicate that a similarly oriented submerged cuesta ridge morphology extends offshore for at least 20km.

- 3.5.2 GLACIAL TILL / ICE CONTACT DEPOSITS

Based on seismic data the glacial till / ice contact deposits in the offshore are acoustically massive and unstratified directly overlying bedrock. These sediments are variable in occurrence ranging from discontinuous deposits a few metres or less in thickness to morainal deposits up to 60 m thick. The upper surface of this unit characteristically is irregular to undulating. Sediments of this unit are exposed at the seabed in the nearshore on the crests of the submerged cuesta ridges and as a massive deposit seaward the mouth of Manitounuk Sound and the Manitounuk Islands (Zevenhuizen, 1993). Sidescan sonograms in the nearshore show abundant point source reflectors indicative of boulders this is supported by diver observations which indicate the presence of large boulders at the seabed in the areas of interpreted till outcrop. 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). Grab samples indicate that the sediments of this unit 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 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.

- 3.5.3 GLACIOLACUSTRINE/MARINE SEDIMENTS

The glaciolacustrine/marine sediment unit is an acoustically well stratified, conformably draped unit with a fairly uniform thickness in the offshore. In the inner basin of Manitounuk Sound this unit thickens substantially (Figure 7). This unit directly overlies the bedrock and till where present and mimics the surface morphology of these units. It is overlain in basinal areas by postglacial sediments. 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. Based on the conformable character of this unit it is interpreted to have been deposited in less dynamic, deeper water conditions than occur in the present day. In Manitounuk Sound this unit is present everywhere with the exception of Schooner Passage and near Paint Islands. The sediments assigned to this unit 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 in other parts of the region, it is possible that the acoustically stratified sequences in Manitounuk Sound also contain nearshore facies equivalents of the postglacial / recent sediments. Elsewhere in the Grande Riviere de la Baleine - Petite Riviere de la Baleine offshore region this unit is restricted to the deeper basins below present day water depths of at least 50 metres.

Where observed in cores the 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)). In most cores these rhythmically banded sediment show microfaulting and deformation. The deformed zones are composed of subrounded clay clasts with a lumpy texture with traces of the original bedding preserved. 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 69 and 4.4-10.0 kPa in Core 43; water content ranged from 43 to 97% in Core 69 and from 25-99% in Core 43; bulk density ranged from 1.54 to 1.86 gr/cc in Core 69 and from 1.53 to 2.07 gr/cc in Core 43; velocities ranged from 1443-1648 m/sec in Core 69 and from 1438 to 1708 m/sec in Core 43 (Marsters, 1988).

Comparison with the onshore section suggests that the rhythmically bedded sediments represent lacustrine deposits of pro-glacial Lake Obijway (Hillaire-Marcel and Vincent, 1980). Based on low abundance of foraminifera and dynocysts, and the presence of the freshwater ostracod genus Candona Bilodeau et al. (1990) interpreted this sequence as glaciolacustrine. At the top of the sequence sparse forams have been recognized which suggests that those sediments are of glaciomarine origin. Further analysis is required before this unit can be positively identified.

- 3.5.4 POSTGLACIAL/RECENT SEDIMENTS

The postglacial/recent sediments 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 Riviere de la Baleine and Petite Riviere de la Baleine and inner Manitounuk Sound is well stratified. Within this well stratified material three to four episodic (?) sets/pulses of high amplitude reflectors are observed. Seaward this unit changes from a generally draped to ponded character. Within the central and outer Manitounuk Sound stratification is also not well defined and occasionally this unit is cut by channel or debris flow events. 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.

Where observed in cores this unit consists of a heavily bioturbated olive gray mud with black reduction spots (gravel 0 - 31%, sand 1 - 78%, silt 12 - 81 %, clay 6 - 87% (Henderson, 1989). The geotechnical parameters of this unit are: peak shear strengths 3.7 to 14.0 KPA; water content 60 to 104%; bulk density 1.52 to 1.74 gr/cc ; and velocities 1443 - 1648 m/sec. (Marsters, 1988).

The postglacial sediments blanket seventy per cent or more of the area. Sidescan sonogram and high resolution seismic reflection data indicate that the distribution of these sediments is influenced by the outcrop of bedrock scarps, current controlled nondeposition at bathymetric highs and sedimentary furrows in the offshore basins. In the nearshore, sidescan sonogram and subbottom profiler data indicate partially eroded bedforms, and above 22 metres water depth intensive reworking by icekeel scouring.

4 COASTLINE

- 4.1 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; 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.

- 4.2 COASTAL EMERGENCE

Shortly after ice retreat (approx. 8.0 ka) Hudson Bay covered a 30% greater area, with a significantly different coastal configuration. As the ice margins retreated to the perimeter of present day Hudson Bay sea levels were between 275m and 315m higher than present (Parent and Paradis, 1994, 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) occur around 8.0 ka. In the southeastern area of Hudson Bay a sealevel of up to 315 m above present day sealevel (Vincent, 1989) has been observed. The area is rapidly emerging, a minimum emergence curve for Richmond Gulf (Vincent, 1989, Hilliare-Marcel, 1976,1979) indicates that at the time of deglaciation, 8.1 ka (Hilliare-Marcel, 1976), uplift was 10.0-6.5m/century decreasing linearly to 1.1m/century for the present day.

- 4.3 COASTAL ELEMENTS

The coastal elements of Manitounuk Sound are consistant 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 unconsolidated (moraine (?)) is present along the southern shore. The eastern mainland shore from the head of the sound to the Paint Islands has broad tidal flats seperated by rocky promotories. The outer sound has an irregular coast of low slope with small embayments in which small pocket beaches and narrow tidal flats are present. An excellent overview of the coastal element can be viewed on a coastal video collected during the 1992 summer field season (Michaud and Frobel, 1994).

5 SEABED FEATURES

The distribution of seabed features determined from sidescan sonar and sub-bottom profiler data have been mapped. These include sediment failure/slump deposits, current features, sandwaves/megaripples and icekeel scouring.

- 5.1 SEDIMENT FAILURE / SLUMP DEPOSITS

Slumping occurs throughout the study area in varying degrees of magnitude. Slumping is only observed within the well stratified glaciolacustrine/marine and postglacial sediments. 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, and at the delta fronts of the Grande Riviere de la Baleine and Petite Riviere de la Baleine rivers. The largest observed sediment failure scarp located along the western shore of outer Manitounuk Sound (Hydro-Quebec line 6, shot points 370-374).

- 5.2 CURRENT FEATURES

Within the deeper basins, areas of non-deposition and sedimentary furrows (Josenhans et al, 1991, Zevenhuizen, 1993) occur while in the Manitounuk Sound outer basin and seaward of Grande riviere de la Baleine asymetric deposition of the postglacial/recent sediments suggest the presence of strong tidal currents.

- 5.3 SANDWAVES / MEGARIPPLES

Within Manitounuk Sound the only sandwaves observed occur at approximately 35 metres water depth at the entrance to Schooner Opening.

- 5.4 ICEKEEL SCOURING

Icekeel scouring has been observed to present day water depths of greater than 26 metres. 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 riviere de la Baleine, along the eastern shore of Manitounuk Sound and offshore the Manitounuk Island chain from Schooner Opening to riviere Second. No scour were observed along the coast from north of Grande riviere 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 offshore riviere Kuugaapik in

Manitounuk Sound. A detailed mosaic of this area was compiled by Hydro-Quebec and the region was resurveyed in 1992.

6 DETAILED SURVEY AREA - MANITOUNUK SOUND

Manitounuk Sound is located in southeastern Hudson Bay situated between the north of Petite riviere de la Baleine and Grande riviere de la Baleine. The mouth of Manitounuk Sound lies approximately 10 km NW of the Grande riviere de la Baleine estuary (Figure 6).

Manitounuk Sound overall length is 58 km. The width of the sound ranges from a maximum of 5.7 km between the southern tip of Merry Island and the mainland with a minimum of 1 km separating central and inner Manitounuk Sound. The sound has a total surface area of 168 km^2. It is flanked on the west by a belt of exposed cuestas, called the Manitounuk Islands. The mouth of Manitounuk Sound is at the southeastern end (3.5 km wide) and opens into the Hudson Bay. Considered the entrance to the Manitounuk Sound, this opening is near the mouth of the Grande riviere de la Baleine. Several small channels opening into the Hudson Bay run between the Manitounuk Islands. These channels range in widths from less than 100 m to 375 m.

The drainage basin of Manitounuk Sound covers 970 km^2 and includes approximately 20 small rivers (Hydro-Quebec, 1993). These include (from north to south) Riviere Piquard, Riviere Kuugaajaq, Riviere Mitirtuup Kuunga, Riviere Domanchin, Riviere Kuugaapik, Riviere Ruisseau Paschiskw, Riviere Minguarutiit Kuunga and Grande Riviere de la Baleine. These rivers contribute an annual sediment load of some 20m^3 (21.5m^3 in 1987). The largest river, the Domanchin, contributed a sediment load of 6.5m^3 in 1987 (Hydro-Quebec, 1993).

The shoreline of the sound is marked by a high angle slope western shore and a low angle slope eastern shore. The western shore of Manitounuk Sound consists of sharp cliffs at the foot of which boulders and pebbles form steep beaches (CSSA 1992a). A gentler shoreline or sandy beaches are found in some protected coves. The mainland coast of the Manitounuk Sound has three types of shoreline. By Neilson Island, at the entrance of the Manitounuk Sound, there are small islands, tombolos, and sheltered rocky outcrops where sandy deposits collect. Between Neilson Island and the Paint Islands and the northeastern end of Manitounuk Sound, bedrock, boulders, and pebbles are interspersed with 2m. to 3m. berms composed of a varying mixture of sand, silt, and clay. At this point, well-fed deltas are created by small rivers flowing down the gently sloping platform that rises inland. The surface deposits from this platform are composed of a varying mixture of sand (20% to 90%), silt (10% to 60%), and clay (0% to 50%), often scattered with pebbles and exposed boulders.

For the purpose of this study the Sound is subdivided into three distinct basins; named outer, central and inner sound. The subdivisions are based upon boundaries occurring at natural restrictions influencing water exchange between the basins and deposition style displayed by the sediments.

- 6.1 INNER SOUND

The inner sound, with a total surface area of 33.8 km^2 has a total length of 16.5 km and average width of 2 km. Widths range from 1 km at the entrance separating central and inner to 3.25 km NW of Boat Opening. Inner Manitounuk Sound opens to Hudson Bay proper through Boat Opening and into central Manitounuk Sound through a 1 km wide channel.

In the inner sound a longitudinal basin attains a maximum water depth greater than 30 m occurs 1.25 km east of Boat Opening. From here the basin slopes very gently to the head of the Sound. The inner sound is generally shallow.

The inner sound (Figures 7, 10, 11 and 21) displays a relatively undisturbed, continuous depositional pro/postglacial sediment section. These exceed 70m in places with extensive gas masking at the head of the Sound. The localized gas masking is associated with the decomposition of organic material within the sediments. Virtually the entire inner Sound mapped area is blanketed by a layer of postglacial-estuarine muds with the exception of a narrow outcrop of glaciolacustrine/marine sediments flanking the eastern shore (Figure 16).

Postglacial sediment thicknesses exceed 30m towards the head of the Sound with a total volume of $4x10^8 m^3$ (Figure 17). The shallow subtidal and tidal flat areas of the inner Sound have a total area of $7.03x10^6 m^2$ (Figure 18). These areas are scoured by the icekeels of storm induced ice ridging. For the head of the Sound these scours are well preserved while towards the south those in shallower depths (<15m) appear degraded (Figure 19). The Hudson Bay coastline in this area is marked by the presence of beaches and flats on the exposed coast indicating substantial deposits of unconsolidated material (Figure 18).

The presence of an oxidized surface layer is mapped based on observations of bottom grab and core samples (Figure 21). 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 (Figure 7) but concentration of this layer seems to occur in these areas (Figure 21).

- 6.2 CENTRAL SOUND

Central Sound, with a total surface area of 52 km^2, has a total length of 19.75 km and average width of 2.6 km. Maximum width of 3.75 km occurs in the deepest portion of the basin just southwest of Riviere Kuugaapik. Central Manitounuk Sound opens to Hudson Bay proper through Schooner Opening and to outer Manitounuk Sound through a series of channels at the Paint Islands.

In the central sound the maximum depth of greater than 45m occurs 350 m east of Merry Island (Figure 29). The Paint Islands are the surface expression of a submerged cuesta ridge extending from the Paint Islands to just seaward of the point just north of Riviere Kuugaapik. This ridge separates the southern portion of the central Manitounuk Sound into two distinct basins with the west basin being the deeper. North of Schooner Opening only one basin is observed with a maximum depth of 35 m (Figure 29).

The postglacial/recent sediments in the central sound (Figures 7,24-27 and 37) show a ponded depositional style. A transverse section across central Manitounuk Sound from the mouth of riviere Kuugaapik through Schooner Opening to Hudson Bay displays a thick accumulation of pro/postglacial sediments off the mouth of riviere Kuugaapik and asymmetric deposition of postglacial sediments within the deeper parts of Manitounuk Sound. Sediments are disturbed by icekeel scouring to depths of 22m and sandwaves occur at 35m water depth at the mouth of Schooner Opening.

Most of the central sound mapped area is blanketed by a layer of postglacial-estuarine muds. Exceptions are the narrow outcrop of glaciolacustrine/marine sediments flanking the eastern shore and capping the submerged cuesta ridge and numerous slump deposits (Figure 32). These slump deposits have a total surface area of $1.36x10^6m^2$ (Figure 36).

Postglacial sediment thicknesses locally exceed 30m in both the northern and southern basins and have a total volume of $4x10^8m^3$ (Figure 33). Postglacial muds are not present through Schooner Opening and in the series of channels at the Paint Islands. These two areas are sandy and appear to be a winnowing environment. The shallow subtidal and tidal flat areas of the central sound have a total area of $11.1x10^6m^2$ (Figure 34). These areas are scoured by the icekeels of storm induced ice ridging. All along the eastern shore scours below 18m and those sheltered towards the east of the submerged cuesta ridge are well preserved while towards the south those in shallower depths (<18m) appear degraded (Figure 35).

The presence of an oxidized surface layer is mapped based on the presence as observed in bottom grab and core samples (Figure 37). The oxidized surface layer appears to be concentrated at the constriction which separates the inner and central sound and in the deeper basins.

- 6.3 OUTER SOUND

The outer Sound, with a total surface area of 82.2 km^2, has a total length of 21.75 and average width of 3.8 km. Widths range from minimum of 2.4 km separating Neilsen Island from the mainland and a maximum of 5.7 km occurring between the southern tip of Merry Island and the mainland. In the outer sound there are five connecting passages from the Manitounuk Sound to Hudson Bay. These are generally quite shallow.

The outer sound has a maximum depth of >100 m occurring 600m southeast of Bill of Portland Island. From here the sea floor slopes gradually to the mainland shore. In the central portion of the outer Sound there is a complex terrain of isolated highs separating small basins (Figure 44). Five kilometres southwest of the Paint Islands the Outer Sound is divided into two separate basins separated by a submerged cuesta ridge which surfaces at the Paint Islands, with the western basin being the deepest. This ridge does not appear to be present south of here.

The deposition of the postglacial/recent sediments in the outer sound (Figures 7, 40-42 and 52) is highly variable which is very characteristic of the outer sound. Also note gas occurrence within the deeper portion of the basin. These sediments display an asymmetric depositional style marked by areas of non-deposition/erosion. The outer basin is marked by frequent failure scarps and associated disturbed sediments (Figure 51).

Most of the outer sound mapped area is blanketed by a layer of postglacial-estuarine muds. Exceptions are the outcrops of glaciolacustrine/marine sediments and bedrock in areas of non-deposition/erosion (Figure 47). From the postglacial sediment isopach map (Figure 48) note the complex distribution of these muds in a series of small basins. Postglacial sediment thicknesses locally exceed 30m in small basins but is generally thin at the mouth of the sound and along the eastern shore. Total volume of postglacial muds is approximately $7x10^8m^3$ (Figure 48). Large slump deposits occur along the base of the cuesta ridge. These have a total surface area of $3.05x10^6m^2$ (Figure 51).

Observations from the coastal video (Michaud and Frobel,1994) indicates that the tidal flat areas of the outer sound are minimal. Figure 49 was digitized from CHS field sheets and represents the shallow subtidal areas, total area of $5.2x10^6m^2$. All along the eastern shore these areas are scoured by the icekeels of storm induced ice ridging. Due to the survey being limited to the deeper portions of the outer sound the change from heavily to degraded scour was not observed along the eastern shore. A shore parallel survey along the coastline from the mouth of the sound to the Grande riviere de la Baleine estuary shows that no icekeel scours are preserved in this region, this is due to exposure to the open water conditions of Hudson Bay.

The presence of an oxidized surface layer is mapped based on the presence as observed in bottom grab and core samples (Figure 52). In the central area of the outer sound there is a complex terrain of isolated highs separating small basins. These sediment display an asymmetric depositional style marked by areas of non-deposition/erosion attributed to scour by strong tidal currents. This also occurs at the bedrock sill that separates the central and outer sound at the Paint Islands (Figure 52). The oxidized surface layer appears to be concentrated at the southern edge of the bedrock sill. The oxidized layer is present in the central portions of the outer sound but does not appear to be present at the mouth.

7 SEDIMENT BUDGET - MANITOUNUK SOUND

Sediment sources considered for the sediment budget calculations are; 1. fluvial input from both rivers and streams within Manitounuk Sound and the possible contribution by the Grande riviere de la Baleine, 2. tidal flat exposure and erosion attributed to coastal emergence due to isostatic recovery, 3. resuspension of coastal zone sediments by icekeel scouring and ice rafting, 4. resuspension of sediments by wave-base reworking especially those sediments experiencing changes in geotechnical properties due to freeze-thaw processes on the tidal flats, 5. current scour, resuspension and reworking, 6. coastal erosion especially thermal erosion along the microcliff associated with the tidal flats of the eastern shoreline, 7. aeolian input from the sand dunes at the head of the sound, and 8. material associated with biological productivity.

- 7.1 FLUVIAL INPUT

The drainage basin of Manitounuk Sound covers 970 km^2 and includes approximately 20 small rivers. These include (north to south) Riviere Piquard, Riviere Kuugaajaq, Riviere Mitirtuup Kuunga, Riviere Domanchin, Riviere Kuugaapik, Riviere Ruisseau Paschiskw, Riviere Minguarutiit Kuunga and Grande Riviere de la Baleine (fig. 2.2)(Hydro-Quebec, 1993). These rivers carry an annual run-off of some 20 m^3/sec (21.5 m^3/sec in 1987). The largest river, the Domanchin, carried a run-off of 6.5 m^3/sec in 1987 (Hydro-Quebec, 1993).

The rivers and streams which flow into the Manitounuk Sound carry very little solid material as in the upper reaches these have beds of coarse material. Substantial glacial, proglacial and estuarine sections such as those documented the Petite riviere de la Baleine and the Grande riviere de la Baleine are preserved in the lower reaches of some of these rivers, but these rivers are not thought to have any great effect on sedimentation dynamics. The two largest of these watercourses, the Ruisseau Pachiskw and the Riviere Domanchin, dump very little sediment, their beds being comprised of rather coarse material (Consortium SOGEAM 1980a). At the mouths of these rivers, on the foreshore of the Manitounuk Sound are small deltas of gravelly sand which are shaped by waves and ice, sometimes forming spits, beaches, or tombolos. The deposits vary in thickness from a few centimetres to a metre and do not stretch far beyond the mouths of the rivers (CSSA 1992b).

MANITOUNUK SOUND SUSPENDED SEDIMENT SURVEY JUNE 22 - JULY 7, 1993

Suspended sediment samples were obtained throughout Manitounuk Sound during the 1993 ice breakup. Stations were occupied six times during the June 22 to July 7, 1993 period. Results, presented in the table below, are surprisingly low considering the seasonal high fluvial input.

Station Number	Range mg/l	Average mg/l	Number of samples	Location
GB-4	1.5-5.9	3.7	6	mouth of outer sound
GB-5	1.7-4.1	3.1	6	central outer sound
GB-6	0.8-4.5	2.3	6	northeast outer sound
GB-7	2.3-5.1	3.5	6	northwest of Paint Is
GB-8	1.6-3.8	3.2	6	off riviere Kuugapik
GB-9	2.6-6.4	4.2	6	east of Castle Is, central sound
GB-10	1.1-7.2	3.5	6	southern inner sound
GB-11	1.6-3.8	3.1	6	central inner sound
GB-12	2.6-6.6	4.7	6	northern inner sound
GB-13	1.2-3.2	2.1	6	offshore boat opening
GB-16	0.7-3.0	1.7	6	offshore Schooner Opening

TABLE 2 - SUSPENDED SEDIMENT CONCENTRATIONS - MANITOUNUK SOUND JUNE 22 TO JULY 7, 1993

Visual observation during the spring breakup 1993 shows that very little suspended sediment is present in the river water. Photographs of the riviere Kuugaapik and riviere Domanchin plume during this time indicate that substantial suspended sediment concentrations can be attributed to the coastal microcliff and the tidal flats but that the river plume is clear.

It is estimated that the Grande riviere de la Baleine delivers approximately 176,000 metric tons (t) of solid sediment annually, 131,000 t of fine suspended material, and 45,000 t of sandy material (Hydro-Quebec, 1993) to the head of the estuary annually. The bulk of the sand is deposited in the estuary while the finer material flows into the bay. During favourable weather conditions the Grande riviere de la Baleine could represent a source of suspended matter, but most of its sediment is deposited in Hudson Bay (CSSA, 1992b).

- 7.2 COASTAL EMERGENCE DUE TO ISOSTATIC RECOVERY AND RESULTANT TIDAL FLAT EXPOSURE AND EROSION

Due to isostatic recovery (currently approximately 0.01m/year)(Figure 3) 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 hereby transported to the deeper basins and possibly out into Hudson Bay through the various openings. Figure 4 indicates the changing shoreline from 6 ka to present. Note that the recovery rates (Figure 3) 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 Kuugaapik 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 - RADIOCARBON DATING OF RIVIERE KUUGAAPIK TIDAL FLATS

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 Kuujjuaraapik 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).

Shallow subtidal and tidal flat areas were determined from CHS field sheets. From this data it was determined that the inner sound area was equal to $7.032 \times 10^6 m^2$ (Figure 18), for the central sound $11.085 \times 10^6 m^2$ (Figure 34), and for the outer sound, $5.244 \times 10^6 m^2$ (Figure 49). Total shallow subtidal and tidal flat area would be approximately $23.366 \times 10^6 m^2$. If 0.01m/yr of sediment was removed from shallow subtidal and tidal flat areas, then the volumes would be $7.032 \times 10^4 m^3$ for the inner sound, $11.085 \times 10^4 m^3$ for the central sound, $5.244 \times 10^4 m^3$ for the outer sound for a total of $23.366 \times 10^4 m^3$ for the entire sound.

Sediment samples obtained by Hydro-Quebec over the riviere Kuugaapik mudflat the gravel content ranged from 0.0-8.0 % (average 1.4 %), sand content ranged from 5.0-90.0 % (average 42.1 %), silt content ranged from 9.0-63 % (average 51.5 %) and clay content ranged from 0.0-47.0 % (average 17.6 %), while those collected along diver transects all around the sound the gravel content ranged from 0.0-26.0 % (average 2.3 %), sand content ranged from 4.0-99.0 % (average 60.8 %), silt content ranged from 0.0-73.0 % (average 27.3 %) and clay content ranged from 0.0-29.0 % (average 9.7 %) (CSSA, 1991). It is apparent from these samples that not all the material would be transported to the deeper basins of the sound where the postglacial muds observed in cores consists of a heavily bioturbated olive gray mud with black reduction spots (gravel 0 - 31%, sand 1 - 78%, silt 12 - 81 %, clay 6 - 87% (Henderson, 1989).

- 7.3 ICEKEEL SCOURING AND ICE RAFTING

The ice cover of Manitounuk Sound is formed as new ice. Ice development starts with a rim of shorefast ice. Ice thickness in level shorefast ice average 0.8-1.0m by January 1 and 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. As temperatures rise in May and June leads develop. The pack ice generally clears towards the west from the Quebec shore. During late August the last of the ice cover has melted completely (Markham, 1986).

The ice rafting component in to the sediment budget of Hudson Bay has always been considered an important contributor (Pelletier, 1965, 1986, Henderson 1989). Resuspension of coastal zone sediments by icekeel scouring and ice rafting of sediment incorporated within the shorefast ice over the shallow intertidal to tidal zone was considered to represent a major contribution to the sediment budget (Ruz et al, 1994).

Manitounuk Sound is totally ice covered during the winter months with ice thicknesses > 1.2m (Ruz et al, 1994). Ice which forms over the tidal flats freezes down to seabed in the process incorporating substantial volumes of sediments at the base. Cores collected along profiles over the riviere Kuugapik and riviere Domanchin mudflats (April 1993) indicate that substantial volumes of sediment are incorporated into the ice 0.00-62.69% per unit volume, average 28.89%. A substantial contribution was anticipated by ice rafting but visual observations during breakup indicated that the bulk of the ice cover over the tidal flats melted in situ therefore not contributing directly to the overall sediment budget.

Temperature profiles collected through the ice into the substrate in areas where ice cover extended to the seafloor indicated temperature minimums of -4 degrees C with the 0 degrees C isotherm depth below seafloor ranging in depth from 1.5-4.0m (Ruz et al, 1994). Normal summer salinity range of Manitounuk Sound ranges from 25 to 33 ppm (Hydro Quebec, 1993). Salinities of the ice core material ranged from 0-3.05 parts per thousand, averaging 0.43 parts per thousand indicating salt rejection during ice formation and a resultant high fresh water input during breakup.

The combined effects of sediment incorporation into the sea ice and subsequent meltout, freezing of substrate to depths of up to 4m and the high input of fresh water would alter the geotechnical properties of the sediments making them more susceptible to erosion. Sediment sampled in the cores were described as frozen sediment, soft clay to sand and gravel. Sediment samples obtained by Hydro-Quebec over the riviere Kuugaapik mudflat had gravel contents ranged from 0.0-8.0 % (average 1.4 %), sand content ranging from 5.0-90.0 % (average 42.1 %), silt content ranged from 9.0-63 % (average 51.5 %) and clay content ranged from 0.0-47.0 % (average 17.6 %), while those collected along diver transect all around the sound the gravel content ranged from 0.0-26.0 % (average 2.3 %), sand content ranged from 4.0-99.0 % (average 60.8 %), silt content ranged from 0.0-73.0 % (average 27.3 %) and clay content ranged from 0.0-29.0 % (average 9.7 %).

- 7.4 RESUSPENSION BY WAVE-BASE REWORKING

Due to the short navigation season and limited shipping activity only 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.

Westerly to south-southeasterly gales are common during the ice free season from June to November. These wind directions cause maximum fetch and can result in significant wave height exceeding 2m (Riel, pers comm) throughout the sound. Wave base reworking of the sediments of the shallow subtidal and tidal flat areas creates very turbid conditions. A coastal video (Michaud and Frobel, 1994) was flown during strong southwesterly winds during which both the inner and central sound tidal flats were exposed. A wide zone of turbid water was observed along the tidal flat seaward margin. Also detailed analysis of the icekeel scouring data preserved in the central Sound indicates that only the scours occuring in water depths deeper than 18m and those in the lee of ridges are well preserved (Figure 35).

The change from well preserved to degraded scour provides a rough estimate of the limits of significant wave base reworking. The shallow subtidal and tidal flat sediments experience substantial changes in geotechnical properties due to freeze-thaw processes and incorporation into the shorefast ice. This influences the upper portion of the section making it more susceptible to erosion.

The wind data for the area is summarized below from the Hudson Bay Sailing Directions (DFO,1990). Strong winds are not frequent during the May to August period. The higher frequencies are reached in November when major storms cross the bay. During September and October stronger winds are from the west and sometimes the east. These directions are reflections of the cyclonic activity over the bay in the fall (DFO,1990). The highest hourly winds observed in the stormy periods of the months July-December(1957-1980) are

Month	extreme maximum hourly wind speed (kph)	direction (sev.= several dir.)	percentage frequency from the S-WSW	mean wind speed (kph)	maximum gust speed (kph)	
July	70	sev.	15.2%	20.5	108	S
August	75	sev.	28.5%	21.9	103	WSW
September	74	WSW	23.3%	22.2	99	S
October	77	NW	24.6%	22.4	106	NW
November	93	W	26.6%	23.5	97	SAL

TABLE 4 - WIND DATA SUMMARY - KUUJJUARAAPIK (DFO,1990)

Observation for the month of December (daily average temperature -15.9^{0}C) are not noted eventhough some open water conditions persist in localized areas of high tidal flow such as Schooner and Boat Opening

During the 1993 ice breakup suspended sediment samples were obtained throughout Manitounuk Sound . Stations were occupied six times during the June 22 to July 7, 1993 period. The results from samples collected in the sound (Figures 22, 38 and 53) are surprisingly low considering the seasonal high fluvial input and range from 0.7-7.2 mg/l. There is an insignificant amount of suspended matter in the waters of Manitounuk Sound. GIROQ (1977b) observes that the concentration of suspended matter in the Manitounuk Sound (ranging from 2 mg/L to 9 mg/L) is remarkably stable over time and with respect to depth and distance from the entrance of Manitounuk Sound. Suspended sediment measurements obtained during storm conditions along a transect from the Paint Islands to Schooner Opening maximum value recorded was 20 mg/l with an average of 10 mg/l (Solley, pers comm).

- 7.5 CURRENT SCOUR AND REWORKING

Bottle drift data (Hachey, 1935, Barber, 1967) indicates a southeasterly flow along the south coast veering to the north in the study area. 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, 1983). 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.

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. It starts from the entrance in the northwestern bay at about 2m amplitude, with tidal current 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. Mean tidal range in Manitounuk Sound region ranges is 1.5m. Tidal amplitudes are greater in summer, but dampened in the winter months by ice cover (Prinsenberg and Freeman, 1986).

The style of deposition of the postglacial/recent sediments is highly variable in Manitounuk Sound. Variation can be primarily defined by the three basins with decreasing dynamic conditions from the mouth to the head of the sound.

The inner Sound (Figures 7, 10, 11 and 21) 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.

The postglacial/recent sediments in the central Sound (Figures 7,24-27 and 37) show an asymmetrical ponded depositional style and sandwaves which occur at 35m water depth at the mouth of Schooner Opening.

The deposition of the postglacial/recent sediments in the outer Sound (Figures 7, 40-42 and 52) is highly variable. These sediments display an asymmetric depositional style marked by areas of non-deposition/erosion attributed to scour by strong tidal currents. The bedrock sill that separates the central and outer Sound at the Paint Islands is interpreted as a zone of non-deposition/erosion.

- 7.6 THERMAL EROSION

Zones of both permafrost aggradation and degradation are present in the study area (Michaud et al, 1994). In the central part of the sound facing Schooner Opening erosion affects at least 4 km of shoreline. Average annual erosion rates based on aerial photographs of 1979 and 1990 indicates annual erosion of 0.6m/year. Average height of the coastal microcliff is 1m but 4m can be attained. Fine sediment makes up 60% of all eroded sediments, potential volume of sediments ranges from 720-1440 m^3/year. Coastal erosion in this rapidly emerging coastline is primarily the result of permafrost thermal erosion along the microcliff associated with the tidal flats of the eastern shoreline.

During April 1993 frost blisters were observed on the coastal microcliff. Observation in June 1993 indicated that the face of this microcliff thaws and then collapses. The fine grained portion of the slumped sediment is the carried off to the tidal flat area and beyond through a network of shore parallel and tidal channels. Visual observation during the spring breakup 1993 show that a plume of turbid water originates from the collapse of the microcliff and erosion of the tidal flats with little fluvial suspended sediment input (Ruz et al, 1994).

- 7.7 AEOLIAN INPUT

A large sand dune field is present at the head of the sound and smaller areas of dunes are present on the northern end of Castle Island and along the shore of the outer sound. Aeolian input into the sediment budget consists of material from the dunes and organic materials such as spores and pollen aeolian input from the sand dunes at the head of the sound.

- 7.8 BIOLOGICAL PRODUCTIVITY

Hudson Bay is an oligotrophic body of water of low productivity, heavily influenced by freshwater runoff (Environmental Application Group, 1983). The lack of vertical mixing and the vertical stability attributed to the large freshwater runoff affect primary production in a negative way due to the incomplete mixing and resultant low generation rates of nitrogen (Pett and Roff,1982). Roff and Legendre (1986) also attribute the low phytoplankton biomass and productivity of the central Hudson Bay region to persistent vertical stratification.

Organic carbon content of the offshore surface sediment as determined by D'Anglegan and Biksham (1988) was well below 1%. Within the sound organic carbon in the surface sediments as measured by Buckley et al (1993) ranges from 0.3 - 0.8% with an average value of 0.5%. This coincides with organic carbon measurements obtained during the 1992 survey of 0.2-0.6%. These contrast sharply with the observed particulate organic matter measurements within sediment traps (D'Anglegan an Biksham,1988) and Sea Carousel deployments.

Sediment trap data collected by D'Anglegan and Biksham (1988) indicate total particulate carbon values ranging from a high of 30% in winter to between 8-12% in the May to July period. Total organic matter were also measured by Terri Sutherland during Sea Carousel deployments, August 1992.

The Sea Carousel a benthic annular flume capable of submarine monitoring of seabed erosion (Amos et al, 1992) was deployed in Manitounuk Sound. Eroded material collected from the Sea Carousel deployments performed at stations located inside Manitounuk Sound contained approximately 6-10% organic matter. The organic content of eroded material collected from stations at the Paint Island Sill (Figure 40) located between the central and outer sound ranged between 15-20%, while a station just outside the sound ranged between 9-14%. Carbon and nitrogen values standardized by per gram of sediment and averaged over the deployment period were determined for the eroded material collected from one of the Paint Island Sill stations. The average carbon and nitrogen values were 0.22% and 0.03% resulting in a carbon:nitrogen ratio of 8:1. Carbon and nitrogen values were determined for a core collected from the low intertidal region near riviere Kuugaapik during the same time period. The average carbon and nitrogen values over the surface 0.08m were 0.27% and 0.39% resulting in a carbon:nitrogen ratio of 0.73.

Similarly, during grab sample transects, highly productive environments were observed in all the restricted openings to Hudson Bay such as Schooner Opening. In comparing the sediment trap data with the organic carbon content of the surface sediment from core data D'Anglegan and Biksham (1988) conclude that most organic remains reaching the seafloor have ample time to decompose. Regionally gas occurrence in the sediment column is observed at the mouths of the large estuaries (Zevenhuizen, 1993) and within the inner sound (Figure 11) and the outer sound (Figure 40). Gas charged sediments were not observed in the central sound (Figures 7, 24 and 25). It is unlikely that the gas occurrences can be attributed to deep seated gas seeping from the bedrock and are therefore biogenically produced. Minimum organic carbon values at which gas can be detected with reflection seismic techniques in marine sediments is 0.7% (Hovland and Judd, 1988).

TABLE 5 - Organic Carbon content and sediment size analysis (Buckley et al, 1993)

Depth (cm)	Organic Carbon (%)	Sediment size analysis Sand (%)	Silt (%)	Clay (%)	Mean Grain Size (microns)	
0	0.6	0.2	48.2	51.6	4.1	Core 92-028S-204
5	0.4	0.1	45.8	54.1	3.7	
15	0.5	0.5	48.9	50.6	4.3	
25	0.4	0.9	57.6	41.5	5.6	
35	0.4	0.7	53.7	45.6	4.9	
45	0.4	0.2	56.8	43.0	5.2	
55	0.4	0.1	56.2	43.7	5.1	
65	0.3	0.3	58.9	40.7	5.7	
75	0.4	0.9	60.1	39.0	6.2	
85	0.5	1.2	55.9	42.9	5.1	
0	0.6	0.0	53.9	46.1	4.9	Core 92-028S-212
5	0.4	0.0	62.7	37.3	5.9	
10	0.4	0.0	62.3	37.7	5.9	
20	0.4	0.3	61.6	38.2	5.8	
30	0.2	0.0	59.6	40.4	5.4	
40	0.4	0.5	58.7	40.8	5.3	
50	0.5	0.2	59.3	40.5	5.5	
60	0.4	0.1	57.6	42.3	5.5	
70	0.4	0.3	53.5	46.4	4.8	
80	0.4	0.6	52.4	47.0	4.8	
90	0.5	0.3	65.5	34.2	6.6	
100	0.5	0.0	62.8	37.2	5.9	
110	0.4	0.0	61.0	39.0	5.5	
120	0.5	0.2	58.9	40.9	5.4	
130	0.5	0.5	60.9	38.6	5.6	
0	0.8	0.2	64.3	35.5	6.5	Core 92-028S-228
3	0.5	0.7	59.0	40.4	5.9	
10	0.5	0.4	63.2	36.5	6.4	
25	0.5	0.4	55.1	44.6	5.2	
40	0.5	0.4	56.0	43.7	5.2	
50	0.5	0.2	60.8	39.1	5.8	
65	0.6	0.0	60.5	39.5	5.5	
80	0.5	0.1	60.6	39.4	5.8	
95	0.5	1.3	57.4	41.3	5.7	
115	0.5	0.8	62.9	36.3	6.2	
135	0.5	0.6	63.3	36.1	6.2	

- 7.9 SEDIMENT FAILURE AND SLUMP DEPOSITS

Slumping occurs throughout the study area in varying degrees of magnitude. Within the outer and central sections of the sound there are frequent sediment failure/slump deposits but as these events only rework the already inplace sediments and are not a source of new sediment the calculated volumes are presented in the following sections but not used in the overall sediment budget calculations.

Slumping is only observed within the well-stratified glaciolacustrine/marine and postglacial sediments. 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 in the outer and central Sound and at the delta fronts in the central Sound. The largest observed sediment failure scarp is located along the western shore of outer Manitounuk Sound (Hydro-Quebec line 6, shot points 370-374).

Within the central Sound 11 slump deposits (Figure 32) can be recognized on sidescan sonar data. These slump deposits have a total surface area of $1.36x10^6m^2$. In the outer basin 5 large slump deposits occur along the base of the cuesta ridge (Figure 51) these have a total surface area of $3.05x10^6m^2$. Slump deposits observed within the sound and mapped represent only those currently visible on the sidescan sonar data and do not include paleo/buried slump deposits. The mapped slump deposit therefore only represent recent (?) events where recent could represent the last 1-200 years. Total observed slump deposit area equals approximately $4.86x10^6m^2$.

-Fluvial input of 20 cu m/sec with annual input of 63 072 000 m^3 equals 63 072 000 000 litres therefore at:

1 mg/l	63 072 kg	average bulk density 1.7	37.1 m^3
5	315 360 kg		185.5
10	630 720 kg		371.0
15	946 080 kg		556.5
20	1261 440 kg		742.0

- Organic material			
total organic carbon	0.3-0.6%	0.2-0.6%	0.5-0.8%
total organic matter			
Sea Carousel	6-10%	6-10%	9-14%
(15-20% at sill)			

TABLE 6 - SEDIMENT BUDGET AREA AND VOLUME MEASUREMENTS

- 7.10 DEPOSITION RATES

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.

Throughout the study area postglacial basinal muds are overlain by a layer of brown, oxidized, soupy muds ranging in thickness from a veneer - 0.05m (Figure 5). This layer is presently interpreted as representing an annual deposit. When the accumulation of these sediments is averaged out over the extent of the mapped postglacial mud deposits (Figures 17,33 and 48) it represent approximately the surface 0.01m. Previously calculated sediment rates (GIROQ,1977b, CSSA, 1992) are 0.01m per year. Postglacial mud volume calculations indicate that at an average deposition rate of 0.01m/yr, the inner basin would have reached its present volume in 2700 years, the central basin 4500 years and the outer basin 2600 years.

The mapping of coastal changes based on the minimum emergence curve for Richmond Gulf (Hilliare-Marcel, 1979) indicates that Manitounuk Sound was probably 20m deeper and more than 1km wider but similar to its present day configuration at 4 ka (Figure 4). In the offshore the average combined till glaciolacustrine/marine sediment thickness is approximately 4m. Assuming erosion of up to 4m of material over this 1km wide, 60km long coastal section which would have emerged over the past 4000 years the volume available is $2.4 \times 10^9 m^3$.

Detailed sediment analysis of the present day coastal microcliff section indicates that 60% of the sediments are fine grained.

MANITOUNUK SOUND - PHYSICAL CHARACTERISTICS

	Inner Sound	Central Sound	Outer Sound	Total
-Length	16.5 km	19.75 km	21.75 km	58 km
-Width	1-3.25 km	1.4-3.75 km	2.4-5.7 km	1-5.7km
-Av. width	2 km	2.6 km	3.8 km	
-Total surface area	$33.8x10^6 m^2$	$52.0x10^6 m^2$	$82.2x10^6 m^2$	$168x10^6 m^2$
-Mapped area	$17.7x10^6 m^2$	$31.0x10^6 m^2$	$59.7x10^6 m^2$	$108.4x10^6 m^2$
	52%	60%	73%	65%
-Outlets to Hudson Bay	3	1	5	9
-Postglacial sediment outcrop	$14.7x10^6 m^2$	$25.6x10^6 m^2$	$48.1x10^6 m^2$	$88.4x10^6 m^2$
- Sediment required for 0.01m/yr	$14.7x10^4 m^3$	$25.6x10^4 m^3$	$48.1x10^4 m^3$	$88.4x10^4 m^3$
-Total postglacial sediment volume in place	$0.4x10^9 m^3$	$0.4x10^9 m^3$	$0.7x10^9 m^3$	$1.5x10^9 m^3$
-Time required to accumulate this volume at 0.01m/yr	2700 years	1600 years	1500 years	1700 years
-Shallow subtidal and tidal flat area				
Total	$7.032x10^6 m^2$	$11.085x10^6 m^2$	$5.244x10^6 m^2$	$23.366x10^6 m^2$
-Material avail. with 0.01m emergence	$7.032x10^4 m^3$	$11.085x10^4 m^3$	$5.244x10^4 m^3$	$23.366x10^4 m^3$
Eastern shore area	$6.839x10^6 m^2$	$10.551x10^6 m^2$	$5.003x10^6 m^2$	$22.393x10^6 m^2$
-Material avail. with 0.01m ice rafting off eastern shore tidal flat	$6.839x10^4 m^3$	$10.551x10^4 m^3$	minimal	$17.390x10^4 m^3$
-Icekeel scour occurance				
Heavily scoured				
Eastern shore	$4.84x10^6 m^2$	$2.40x10^6 m^2$	$1.85x10^6 m^2$	$9.09x10^6 m^2$
Western shore	$0.77x10^6 m^2$	$0.67x10^6 m^2$	$0.69x10^6 m^2$	$2.13x10^6 m^2$
Lightly scoured (degraded)				
Eastern shore	$2.75x10^6 m^2$	$8.01x10^6 m^2$	$0.52x10^6 m^2$	$11.28x10^6 m^2$
Western shore	$0.70x10^6 m^2$	$0.67x10^6 m^2$	$0.96x10^6 m^2$	$2.33x10^6 m^2$
Total scoured area	$9.06x10^6 m^2$	$11.75x10^6 m^2$	$4.02x10^6 m^2$	$24.83x10^6 m^2$
-Recent sediment failure/slump deposits	$0.24x10^6 m^2$	$1.36x10^6 m^2$	$3.05x10^6 m^2$	$4.65x10^6 m^2$ -
Thickness range of oxidized surface layer	0-0.04 m	0-0.05 m	0-0.05 m	0-0.05 m
-Thermafrost degradation of coastal microcliff average 1 m	7500m	7500m	minimal	15000m

(Based on composition of 60% fine grained material sediments available and a retreat rate of 1.0 m/year)

- Sediment volume	$4500m^3$	$4500m^3$	minimal	$9000m^3$
-Aeolian input	yes	minimal	yes	minor

Size analysis of the cores collected to sample the postglacial mud indicates total mud fraction of 98.3-100% (Buckley et al, 1993). Therefore only the fine-grained muds are currently being deposited in the deeper basins, with the only exception being the sediment failure / slump deposits. If 60% of the eroded section accumulates in the basins than anticipated volume would be approximately $1.44x10^9m^3$. Calculated postglacial volume for the three sections of Manitounuk Sound (Figures 17,33 and 48) is $1.5x10^9m^3$. Using this calculated volume to determine an average sedimentation rate for the past 4000 years of $3.75x10^5m^3$ spread over a total postglacial sediment outcrop area of $58.3x10^6m^2$ equals 0.006m per year.

Inner sound core 92-028S-204 sand 0.1-1.2%, silt 48.2-60.1% and clay 39.0-54.1%
Central sound core 92-028S-212 sand 0.0-0.6%, silt 52.4-65.5% and clay 34.2-47.0%
Outer sound core 92-028S-228 sand 0.0-1.3%, silt 55.1-64.3% and clay 35.5-44.6%

TABLE 7 - POSTGLACIAL MUD SEDIMENT SIZE ANALYSIS FOR INNER, CENTRAL AND OUTER SOUND CORES

Detailed analysis of the inner, central and outer sound indicate that present day deposition rates vary in each of the basins.

- 7.10.1 INNER SOUND SEDIMENT BUDGET

In summary the inner sound has a present day total surface area $33.8x10^6m^2$ of which 52% is mapped in detail. Postglacial sediment outcrop is $14.7x10^6m^2$. Sediment required for 0.005m/yr deposition rate would be $7.35x10^4m^3$. The total postglacial sediment volume currently in place equals $0.4x10^9m^3$. The total shallow subtidal and tidal flat areas subject to exposure to erosion due to isostatic recovery of 0.01m/year totals $7.032x10^6m^2$ which would make available $7.032x10^4m^3$/yr of material. In the inner sound heavily icekeel scouring is observed over $4.84x10^6m^2$ of the eastern shore and $0.77x10^6m^2$ of the western shore (Figure 19). The area is lightly scoured in water depths less than 15m (Figure 19) which depth is interpreted as representing the present day depth of wave-base reworking. Only three small recent sediment failure/slump deposits with a total surface area of $0.24x10^6m^2$ of undetermined age were found in the inner sound. If these slump deposits are 0.5m thick than the total volume would be $1.2x10^4m^3$ which if calculated to represent 50-200 years would be 600-$2400m^3$/year. The thickness range of oxidized surface layer (Figure 21) is 0-0.04 m with maximum concentrations in the lee of maximum current velocities such as the constriction between the inner and central sound and near Boat Opening. Thermal erosion of coastal microcliff with an average of 1m along 4000m of coastline with a composition of 60% fine grained material would provide an input of 720-1440m^3/yr. Aeolian erosion and input from a 20km^2 dune field at the head of the sound was not considered as little or no sand was present in the postglacial muds. Fluvial input based on a suspended sediment range of 5-10 mg/l and the inner sound receiving 30% of the total would be minimal ranging 60-125m^3/year. Organic material determine from total organic carbon content of cores collected in the inner sound range from 0.3-0.6% for the upper 1m of section and amount to 70-280m^3.

Emergence volume available	$7.032x10^4m^3$
- 60% fine grained available for erosion	$4.219x10^4m^3$
- 50-100% removal by tidal currents and wave base reworking	$2.110-4.219x10^4m^3$
Thermal erosion	720-1440m^3.
Aeolian erosion	minimal
Fluvial input	60-125m^3
Total input without organic material	$2.188-4.3755x10^4m^3$
Organic material	70-280m^3
Total input with organic material	$2.195-4.4035x10^4m^3$
Deposition rates	0.0015-0.0030m/yr

If 0.01m of sediment were incorporated into the shorefast ice the ice rafted sediment contribution would be $6.839x10^4m^3$/yr. This volume of material appears to be deposited in situ and is therefore not included in the calculations. Recent slump deposits (600-2400m^3/yr) represent reworked material which was already included in the sediment budget. Deposition rates calculated as total input volume per year/postglacial sed outcrop area.

TABLE 8 - SEDIMENT BUDGET SUMMARY - INNER SOUND

- 7.10.2 CENTRAL SOUND SEDIMENT BUDGET

In summary the central sound has a present day total surface area of $52.0x10^6m^2$ of which 60% is mapped in detail. Postglacial sediment outcrop is $25.6x10^6m^2$. Sediment required for 0.005m/yr deposition rate would be $12.8x10^4m^3$. The total postglacial sediment volume currently in place equals $0.4x10^9m^3$. The total shallow subtidal and tidal flat areas subject to erosion due to isostatic recovery of 0.01m/year totals $11.085x10^6m^2$ which would make available $11.085x10^4m^3$. In the central sound heavily icekeel scoured terrain is observed over $2.40x10^6m^2$ of the eastern shore and $0.67x10^6m^2$ of the western shore. The scours are degraded in water depths >18m and in protected areas (Figure 35). This depth is interpreted as representing the present day depth of wave-base reworking. Total surface area of sediment failure/slump deposits is $1.36x10^6m^2$. If these slump deposits are 0.5m thick than the total volume would be $6.8x10^5m^3$ which if calculated to represent 50-200 years of activity would be over 3400-13600m^3/year. The thickness of the oxidized surface layer (Figure 21) is 0-0.05 m. Thermal erosion of the coastal microcliff with an average of 1m along 4000m of coastline with a composition of 60% fine grained material would provide an input of 720-1440m^3. Aeolian erosion and input is minimal and was not considered. Fluvial input based on a suspended sediment range of 5-10 mg/l and the central sound receiving 50% of the total would be minimal ranging 90-180m^3/year. Organic material determine from total organic carbon content of cores collected in the central sound range from 0.2-0.6% for the upper 1m of section and amount to 75-490m^3.

Emergence volume available	$11.085 \times 10^4 m^3$
- 60% fine grained available for erosion	$6.651 \times 10^4 m^3$
- 50-100% removal by tidal currents and wave base reworking	$3.325\text{-}6.651 \times 10^4 m^3$
Thermal erosion	720-1440m^3.
Aeolian erosion	minimal
Fluvial input	90-180m^3
Range without organic material	$3.406\text{-}6.813 \times 10^4 m^3$
Organic material	75-490m^3
Range with organic material	$3.4135\text{-}6.862 \times 10^4 m^3$
Deposition rates	0.0013-0.0026m/year

If 0.01m of sediment were incorporated into the shorefast ice the ice rafted sediment contribution would be $10.551 \times 10^4 m^3$/yr. This volume of material appears to be deposited in situ and is therefore not included in the calculations. Recent slump deposits (3400-13600m^3/yr) represent reworked material which was already included in the sediment budget. Deposition rates calculated as total input volume per year/postglacial sed outcrop area.

TABLE 9 - SEDIMENT BUDGET SUMMARY - CENTRAL SOUND

- 7.10.3 OUTER SOUND SEDIMENT BUDGET

In summary the outer sound has a present day surface area $82.2 \times 10^6 m^2$ of which 73% is mapped in detail. Postglacial sediment outcrop is $48.1 \times 10^6 m^2$. Sediment required for 0.005m/yr deposition rate would be $24.05 \times 10^4 m^3$. The total postglacial sediment volume currently in place equals $0.7 \times 10^9 m^3$. The total shallow subtidal and tidal flat areas subject to exposure to erosion due to isostatic recovery of 0.01m/year totals $5.244 \times 10^6 m^2$ which would make available $5.244 \times 10^4 m^3$ of material. Due to the greater depth of the outer sound no data was available to determine the depth of wave-base reworking, due to increased exposure to the Hudson Bay it is assumed that the >18m water depth indicated for the central sound is applicable to the outer sound. Sediment failure / slump deposits of the central sound have a surface area of

$3.05x10^6m^2$. This value predominantly represents one large sediment failure east of Merry Island which is the largest failure observed in the entire area from Anderson Island in the north to the Bear Islands in the south and extending over 30km offshore (Zevenhuizen, 1993). If these slump deposits are 0.5m thick than the total volume would be $15.25x10^5m^3$ which if calculated to represent 50-200 years of activity would be over $7625-30500m^3$/year. The thickness of the oxidized surface layer (Figure 21) is 0-0.05 m. No thermal erosion was observed. Aeolian erosion and input appears to be minimal and was not considered. Fluvial input based on a suspended sediment range of 5-10 mg/l and the outer sound receiving 17% of the total would be minimal ranging $30-65m^3$/year. Organic material determine from total organic carbon content of cores collected in the inner sound range from 0.5-0.8% for the upper 1m of section and amount to .

Emergence volume available	$5.244x10^6m^2$
- 60% fine grained available for erosion	$3.1464x10^4m^3$
- 50-100% removal by tidal currents and wave base reworking	$1.573-3.1464x10^4m^3$
Thermal erosion	not observed
Aeolian erosion	minimal
Fluvial input	$30-65m^3$
Range without organic material	$1.576-3.1529x10^4m^3$
Organic material	$120-500m^3$
Range with organic material	$1.588-3.2029x10^4m^3$
Deposition rates	0.0003-0.0007m/year

If 0.01m of sediment were incorporated into the shorefast ice the ice rafted sediment contribution would be $5.003x10^4m^3$/yr. This volume of material appears to be deposited in situ and is therefore not included in the calculations. Recent slump deposits ($7625-30500m^3$/yr) represent reworked material which was already included in the sediment budget. Deposition rates calculated as total input volume per year/postglacial sed outcrop area.

TABLE 10 - SEDIMENT BUDGET SUMMARY - OUTER SOUND

inner sound	0.0015-0.0030m/year
central sound	0.0013-0.0026m/year
outer sound	0.0003-0.0007m/year

TABLE 11 - DEPOSITION RATES

8 DISCUSSION

It is important to note that sediments which are accumulating within the deeper portions of the sound primarily involve a continuous cycle of deposition, reworking, resuspension and redeposition of sediments originating in the sound and small drainage basin. Fluvial input from the Grande riviere de la Baleine and biogenic material components appear to be small.

Sediment supplied to the Manitounuk Sound system is episodic, only tidal currents occur all year although the range would be dampened with total ice cover and would not influence the tidal flat areas where the ice extends down to the seabed. There is high organic deposition during the ice algal bloom which occurs when sufficient sunlight is available to penetrate the ice cover (D'Anglejan and Biksham, 1988). Fluvial suspended sediment input during the spring freshet peaks in June/July with little suspended sediment observed further into the sound (Figure 22, 38 and 53). Large volumes of sediment are incorporated within the ice which forms over the shallow subtidal and tidal flat areas. Average volume values of sediments incorporated into the ice was 28.89% (range 0.00-62.69% per unit volume). This would provide a substantial ice rafted contribution to the sediment budget. Visual observations during breakup 1993 indicated that the bulk of the ice cover over the tidal flats melted in situ therefore it does not contribute to the overall sediment budget. Coastal retreat due to thermal eroision of the shoreline microcliff occurs over a relatively short time span (2-3 weeks) contributing from 1440-4880m^3. Total annual fluvial contribution is calculated as 185-370m^3.

Wave base, storm surge and tidal current erosion of the tidal flats, which rise at the rate of isostatic uplift of approximately 0.01m/year, appears to be the main source of sediment in the Manitounuk Sound. The freeze-thaw cycle, through the ice segregation process, softens the deposit, while ice and waves act as erosive agents.

The following are the published sedimentation rates for the Grande riviere de la Baleine - Manitounuk Sound region. Sedimentation surveys conducted by GIROQ (1977b) show 1m/100 years rate of sedimentation in the Manitounuk Sound. Using this data CSSA (1992b) consider the foreshore that is subject to erosion as $30x10^6m^2$, the annual volume of sediment subject to erosion of $15x10^6m^3$. Using 210Pb data D'Anglejan and Biksham (1988) calculated rates of sedimentation of 0.063$\pm$ 0.0077m/100 years for their offshore station 583 and 0.053m/100 years at station 40 at the mouth of Manitounuk Sound. Bilodeau et al (1990) using microfaunal and dinocyst assemblages determined a postglacial sediment thickness of 7m. A rough sedimentation rate from these data is 0.09m/100 years. At the mouth of the Grande riviere de la Baleine Gonthier et al (1993) calculated maximum rates of 0.086m/100 years

For 0.01m of material to be deposited in the basinal areas of Manitounuk Sound annually, would require a supply of 89,000m^3 for the inner sound, 256,000m^3 for the central sound, 481,000m^3 for the outer sound, therefore a total of 884,000m^3 would be required.

Calculations derived during this study total annual volume of available material for the inner sound ranges from 21 950-44 035m^3, central sound ranging from 34 135-68 620m^3 and the outer sound ranging from 15 880-32 029m^3 for a total range of 71 965-144 684m^3. Resultant sedimentation rates range from 0.0003-0.0030m/year.

In summary, the Manitounuk Sound receives very little outside sediment and is characterized by the movement of postglacial sediment from the shallow subtidal and tidal flat area.

Emergence volume	7.008-14.164x10^4m^3
Slump deposits	11625-46400m^3
Thermal erosion	1440-2880m^3.
Aeolian erosion	minimal
Fluvial input	185-370m^3
Organic material	265-1270m^3
Range with organic material	7.1965-14.4684x10^4m^3
Range of deposition rates	0.0003-0.0030m/year

TABLE 12 - SEDIMENT BUDGET SUMMARY - MANITOUNUK SOUND

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10 FIGURES AND MAPS

Fig. 1 - Study area

Fig. 2 - Glacial limits at 8 ka and 7 ka (from Dyke and Prest, 1987)

Fig. 3 - Regional minimum emergence curves for 6 areas of southeast Canadian Shield (from Dyke et al, 1989)

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Fig. 5 - Upper section of CSS Hudson core 92-028H-081, note the presence of surface (0.02-0.03m) brown, well oxidized layer

Fig. 6 - Generalized cross-sections and figure locations

Fig. 7 - Generalized Manitounuk Sound cross-section, note the subdivision of the sound into inner, central and outer sound and the variations in depositional style of the postglacial/recent sediments from basin to basin

Fig. 8 - Fluvial suspended sediment input

INNER SOUND MAPS AND FIGURES

Fig. 9 - Digitized terrain model generated using the AGC CARIS system with the assistance of Phil Moir, Atlantic Geoscience Centre. Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate diagram(Contour intervals: 40 m)

Fig. 10 - Generalized cross-section for the inner sound based on interpreted reflected seismic data. Note the relatively undisturbed, continuous depositional style of the pro/postglacial sediments. These locally exceed 70m. Extensive gas masking occurs at the head of the sound. See Figure 6 for location.

Fig. 11 - Huntec Sea-Otter boomer profile along inner Manitounuk Sound displaying thick undisturbed section of pro/postglacial sediments. Note localized gas masking associated with the decomposition of organic material within the sediments. See Figure 6 for location.

Fig. 12 - Limit of marine surveys used for mapping surficial marine geology of the inner sound

Fig. 13 - Inner sound bathymetry (Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate map)

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Fig. 18 - Shallow subtidal and tidal flat area of the inner sound

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Fig. 20 - Inner sound sediment failure / slump deposits (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

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Fig. 22 - Inner sound observed suspended sediment concentrations: June 22/93 -> July 7/93

CENTRAL SOUND MAPS AND FIGURES

Fig. 23 - Digitized terrain model generated using the AGC CARIS system with the assistance of Phil Moir, Atlantic Geoscience Centre. Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate diagram(Contour intervals: 40 m)

Fig. 24 - Generalized central sound longitudinal cross-section based on interpreted reflected seismic data indicating ponded depositional style of the postglacial/recent sediments. See Figure 6 for location.

Fig. 25 - Generalized transverse cross-section of the central sound based on a composite of interpreted reflected seismic data (including Figure 27). See Figure 6 for location.

Fig. 26 - Huntec Sea-Otter boomer profile displaying longitudinal section of central Manitounuk Sound. Note the ponded depositional style of the postglacial/recent sediments. See Figure 6 for location.

Fig. 27 - Composite Huntec Sea-Otter boomer profile and 100kHz sidescan sonogram across central Manitounuk Sound from the mouth of riviere Kuugapik through Schoone Opening to Hudson Bay. On the boomer profile note the thick 40m accumulation of pro/postglacial sediments off the mouth of riviere Kuugapik and the assymetric deposition of postglacial sediments within the deeper parts of Manitounuk Sound. On the accompanying sidescan sonogram note morphological features and disturbed sediments associated with icekeel scouring and the sandwave field at the mouth of Schooner Opening at 35m water depth. Icekeel scouring occurs to water depths >22m. See Figure 6 for location.

Fig. 28 - Detailed map area indicating limit of marine surveys used for mapping surficial marine geology of the central sound

Fig. 29 - Central sound bathymetry (Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate map)

Fig. 30 - Central sound seismic reflection and sidescan sonar data (also includes CSSA, 1991a data)

Fig. 31 - Central sound Atlantic Geoscience Centre bottom sample control

Fig. 32 - Central sound surficial geology (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 33 - Central sound postglacial sediment isopach (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993)

Fig. 34 - Shallow subtidal and tidal flat area of central sound

Fig. 35 - Central sound icekeel scour occurrence (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 36 - Central sound sediment failure / slump deposits (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 37 - Oxidized surface layer thickness as observed from core and grab samples, mapped extent of postglacial sediments and current features of the central sound

Fig. 38 - Central sound observed suspended sediment concentrations: June 22/93 -> July 7/93

OUTER SOUND MAPS AND FIGURES

Fig. 39 - Digitized terrain model with the assistance of Phil

Moir, Atlantic Geoscience Centre. Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate diagram (Contour intervals: 40 m).

Fig. 40 - Generalized outer sound cross-section based on interpreted reflection seismic data. This section displays the variable depositional styles of the recent sediments characteristic of the outer sound. Also note gas occurence within the deeper portion of the basin. See Figure 6 for location.

Fig. 41 - Huntec Sea Otter boomer profile illustrating the assymetric depositional style of the pro/postglacial sediments. Note possible failure scarp in the southwest and associated disturbed sediments. Sediment failure occurred at the base of the cuesta ridge southeast of Merry Island. See Figure 6 for location.

Fig. 42 - Huntec Sea Otter boomer profile showing the bedrock sill that seperates the central and outer sound at the Paint Islands. Note non-deposition/erosion of recent materials over the bedrock outcrop and assymetric deposition of the postglacial/recent sediments on the southwest side of the sill. See Figure 6 for location.

Fig. 43 - Detailed map area indicating limit of marine surveys used for mapping surficial marine geology in the outer sound

Fig. 44 - Outer sound bathymetry (Canadian Hydrographic Service and Hydro-Quebec bathymetric data were used to generate map)

Fig. 45 - Outer sound seismic reflection and sidescan sonar data (also includes CSSA, 1991a data)

Fig. 46 - Outer sound Atlantic Geoscience Centre bottom sample control

Fig. 47 - Outer sound surficial geology (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 48 - Outer sound postglacial sediment isopach (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 49 - Shallow subtidal and tidal flat area of outer sound

Fig. 50 - Outer sound icekeel scour occurrence (based on CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 51 - Outer sound sediment failure / slump deposits (based on

CSSA (1991) maps updated with 1992 Atlantic Geoscience Centre data (Amos et al, 1992, Zevenhuizen, 1993))

Fig. 52 - Oxidized surface layer thickness as observed from core and grab samples, mapped extent of postglacial sediments and current features of the outer sound

Fig. 53 - Outer sound observed suspended sediment concentrations: June 22/93 -> July 7/93

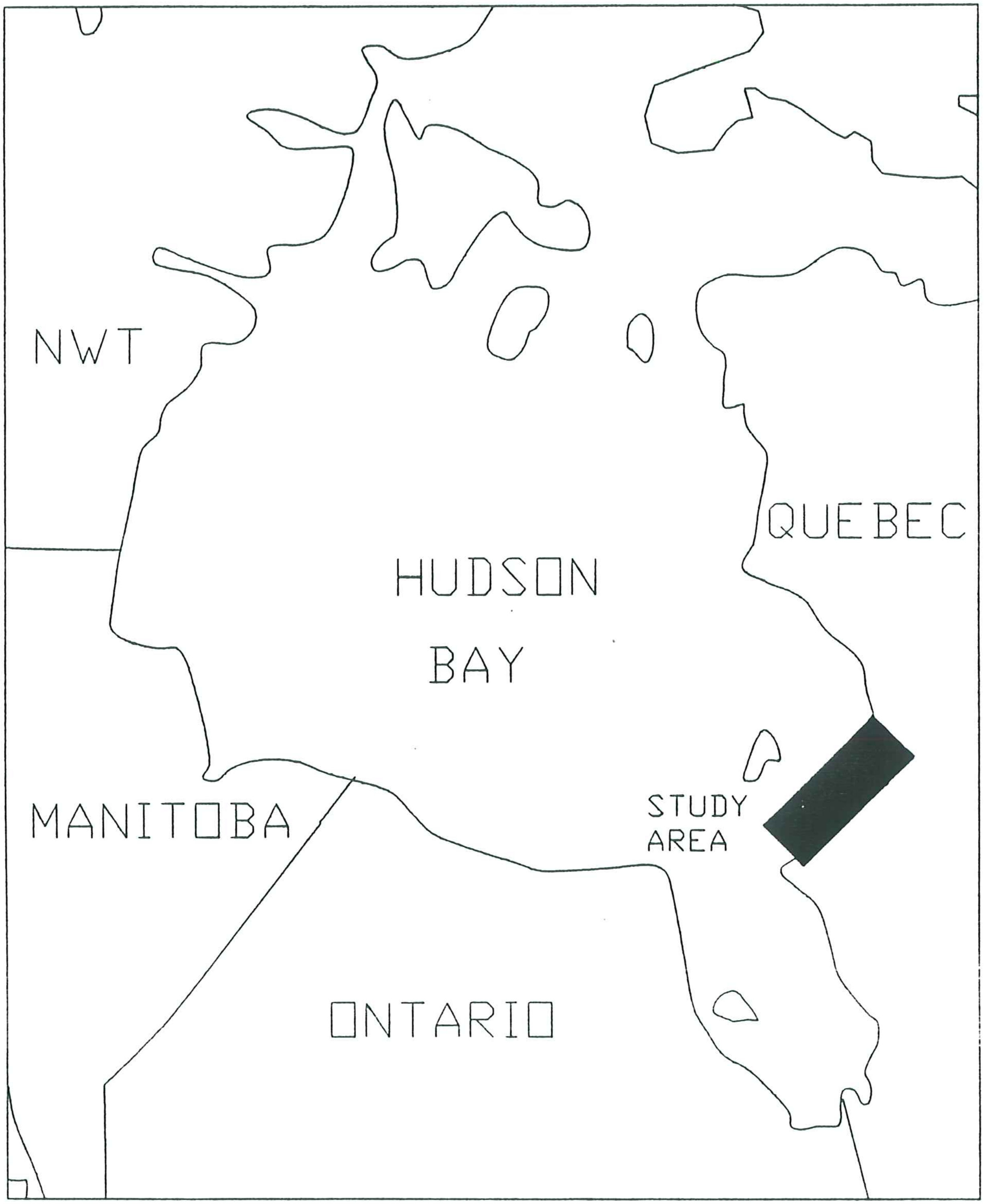

FIGURE 1

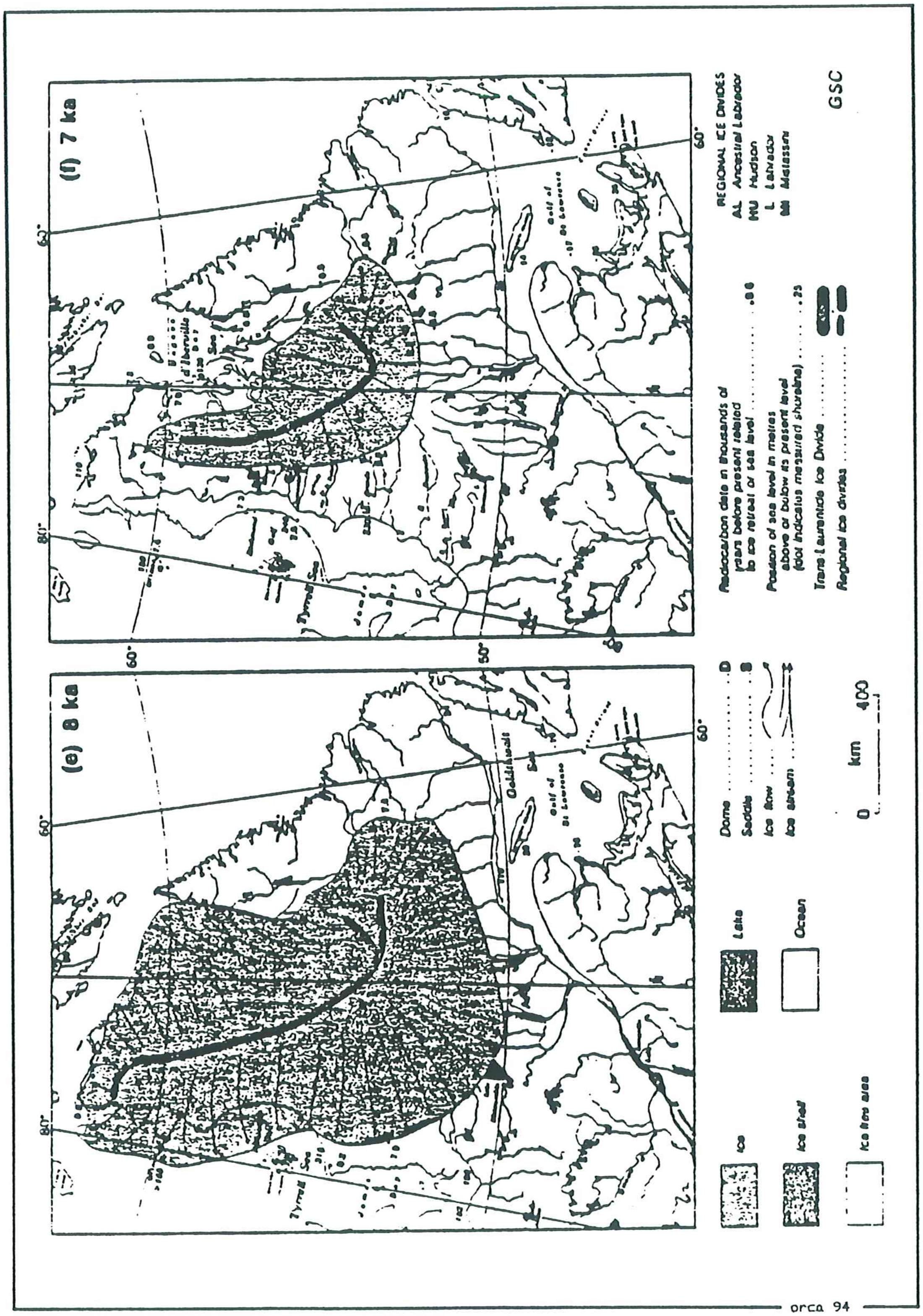

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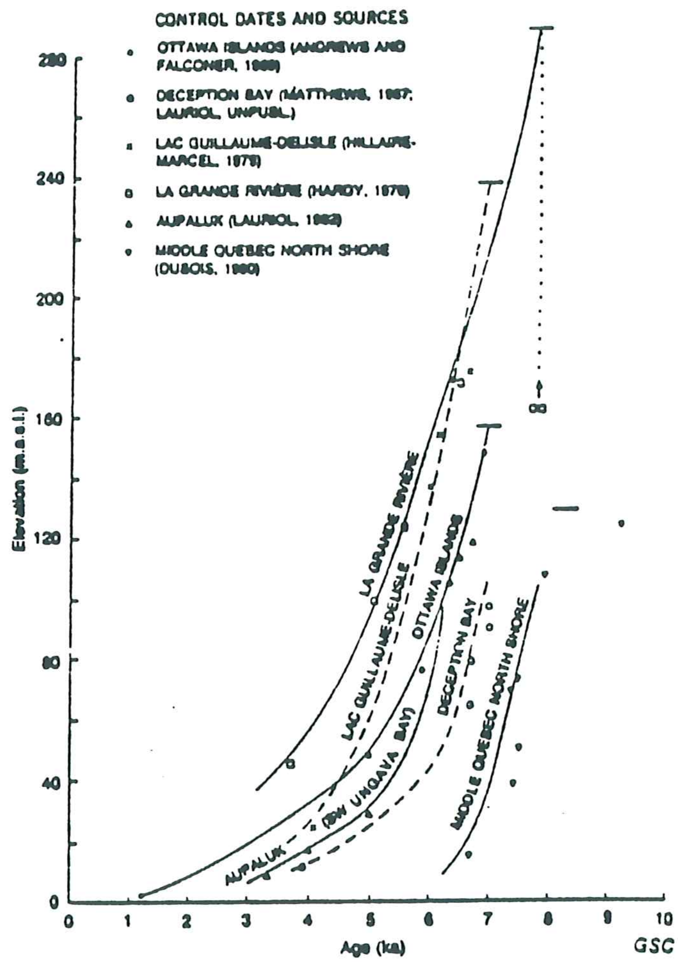
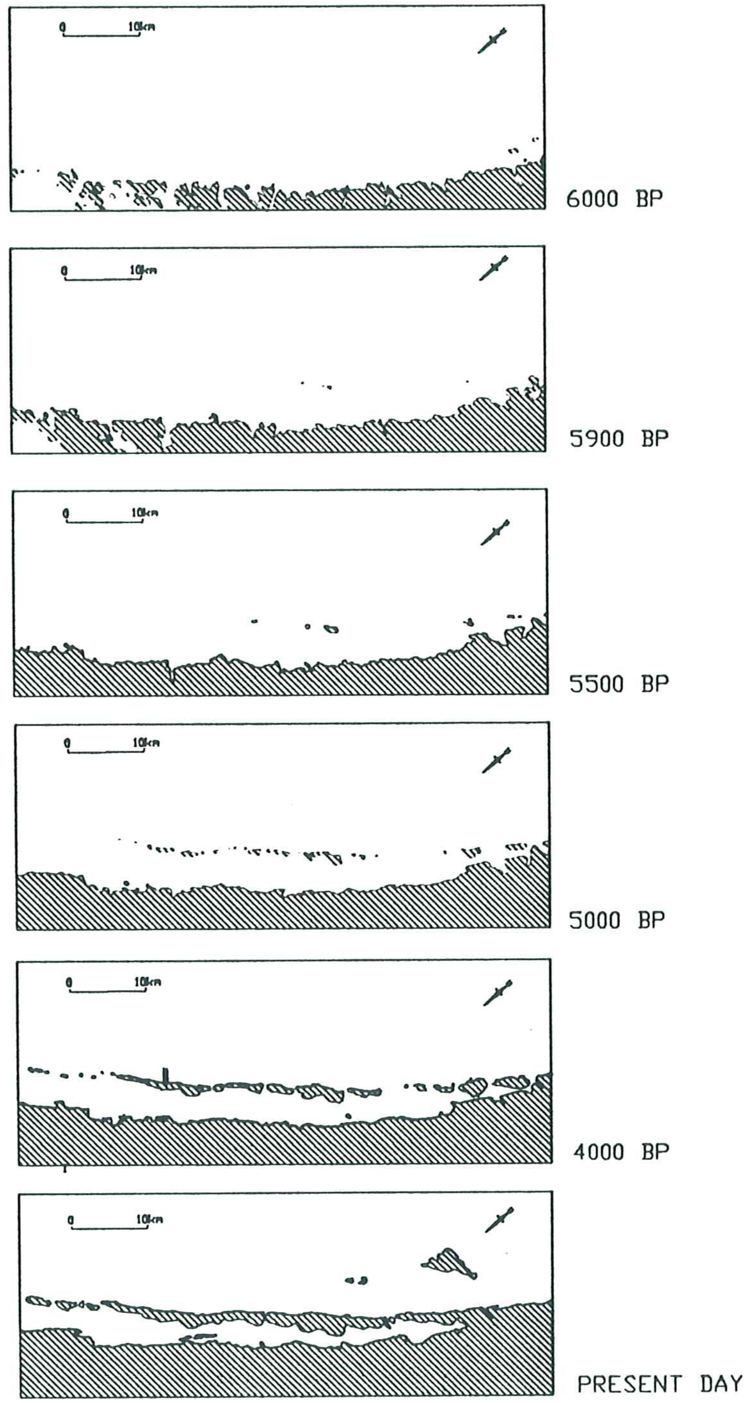
FIGURE 2



Minimum emergence curves for six areas of the southeastern Canadian Shield.

FIGURE 3



COASTLINE CHANGES OVER TIME BASED ON MINIMUM EMERGENCE CURVE FOR RICHMOND GULF (AFTER HILLIARE-MARCEL,1979)

FIGURE 4

Core 92-028H-081
Interval 0-100 cm

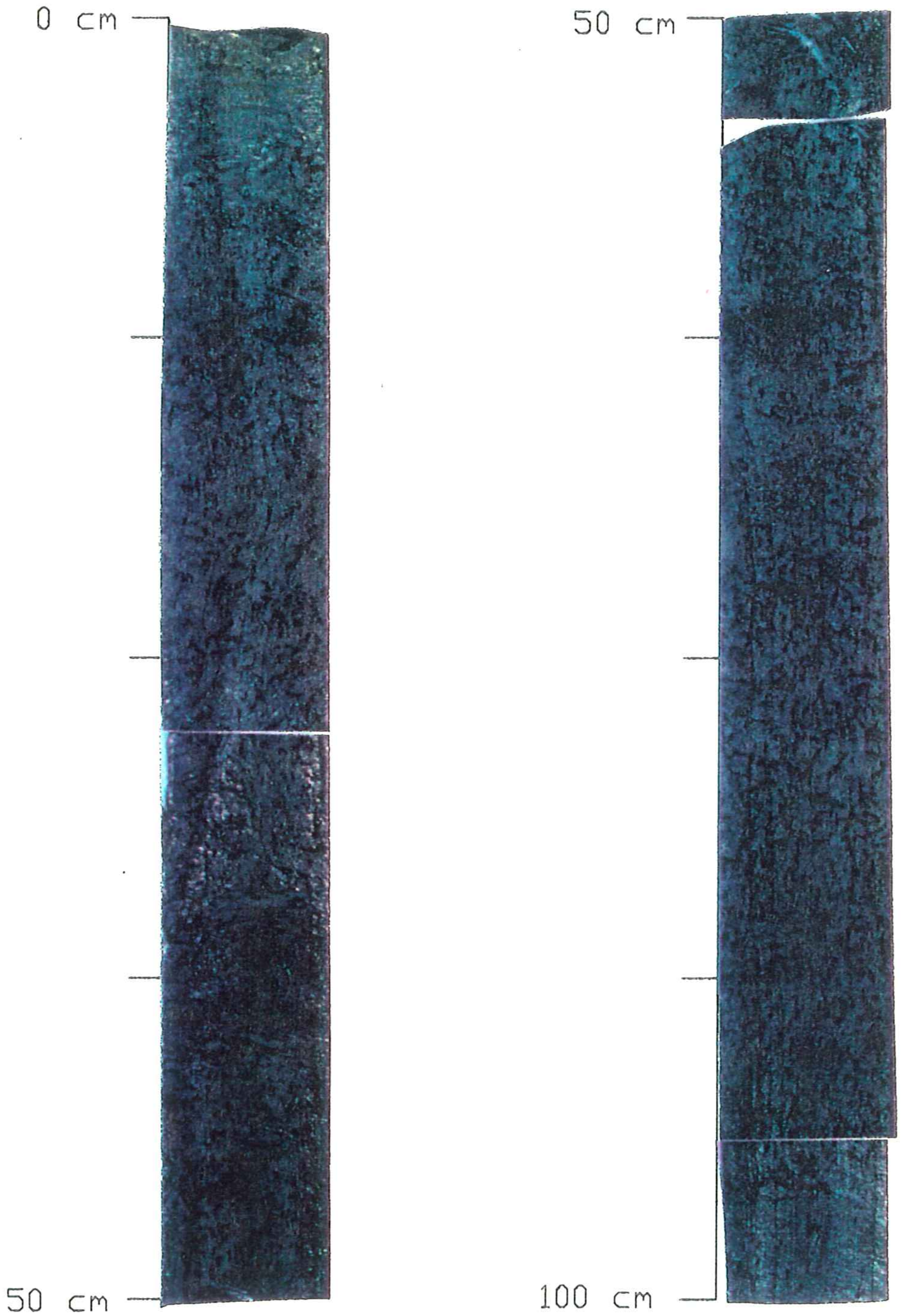


FIGURE 5

FIGURE LOCATIONS

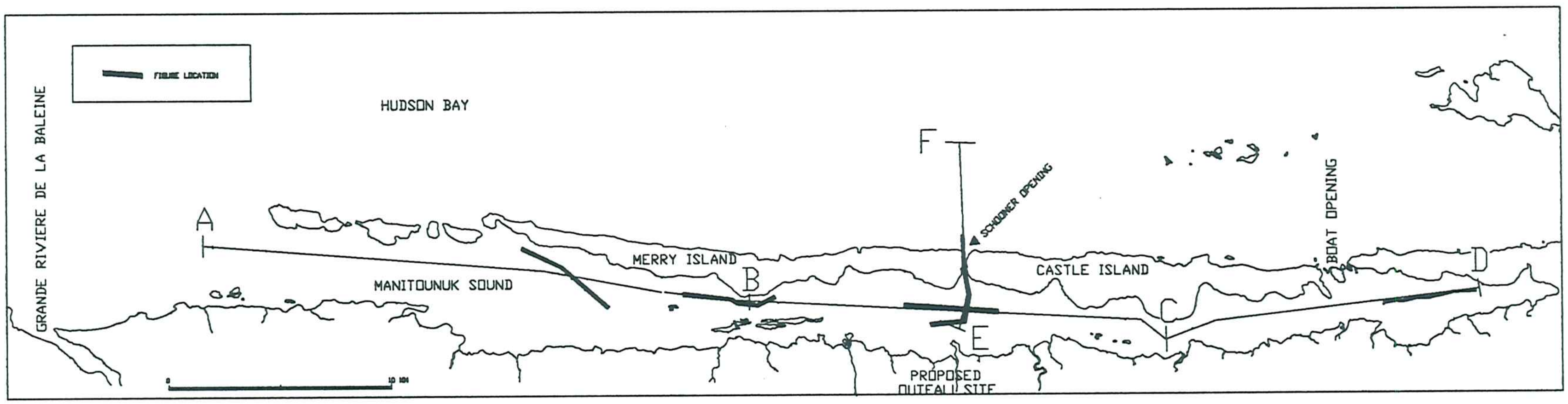


FIGURE 6

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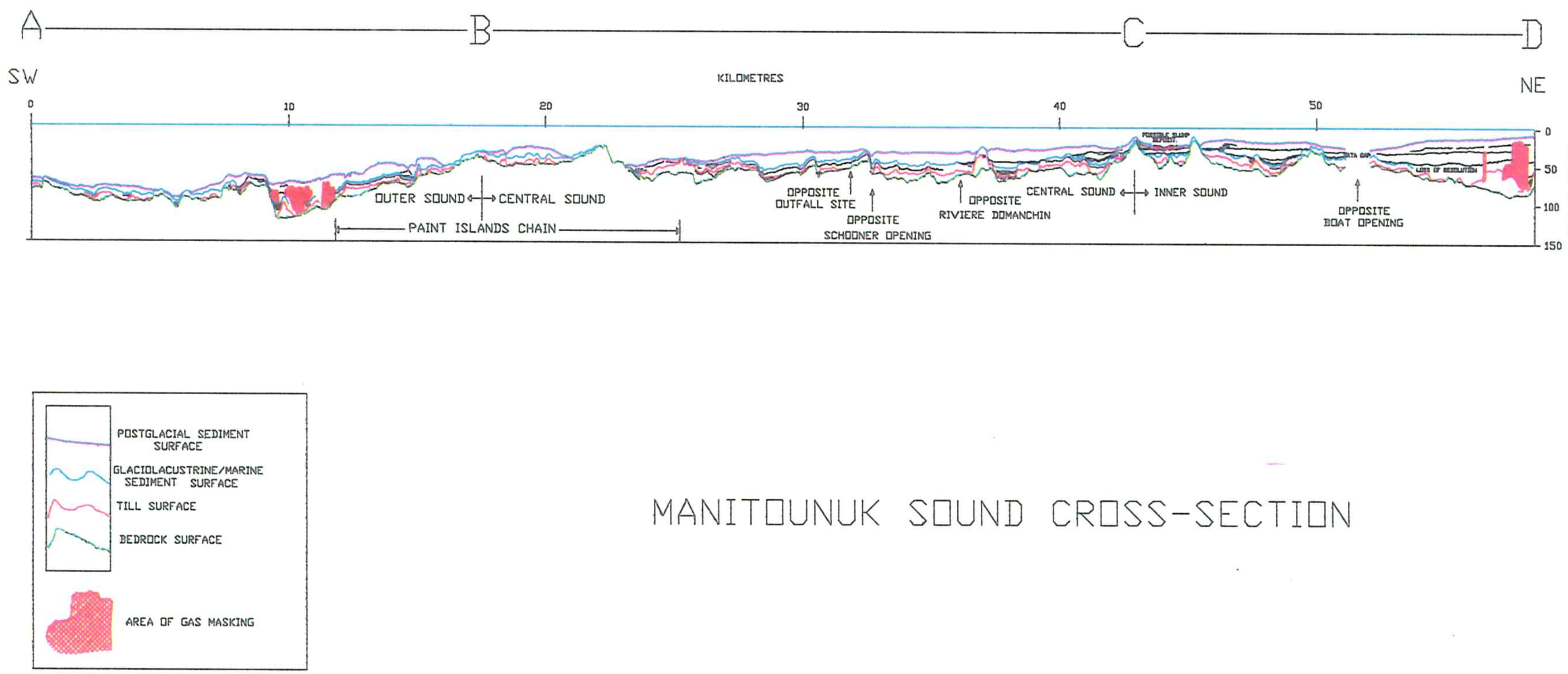

MANITOUNUK SOUND CROSS-SECTION

FIGURE 7

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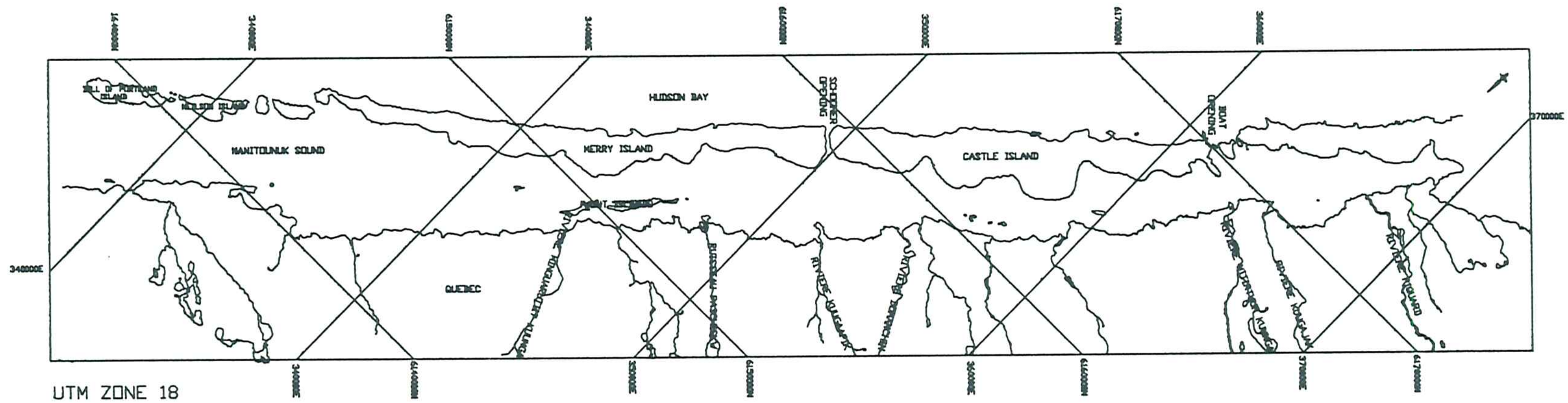

FLUVIAL SUSPENDED SEDIMENT INPUT
DRAINAGE BASIN AREA 1720 SQ KM
TOTAL ESTIMATED FLUVIAL INPUT 21 CU M
(RIVIERE DOMANCHIN 6 CU M)
GRANDE RIVIERE DE LA BALEINE INPUT HIGHLY VARIABLE (SEE TEXT)

FIGURE 8

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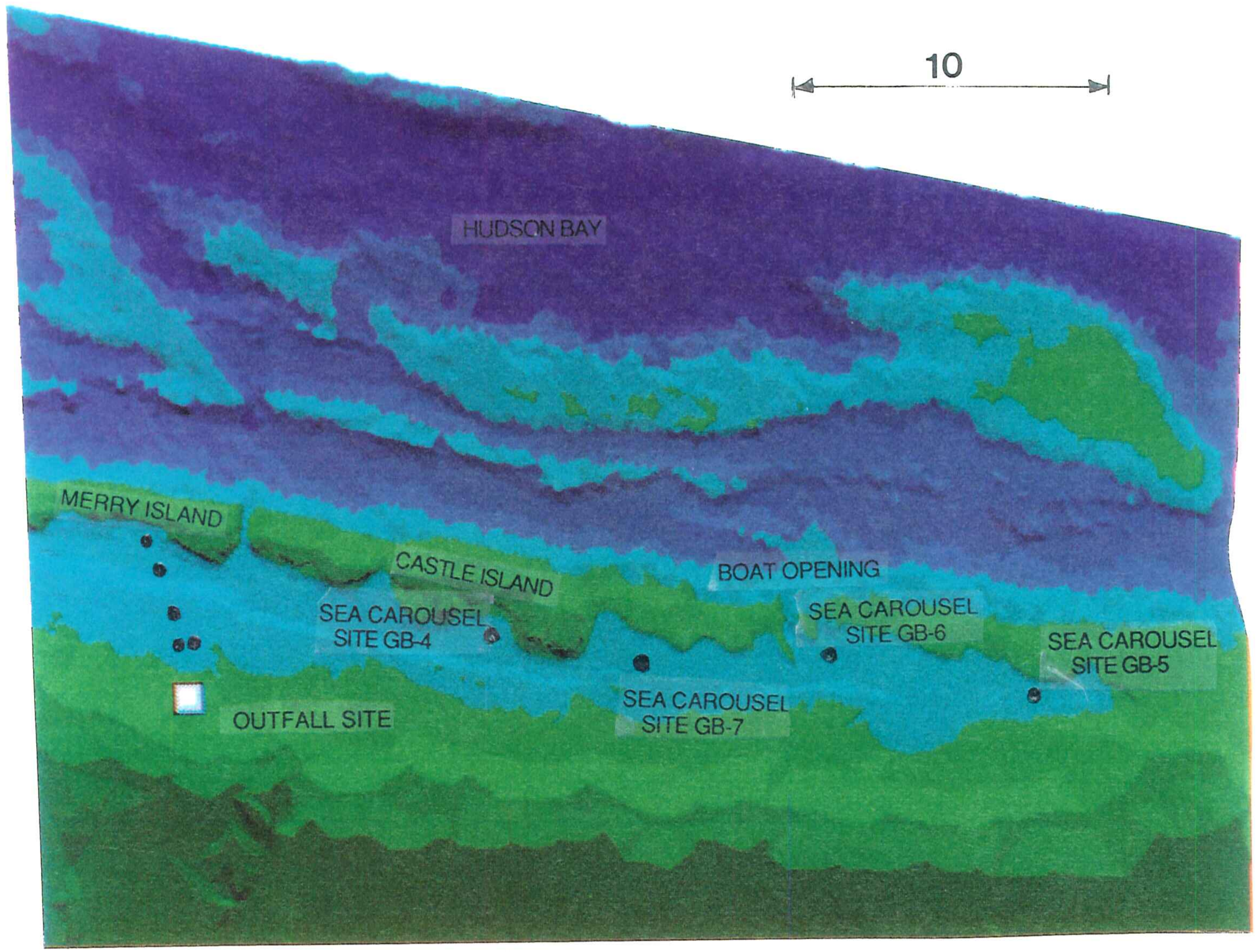

INNER SOUND

FIGURE 9

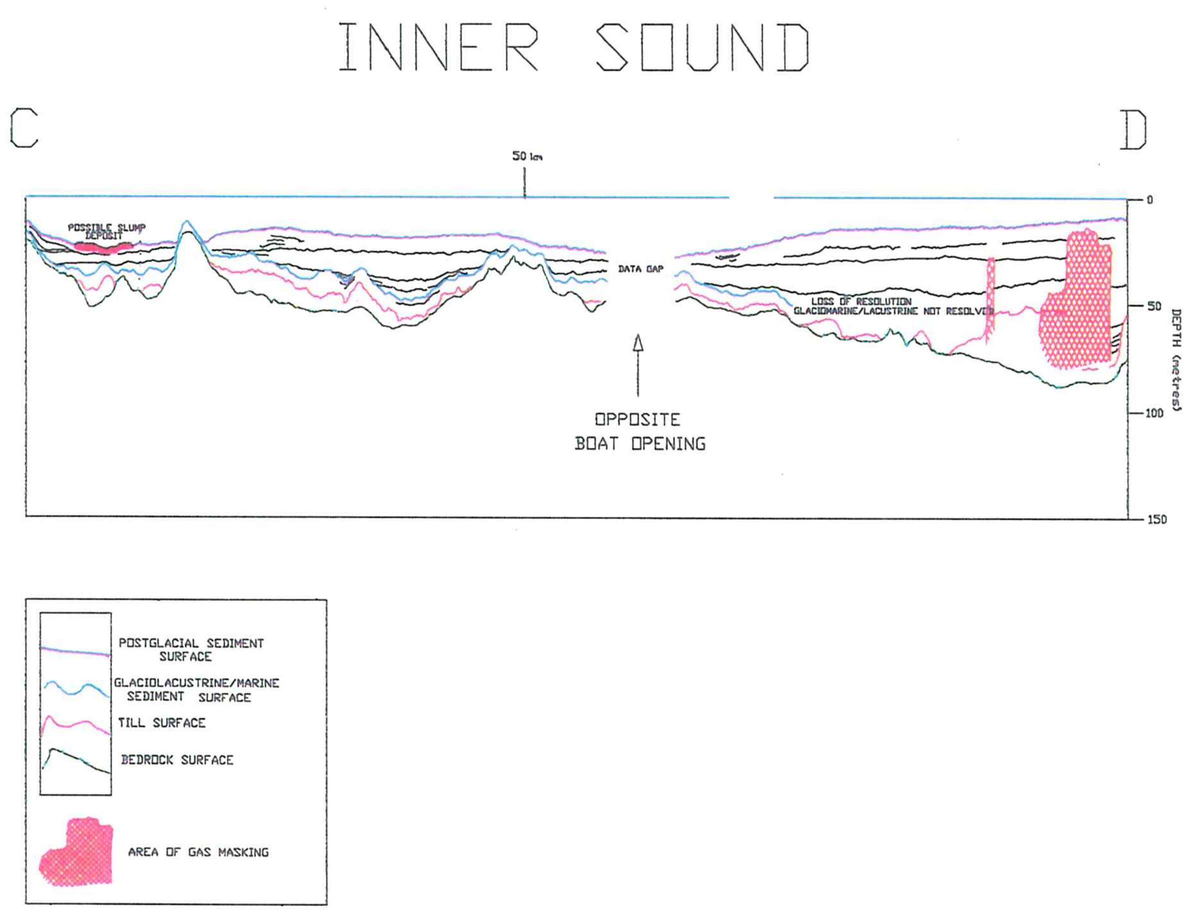
INNER SOUND
C
D
50 km
POSSIBLE SLUMP DEPOSIT
DATA GAP
LOSS OF RESOLUTION
GLACIOMARINE/LACUSTRINE NOT RESOLVED
OPPOSITE
BOAT OPENING
0
50
100
150
DEPTH (metres)
POSTGLACIAL SEDIMENT SURFACE
GLACIOLACUSTRINE/MARINE SEDIMENT SURFACE
TILL SURFACE
BEDROCK SURFACE
AREA OF GAS MASKING

FIGURE 10

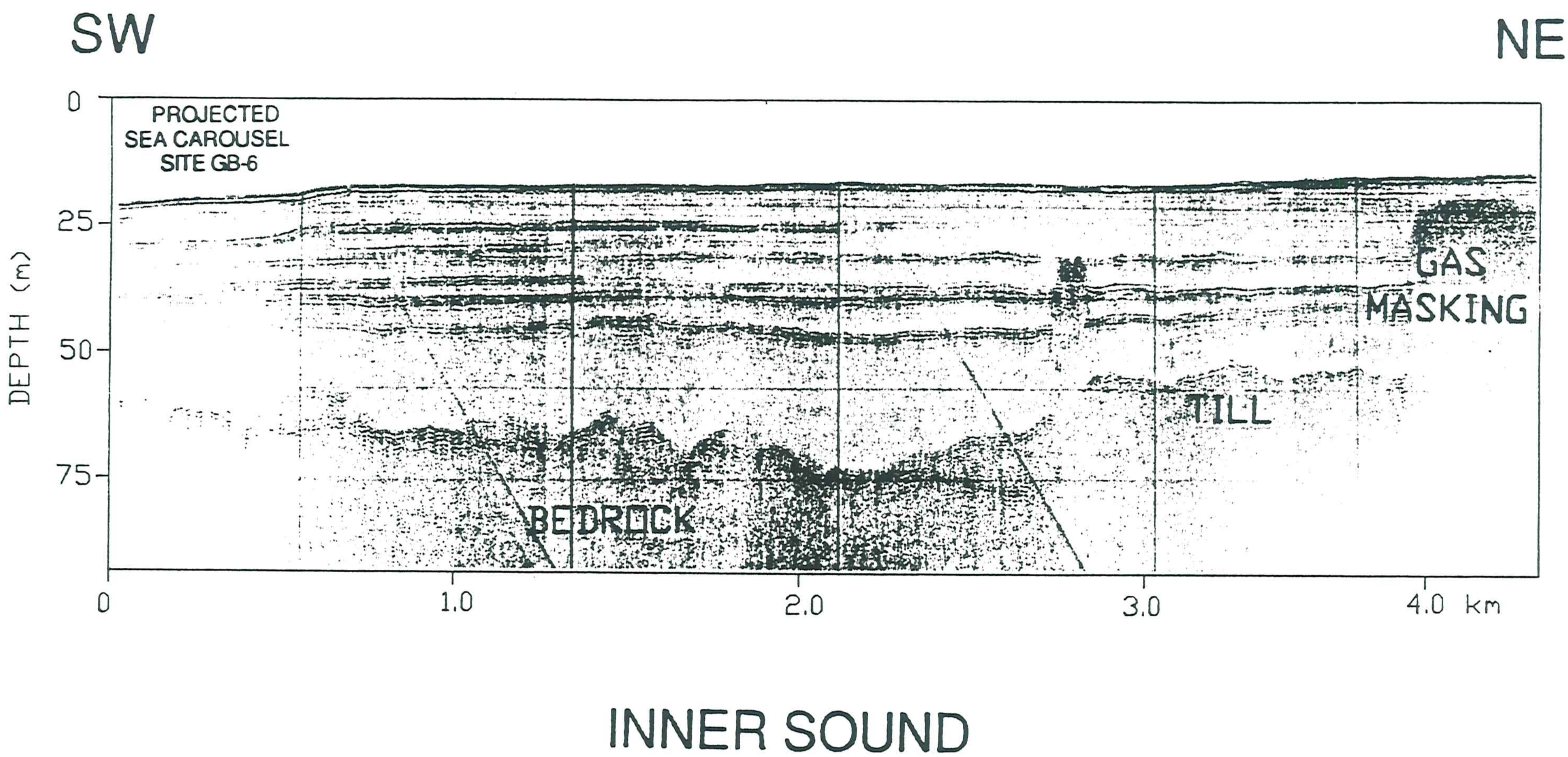

FIGURE 11

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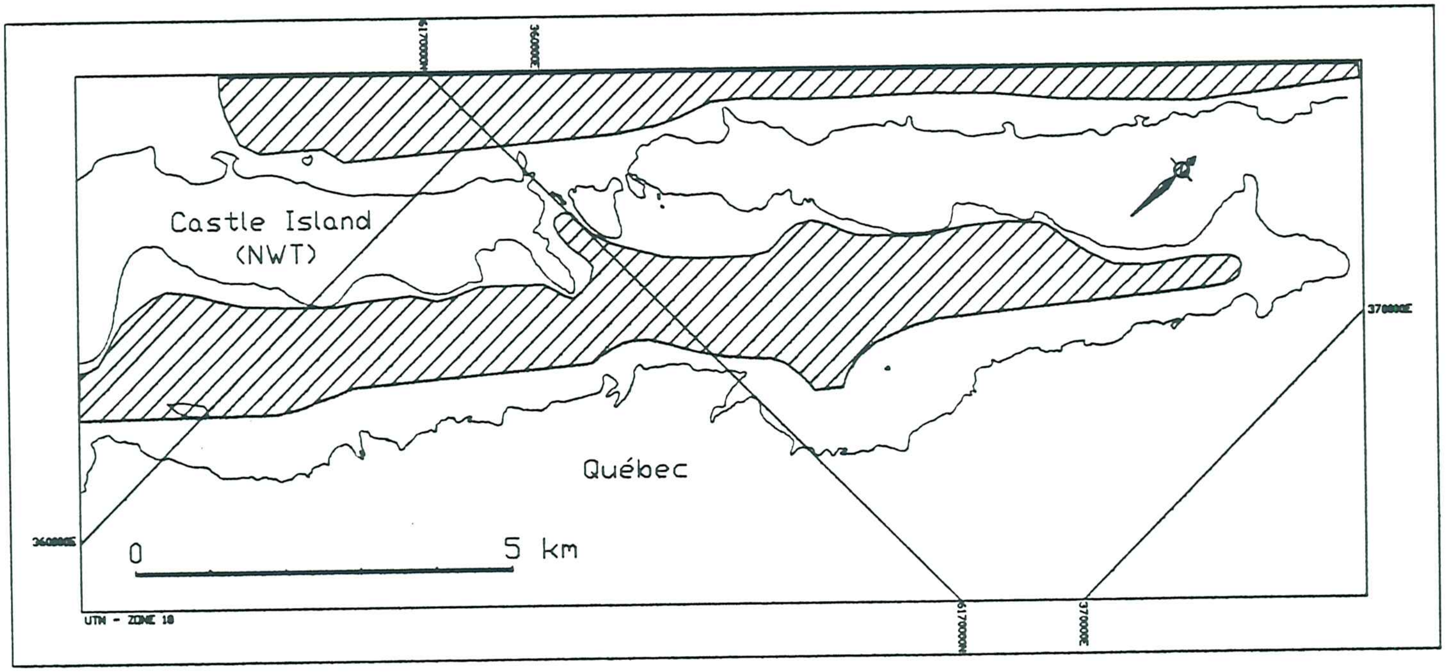

DETAILED MAP AREA

FIGURE 12

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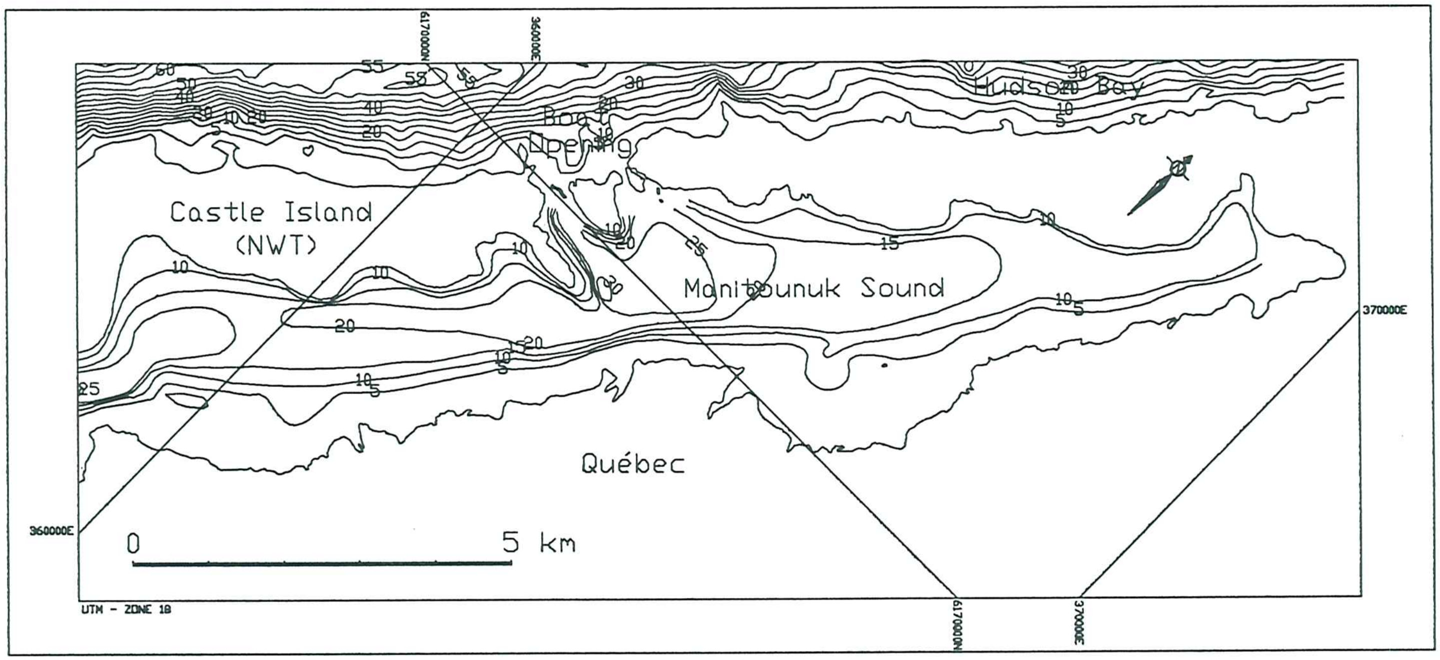
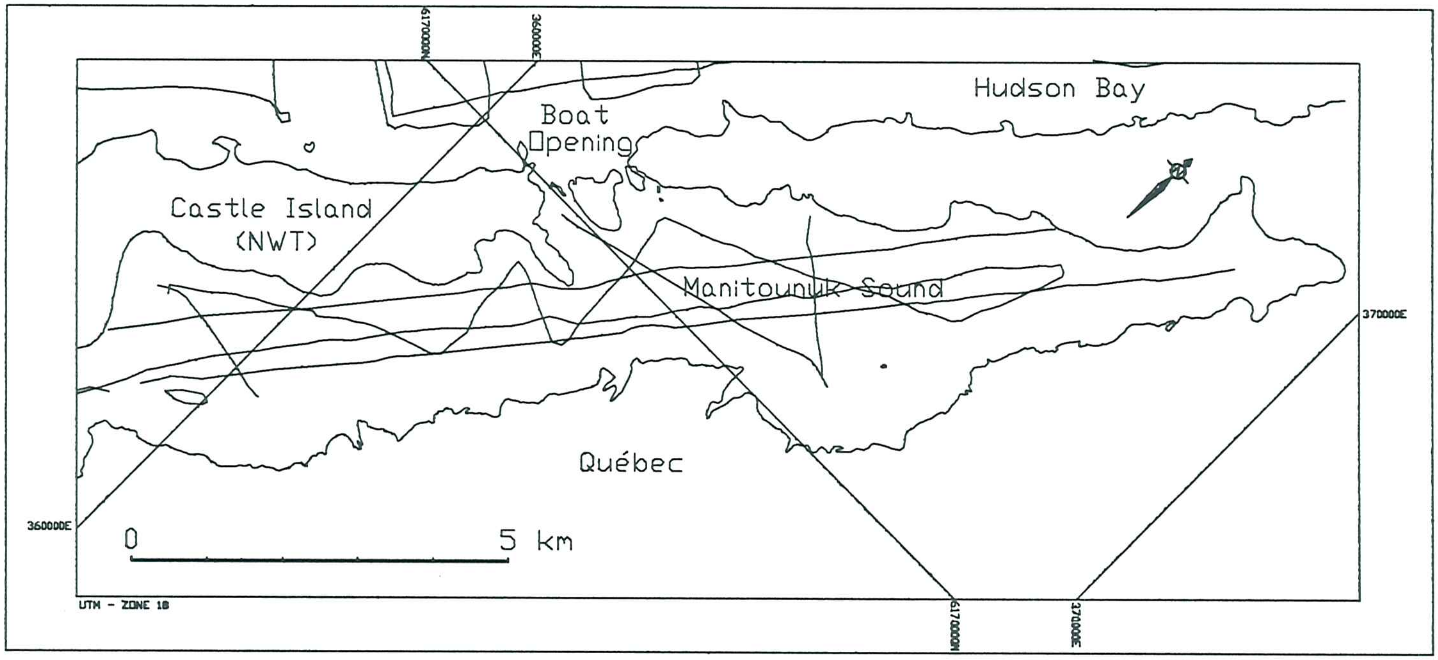


BATHYMETRY
(contours in metres)

FIGURE 13



SEISMIC REFLECTION AND SIDESCAN SONAR DATA

FIGURE 14

orca 94

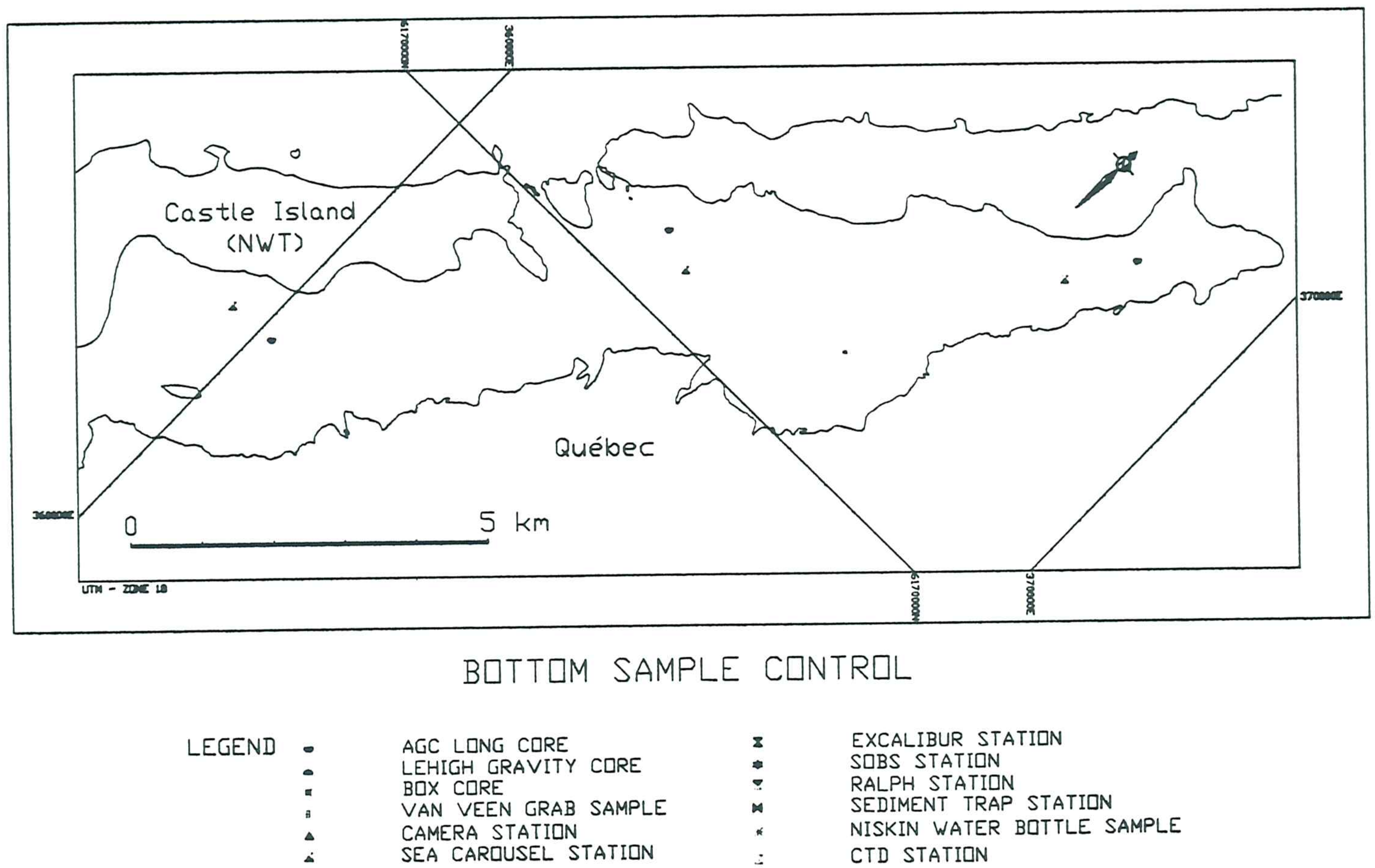


FIGURE 15

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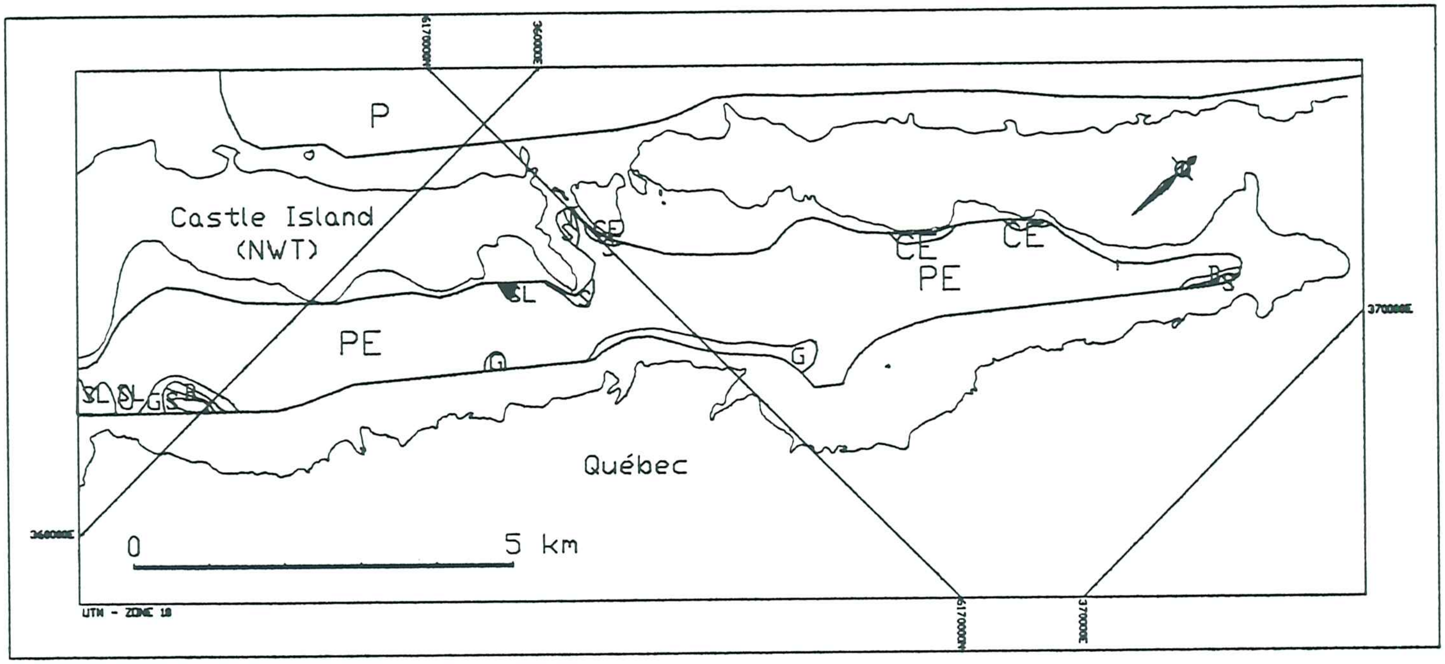
SURFICIAL GEOLOGY
SEISMOSTRATIGRAPHIC UNITS



LEGEND

P	POSTGLACIAL MUDS	UD	THIN VENEER OF UNDIFFERENTIATED SEDIMENTS OVER BEDROCK
PE	POSTGLACIAL - ESTUARINE MUDS	SL	SEDIMENT FAILURE / SLUMP DEPOSIT
G	GLACIOLACUSTRINE / MARINE SEDIMENTS	B	BEDROCK
T	TILL / ICE CONTACT DEPOSITS	S	SAND
T/B	DISCONTINUOUS TILL OVER BEDROCK	CE	COMPLEX ESCARPMENTS

INTERPRETATION BASED ON HIGH RESOLUTION REFLECTION SEISMIC AND SIDESCAN SONAR DATA

FIGURE 16

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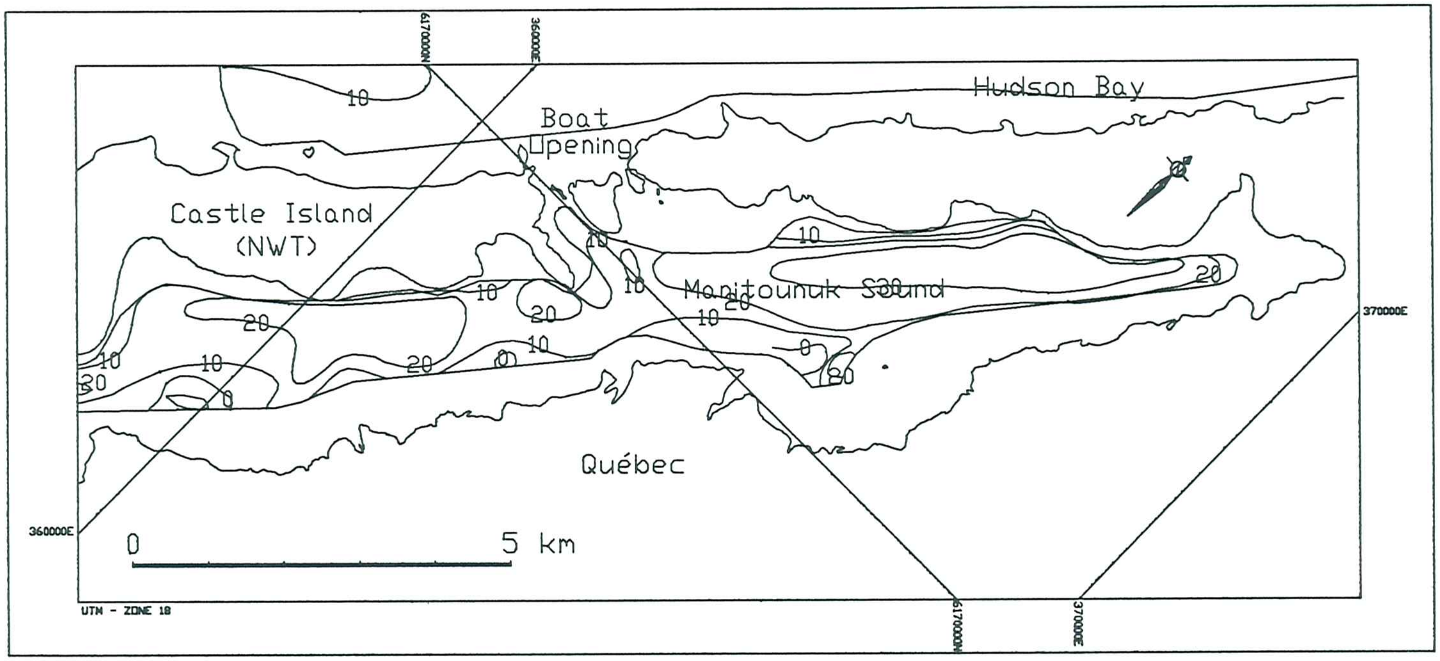

POSTGLACIAL SEDIMENT ISOPACH
(Contours in Metres)

TOTAL SURFACE AREA	33.8 SQ KM
MAPPED AREA	17.7 SQ KM
POSTGLACIAL SEDIMENT OUTCROP	14.7 SQ KM
POSTGLACIAL VOLUMES	0.4 CU KM

FIGURE 17

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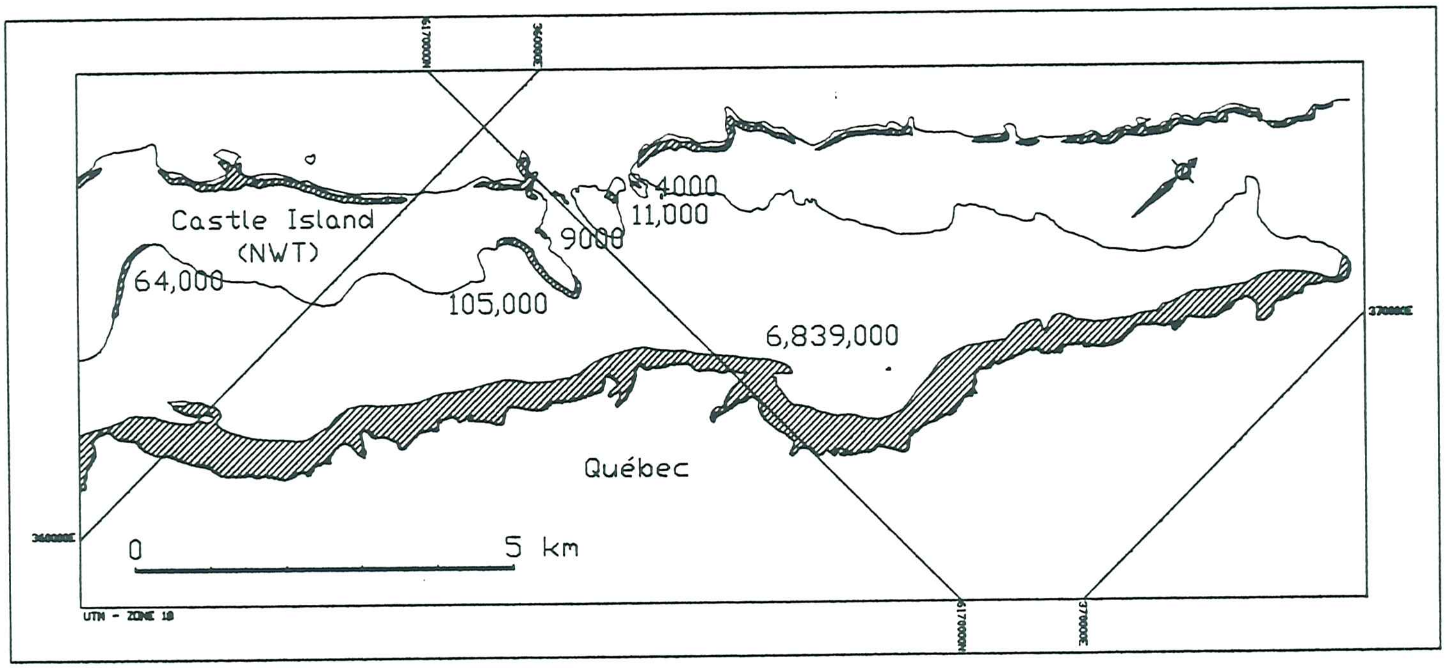
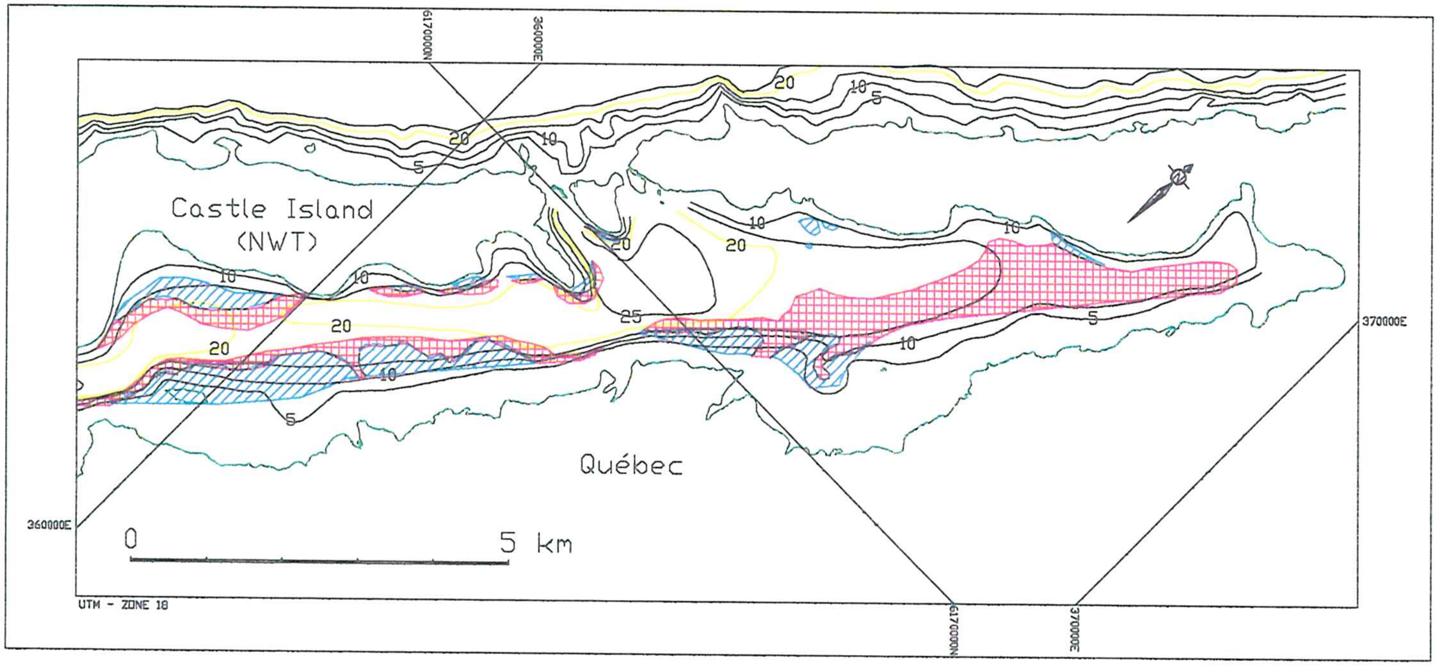


SHALLOW SUBTIDAL AND TIDAL FLAT AREA

TOTAL AREA 7.032 SQ KM
EASTERN SHORE AREA 6.839 SQ KM

FIGURE 18

orca 94



ICEKEEL SCOUR OCCURANCE

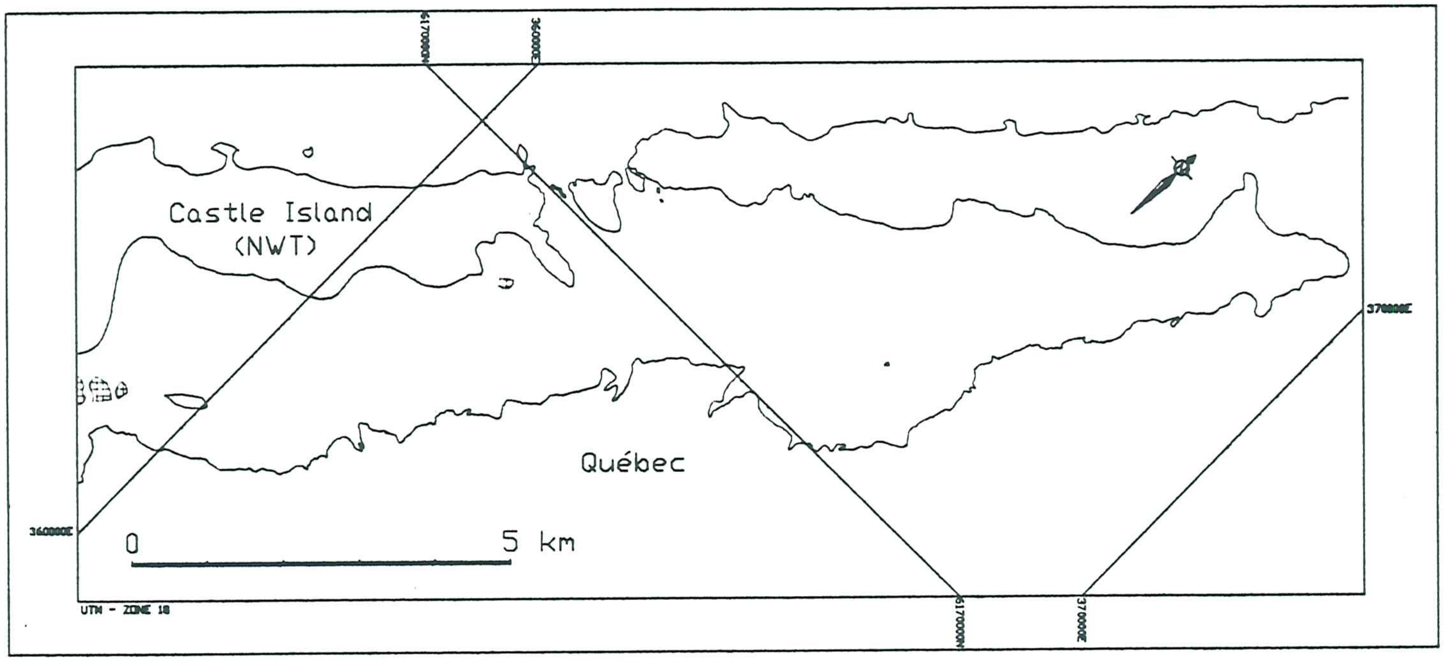
HEAVILY SCOURED
(eastern shore 4.84 sq km, western shore 0.77 sq km)

LIGHTLY SCOURED (DEGRADED)
(eastern shore 2.75 sq km, western shore 0.70 sq km)

BATHYMETRY IN METRES (5, 10, 15, 20 and 25m contours only)

FIGURE 19

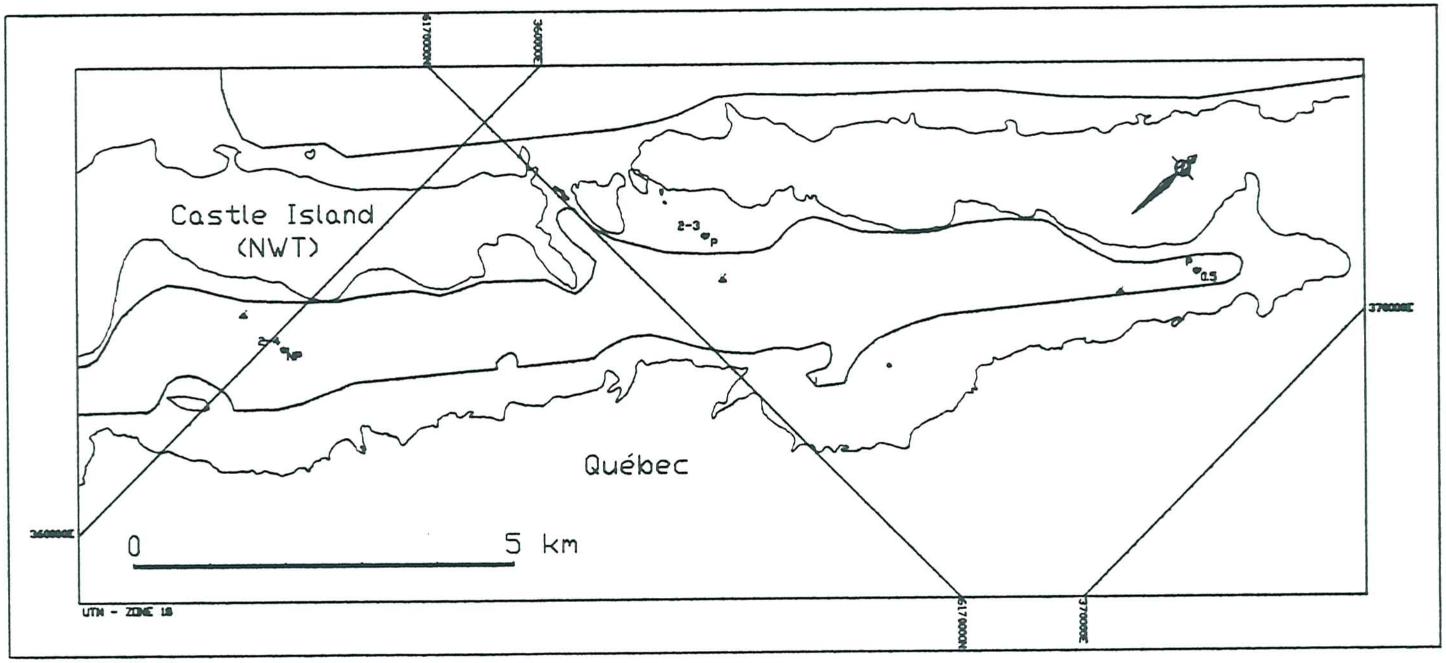
arca 94



SEDIMENT FAILURE / SLUMP DEPOSITS

Surface area of slump deposits observed in the inner sound are 0.24 sq km, this includes 0.22 sq km occuring at the border between the inner and central sound (also used in central sound calculations).

FIGURE 20



OXIDIZED SURFACE LAYER THICKNESS AS OBSERVED FROM GRAB AND CORE SAMPLES

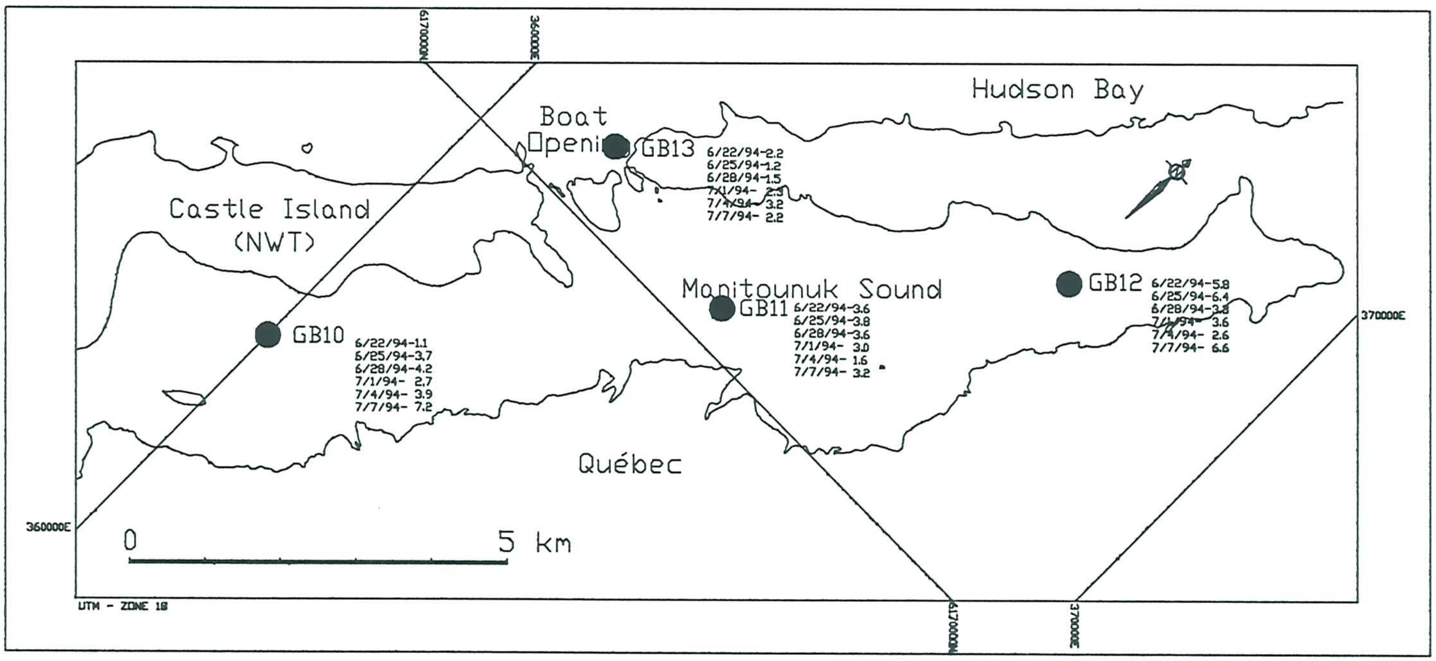
•4-5 - Thickness in centimetres

~ - Area indicates extent of postglacial sediments as mapped from reflection seismic data

(P = Present but no value recorded, V = Thin veneer and NP = Not present)

FIGURE 21

orca 94



SUSPENDED SEDIMENT DATA COLLECTED DURING ICE BREAKUP 1994

GB4 — SAMPLE STATION LOCATION
STATION NUMBER
DATE AND CONCENTRATION IN MG/L

6/14/94-3.4
6/22/94-3.0
6/25/94-1.5
6/28/94-2.7
7/1/94-5.9
7/4/94-2.8
7/7/94-3.8

FIGURE 22

orca 94

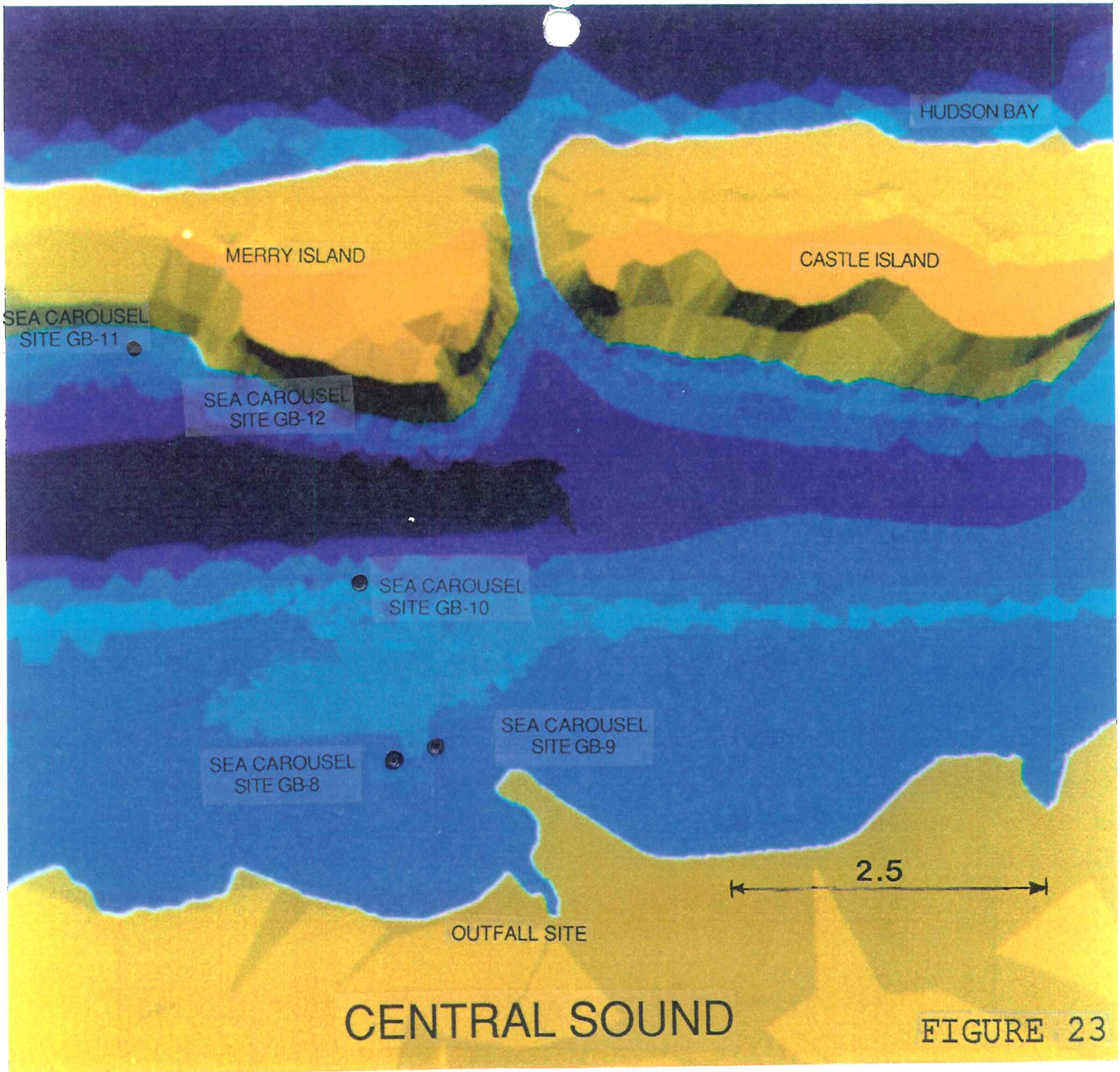

HUDSON BAY
MERRY ISLAND
CASTLE ISLAND
SEA CAROUSEL SITE GB-11
SEA CAROUSEL SITE GB-12
SEA CAROUSEL SITE GB-10
SEA CAROUSEL SITE GB-9
SEA CAROUSEL SITE GB-8
2.5
OUTFALL SITE
CENTRAL SOUND

FIGURE 23

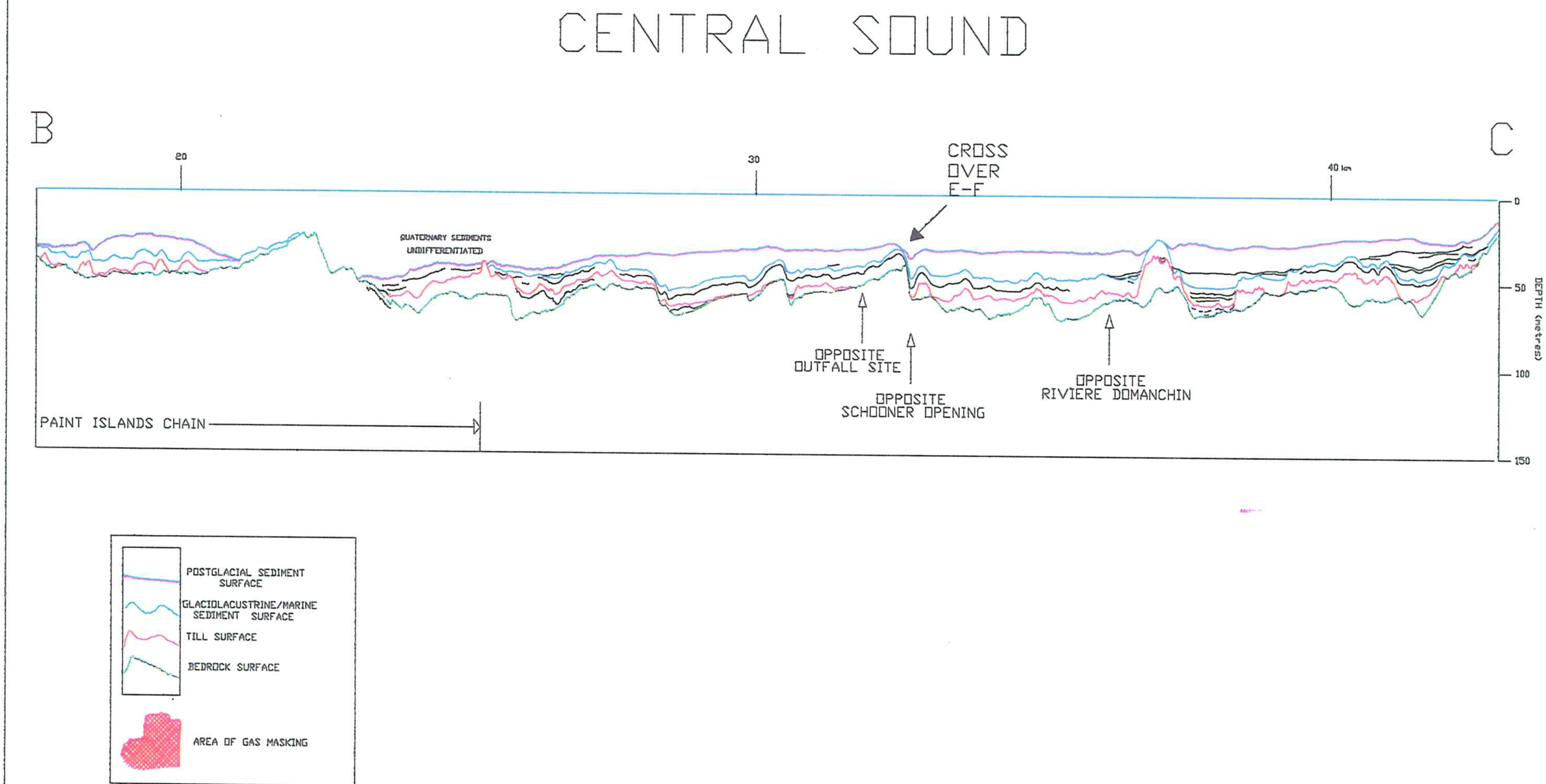
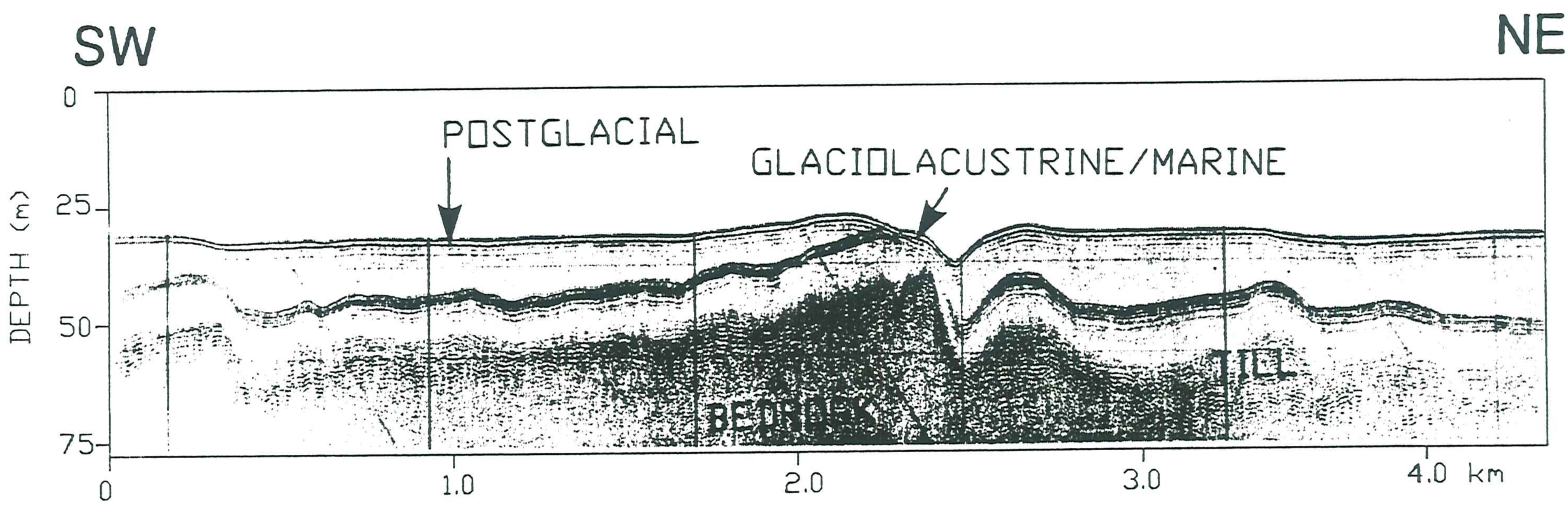


FIGURE 24

orca 94



CENTRAL SOUND

FIGURE 25

orca 94

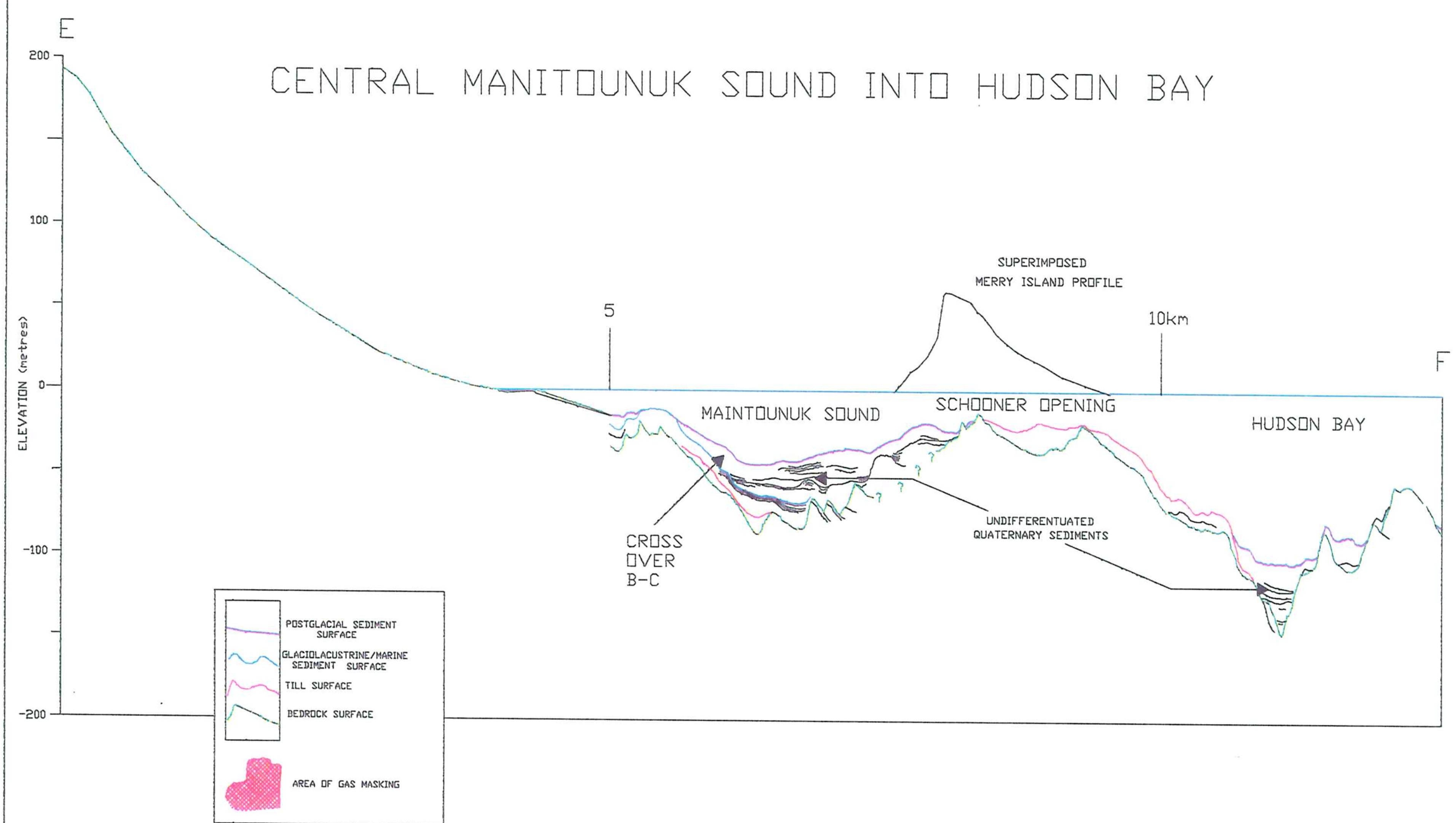
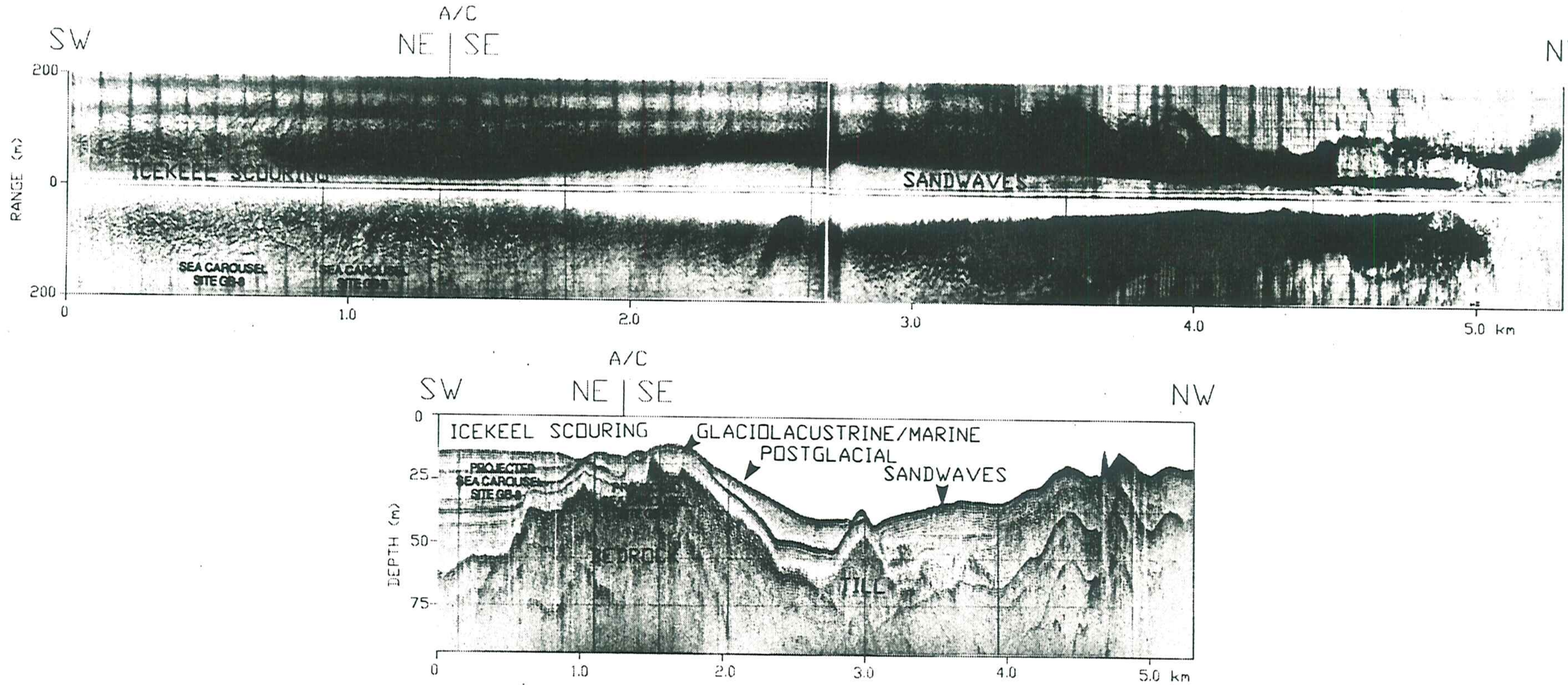


FIGURE 26

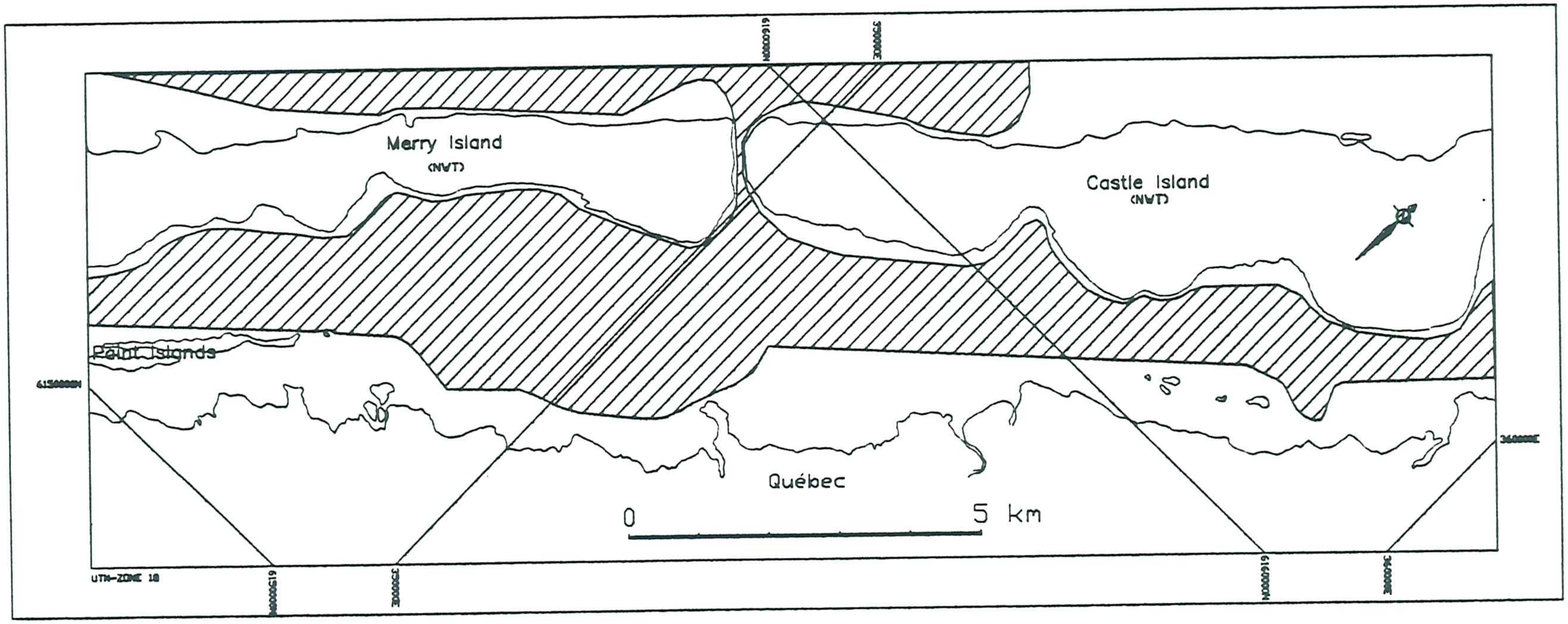
orca 94



CENTRAL SOUND

FIGURE 18

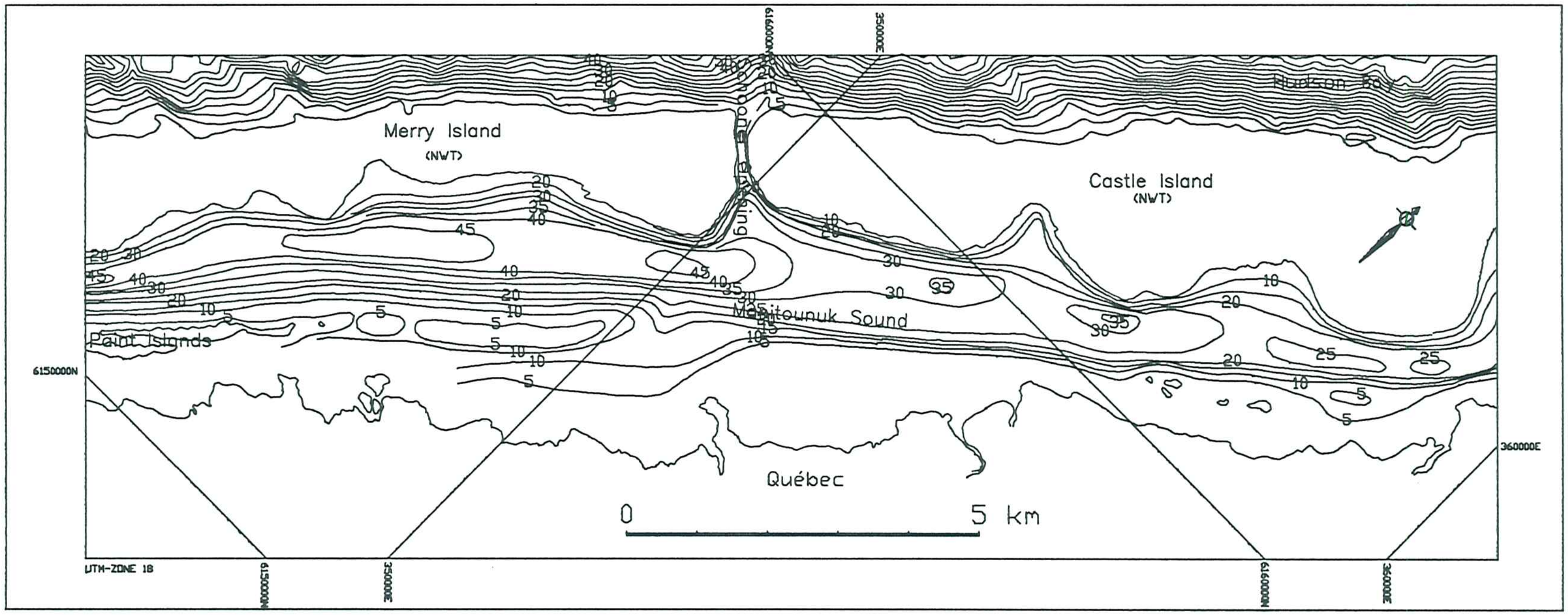
orca 93



DETAILED MAP AREA

FIGURE 28

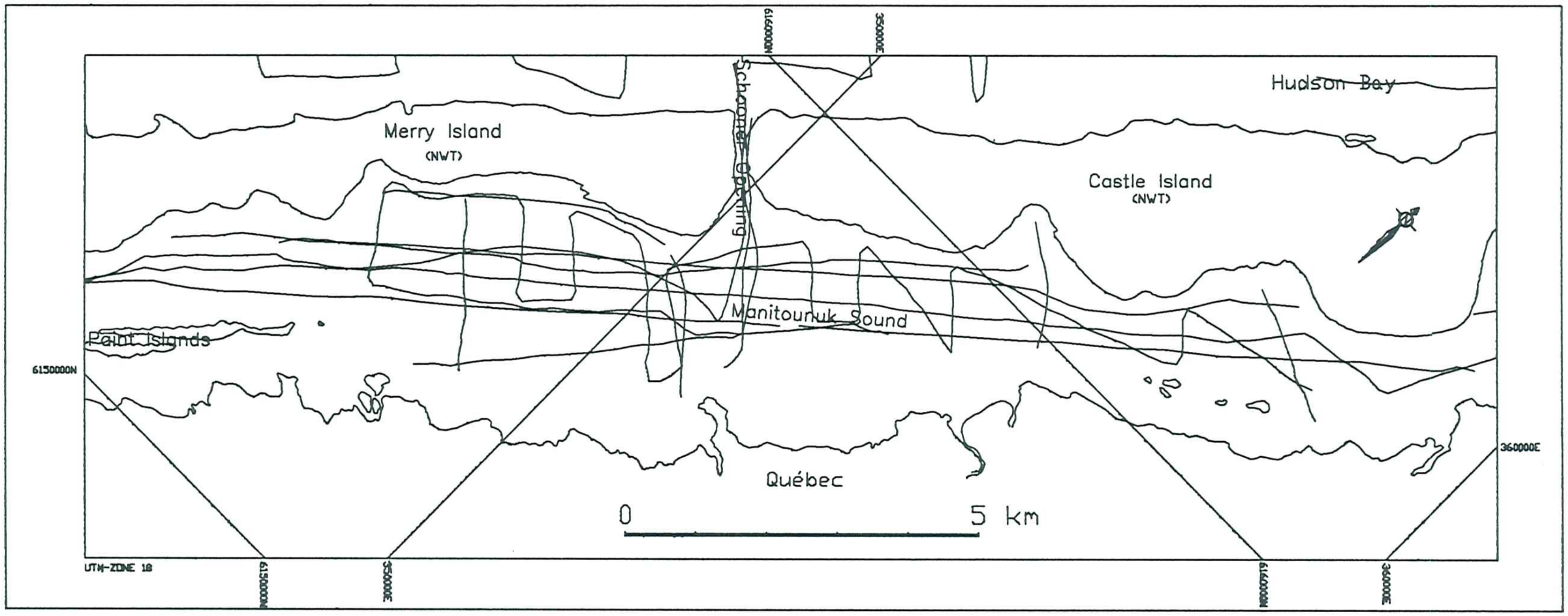
orca 94



BATHYMETRY
(contours in metres)

FIGURE 29

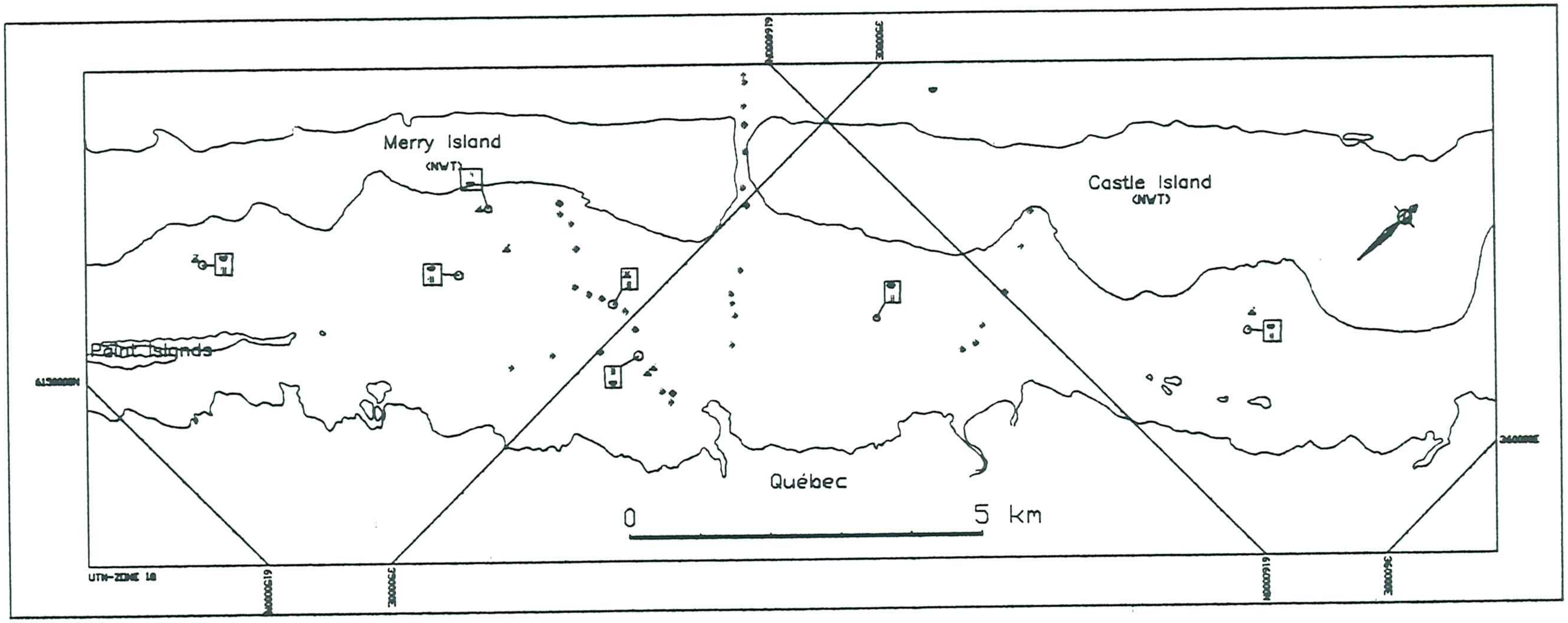
orca 94



SEISMIC REFLECTION AND
SIDESCAN SONAR DATA

FIGURE 30

orca 94



BOTTOM SAMPLE CONTROL

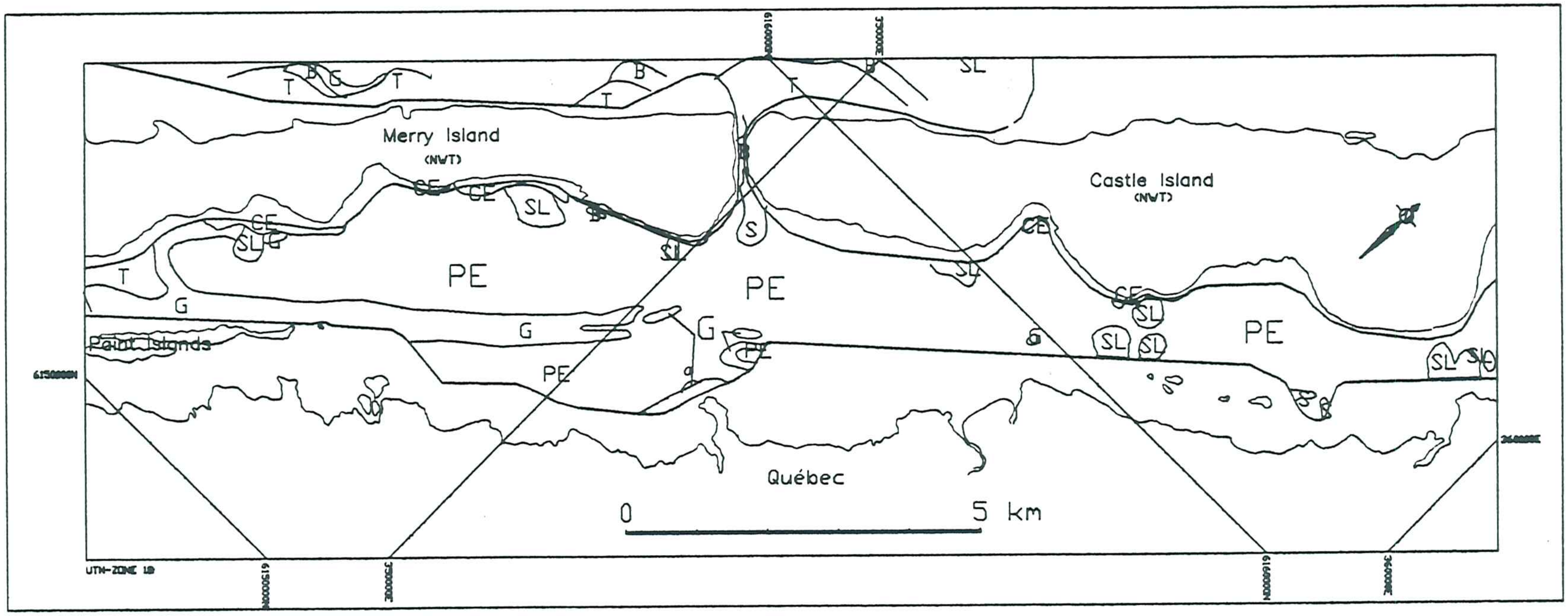
LEGEND

AGC LONG CORE
LEHIGH GRAVITY CORE
BOX CORE
VAN VEEN GRAB SAMPLE
CAMERA STATION
SEA CAROUSEL STATION
EXCALIBUR STATION
SOBS STATION
RALPH STATION
SEDIMENT TRAP STATION
NISKIN WATER BOTTLE SAMPLE
CTD STATION

FIGURE 31

orca 94

SURFICIAL GEOLOGY
SEISMOSTRATIGRAPHIC UNITS



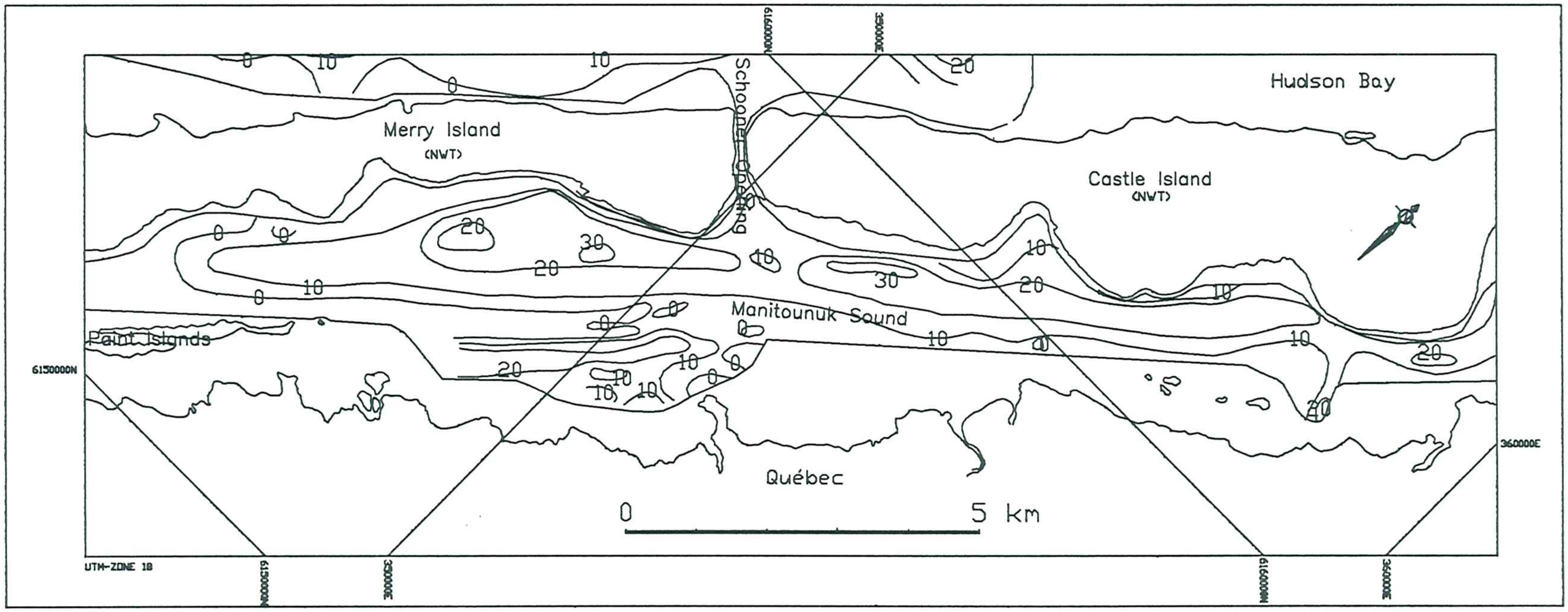
LEGEND

P	POSTGLACIAL MUDS	UD	THIN VENEER OF UNDIFFERENTIATED SEDIMENTS OVER BEDROCK
PE	POSTGLACIAL - ESTUARINE MUDS	SL	SEDIMENT FAILURE / SLUMP DEPOSIT
G	GLACIOLACUSTRINE / MARINE SEDIMENTS	B	BEDROCK
T	TILL / ICE CONTACT DEPOSITS	S	SAND
T/B	DISCONTINUOUS TILL OVER BEDROCK	CE	COMPLEX ESCARPMENTS

INTERPRETATION BASED ON HIGH RESOLUTION REFLECTION SEISMIC AND SIDESCAN SONAR DATA

FIGURE 32

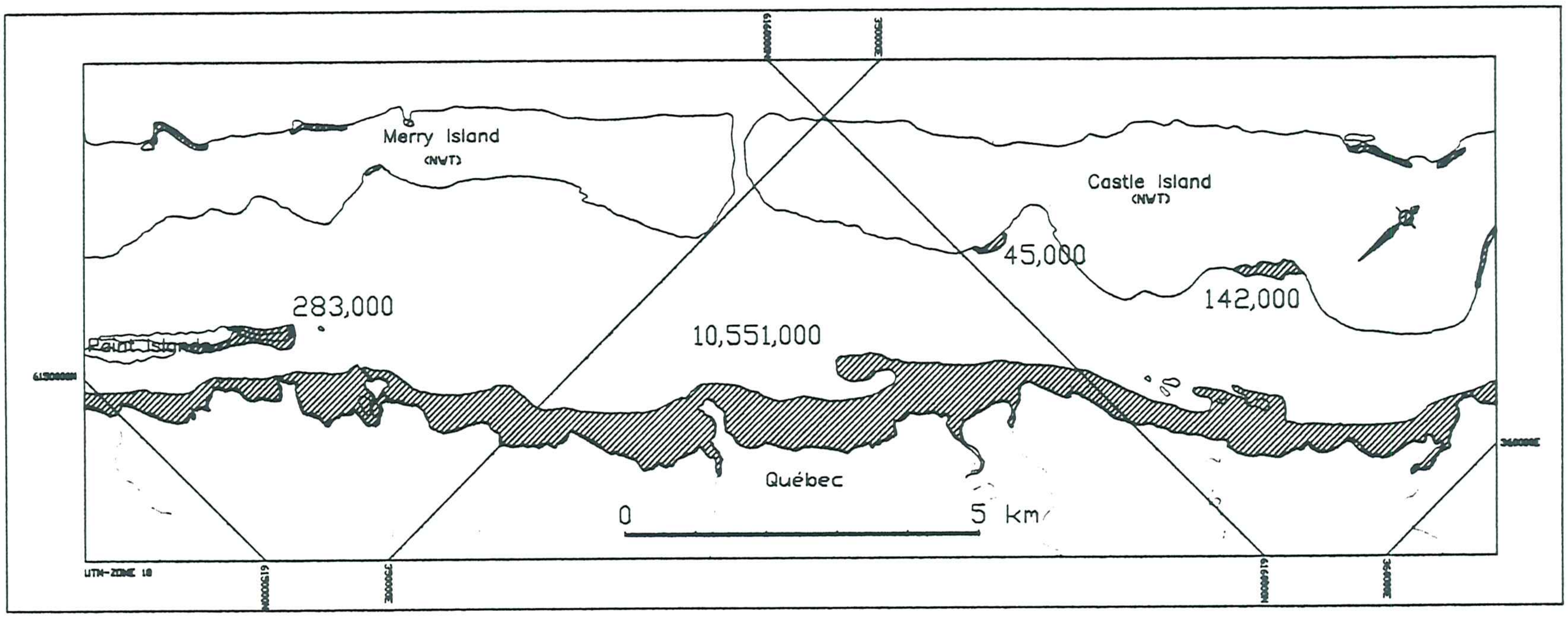
orca 94



POSTGLACIAL SEDIMENT ISOPACH
(Contours in Metres)

TOTAL SURFACE AREA	52.0 SQ KM
MAPPED AREA	31.0 SQ KM
POSTGLACIAL SEDIMENT OUTCROP	25.6 SQ KM
POSTGLACIAL VOLUMES	0.4 CU KM

FIGURE 33

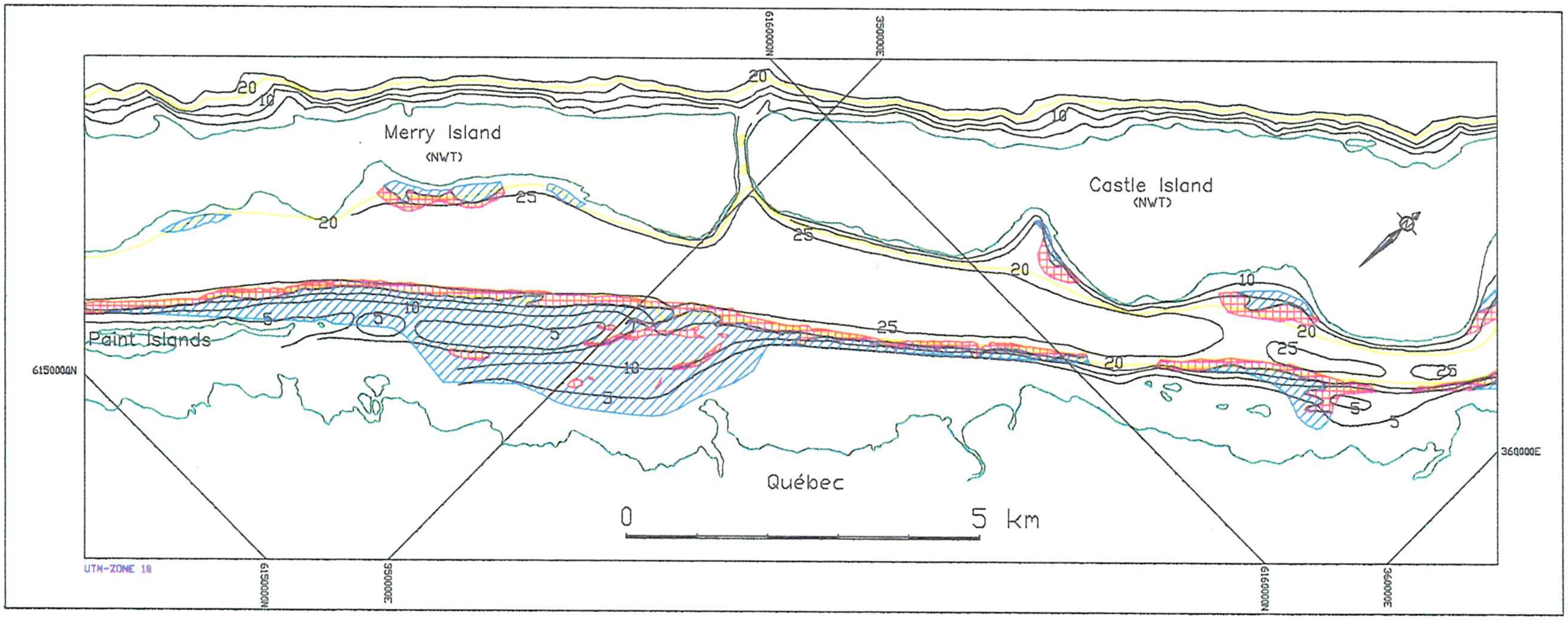


SHALLOW SUBTIDAL AND TIDAL FLAT AREA

TOTAL AREA 11.085 SQ KM
EASTERN SHORE AREA 10.551 SQ KM

FIGURE 34

orca 94



ICEKEEL SCOUR OCCURANCE

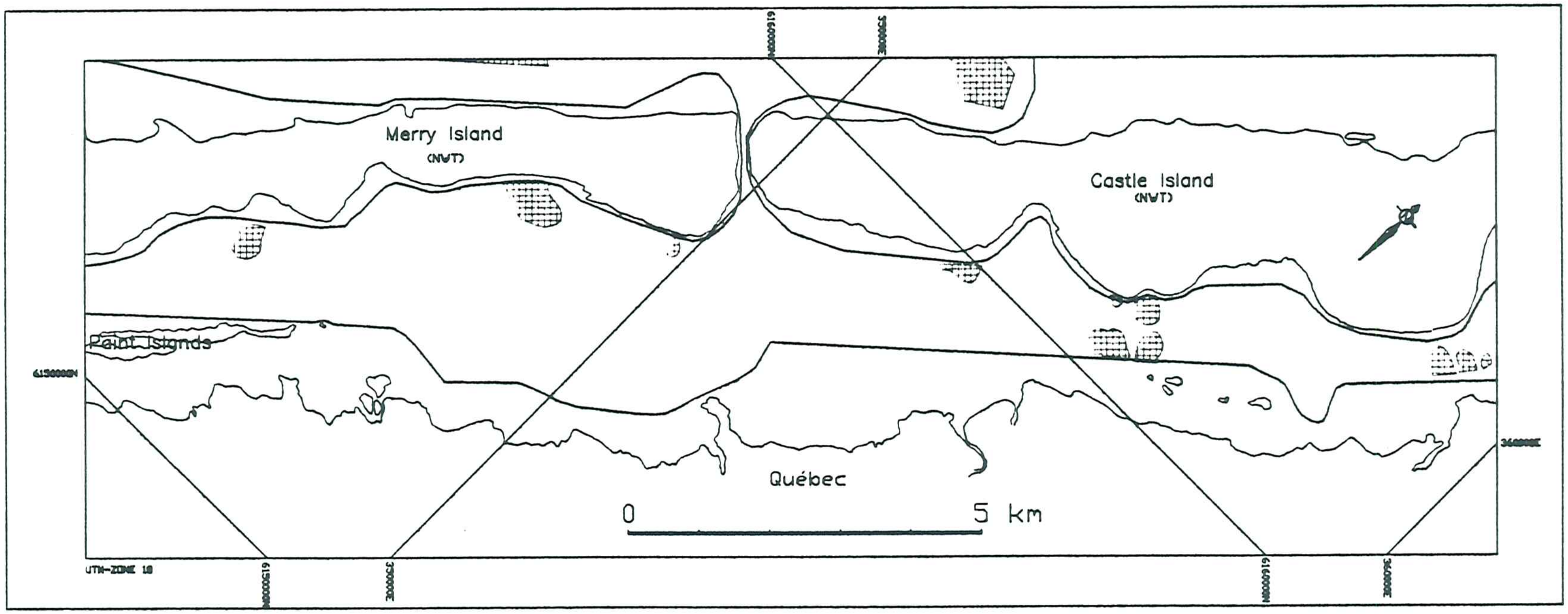
HEAVILY SCOURED
(eastern shore 2.40 sq km, western shore 0.67 sq km)

LIGHTLY SCOURED (DEGRADED)
(eastern shore 8.01 sq km, western shore 0.67 sq km)

BATHYMETRY IN METRES (5, 10, 15, 20 and 25m contours only)

FIGURE 35

orca 94

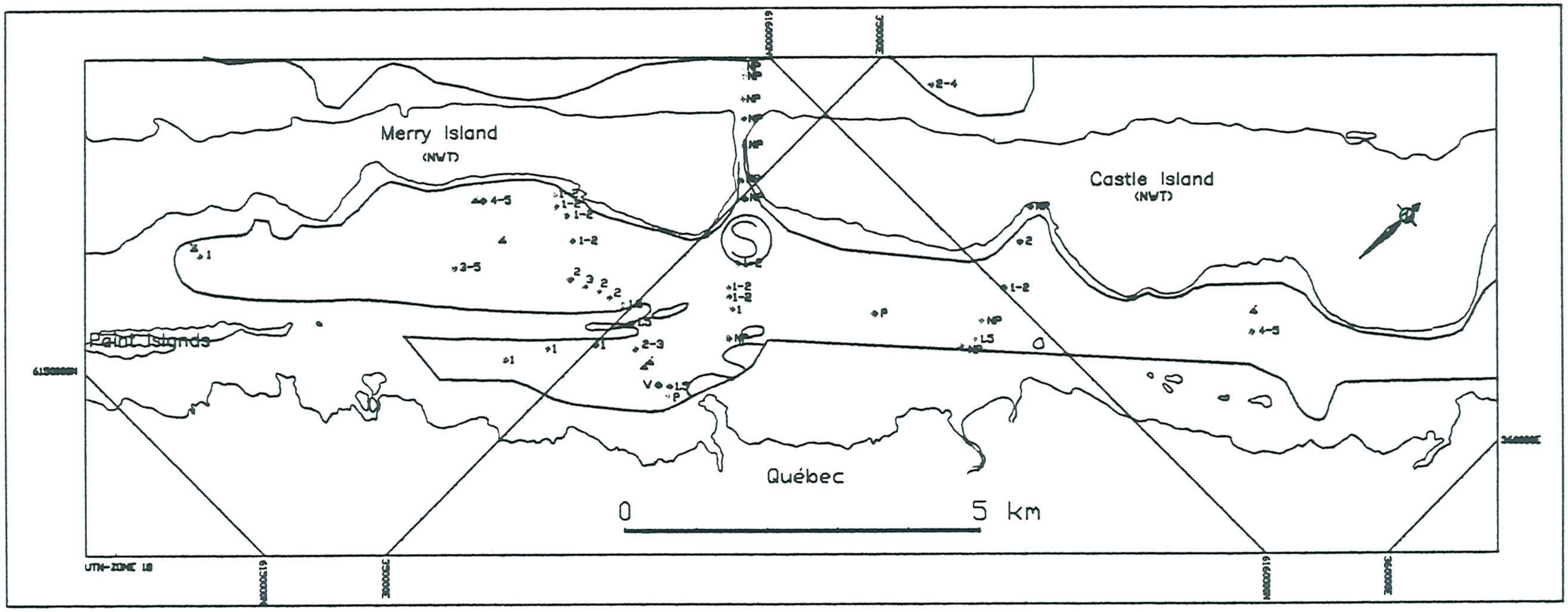


SEDIMENT FAILURE / SLUMP DEPOSITS

Surface area of slump deposits along the western shore (below cuesta ridge cliff face) 0.80 sq km
Surface area of slump deposits along the low slope eastern shore 0.56 sq km

FIGURE 36

orca 94



OXIDIZED SURFACE LAYER THICKNESS AS OBSERVED FROM GRAB AND CORE SAMPLES

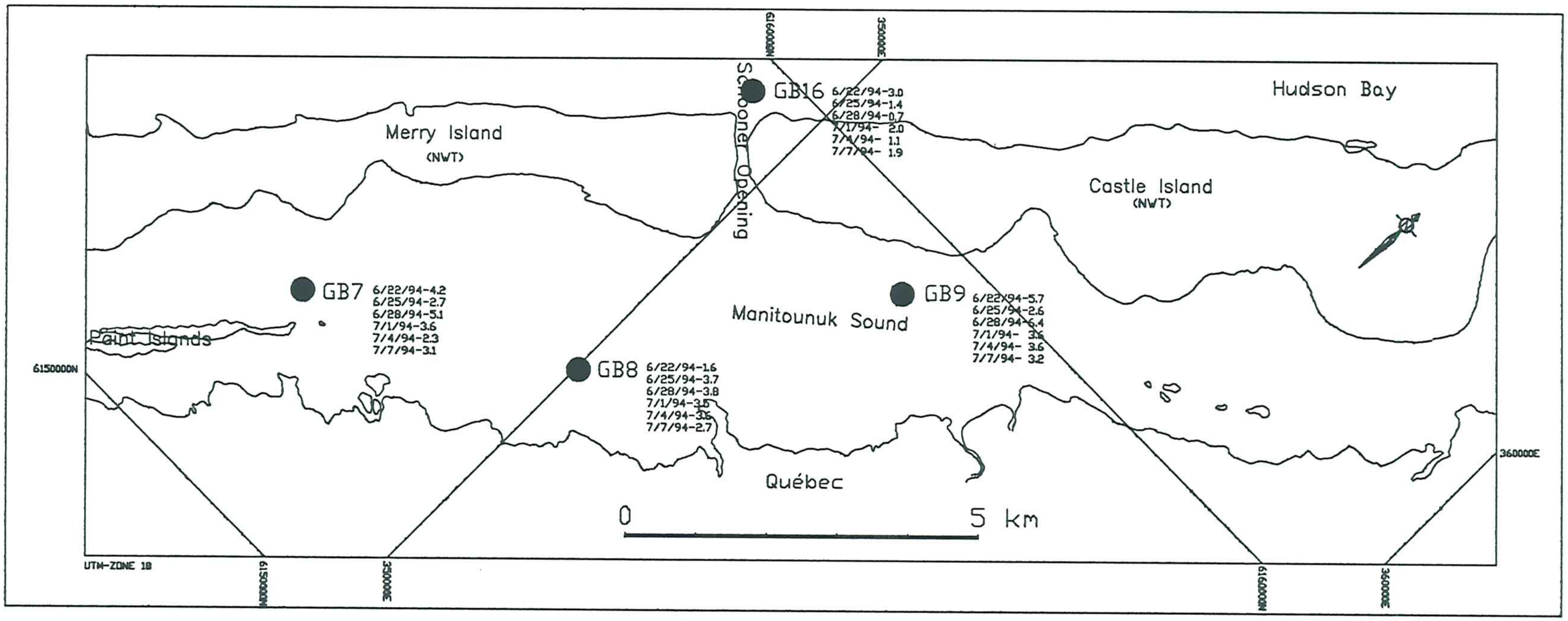
4-5 - Thickness in centimetres

~ - Area indicates extent of postglacial sediments as mapped from reflection seismic data

(S) - Sandwave / megaripple occurance

(P = Present but no value recorded, V = Thin veneer and NP = Not present)

FIGURE 37



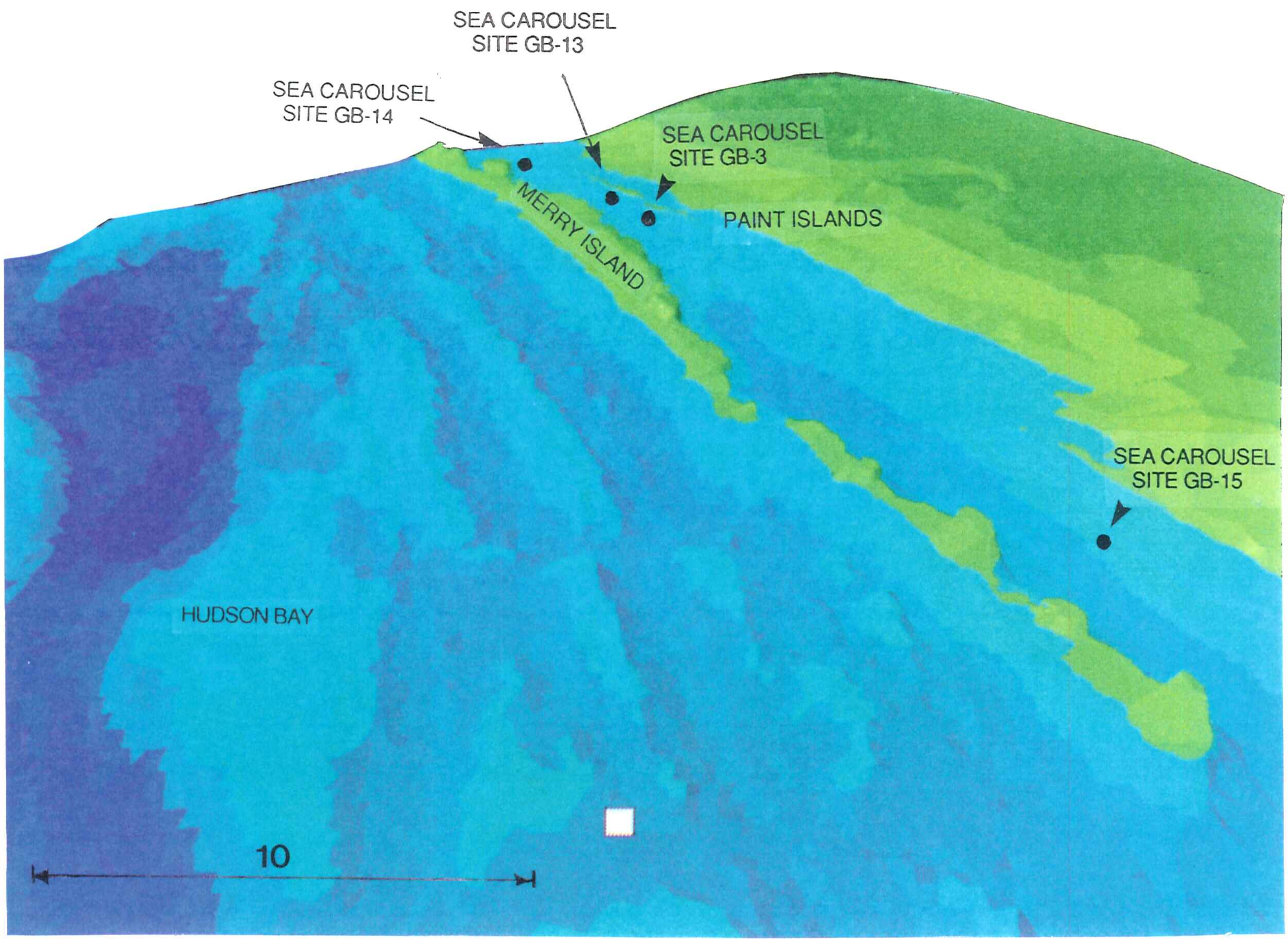
SUSPENDED SEDIMENT DATA COLLECTED DURING ICE BREAKUP 1994

GB4
6/14/94-3.4
6/22/94-3.0
6/25/94-1.5
6/28/94-2.7
7/1/94-5.9
7/4/94-2.8
7/7/94-3.8

SAMPLE STATION LOCATION
STATION NUMBER
DATE AND CONCENTRATION IN MG/L

FIGURE 38

orca 94



OUTER SOUND – PAINT ISLANDS SILL

FIGURE 39

OUTER SOUND

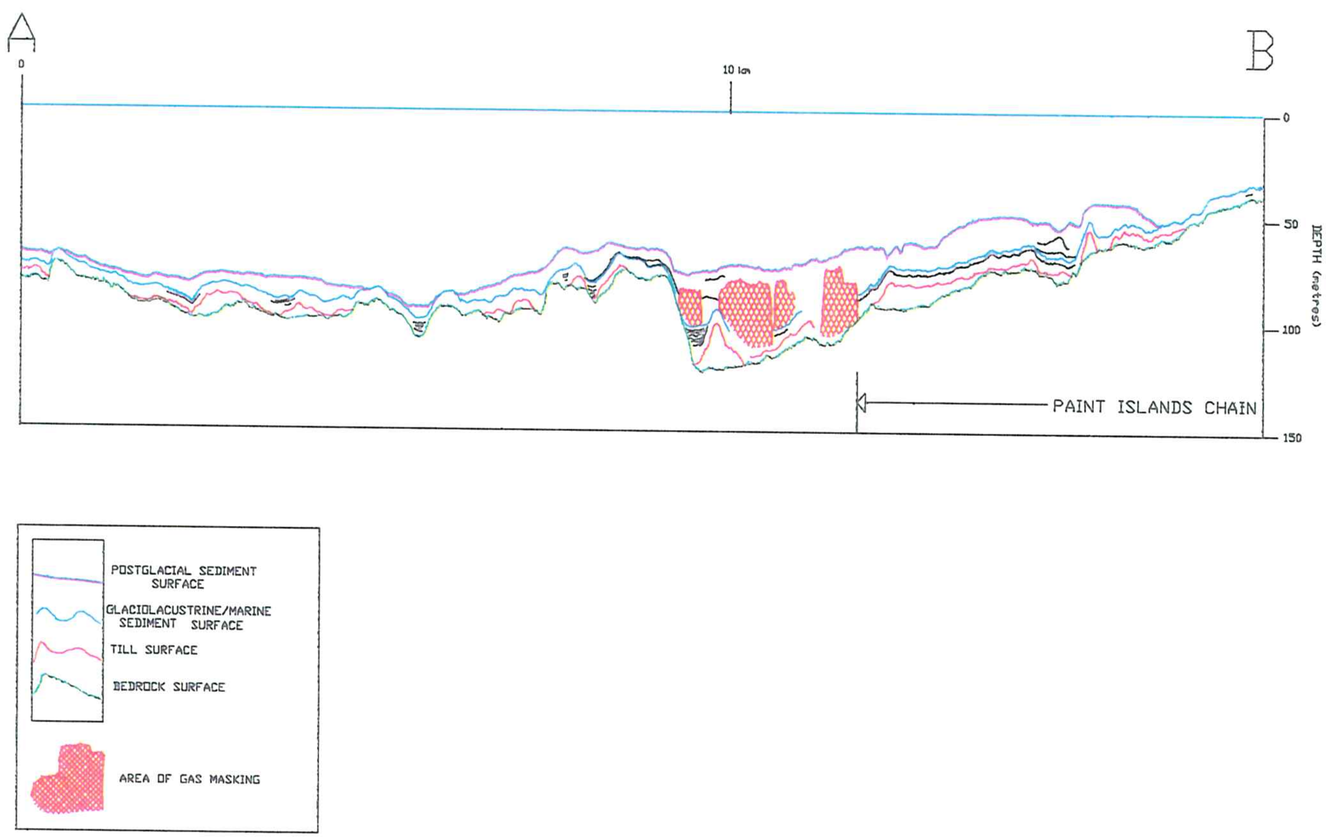
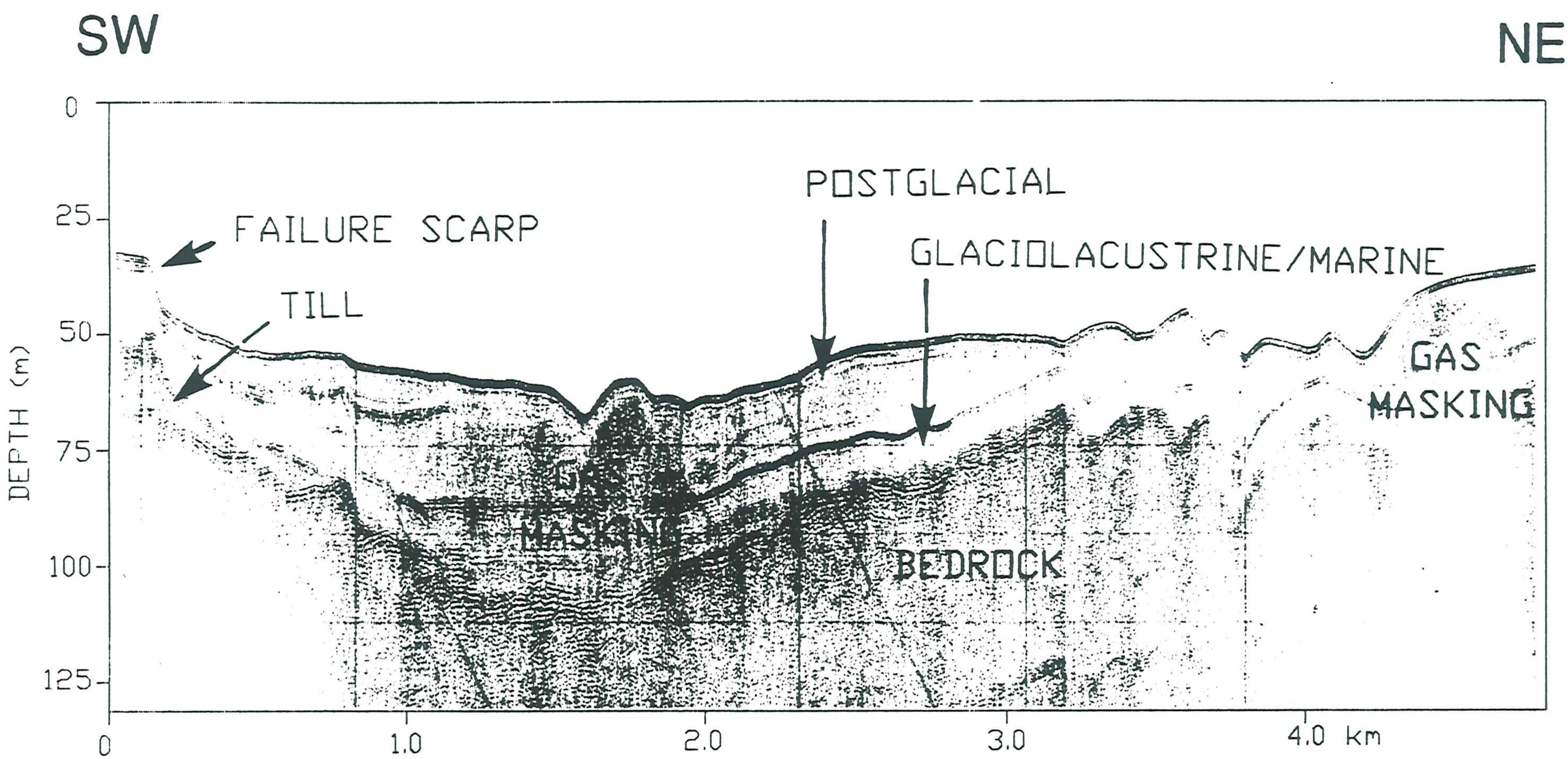


FIGURE 40

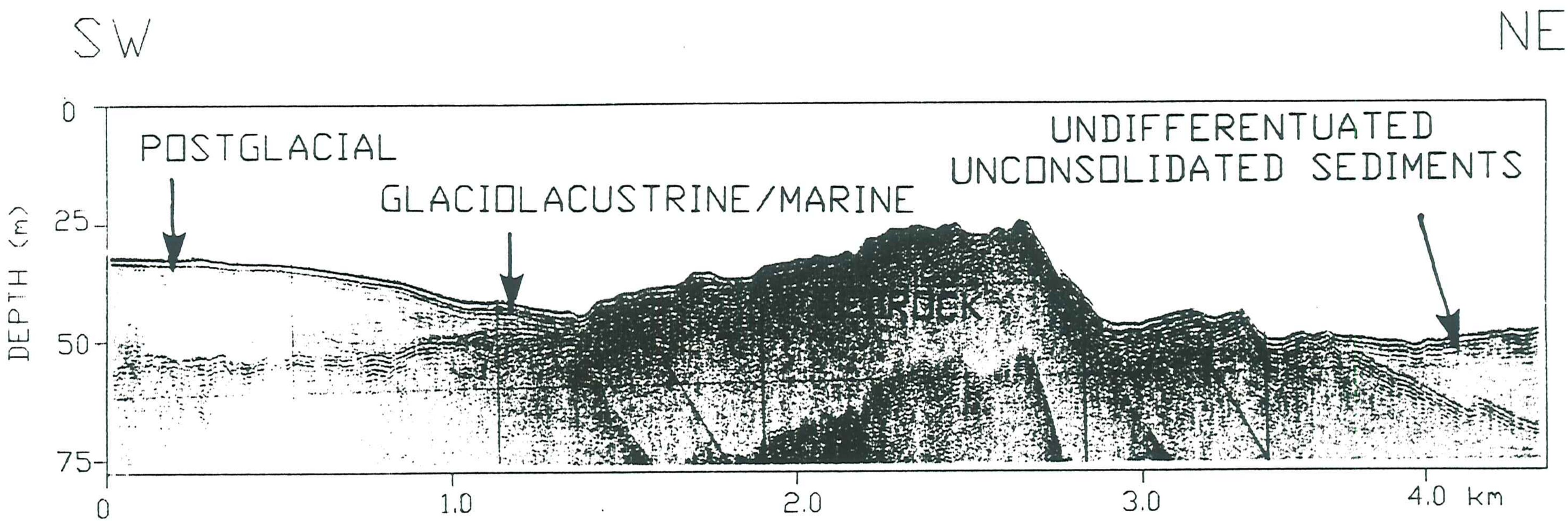
orca 94



OUTER SOUND

FIGURE 41

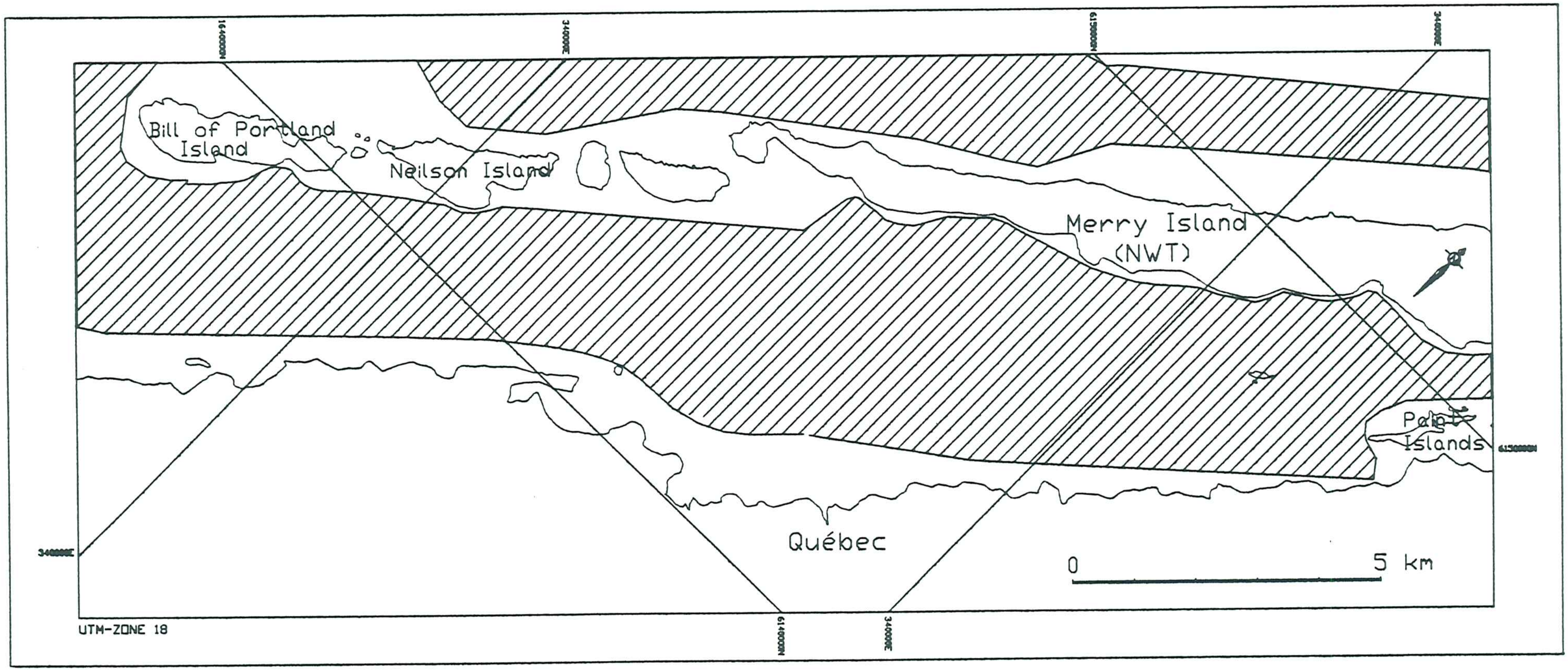
orca 94



PAINT ISLANDS SILL

FIGURE 42

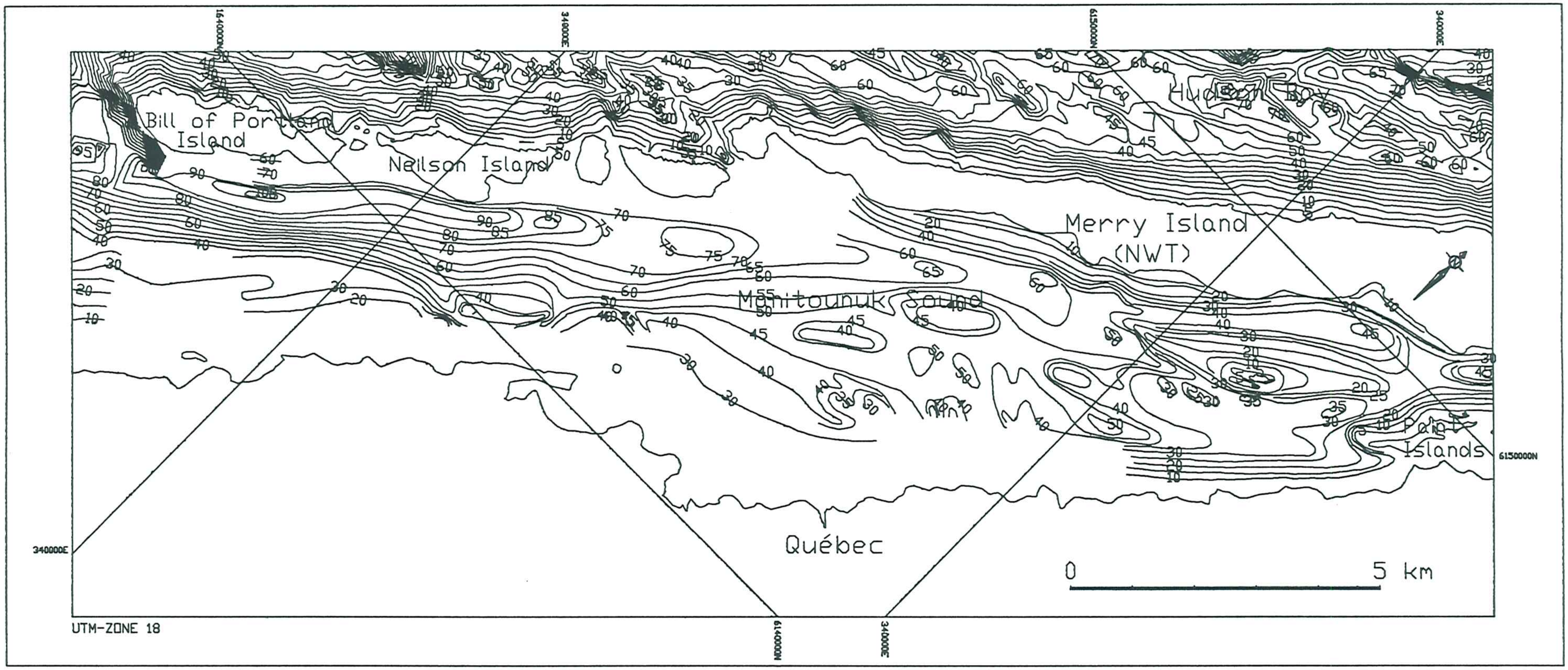
orca 94



DETAILED MAP AREA

FIGURE 43

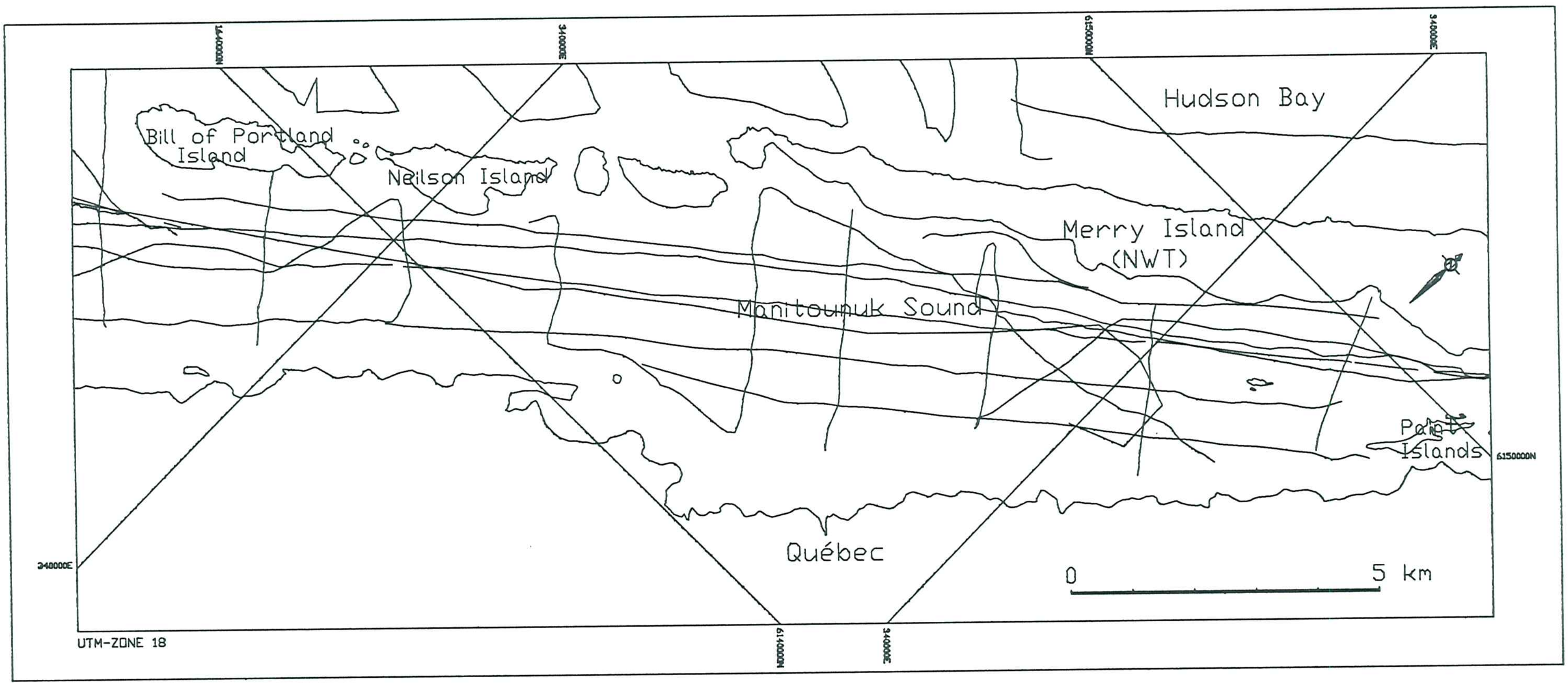
orca 94



BATHYMETRY

(contours in metres)

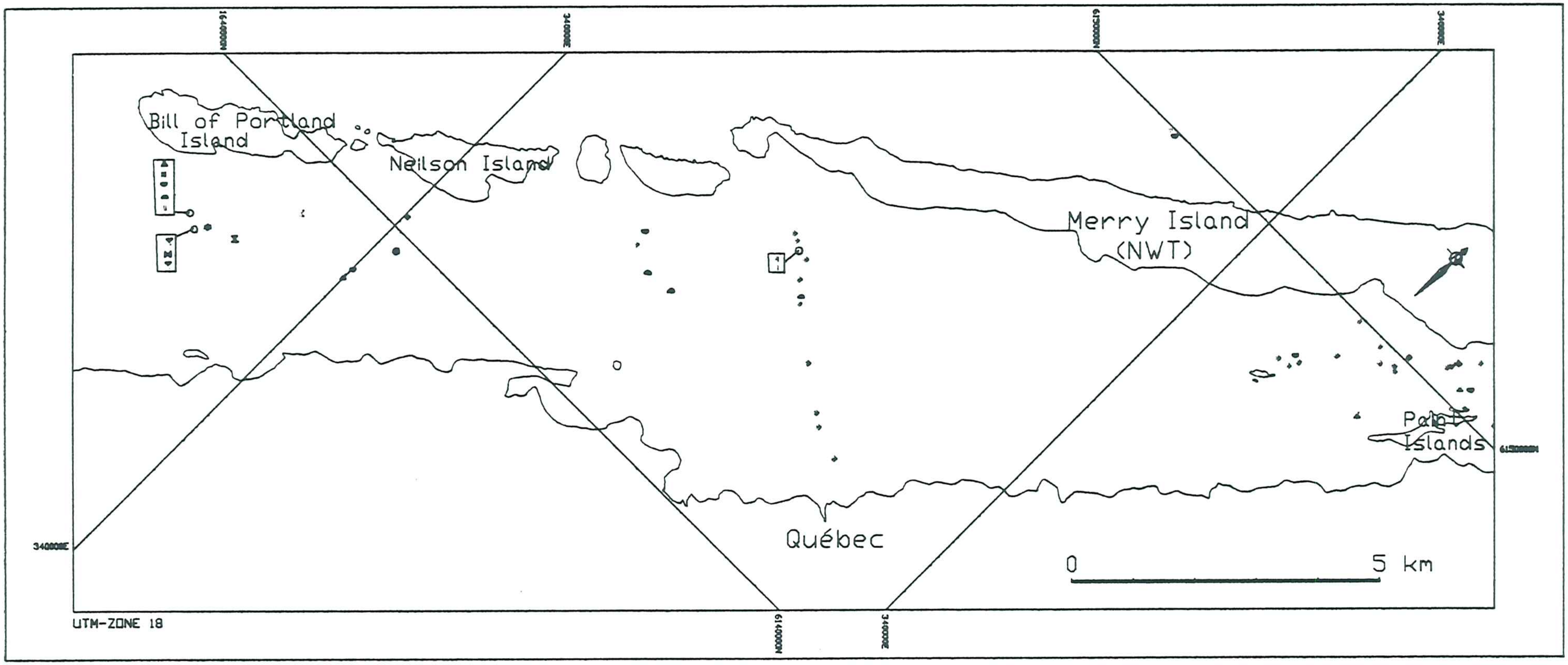
FIGURE 44



SEISMIC REFLECTION AND
SIDESCAN SONAR DATA

FIGURE 45

orca 94



BOTTOM SAMPLE CONTROL

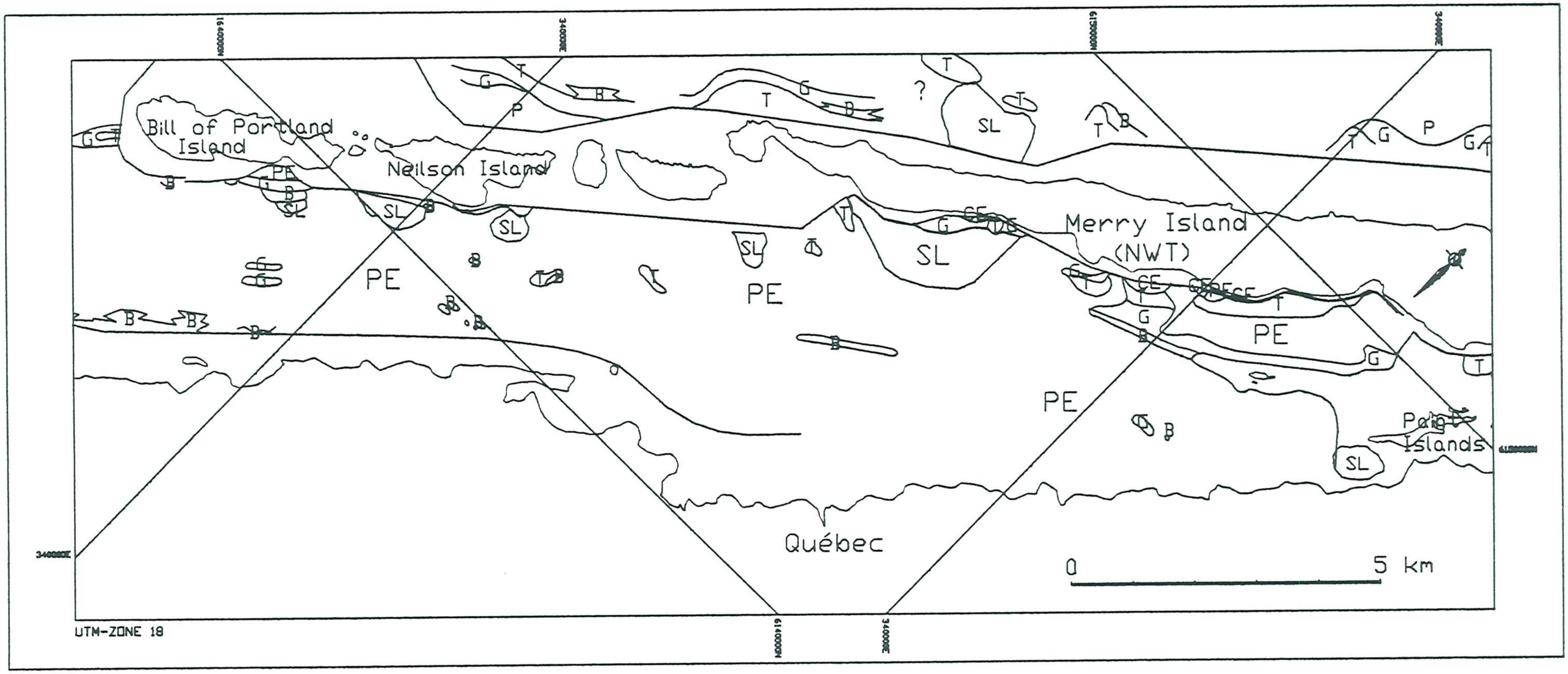
LEGEND

- AGC LONG CORE
- LEHIGH GRAVITY CORE
- BOX CORE
- VAN VEEN GRAB SAMPLE
- CAMERA STATION
- SEA CAROUSEL STATION
- EXCALIBUR STATION
- SOBS STATION
- RALPH STATION
- SEDIMENT TRAP STATION
- NISKIN WATER BOTTLE SAMPLE
- CTD STATION

FIGURE 46

orca 94

SURFICIAL GEOLOGY
SEISMOSTRATIGRAPHIC UNITS



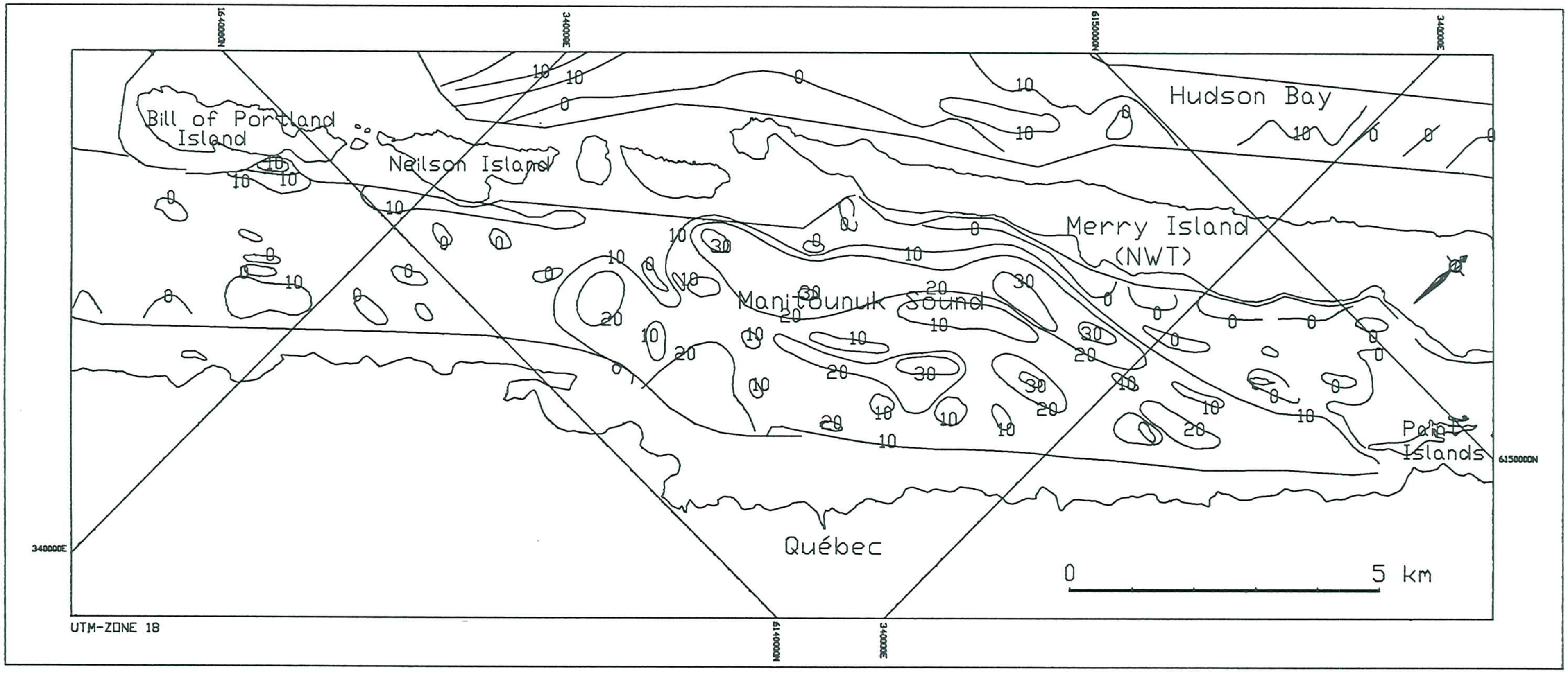
LEGEND

P	POSTGLACIAL MUDS	UD	THIN VENEER OF UNDIFFERENTIATED SEDIMENTS OVER BEDROCK
PE	POSTGLACIAL - ESTUARINE MUDS	SL	SEDIMENT FAILURE / SLUMP DEPOSIT
G	GLACIOLACUSTRINE / MARINE SEDIMENTS	B	BEDROCK
T	TILL / ICE CONTACT DEPOSITS	S	SAND
T/B	DISCONTINUOUS TILL OVER BEDROCK	CE	COMPLEX ESCARPMENTS

INTERPRETATION BASED ON HIGH RESOLUTION REFLECTION SEISMIC AND SIDESCAN SONAR DATA

FIGURE 47

orca 94

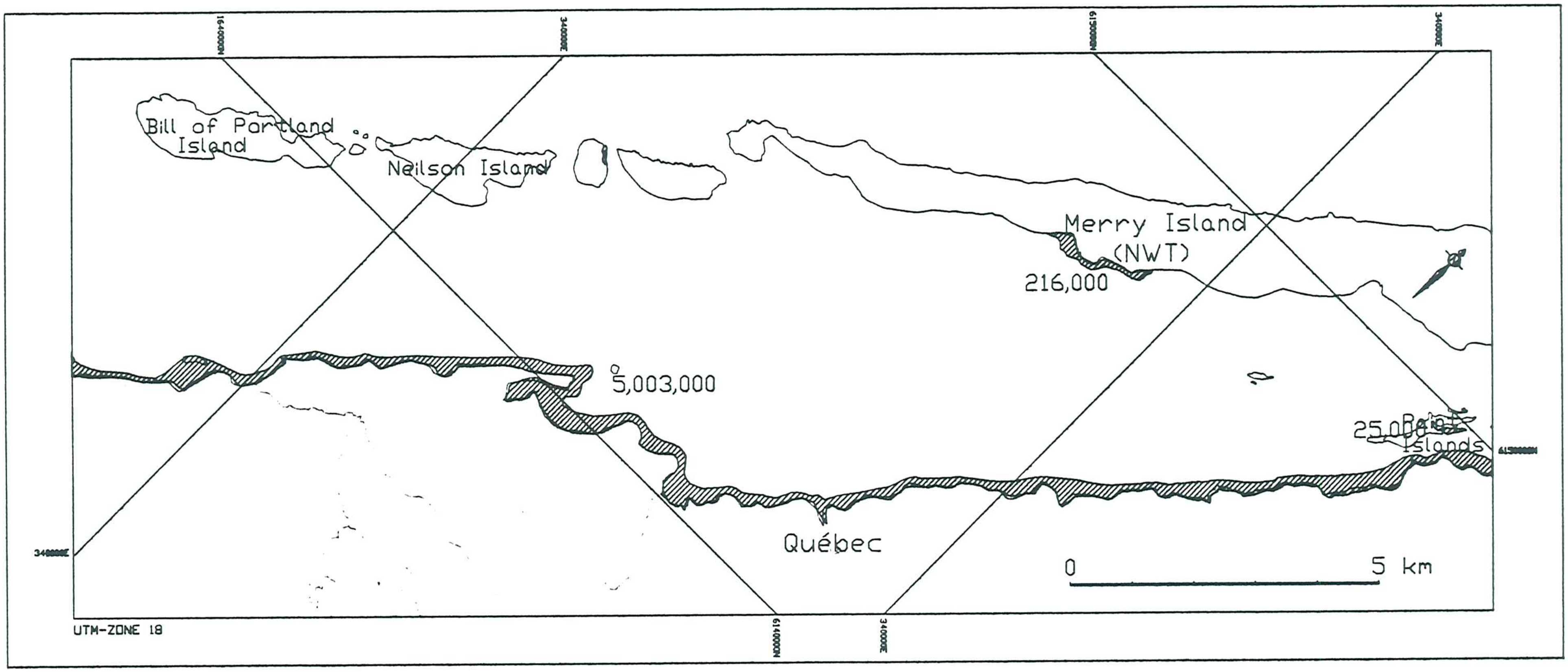


POSTGLACIAL SEDIMENT ISOPACH
(Contours in Metres)

TOTAL SURFACE AREA	82.2 SQ KM
MAPPED AREA	59.7 SQ KM
POSTGLACIAL SEDIMENT OUTCROP	48.1 SQ KM
POSTGLACIAL VOLUMES	0.7 CU KM

FIGURE 48

orca 94

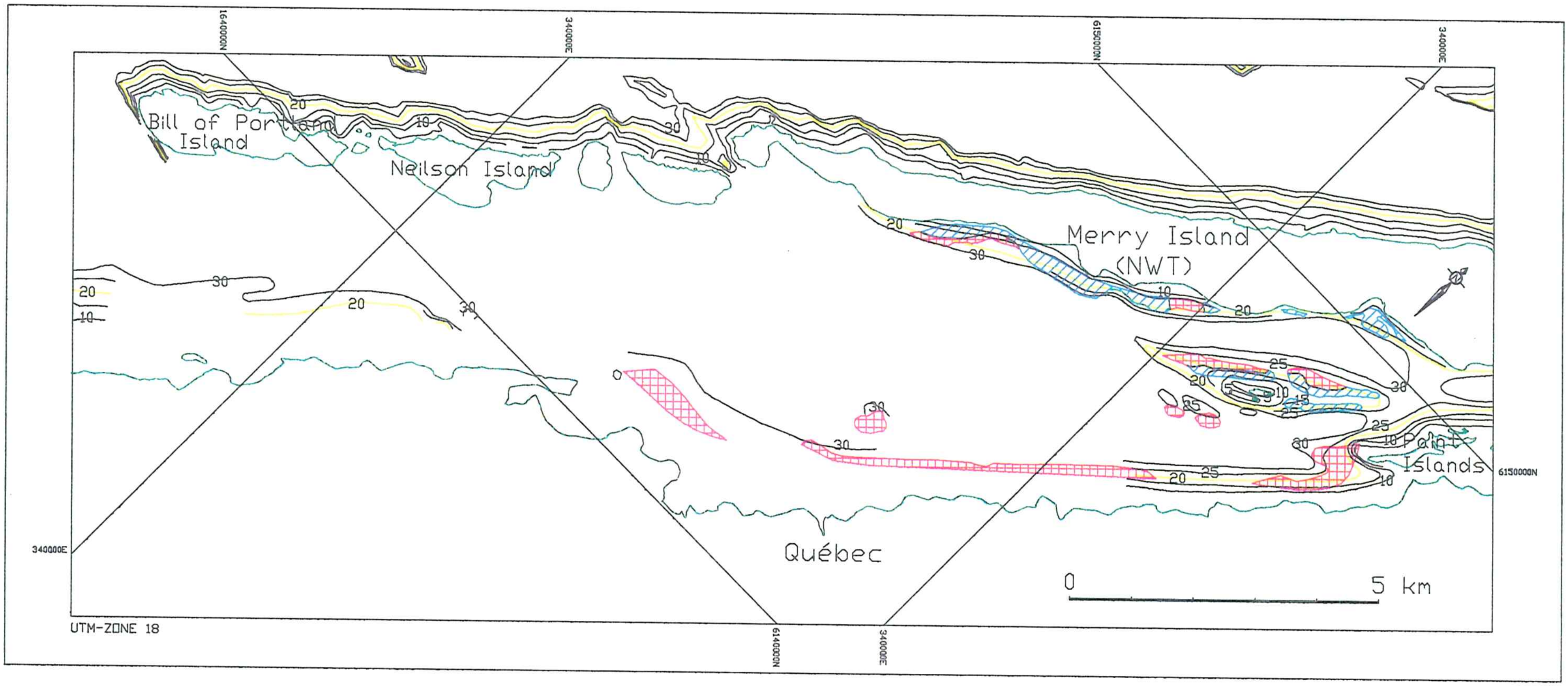


SHALLOW SUBTIDAL AND TIDAL FLAT AREA

TOTAL AREA 5.244 SQ KM
EASTERN SHORE AREA 5.003 SQ KM

FIGURE 49

orca 94



ICEKEEL SCOUR OCCURANCE

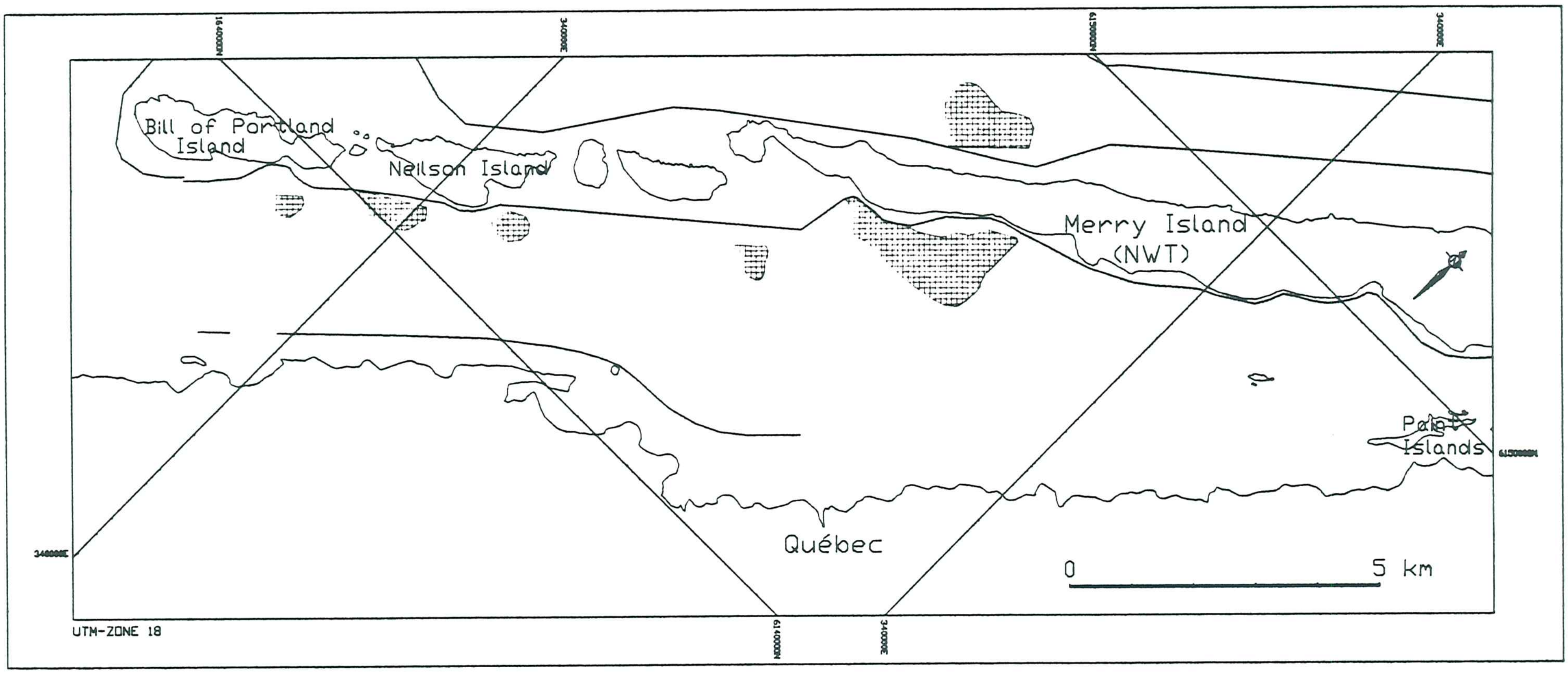
HEAVILY SCOURED (eastern shore 1.85 sq km, Paint Islands 0.45 sq km, western shore 0.24 sq km)

LIGHTLY SCOURED (DEGRADED) (eastern shore mapped area too deep, Paint Islands 0.52 sq km, western shore 0.96 sq km)

BATHYMETRY IN METRES (5, 10, 15, 20, 25 and 30m contours only)

FIGURE 50

orca 94

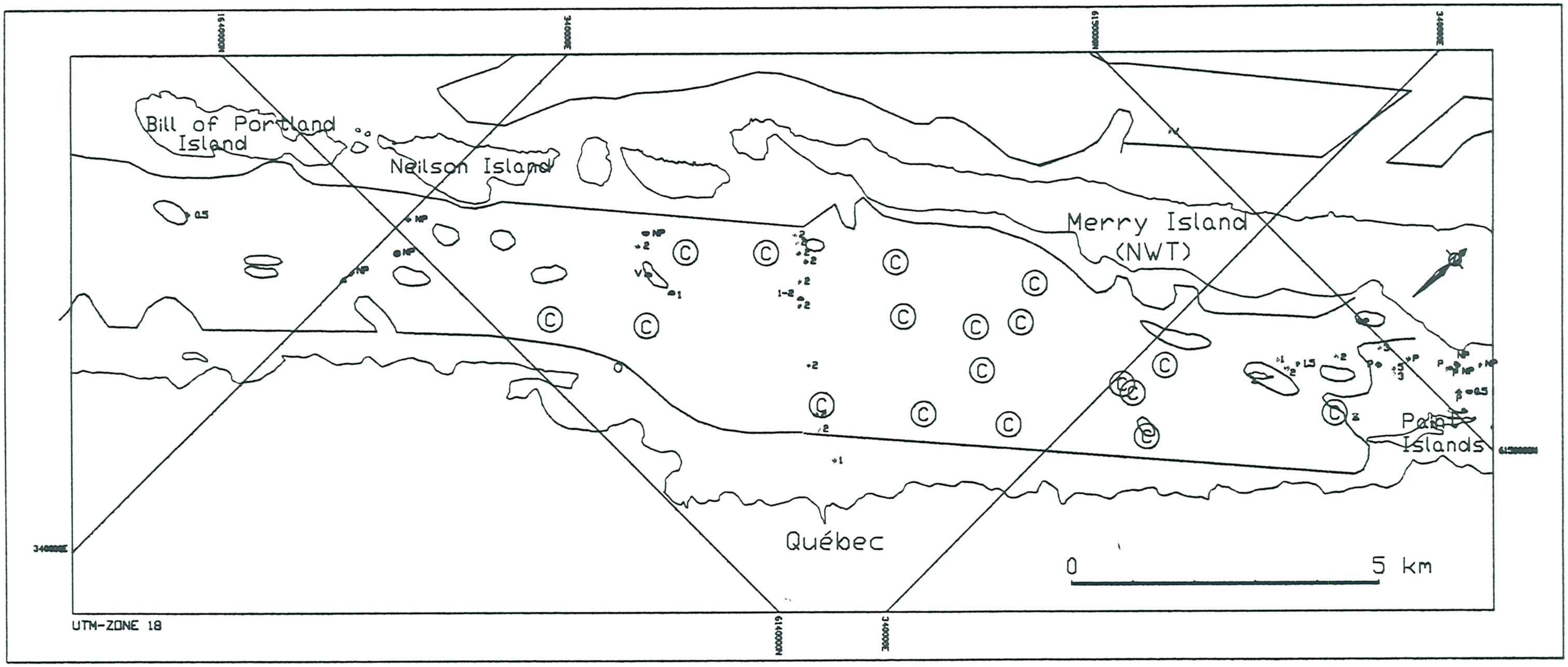


SEDIMENT FAILURE / SLUMP DEPOSITS

Surface area of slump deposit along the western shore (below cuesta ridge cliff face) 3.05 sq km
No large scale sediment failure observed along the low slope eastern shore

FIGURE 51

orca 94



OXIDIZED SURFACE LAYER THICKNESS AS OBSERVED FROM GRAB AND CORE SAMPLES

·4-5 – Thickness in centimetres

~ – Area indicates extent of postglacial sediments as mapped from reflection seismic data

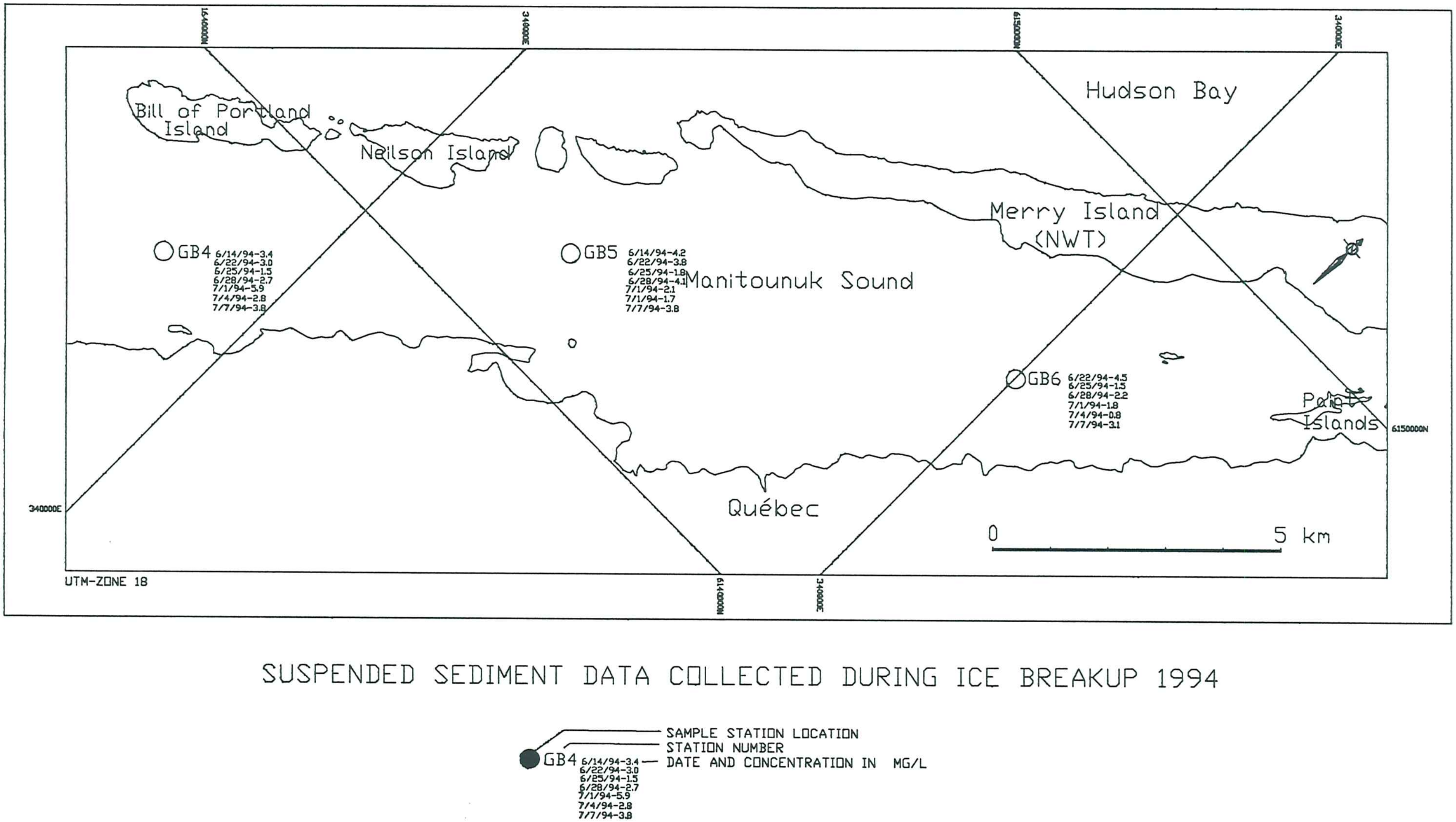
(S) – Sandwave / megaripple occurance

(C) – Area of non-deposition/erosion by topographically steered bottom currents

(P = Present but no value recorded, V = Thin veneer and NP = Not present)

FIGURE 52

orca 94



SUSPENDED SEDIMENT DATA COLLECTED DURING ICE BREAKUP 1994

FIGURE 53

orca 94