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Nearshore Sediments of Lake Ontario with Special Reference to the Presqu`ile-Wellington Bay Area

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by

I.P. Martini, and J.K.P. Kwong

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V.G. Milne

V.G. Milne, Director
Ontario Geological Survey

FOREWORD

The authors of this report have, under contract to the Ontario Geological Survey, conducted a study of nearshore sediments found in part of Lake Ontario. The study has extended the land base studies of the glacially derived sediments and has looked at the result of the processes that have been operating on the glacial deposits for the last 10,000-12,000 years since the ice disappeared.

No evidence has been found for any potential valuable deposit of sand in the study area within Lake Ontario but the report has served to emphasize the significant nature of the processes acting upon the materials in the bluffs along the shoreline and on the lake bottom sediments.

V.G. Milne, Director
Ontario Geological Survey

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ACKNOWLEDGEMENTS

Several people and organizations have helped with data and support. Most information and materials were kindly provided by N.A. Rukavina of the National Water Research Institute. He critically read an early version of the manuscript. We like to thank O. White for supporting the project and reviewing the manuscript, P.G. Sly for providing pre-prints of his papers, L. Smith for providing copies of unpublished B.Sc. Theses he supervised, and J.G. Leyland for providing draft copies of his Pleistocene maps of the area. R. Davidson-Arnott calculated the threshold orbital velocity of waves. R. Krueger determined the heavy minerals of the offshore sands, R. Lohr ran the computer programs, A. McLennan, Marie Puddister, and D. Irvine drafted the figures, and Kelly Beitz typed the manuscript.

We retain sole responsibility for statements and interpretations presented in this report.

Financial support was provided by the Ontario Geological Survey and a NSERC Grant (A 7371) to the senior author.

ABSTRACT

Four major sand deposits have formed along the Canadian shores of Lake Ontario, at Niagara, Hamilton, Toronto, and Presqu'ile-Wellington Bay. They have been interpreted in the past as formed primarily by longshore drift of material obtained from erosion of coastal bluffs and tills exposed in the shallow shelf. Results of this study in the Presqu'ile-Wellington Bay area indicate that some sands deposited in the various coastal embayments of the Wellington and Athol Bay area have local origin. The grain size distributions are somewhat adjusted to the local hydrodynamic conditions by either developing fine textures in protected areas, or showing fining downcurrent trends in beaches and nearshore zones. Longshore drift is limited however, to each embayment, and except for a possible spill-over from Presqu'ile into Wellers Bay (the two northernmost embayments) the various re-entrances are not linked by a major long-range drift. Other typical grain size distributions indicate thin lag materials over bedrock or hard substratum, or they are associated with linear features which can be mapped by echosoundings and may represent partially filled Pleistocene valleys.

Heavy minerals of the sands show sorting with respect to till assemblages. However, it can be shown through multivariate statistical analysis that the garnet varieties behave hydrodynamically in a similar way, thus their ratios can be used as source-area indicators. The southernmost embayments (Wellington and Athol Bays) have consistently higher purple to red garnet ratios than those of Presqu'ile and Wellers Bay. This correlates well with the high garnet ratios found in areas near Montreal and north of the Adirondack. Indeed, recent mapping indicates that the study area has been affected by two glacial ice lobes: one moving southwestward and

carrying the high garnet ratios in the southern embayments. The second ice lobe moved south-southwestward directly from the Precambrian shield and deposited the lower garnet ratio materials in Presqu'ile and Wellers Bay and on the northshore region which contributes material to longshore drift.

Nearshore sediments of Lake Ontario with special reference to the Presqu'ile-Wellington Bay area

by

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INTRODUCTION

OBJECTIVES

The objectives of this research were to investigate the geology and offshore sediments of the Presqu'ile-Wellington Bay area, to understand the origin and potential dynamics of the nearshore sands, and to report on these findings (Fig. 1).

The following approaches were adopted for this study:

1. A review and integration was made of the most pertinent geological information about the area. Much information has only recently become available.
2. The textures of the subaqueous sands have been re-analyzed and re-interpreted.
3. The subaqueous sands were studied for sedimentary structures and mineralogy, with special emphasis on heavy mineral assemblages. For the interpretation of heavy minerals (as well as other variables) a regional outlook was required to try and understand the persistence of the various mineral assemblages in the nearshore environments, and to understand the regional dispersal pattern of the sediments. Accordingly the available information from the shores of Lake Ontario and other inland areas in Ontario have been integrated in our analysis.
4. A renewed interest in the offshore sands as potential mineral aggregates has been expressed recently in Ontario. This called first for an analysis of the quality of the offshore deposits for construction materials (Appendix 1). Secondly a critical look was taken of the longstanding interpretation that the nearshore deposits have been formed by persistent longshore drift. This implies that material extracted from the offshore could be replaced in a certain period of time by

longshore drift. There is no existing sufficiently detailed data for establishment of this replacement time. However, the geology of the coastal areas and the statistical analyses of the textural and mineralogical data of the offshore deposits suggest that certain nearshore sand bodies in the Presqu'ile-Wellington Bay area are partially reworked 'relict deposits' of Pleistocene and/or early Holocene times. This is particularly true for Wellington and Athol Bay and part of the Presqu'ile Tombolo. Without disputing the importance of sediment distribution by longshore drift, some sand bodies of Lake Ontario may have a significant relict component.

MATERIALS AND METHODS

The Presqu'ile-Wellington Bay area is located in Southern Ontario, one of the most densely populated parts of Canada. Most of the sandy coastline is being designated as Provincial Parks. The antecedent Lake Ontario is part of the St. Lawrence seaway and is criss-crossed by busy shipping traffic throughout the summer, and correspondingly, considerable information is available on the climate, winds, waves, currents and lake level changes.

The geology of the region is well known in its broad outlines (Liberty, 1960, 1961; Carson, 1980a, b; 1981; Leyland, 1982, 1983). Recent work by students of Queen's University has analyzed the grain size distributions on the baymouth bars (Peat, 1973; Belenger, 1976; Ernstring, 1976; Mitchell, 1976). The subaqueous portion of the nearshore area was surveyed down to 20 m water depth by the Hydraulic Division of the National Water Research Institute, from 1969 to 1971 (St. Jacques and Rukavina, 1972). The main results of the survey were that active accumulation of sediments have occurred in Wellington Bay in the last 60 years at a rate of approximately 0.2 to 1.0 cm/year, and that the material was derived primarily from the erosion of submerged tills and it was redistributed by longshore drift (Rukavina, 1969, 1970, 1976; St. Jacques and Rukavina, 1972; Owens, 1979).

The present study re-analyse the available information from the subaqueous nearshore area of Presqu'ile-Wellington Bay in eastern Lake Ontario. It also provides new information on the mineralogy of the sands, and integrates these results with what is known from the adjoining shore and inland areas.

The following data and materials were obtained from the nearshore area.

1. Surface grab samples (Shipek sampler) were collected on a 2 km grid.
2. Shallow cores (average length of 1 m) were retrieved in suitably located parts of the sand bodies, generally in their thickest nearshore portion (Fig. 1). The cores were X-rayed and subsampled for grain size and mineralogical determinations.
3. The thickness of the sedimentary bodies was measured by jetting to refusal (Rukavina and LaHaie, 1977).
4. Echo soundings along lines spaced at 2 km intervals were used to establish the bottom topography and to place the boundaries between the unconsolidated sediments and hard substratum (bedrock or compacted glacial sediments) (Rukavina, 1970; Thomas et al., 1972).
5. Grain sizes of the grab and core samples were determined by a modified Emery sedimentation tube, according to the F.A.S.T. and F.A.S.T.'R. procedures of the National Water Research Institute Sedimentology Laboratory (Duncan and LaHaie, 1979).

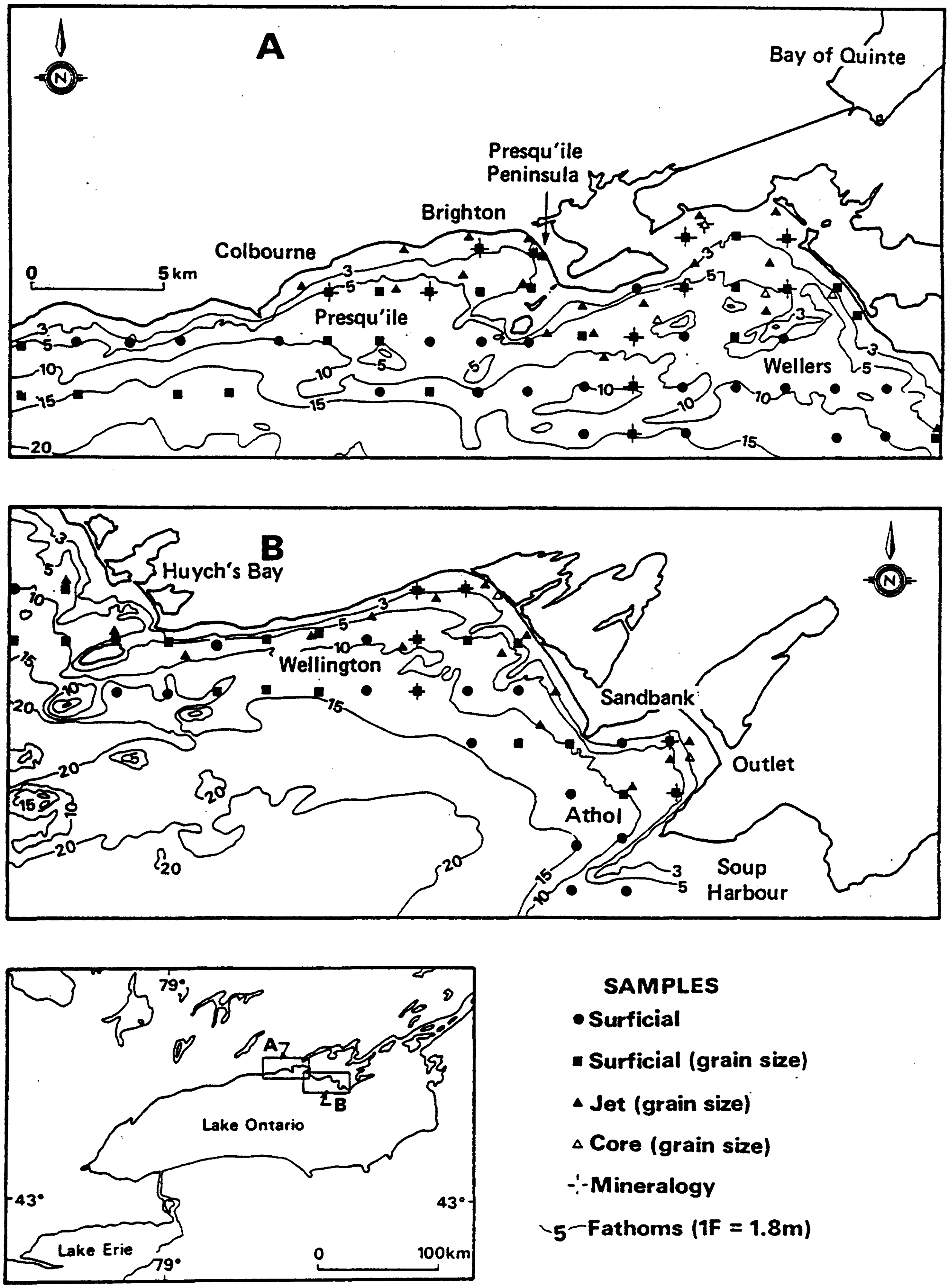


Figure 1. Location map and types of samples available in the offshore area.

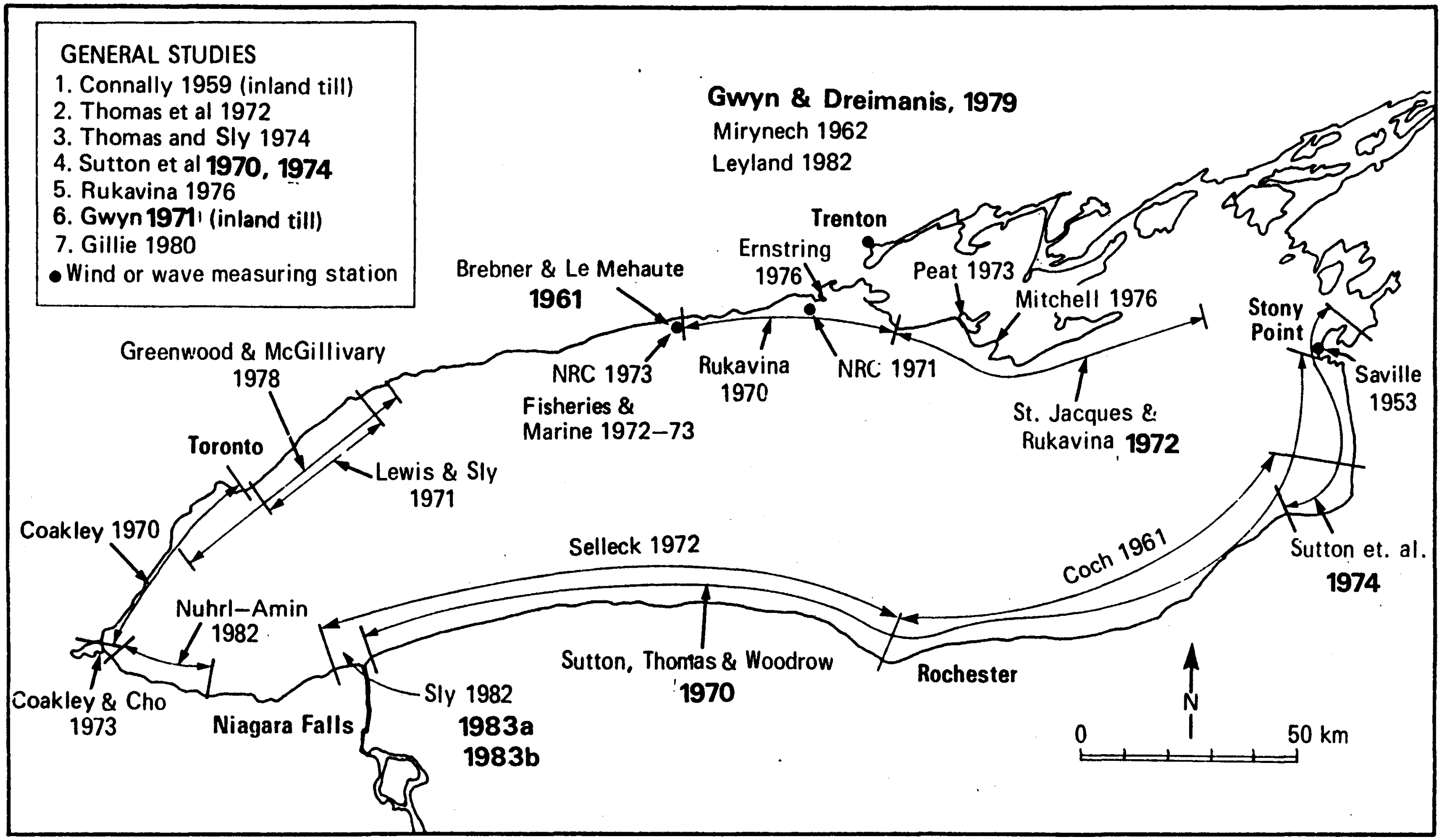


Figure 2. Areas covered by major papers and reports directly pertinent to this sedimentological analysis.

6. Sedimentary structures were studied utilizing X-radiographs of long cores (to 1 metre) obtained by gravity piston, as well as of short cores (3-6 cm) obtained by subsampling the undisturbed Shipek grab sample with 40 drum plastic vials (Rukavina, 1969).

7. Selected piston cores and small vial-cores were further treated to study the mineralogy of the samples and their sedimentary structures:

a) Two long cores were subsampled with small (5 cm x 7.5 cm x 5 cm) tin boxes. Part of the box samples was utilized for heavy mineral determinations. The remainder was impregnated with resin (mixture of Aropol C300 and Methylmethacrylate). The impregnated samples were subsequently cut to obtain two thin slices, one (1-1.5 mm thick) for X-ray and a second slice for thin section preparation.

b) The small vial-cores (40 drum) were similarly treated. Each core was subdivided into two halves along its length. Half was subsampled for mineralogical analysis. The material of the top 1 to 2 mm was collected, then the remainder was sampled according to visible layers recognized either by naked eyes or in X-radiographs. Because the plastic vials are soluble in acetone based resins, the undisturbed half of the core was frozen, transferred into an aluminum container and impregnated. The freezing procedure did not disturb significantly the sandy materials, but it may have slightly disturbed the fabric and the structures of silty samples.

c) The mineralogy of the samples was determined by modal analyses of thin sections with approximately 300-400 point counts per sample.

d) The heavy minerals of each samples were first fractionated out from 2 grams of the fine sand fraction (2-3 ϕ) using Tetrabromoethane (Sp. Gr. 2.96). Then a first count was made of the opaques against non-opaque on a 100 grains (Griffiths, 1969). Subsequently the concentrations of the other minerals were determined based on a minimum of 400 grains per mount. The method of counting is a slightly modified "ribbon" procedure (Galehouse, 1969; Gwyn, 1971), whereby all the "whole grains" contained in a pre-determined central zone of the field of view of the petrographic microscope were counted. The field of view was shifted at 2 mm intervals along a 2 mm spaced transect to ensure that the whole slide was properly covered. This procedure not only provides a number frequency for the concentrations of the heavy minerals, it also ensures against possible sources of errors in the preparation of the grain mounts such as non-uniform distribution of minerals.

Preliminary analyses showed that there are significant differences in heavy mineral estimates between the fine sand (2-3 ϕ) and very fine sand (3-4 ϕ) sand fractions, particularly for tremolite-actinolite, clinopyroxene, epidote, zircon and chlorite concentrations. However, Gwyn (1971) has demonstrated in Southern Ontario that the general regional trends in heavy mineral variations are much the same in using either of the sand classes. The use of the fine sand fraction allows comparison of our data with those of other studies made in the surrounding region, which also used the same sand fraction (Gwyn, 1971; Connally, 1959; Coch, 1961).

STATISTICAL METHODS

The grain size distributions and the heavy mineral concentations of the nearshore area of Presqu'ile-Wellington Bay have been compared with others available for the region, following the standard statistical techniques (Folk, 1964). Some discretion had to be used in data interpretations because slightly different techniques were used by different studies.

The grain size distribution (every 1/2 phi for the sand and silt fractions and 1 phi classes for the clay fraction) and the heavy minerals concentrations of the subaqueous sand bodies in the study area were treated utilizing multivariate statistical procedures. These included tests of normality of the variables (Univariate Analysis, SAS), R-mode factor analysis (BMDP), Q-mode factor analysis with varimax and oblique rotations (Klovan and Imbrie, 1971), cluster analysis, discriminant analysis (Dixon and Brown, 1979) on the computer retrieved clusters obtained treating surficial grab samples, discriminant analysis to classify the subsurface Shipek and cores samples utilizing the discriminant functions pre-determined. Transformations ($\log_{10}(x_i+1)$) of data were initially used, but the untransformed data were subsequently preferred because of a better definition of the gradients in the Q-mode factor analysis. This last procedure does not require a strict adherance of the data to normality (Klovan and Imbrie, 1971).

Correspondence factor analysis was applied to the heavy mineral data. Correspondence analysis combines the R- and Q-mode factor analyses and provides plots with variables superimposed on samples such that the gradients on the variables can be referred directly to specific samples and vice versa (Benzecri, 1970; Teil, 1975). Correspondence factor analysis was originally designed for contingency tables. However, it has been successfully applied to several geological data (Teil and Cheminee, 1975). The program used (ANACOR) is a slightly modified version to provide allowance for simulated three dimensional plots of variables and samples, written by David and Beauchemin (1974).

The stepwise multiple regression analysis (SAS, 1979) was used to try and predict whether linear relations occur between sets of variables such as water depth and grain size parameters. The results showed a low regression coefficient possibly due to the great variety of subaqueous environments in the study area, and the results are not reported here.

The original data from onshore areas obtained by other studies were not available and multivariate analyses similar to those applied to the offshore samples could not be performed. Comparisons between the offshore and onshore areas and between subaqueous bays were made using the statistical parameters (mean size, standard deviation, skewness and kurtosis) calculated according to the procedures suggested by Folk (1964).

In this study statistic is used as a tool. Results of statistical analyses were carefully evaluated and have been found useful in data interpetations. Nevertheless, the final interpretations were based upon a combination of both statistical and geological reasoning.

ENVIRONMENTAL CONDITIONS

CLIMATE

The lower Great Lakes are under the influence of prevailing westerly winds and major storms moving out from the south. These generate high snowfalls in winter in the lee of the lakes and strong freshets following the spring melting. The mean annual temperature measured in Trenton is about 7.9°C, with extremes of -31.7°C in winter and 38.9°C in summer (Atmospheric Environment Service, 1981). The climate of the region is classified as humid continental with cool summer (Trewartha, 1954).

ICE

Although the air temperature of the Great Lakes region is below the freezing point for up to two months of the year, the large amount of heat stored in the deep water basins prevents the formation of a solid ice cover. Ice formation is limited to the shallower nearshore areas. In the Presqu'ile-Wellington Bay area winter ice is present generally from early December to early April (Allen, 1964). The ice foot and the discontinuous ice cover extend lakeward to the 20 m water depth zone (Rondy, 1976).

The main effect of the ice is to protect the shores from winter storms. The cold climate however, enhances shattering of the argillaceous carbonates of the coastal bedrock outcrops providing loose material to the shore. Some of this material can be ice rafted along shore or offshore. The ice rafted deposits however, are difficult to recognize unless they are of pebble size, as the granular nearshore sediments are readily reworked by storm waves.

WINDS

The study area is subjected to variable wind conditions. The prevailing winds approach the area from the southwest and shift to the northeast from December to March (Canada, Dept. of Transport, 1968). In general, wind speeds are at a maximum (18.0 km/hr) in Spring and Autumn when cyclonic activities are most intense (Canada, Dept. of Transport, 1968). The most important winds from the point of view of wave generation along the shore of the study area, are the prevalent westerly and southwesterly ones.

The wind data utilized in wave climate considerations are those recorded at Stoney Point (Saville, 1953), Cobourg (Brebner and LeMahaute, 1961) and Trenton (Canada, Dept. of Transport, 1968). However, the winds measured inland at Trenton are usually 1.2 times in summer and 2.1 times in winter weaker than those measurable on open waters (Derechi, 1976).

WAVES

The best and more accessible set of data for the study area is that obtained off Cobourg by the Department of Fisheries and Oceans, Canada, during the period April, 1972 to December 12, 1973 (Fig. 3; Fisheries & Marine, 1973). Approximately 3100 wave observations were made, but no wind and waves direction were recorded.

The most frequent waves are those with less than 2 m wave height and less than 7 seconds wave period. The larger storm waves mostly develop during spring and autumn. The complex shorelines of the Presqu'ile-Wellington Bay area, and the presence of numerous elongated shoals and islets reduces greatly the effect of waves on the shores. The waves most effectively reworking the sands in the deep narrow embayments are those approaching from the southwest for which the effective fetch vary between 81 to 94 km. As the waves enter the shallow narrow embayments, they are refracted and local strong longshore drift develops.

Assuming an open, unobstructed nearshore zone, the effect of wave-induced shear stress on the lake bottom sediments can be predicted by calculating the near bottom maximum orbital velocity (U_{max}) using the linear Airy wave equation:

$$Um = \frac{\pi H}{T \sinh (2 \pi h/L)}$$

where

Um = bottom orbital velocity necessary for sediment threshold

L = wave length

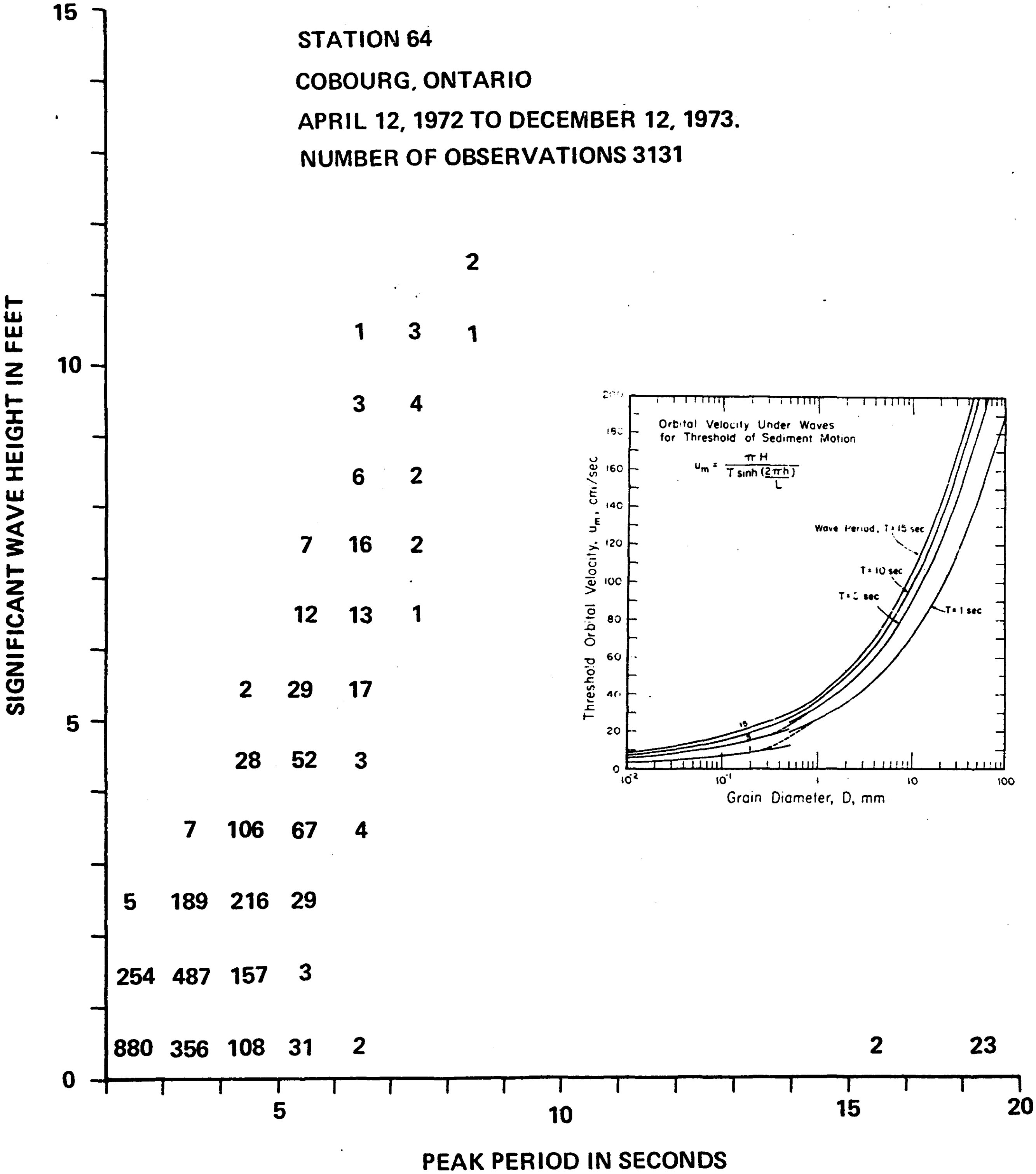


Figure 3. Wave observations at Cobourg. Insert indicates the near-bottom orbital velocity (u_m) for sediment threshold under waves (from Komar and Millar, 1975).

T = wave period

H = wave height

The calculated U_{max} can be compared with the near bottom orbital velocity (U_m) for sediment threshold under waves, using charts such as that prepared by Komar and Millar (1975) (Fig. 3). This indicates that sand particles can be reworked by the frequent waves of 4-5 second period down to about 10 m of water depth. Deeper down to 20 m, sands can be reworked by the more infrequent storm waves having wave height between 2 to 3 m (Table 1). Even allowing for the irregular bottom and irregular outline of the shores, it is expected that most of the nearshore deposits of the Presqu'ile-Wellington Bay area are at some time or another reworked (Fig. 12), and the sandy bottom adjusts to a dynamic quasi-equilibrium profile. Locally on shoals and narrower passages between shoals, erosion of the substratum occurs at depth, forming gravelly sand lag deposits. In other areas, clay and silt deposits can exist at relatively shallow depths under the protection of shoals.

Table 1: Calculated threshold orbital velocity for waves of different period and height and particle size (in phi units) which can be moved at different water depth. (Davidson-Arnott, per. comm. 1983)

Wave Periods (sec)	Water Depth (m)	Threshold Orbital Velocity (m sec^{-1}) (and maximum particle size moveable in phi values (ϕ))				
8	5	1.93	1.61	1.29	-	-
		(-3ϕ)	(-3ϕ)	(-3ϕ)	-	-
	10	1.10	0.95	0.73	-	-
		(-3ϕ)	(-3ϕ)	(-2ϕ)	-	-
	15	0.76	0.63	0.51	-	-
		(-2ϕ)	(-2ϕ)	(-1ϕ)	-	-
	20	0.56	0.47	0.38	-	-
		(-1ϕ)	(0ϕ)	(1ϕ)	-	-
6	5	1.62	1.35	1.08	0.81	-
		(-3ϕ)	(-3ϕ)	(-3ϕ)	(-2ϕ)	-
	10	0.85	0.71	0.57	0.43	-
		(-3ϕ)	(-2ϕ)	(-1ϕ)	(0ϕ)	-
	15	0-52	0.43	0.35	0.26	-
		(-1ϕ)	(0ϕ)	(1ϕ)	(1.5ϕ)	-
	20	0.32	0.28	0.21	0.16	-
		(1ϕ)	(1.5ϕ)	(1.5ϕ)	(3.5ϕ)	-
4	5	-	-	0.56	0.38	-
		-	-	(-2ϕ)	(0ϕ)	-
	10	-	-	0.18	0.12	-
		-	-	(1.5ϕ)	(2.5ϕ)	-
	15	-	-	0.06	0.04	-
		-	-	(<6ϕ)	(<6ϕ)	-
	20	-	-	0.02	0.01	-
		-	-	(<6ϕ)	(<6ϕ)	-
Wave Height (m)		3	2.5	2.0	1.5	1.0

GEOLOGY AND GEOMORPHOLOGY

PALEOZOIC BEDROCK

Middle Ordovician limestones of the Verulam and Lindsay Formations of the Trenton Group underly the study area (Liberty, 1960; Carson, 1981) (Fig. 4). Softer, middle and upper Ordovician shales underly the scoured out central portion of the lake basin (Hough, 1958). The Verulam Formation is comprised of interbedded pale brown, finely crystalline limestone, gray bioclastic limestone and gray and brown shales. It outcrops along a low lying isthmus between the Bay of Quinte and Wellers Bay, and it rims the eastern shores of the peninsula of Prince Edward County.

The Lindsay Formation is characterized by thin, medium crystalline to nodular limestone separated by shaly seams. It covers the whole of the Prince Edward Peninsula, locally forming 3-4 m high bluffs along the south shores.

The Paleozoic strata are essentially horizontal. Several normal faults dissect the region. A fault system cuts through the area between Picton and Athol Bay. It has a measured northward down-throw of 30 m, bifurcates southwestward, and continues with strong subaqueous topographical alignments into the shelf of Lake Ontario. This fault system is considered to represent an extension of the Claredon-Linden fault system of Western New York by Fackundiny et al. (1978).

PLEISTOCENE

A thin veneer of Wisconsinan glacial drift covers parts of the intensely ice gauged peninsula. The drift thickens in the Picton-Wellington Bay corridor where well developed drumlins comprised of calcareous, moderately stony till are interspersed with eskers and glacio-fluvial and

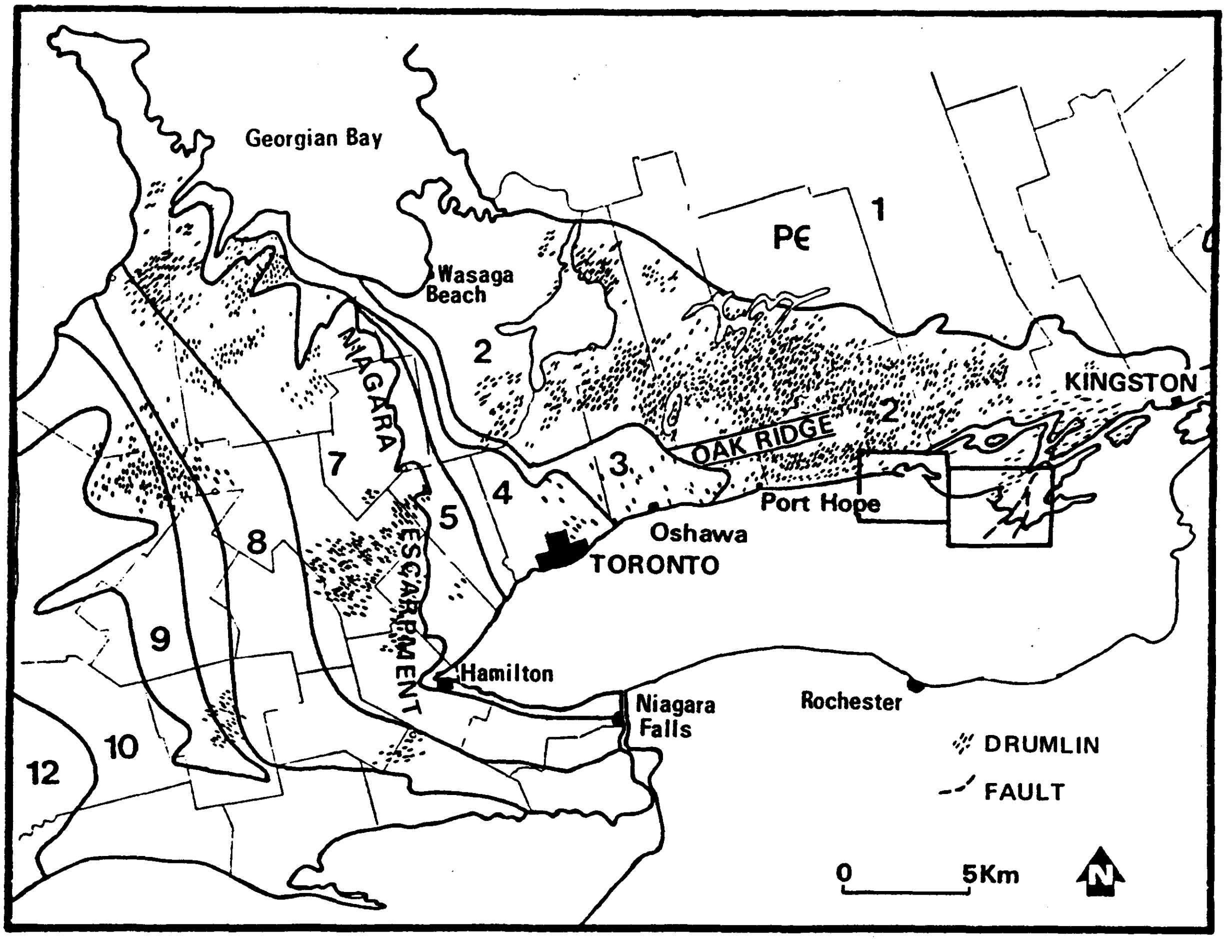


Figure 4. Paleozoic geology and Pleistocene drumlin fields of part of southern Ontario (after Chapman and Putnam, 1966). The units mapped are: PRECAMBRIAN (1); ORDOVICIAN: Trenton-Black River (2), Collingwood (3), Meaford-Dundas, Blue Mountain (4) Queenston (5); SILURIAN: Medina-Clinton (6), Lockport-Guelph (7), Salina and Bass Island (8); DEVONIAN: Bois Blanc (9), Delaware (10); Hamilton (11) (after Martini et al., 1984).

glacio-lacustrine sands (Leyland, 1982). Near Presqu'ile, the northshore of Lake Ontario is underlain by sandy plains onlapping on isolated drumlins and moraines (Leyland, 1982). Whereas in the southern part of the Prince Edward Peninsula there is a strong indication for glaciers flowing to 240-245°, in the northern part another secondary glacial trend is recorded by a few glacial striae trending toward 315-335° (Liberty, 1960; Leyland, 1982).

The stratigraphic sequences exposed along the adjacent bluffs of the Lake Ontario northshore record the existence of several lacustrine phases during Mid-late Wisconsin (Karrow, 1967; Singer, 1974; Martini et al., 1984; Brookfield et al., 1982). Clay-silt rhythmites of relatively deep and protected settings alternate with shallow lacustrine sandy deposits. These lacustrine sequences are interlayered with tills or are locally cut by deep valleys infilled by cross-bedded and ripple-marked sands. The valleys were cut during lower water stages when the glacial lakes were partially drained through outlets exumed from under the retreating glaciers.

HOLOCENE

The glacier retreated from southern Ontario for the last time approximately 13,000 years ago. Lake Iroquois was the glacial lake developed in the Lake Ontario Basin (Coleman, 1937). It has left wave-cut terraces and thin shoreline deposits all along the northshore, well above (up to 35 m) the present day lake level (80 m a.s.l.). Lake Iroquois drained to the Atlantic Ocean through its eastern outlet at Rome (N.Y.). Further retreat of the glaciers into Quebec opened the Covey Hill outlet (Leverett and Taylor, 1915). Lake Iroquois was drained to a level approximately 100 m lower than the present day lake Ontario. The lowest lake level was named the Admiralty Phase (Coleman, 1922). It is marked by a gravel and sand ridge covered by modern muds, mapped by seismic survey approximately 20 km offshore from Hamilton (Lewis, 1969; Lewis and Sly, 1971). A similar feature is believed to exist in the nearshore area in the eastern part of Lake Ontario (Sly and Thomas, 1974).

Post glacial differential isostatic rebound of the eastern shores and outlets of the lake with respect to the western coasts (about 84 m) raised the water line to the Lake Ontario level approximately 10,000 yrs BP (Mirynech, 1962; Sly and Thomas, 1974;Sly and Prior, 1984). The present day level is partially regulated (Blust, 1978; Witherspoon, 1971). It still fluctuates approximately 30 cm annually depending on the season, and up to 1-2 m over longer periods responding to series of wet or dry years. Several nearshore sandy deposits were formed or reworked during the last transgression to the present lake level. The largest deposits are found at the mouth of the Niagara River, at Hamilton, Toronto, and in the Presqu'ile-Wellington Bay area (Rukavina, 1976). During the same transgression, river valleys were drowned and baymouth bars and large spits were formed.

GEOMORPHOLOGY AND COMPOSITION OF SUBSTRATUM

The deep trough of Lake Ontario is subdivided into three major depositional muddy basins by ridges of glacial sediments (Fig. 5; Thomas et al., 1972). The inshore area is locally covered by nearshore sands, but generally contains exposures of till and bedrock.

The inshore study area of Prequ'ile-Wellington Bay is characterized by southwesterly trending, long bedrock ridges protruding onto the shelf as shoals and islets (Fig. 1). The embayments between the shoals extend landwards as drowned valleys barred by well developed baymouth bars

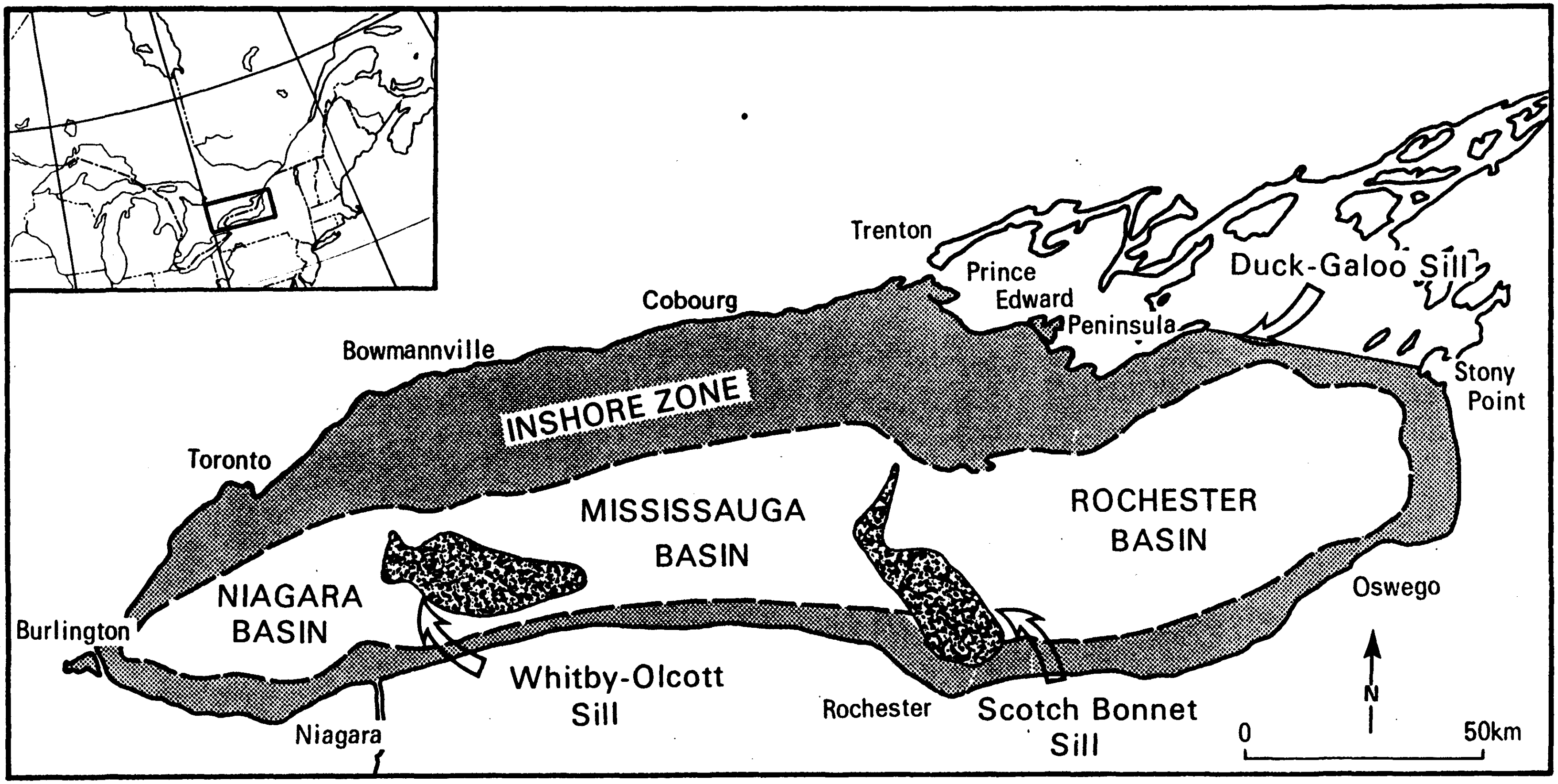


Figure 5. Depositional basins of Lake Ontario.

and tombolos (Presqu'ile, Fig. 1). Each major embayment has developed a nearshore sand cover, generally thick enough to form nearshore bars and smooth out the bottom topography (Gillie, 1974, 1980, 1982). Wellington Bay has a regular offshore gradient of 0.012.

The substratum morphology and the bottom materials were mapped utilizing echograms, bottom samples, cores, jetting, and onshore water well driller's log (Fig. 6; Mirynech, 1962; Rukavina, 1969, 1972; Leyland, 1982; Canadian Hydrographic Services, 1982). Echogram records with smooth, thin density traces are interpreted to represent unconsolidated sediments thick enough to mask underlying bedrock or glacial drift (Fig. 7; Thomas et al., 1972). This is supported by underwater television observations and numerous jettings (Rukavina, 1970). It was not possible to separate consistently the echo-traces of substratum covered by compacted glacial deposits and bedrock. Bottom grab samples and onshore geology aided in arriving at the final representation of the distribution of materials in the nearshore zone (Fig. 8).

Persistent, suitably located, steep dips of the echograms have been interpreted as wide (approximately 600 m) channels, partially buried by Pleistocene or early Holocene sediments (Mirynech, 1962). The generally NE-SW trending channels run along the centre of the embayments of Presqu'ile and Wellers Bay (Figs. 6, 7).

SEDIMENT THICKNESS

The thickness of the loose subaqueous sediments were obtained by jetting to refusal (Rukavina, 1976; Rukavina and LaHaie, 1977). Generally the maximum sediment thickness is found near the baymouth bars and tombolos, and tapers out lakewards (Fig. 8). In the Presqu'ile area a maximum of

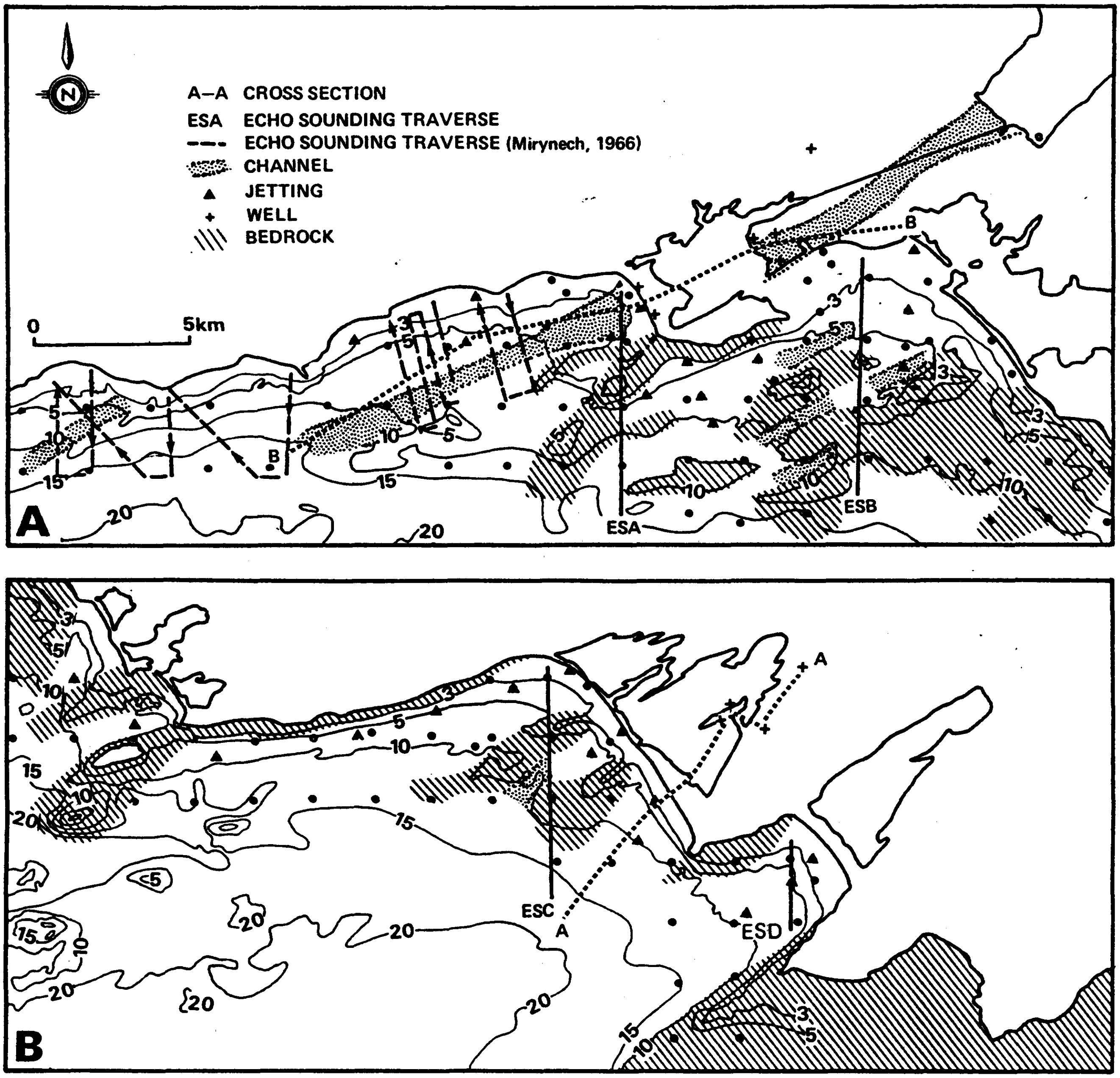


Figure 6. Location of jettings, echosounding records and cross sections reported in this paper.

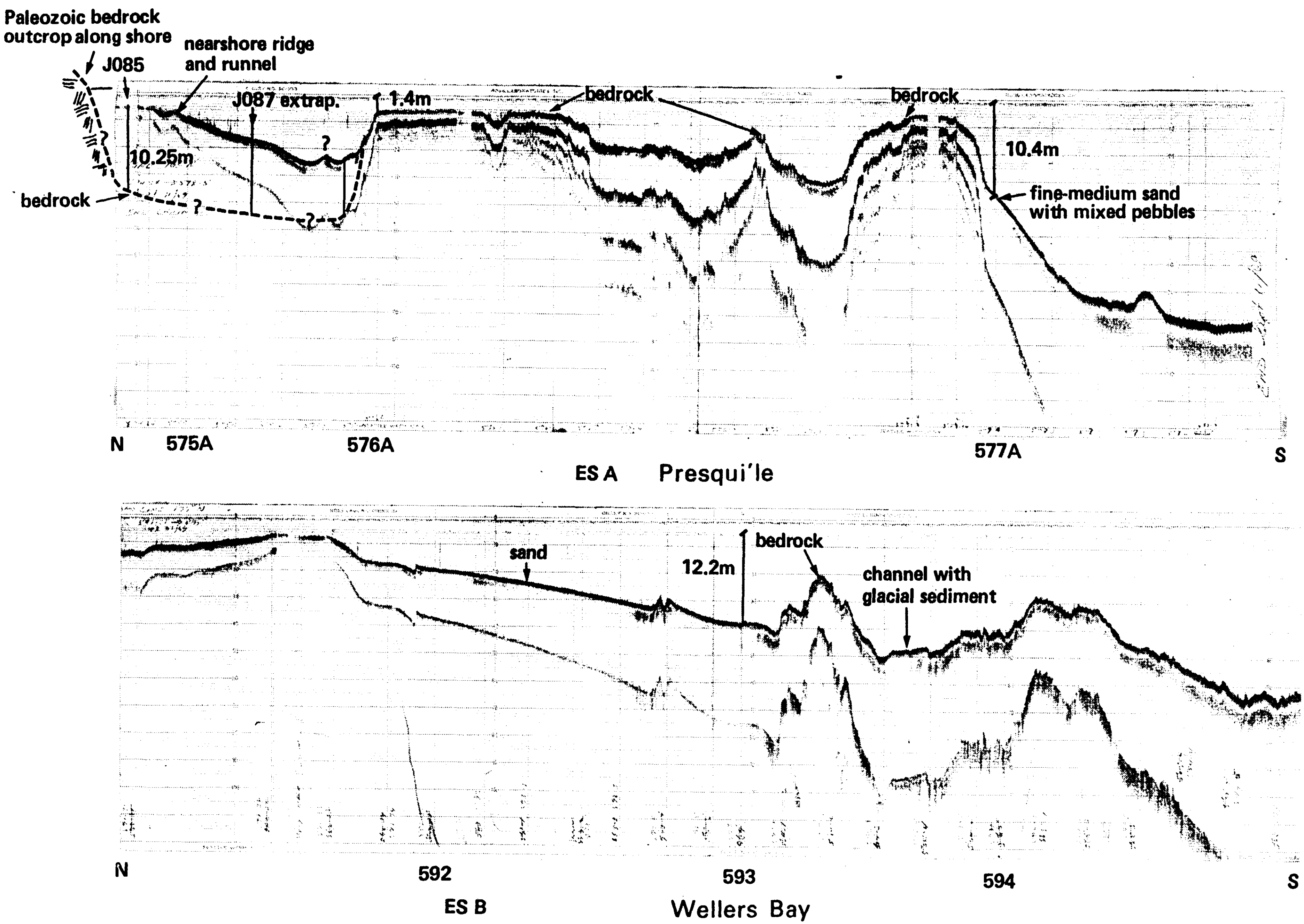
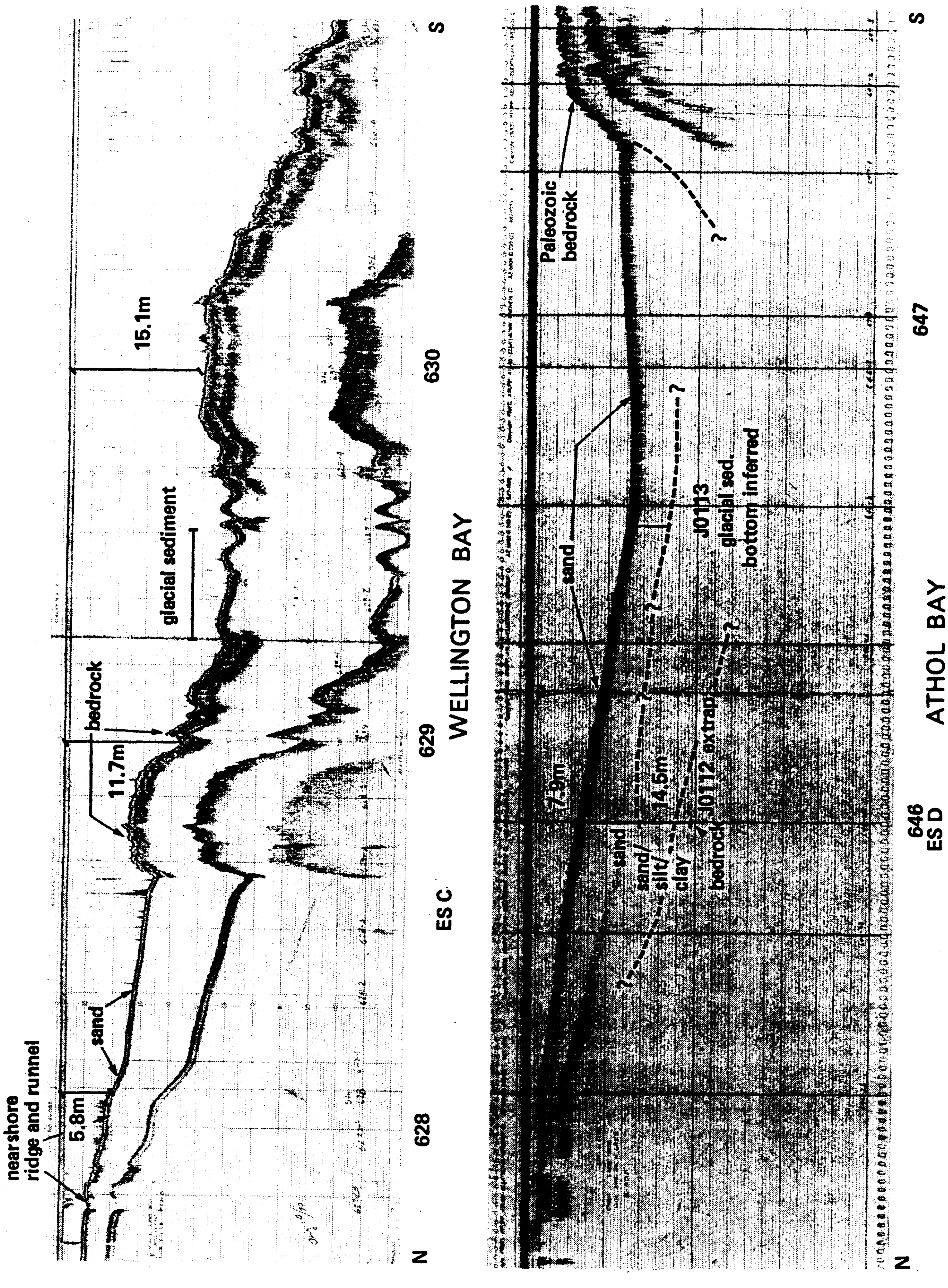


Figure 7. Examples of echosounding traces with superimposed interpretation of types of substratum.


nearshore ridge and runnel
5.8m
sand
11.7m
bedrock
glacial sediment
15.1m
N
628
ESC
629
630
S
WELLINGTON BAY
Paleozoic bedrock
sand
7.9m
14.5m
sand
sand/
silt/
clay
bedrock
J0112 extrap.
J0113
glacial sed.
bottom inferred
N
646
ESD
647
S
ATHOL BAY

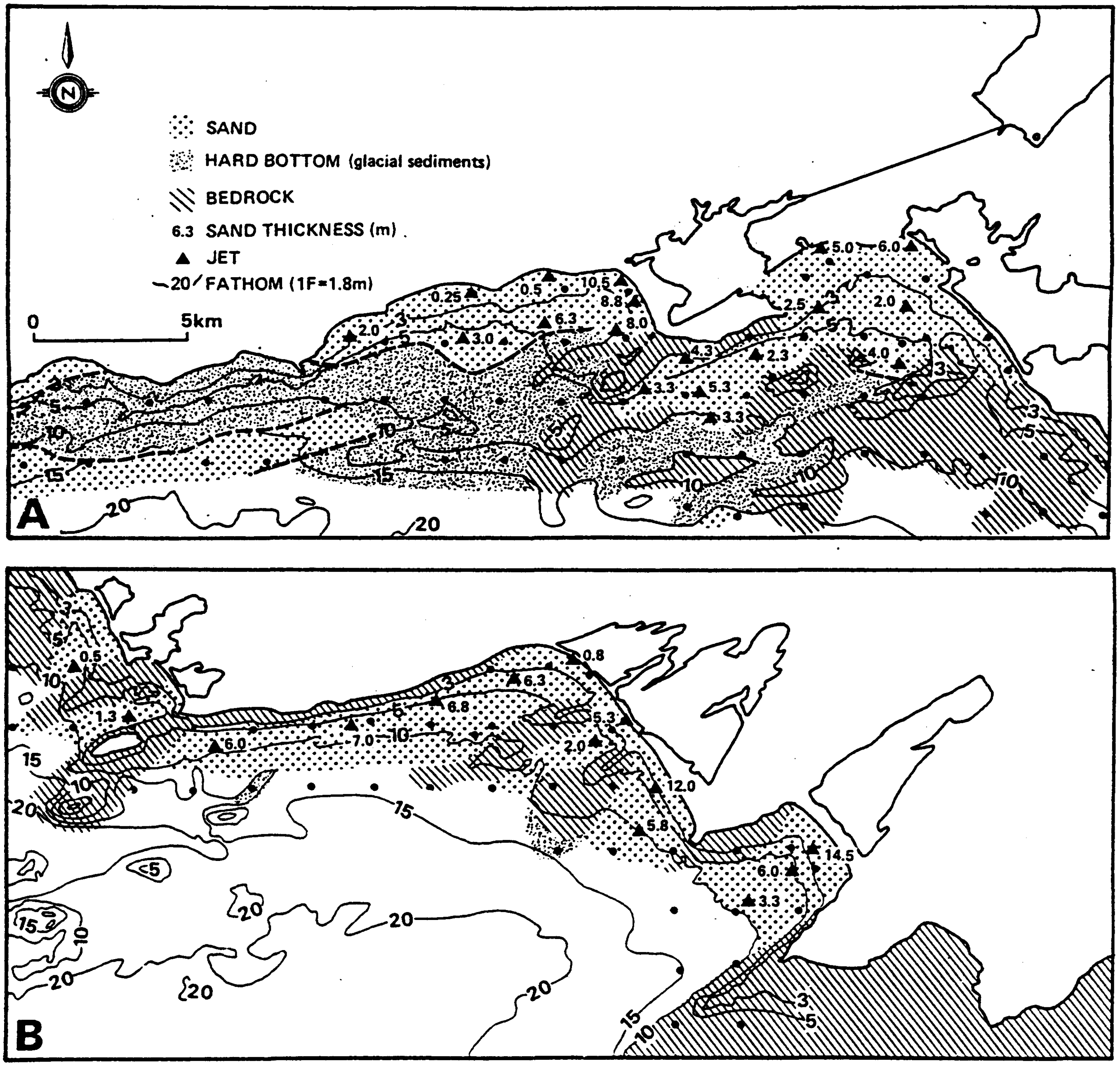


Figure 8. Distribution of types of substratum and thickness of sands obtained from jetting of refusal.

10-25 m of sand was measured near the tombolo. The sand thins lakeward, but its thicker portion follows the partially buried channel. The maximum thickness of sediment in the Wellers Bay area is about 6 m nearshore. However, deposits of up to 2.25 m and 5.25 m thickness are also found at 9 to 20 m of water depth presumably associated to the irregular bottom topography.

The sandy deposits of Wellington Bay are separated by two southwesterly trending subaqueous rock ridges. The northern deposit lies in water deeper than 9 m, it is separated from the rocky shore, and reaches a maximum thickness of 6.75 m. The central sand body is relatively thin and tapers from 5.25 m nearshore to about 2 m in water depth of 12 m. The southernmost sand body is the thickest of the three and reaches 12 m nearshore.

In Athol Bay, the subaqueous sand body is 14.5 m thick nearshore, and has subaerial sand dunes reaching a thickness of 10 m (Leyland, 1982).

SAND PETROGRAPHY

Modal analysis (300 to 400 point counts) of five representative thin sections from the Presqu'ile, Wellington and Athol Bay areas classify those sediments as 'lithic sands' (Pettijohn, 1957). Quartz is the most common mineral (45.8% to 56.4%), followed by carbonate grains (7.03% to 30.94%), heavy minerals (8.1% to 31.28%) and feldspar (3.26% to 11.27%). Few microcrystalline quartz grains and scattered shell fragments are present.

Generally the grains look fresh, except for some feldspars (traces to 2.4%) which show substantial weathering. Heavy minerals do not show any noticeable alteration due to chemical weathering.

The quartz, feldspars and heavy minerals are angular to subrounded. The carbonates grains vary more widely, from angular to well rounded. The zircon and tourmaline grains are generally subangular to subrounded, except for one sample in the Presqu'ile area where they are subrounded to well rounded.

GRAIN SIZE

STATISTICAL ANALYSES

The grain size distributions were subjected to several statistical manipulations to subdivide them into groupings which could potentially indicate the source of the material and/or the environments of sedimentation. The average grain sizes of the Presqu'ile-Wellington area fall in the medium to fine sand classes. The Q-mode factor anaysis applied to all available samples (107 no., Fig. 1) utilizing the untransformed frequencies (percent) of each determined size class (Klovan, 1966; Klovan and Imbrie, 1971) indicates that a three varimax factors account for more than 95% of the variability. The triangular plot of the loadings of the samples on the factors reveals that a good separation exists between Factor I and Factor II. However, a continuous grading occurs between them and Factor III. A scanning of the sample loadings on the correspondent oblique factors, indicates that those samples which load 60% or more on their respective Oblique Factors I and II, have specific diagnostic frequency distributions (Fig. 9). The samples which are grouped with the Oblique Factor III have various types of grain size distributions, some plotting toward the center of the diagrams and represent poorly sorted mixtures of particle sizes.

To improve the separation of the various grain size types and to be able to place objective boundaries between the groups, the cluster and

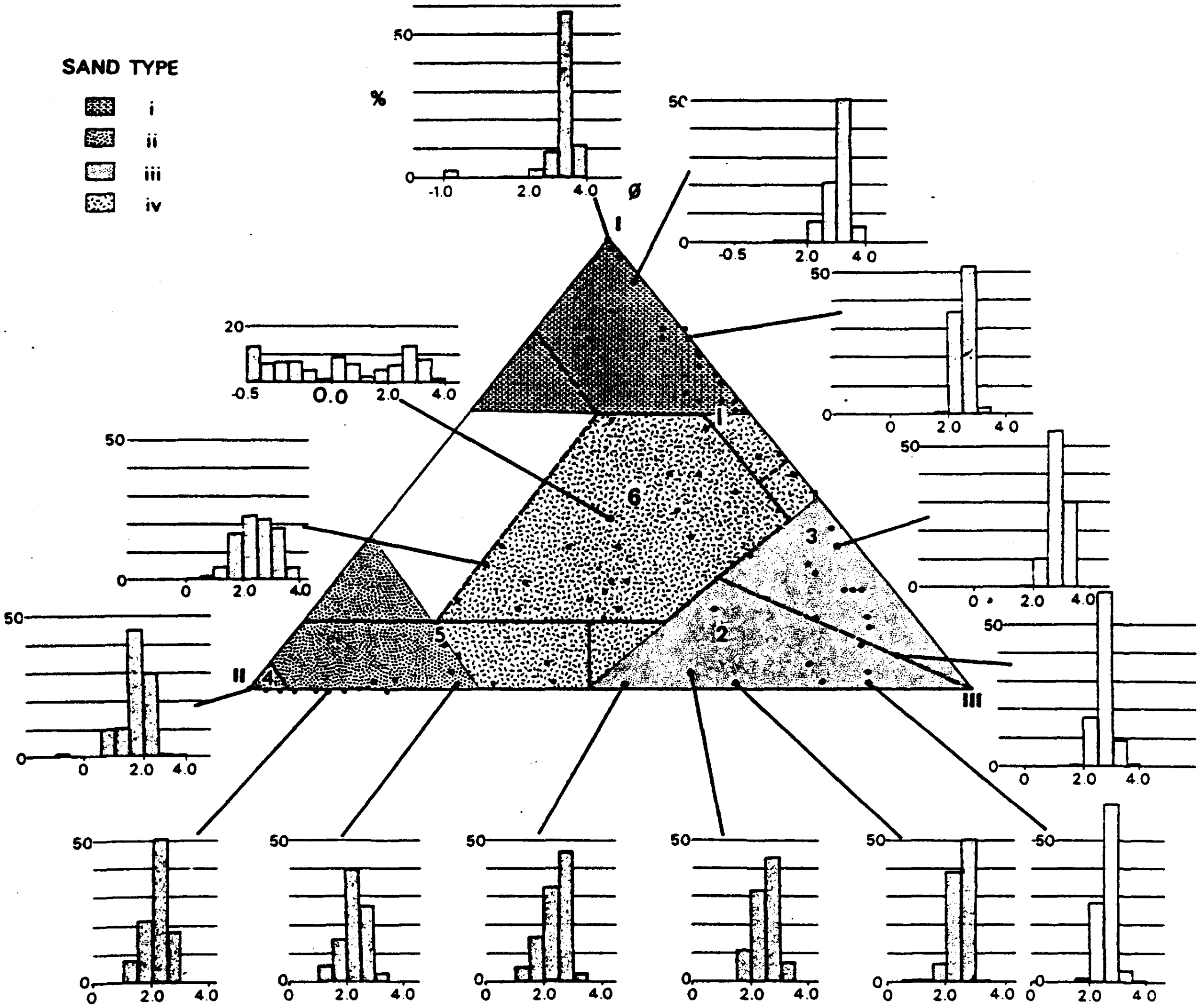


Figure 9. Types of sands (i, ii, iii) are displayed with different patterns on a triangular loading diagram of the three principal Q-Factors (I, II, III). The clusters (1 to 6) determined through cluster and discriminant analyses have been superimposed on the triangular scatter diagram. Their boundaries are indicated by heavy lines. The histograms represent typical grain size distributions.

discriminant analyses were run on the surficial grab samples, and the resultant discriminant functions were used to classify the core samples which were considered as belonging to unknown environments. Cluster analysis separates the data set into six groups with very few cases of misclassification. There is a close relationship between the trends indicated by the factor analyses and the clusters. Cluster 1 retrieves the samples loading heavily on Q-Factor I. The samples loading preferentially on Q-Factor II were subdivided into two clusters, one (Cluster 4) including a few samples representing the extreme samples identified by factor analysis, and a larger cluster (5) which splits the continuum between Factors II and III (Fig. 9). The wide range of grain size distributions originally associated with the Q-Factor III, can be subdivided into two fields by identifying those that load more heavily on the oblique Q-Factor III from those that have similar loadings on all three factors and plot toward the center of the trangular diagram (Fig. 9). Cluster and discriminant analyses recognize the central heterogeneous cluster, and subdivide further the field of samples loading more heavily on the oblique Q-Factor III (Fig. 9).

Essentially, the cluster and discriminant analyses confirm and refine groupings of samples, objectively setting boundaries along the trends indicated by factor analysis. Note that whereas the location of the samples in the triangular diagram is according to the normalized varimax matrix, the shading identifying the factor fields is according to the normalized oblique matrix (Klovan and Imbrie, 1971). The extreme samples identified by the oblique rotation of Factors I and II plots at or near the vertices of the diagram indicating strong similarity between the varimax and oblique factors. Thus the samples loading heavily on these oblique factors cluster around those vertices. The oblique Factor III is forced through an extreme sample which does not plot at the vertix of the varimax triangular diagram, thus the field of samples loading heavily on this oblique Factor III appears distorted (Fig. 9).

TYPES OF SAND

The multivariate statistical analyses carried out indicate that the grain size distributions measured in the nearshore area of Presqu'ile-Wellington Bay can be separated into six groups. From these, four major types of sediments are considered to be geologically significant.

Type i (Factor I, Cluster 1) This is a very fine to fine grained sand (av. 3.33 ϕ), well to moderately sorted (av. S.D. 0.91 ϕ), unimodal to slightly bimodal. This sand generally has a nearly symmetrical to coarsely (negatively) skewed distributions with some finely (+) skewed exceptions, and is generally either mesokurtic to leptokurtic.

Type ii (Factor II, Clusters 4, 5) This type represents the coarsest end member of the measured grain size distributions. It is a fine to medium (av. 2.0 ϕ) grained sand, moderately well sorted (av. S.D. 0.82 ϕ), coarse (-) to fine (+) skewed, leptokurtic. Two sub-classes are distinguished by cluster analysis. Cluster 4 is characterized primarily by a mean grain size of 1.64 ϕ, it is moderately well sorted (av. S.D. 0.67 ϕ), symmetrical to coarse (-) skewed, leptokurtic to extremely leptokurtic. Cluster 5 has a mean grain size of 2.23 ϕ moderately well to poorly sorted (av. 0.96 ϕ), varing from coarse (-) to fine (+) skewed, leptokurtic to very leptokurtic. Cluster 5 represents the gradation of type ii to type iii sand.

Type iii (Factor III, Clusters 2, 3) This is an intermediate type sand, fine grained (av. 2.62 ϕ), well to moderately well sorted (av. S.D. 0.65 ϕ), generally near symmetrical with a few samples coarsely skewed (-), and generally mesokurtic with some leptokurtic samples. Two subclasses (clusters) have been distinguished. Cluster 2 is characterized primarily by a mean grain size of 2.39 ϕ, generally moderately well sorted (av. S.D. 0.56 ϕ) while Cluster 3 has a mean grain size of 2.86 ϕ and it is generally moderately well sorted (av. S.D. 0.73 ϕ). Both Cluster 2 and 3 sands are coarse (-) to fine (+) skewed and mesokurtic to leptokurtic.

Type iv (Factor III, Cluster 6) This type of sand represents a mixed group of samples. In general it is characterized by fine to medium sand (av. 2.60 ϕ), poorly sorted (av. S.D. 1.07 ϕ), occasionally showing multimodality. It has mesokurtic to platykurtic distributions with coarse (-) to fine (+) skewnesses. Essentially this material represents a potential mixed source from which the other types of sand can be derived through sorting and winnowing processes.

AREAL DISTRIBUTION OF SAND TYPES

The four major sand types are generally separated geographically (Fig. 10). Type i occurs primarily in Athol Bay and the southwestern side of Wellington Bay. Few other occurrences generally exist landward from protective shoals (Fig. 10). This sand is found consistently in water depths greater than 5 m in sheltered embayments having regular sloping smooth bottoms (Athol Bay, Fig. 7).

Type ii is restricted primarily to elongated sand bodies in the Presqu'ile-Wellers Bay area (Fig. 10). It is found generally in deep water (10-20 m), although a few samples occur in water less than 5 m deep. The distribution of this sand matches closely the trend of the partially buried

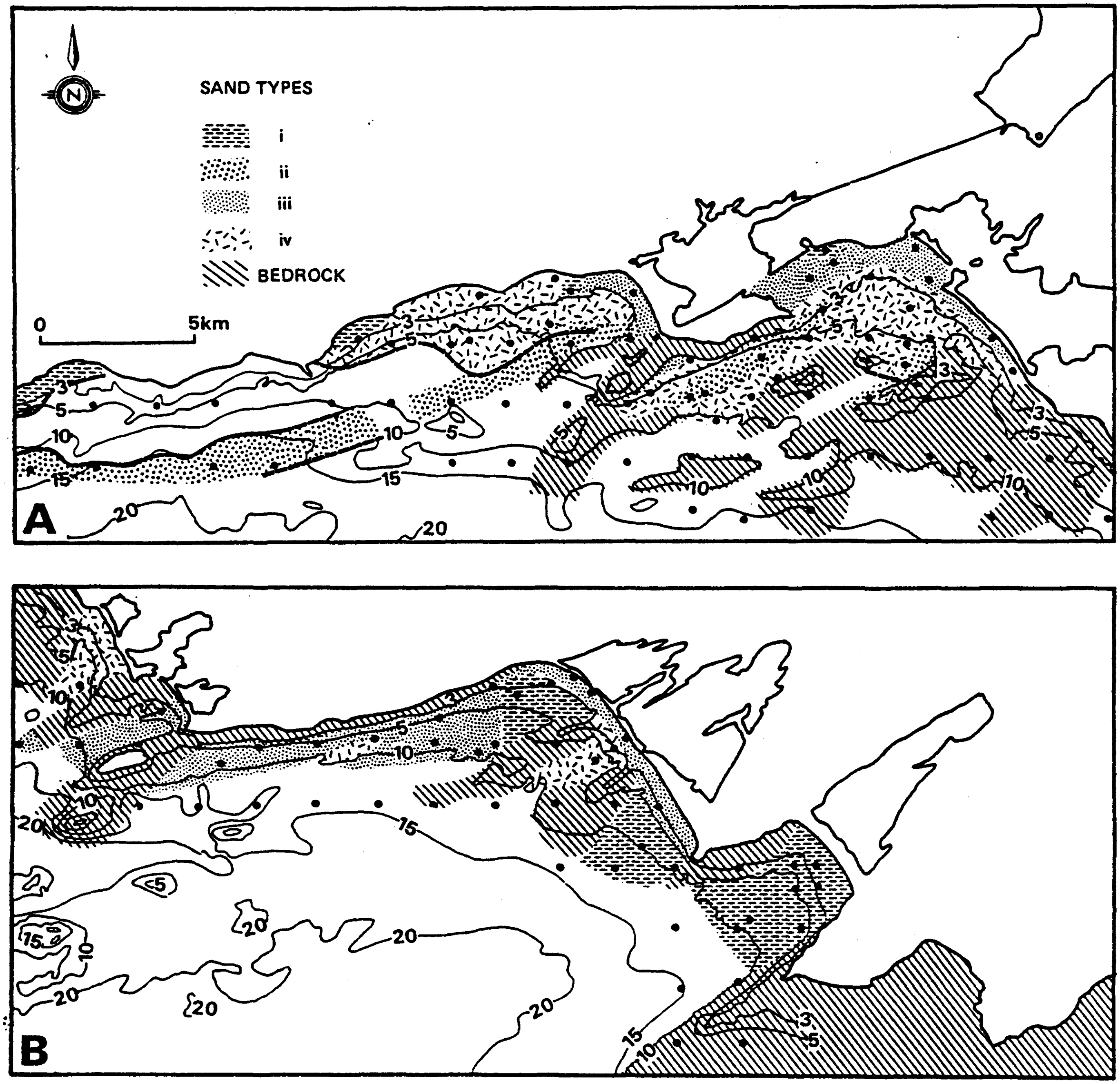


Figure 10. Areal distribution of the types of sand.

Pleistocene channels (Figs. 6, 10). In other areas it characterizes thin lag deposits.

Type iii is restricted to nearshore areas in water depth less than 5 m except in Wellington Bay and Huych's Bay where it reaches down to more than 18 m water depth. Immediately lakeward of the Presqu'ile tombolo and the baymouth bars of Wellers Bay and Wellington Bay, this type of sand show a well defined southeastward alongshore fining trend. Similar downdrift fining has been reported on the onshore beaches of Presqu'ile and Wellington Bay (Ernstring, 1976; Peat, 1973). No such trend has been detected along the beaches of Athol Bay (Mitchell, 1976). The sand bars of Wellers Bay have not yet been studied. Samples of this sand found in deeper waters (10-20 m) along the northshore of Wellington Bay show an overall eastward fining trend, but local anomalies in mean size and sorting suggest that the trend may not be a direct result of present day downdrift variation (Fig. 11).

Type iv sand is found along the northshore of the Presqu'ile area, in large zones in Wellers Bay, and in restricted bands in central Wellington Bay. It is generally found at water depth between 5 and 15 m. However, this "type" of sand collates variable distributions which do not fit in the other "types". Thus Type iv does not indicate a specific environmental setting, except perhaps one of sediment bypass and erosion, where strong local variations may occur.

AREAL DISTRIBUTION OF STATISTICAL PARAMETERS

The statistical parameters of the various subaqueous samples can be compared with those of onshore samples only in a semi-quantitative fashion because only the sand fraction was analysed on the beaches and sand dunes. Due to the usually low amount of fines in those onshore environments

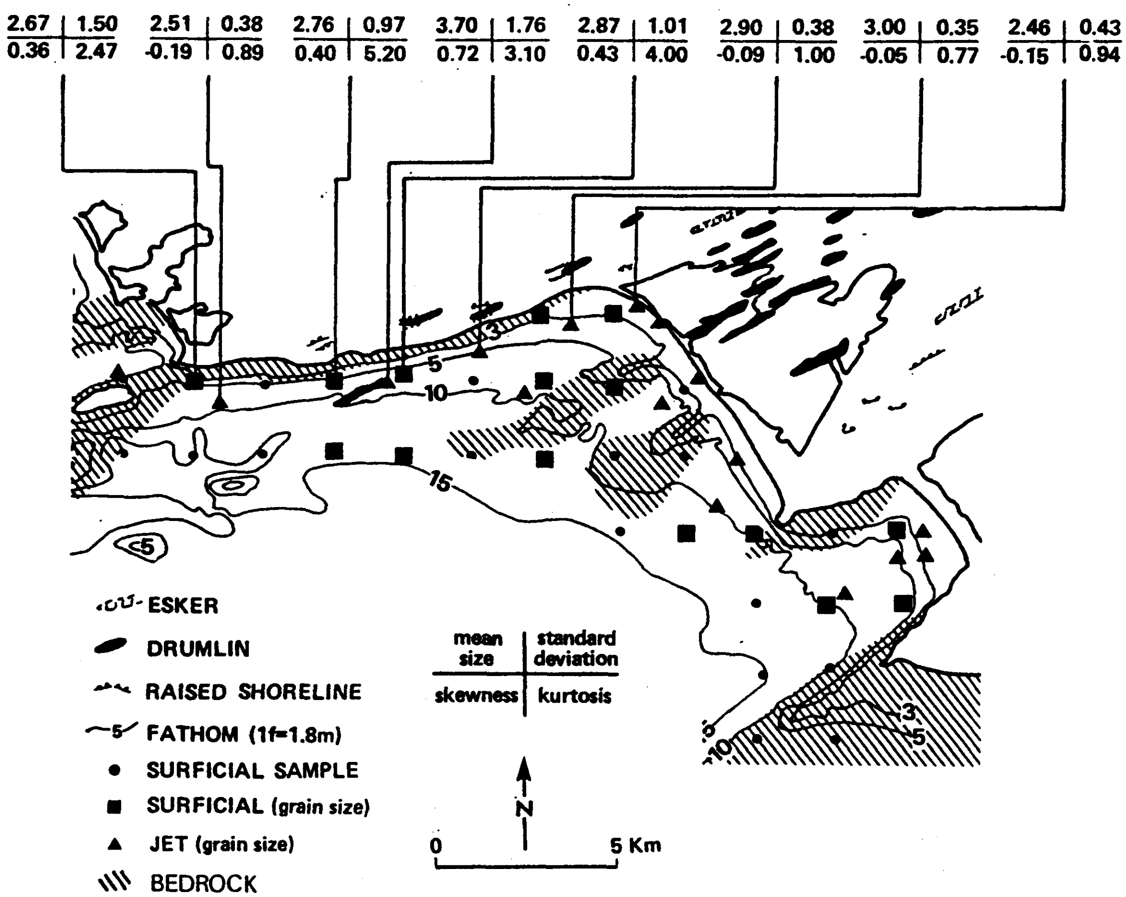


Figure 11. Grain size statistics and distribution of drumlins along the northern flank of Wellington Bay.

the mean grain sizes are not greatly affected, however the sorting parameters may be misleading.

Average grain sizes of the offshore samples show generally coarser materials (Type ii sand) in the Presqu'ile area, intermediate sizes in the Wellers and Wellington Bays, and finer sizes in Athol Bay (Type i sand) (Figs. 10, 12). However, this regional variation is not duplicated in the beaches where coarser size is found in Wellington Bay (av. 1.96 ϕ; Peat, 1973) and relatively finer sizes are found in Presqu'ile (av. 2.5 ϕ; Ernstring, 1976) and Athol Bay (av. 2.4 ϕ; Mitchell, 1976). The various embayments neither behave similarly in the onshore-offshore overall grain size variations, nor in variation with depth below the surface. In Athol Bay the average grain size does not change significantly with water depth below 5 m. In Wellington Bay the expected overall gradual fining offshore of the samples is achieved (Figs. 12, 13A). In Presqu'ile and Wellers the trend is reversed and there is a general overall fining from the offshore deeper samples to the nearshore subaqueous sands (Figs. 12, 13B). As for variation with depth below the surface, the cores from Wellington Bay do not show any vertical consistent variation in grain size (Fig. 14). The cores from Wellers Bay taken near the baymouth bar show instead a well defined coarsening upward trend and a consistent transition from type iii to type i sand (Fig. 12).

Sorting characteristics of the offshore samples, as measured by standard deviation, show a consistent good sorting nearshore (0.36-0.5 ϕ), moderately well sorted distributions in deeper samples (0.5-0.82 ϕ), and poor sorting (up to 2.83 ϕ) of some samples collected from thin (less than 0.5 cm) lag deposits on hard substratum, particularly in the Presqu'ile and Wellers Bay areas. Although the standard deviation values of the onshore

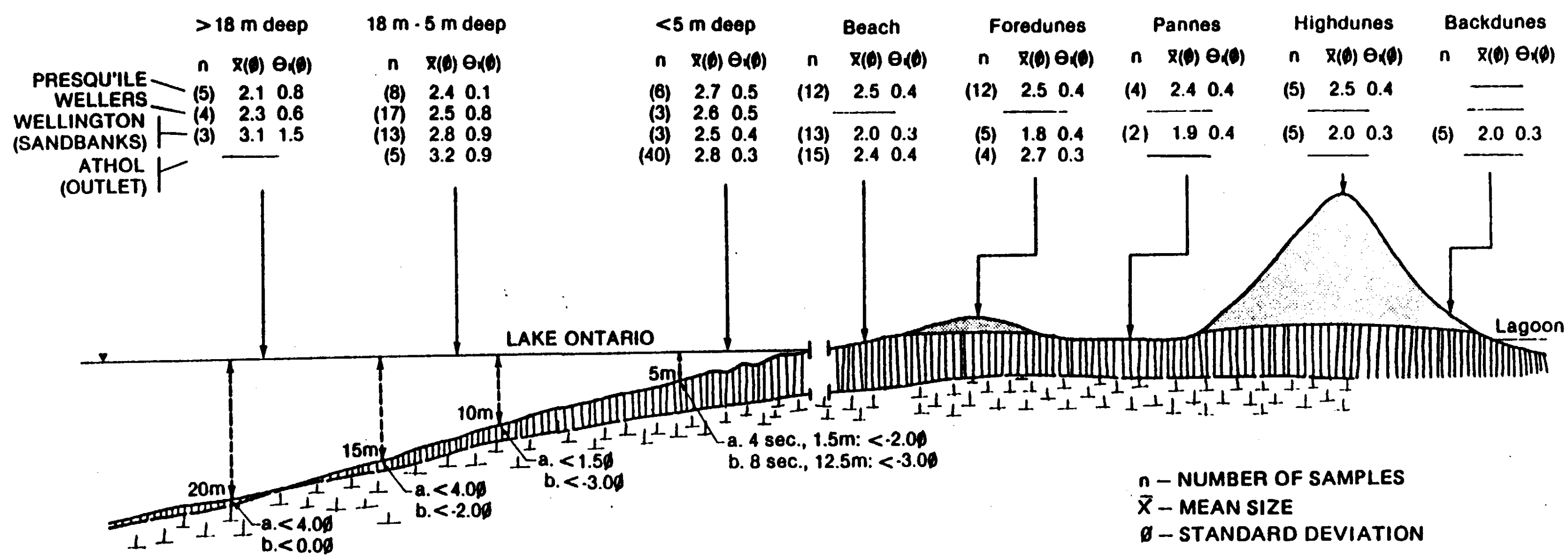


Figure 12. Idealized cross sections of the offshore-onshore system of the Presqu'ile-Wellington Bay area, showing estimated thickness of unconsolidated sediment, average grain size statistics of the different zones, and size of particles that can be reworked at the indicated water depths under waves of different frequency and height.

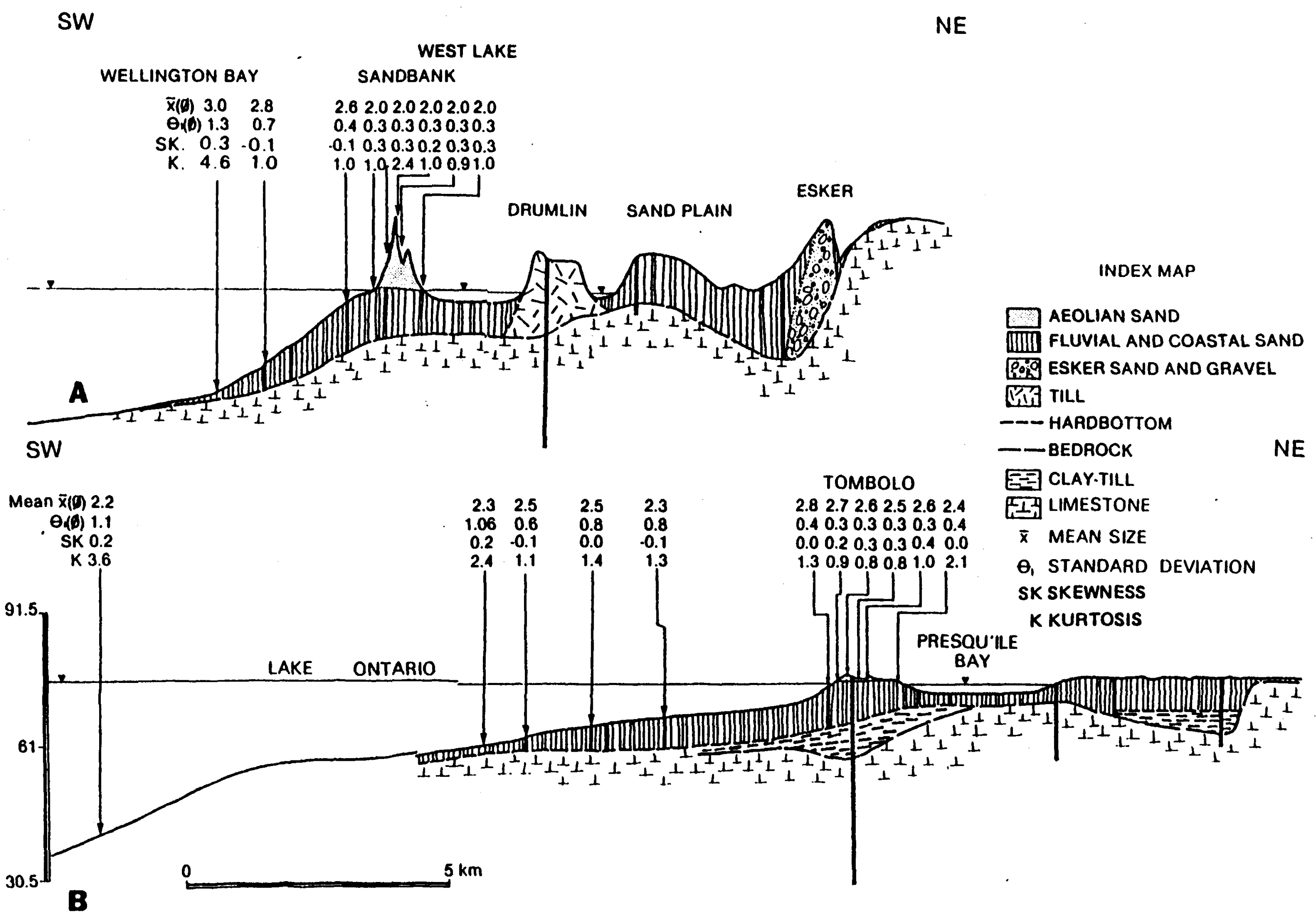


Figure 13. Skematic cross sections of Wellington Bay and Presqu'ile showing thickness of unconsolidated sediments, and grain size statistics (single samples) of the different environments. Onshore, only sand grades were treated by sieving.

samples cannot be strictly compared with those from the offshore, they show the expected improved sorting in most of the beach and in the aeolian dunes (Figs. 12, 13).

The beach and dune sands are generally finely (+) skewed. In the shallow (less than 5 m of water) offshore areas coarse (-) skewed samples are most common (Fig. 13). In deeper (5-18 m) waters and in protected sinks behind shoals, the samples vary from coarse to fine skewed, but generally they are nearly symmetrical, except in Wellington Bay where coarse (-) skewed samples prevail (Fig. 13). Several samples collected from waters deeper than 18 m are finely to strong finely (+) skewed (Fig. 13). Most of these samples have been described as glacial sediments at the time of sampling by geologists of the National Water Research Institute.

Except for a few anomalies such as those in parts of Presqu'ile, the kurtosis of the subaqueous sands show a general gradation from mesokurtic distributions in shallow waters to leptokurtic distributions in deeper water (to 30 m) farther offshore.

SEDIMENTARY STRUCTURES

Sedimentary structures were studied in X-radiographs of small vial-cores (3-6 cm deep) and of five longer piston cores (Figs. 14, 15).

The predominant structures observed in the vial-cores are ripple cross laminations, parallel laminations and slump features. The ripple marks are found exclusively in the shallower areas and they are associated commonly with parallel laminations, possibly formed in the upper phase plane beds (Allen, 1982).

Parallel laminations alternating with apparently massive units and with some burrowed units prevail in the deeper offshore areas. In the

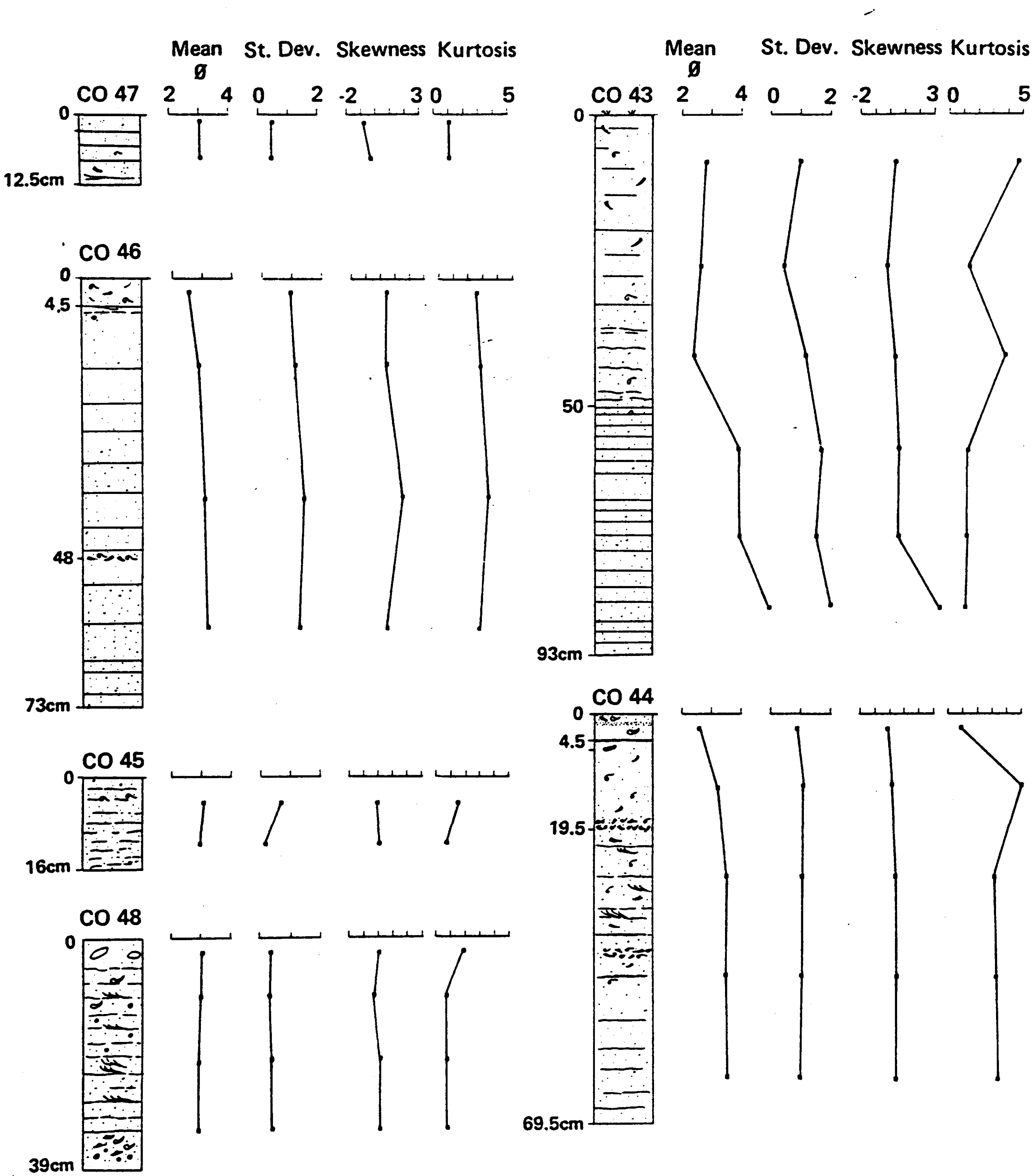


Figure 14. Sedimentary structures, and vertical variations in grain size statistics in long piston cores.

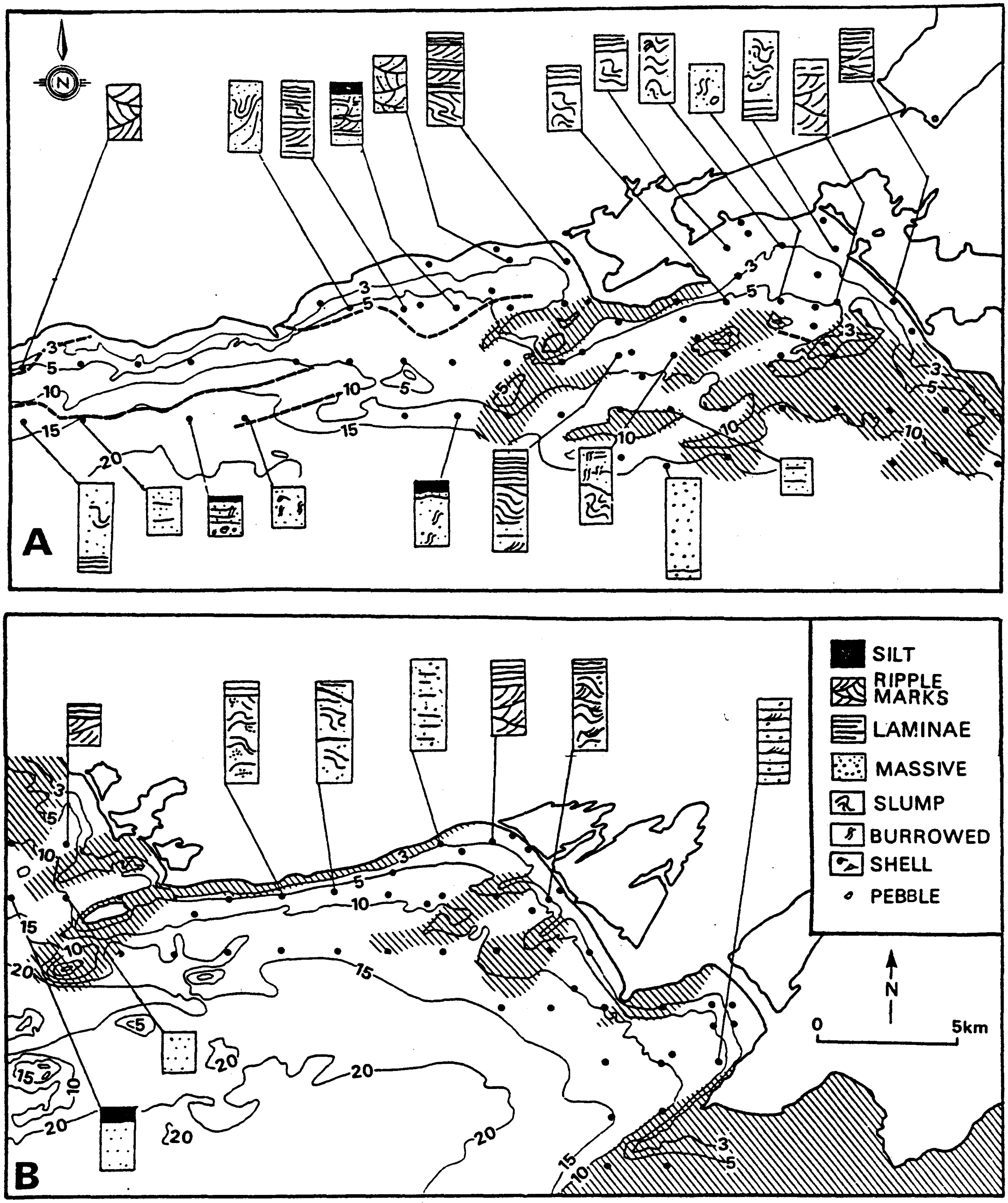


Figure 15. Sedimentary structures observed in X-radiographs of short vial-cores obtained from undisturbed Shipek samples.

deeper areas there is commonly a top thin (1-2 cm) layers of silt in each core. Slumping is relatively common and it does not appear to be related to any specific environment. In many intances slumping may be a sampling artifact.

The longer piston cores show few ripple marks, partly because the thicker samples do not allow the necessary fine resolution in X-radiographs. The flexible sleeves where the samples were collected in, have not prevented them from disturbance. The prevalent visible structures are parallel laminations alternating with non-descriptive apparently massive, to cross-laminated layers. A few shells are scattered throughout the cores or are concentrated in thin laminae possibly representing storm layers. Ripple marks alternating with plane beds and with numerous pebbles scattered throughout are found in a core taken in shallow water in front of the baymouth bar in Wellington Bay. This indicates the possible presence of bedrock near the surface and perhaps some ice rafting of coarse material. The shallow cores taken in front of the Presqu'ile tombolo show scattered iron sulphides dark spot throughout (Fig. 14). No noticeable amount of burrowing activity has been observed.

The distribution of sedimentary structures suggest a storm dominated setting generating ripples and plane beds in shallow waters except for some very fine sand and silt drapes in sheltered areas; and a predominance of parallel laminations due to extreme storm conditions or vertical deposition in the offshore deeper environments. Note that the present sampling does not include the nearshore barred zone. Some of the massive units in the deeper water may be related to glacial deposits.

HEAVY MINERALS

The analysis of heavy minerals in the Presqu'ile-Wellington Bay Area has several objectives: a. whether there are significant differences between the surficial few millimeters of each sample and the underlying laminae; b. whether there is any difference between the various embayments; c. whether there are differences or similarities between the nearshore deposits and the Pleistocene materials exposed both along the northshore bluffs and farther inland. If differences are detected it would be of interest to determine whether they are due to different sources, differential sorting or weathering.

A series of heavy mineral mounts (59) were made from the fine sand fractions of samples from Presqu'ile-Wellington area, the Pleistocene sands exposed along the Bowmanville-Port Hope Bluffs and other areas in Southern Ontario. The resultant data were subjected to multivariate statistical analyses both separately and together with similar data obtained by Gwyn (1971) from tills of central-eastern Ontario and Quebec. Comparison of our results with those of other studies in the lake Ontario Basin had to be made on a qualitative mode as the data were not quantitatively comparable because of slight difference in the techniques used.

HEAVY MINERALS IN PRESQU'ILE-WELLINGTON BAY

Statistical Analyses

The heavy mineral concentrations of samples from Presqu'ile-Wellington Bay have been analyzed through several runs of factor analysis, cluster and discriminant analyses. Transformed ($\log_{10}(x_i+1)$) and untransformed data, and various sets of variables have been used.

The R-factor anaysis indicates that strong correlations occur between the red garnet and several other minerals, and that 72% of the variance is explained by the five factors solution we have retained here. Gwyn and Sutterlin (1972) and Gwyn and Dreimanis (1979) have demonstrated that by manipulating the variables properly, a six factors solution explains more than the 85% of the variance. Our five factors solution was considered satisfactory as it is also useful in interpreting the results of the Q-mode factor analysis and of the correspondence factor analysis.

The five factors (R-Factors) are associated primarily with:

R-Factor I: Purple and red garnet and total heavy mineral concentration

R-Factor II: Staurolite and secondary epidote, chlorite and sphene

R-Factor III: Zircon

R-Factor IV: Horneblende and perhaps mica

R-Factor V: Rutile

The Q-mode factor analysis indicates that the first two factors explain approximately 96.65% of the variance, and that the addition of a third ill-defined factor brings the variance explained to 97.51%. The overfitted three factors solution has been retained (Fig. 16). Q-Factor I is characterized primarily by samples containing high concentrations of zircon and clinopyroxene. Q-Factor II is characterized by purple and red garnet, and relatively high concentrations in opaques and sphene. Factor III is typical of samples with variable compositions, but the extreme sample (identified by oblique rotation of the factor) shows higher concentrations of tourmaline, tremolite-actinolite and more opaques than Q-factor I. This assemblage is similar to that of minerals loading consistently negatively on the five R-Factors.

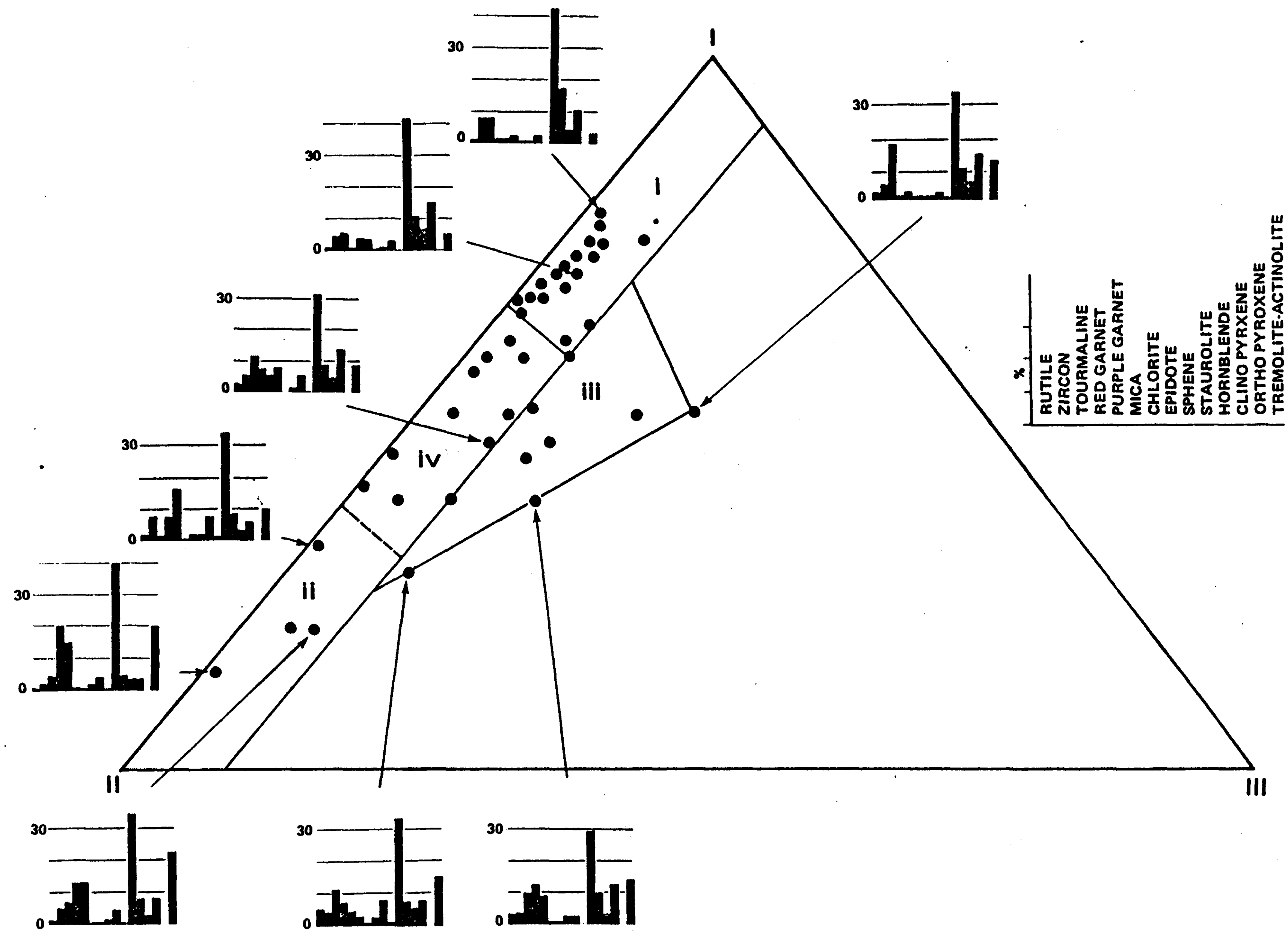


Figure 16. Types of heavy mineral assemblages (i, ii, iii) displayed on a triangular loading diagram of the three principal normalized Q-Factors (I, II, III). Clusters (1 to 4) have been superimposed on the triangular scatter diagram. Histograms show the frequency distribution of heavy minerals. The opaques were measured

The cluster analysis and discriminant analysis succeed in splitting the "gradient" between Q-Factors I and II into four clusters. They have not retrieved the groups of samples loading preferentially on Q-factor III (Fig. 16).

A final step in the statistical analysis was to run a correspondence factor analysis on all samples, including all variables measured except those of the unknown class. This analysis vindicates the choice of five R-Factors as they can all be clearly separated in the correspondence analysis plot (Fig. 17). However the three dimensional display of the results reiterates the danger of working with projections. For instance, the garnet and the total heavy mineral concentrations are clearly separated in correspondence analysis while they are together in R-Factor I. The correspondence analysis re-confirms the loose association between staurolite, epidote and sphene.

Types of Heavy Mineral Assemblages

The statistical results have been used as guidelines to define four types of heavy mineral assemblages.

Type i comprises samples loading heavily (more than 0.740) on oblique Q-Factor I. They are included in cluster 1 and are grouped around the zircon in the correspondence analysis plot (Fig. 17). This assemblage has relatively higher content of tremolite-actinolite and has low concentrations in garnet, epidote and almost no staurolite (Fig. 16).

Type ii comprises the few (3) samples loading heavily (more than 0.740) on the oblique Q-Factor II. These samples belong to Cluster 4 except for one sample which has been included in this assemblage because it is shown to be closely associated with the others by the correspondence

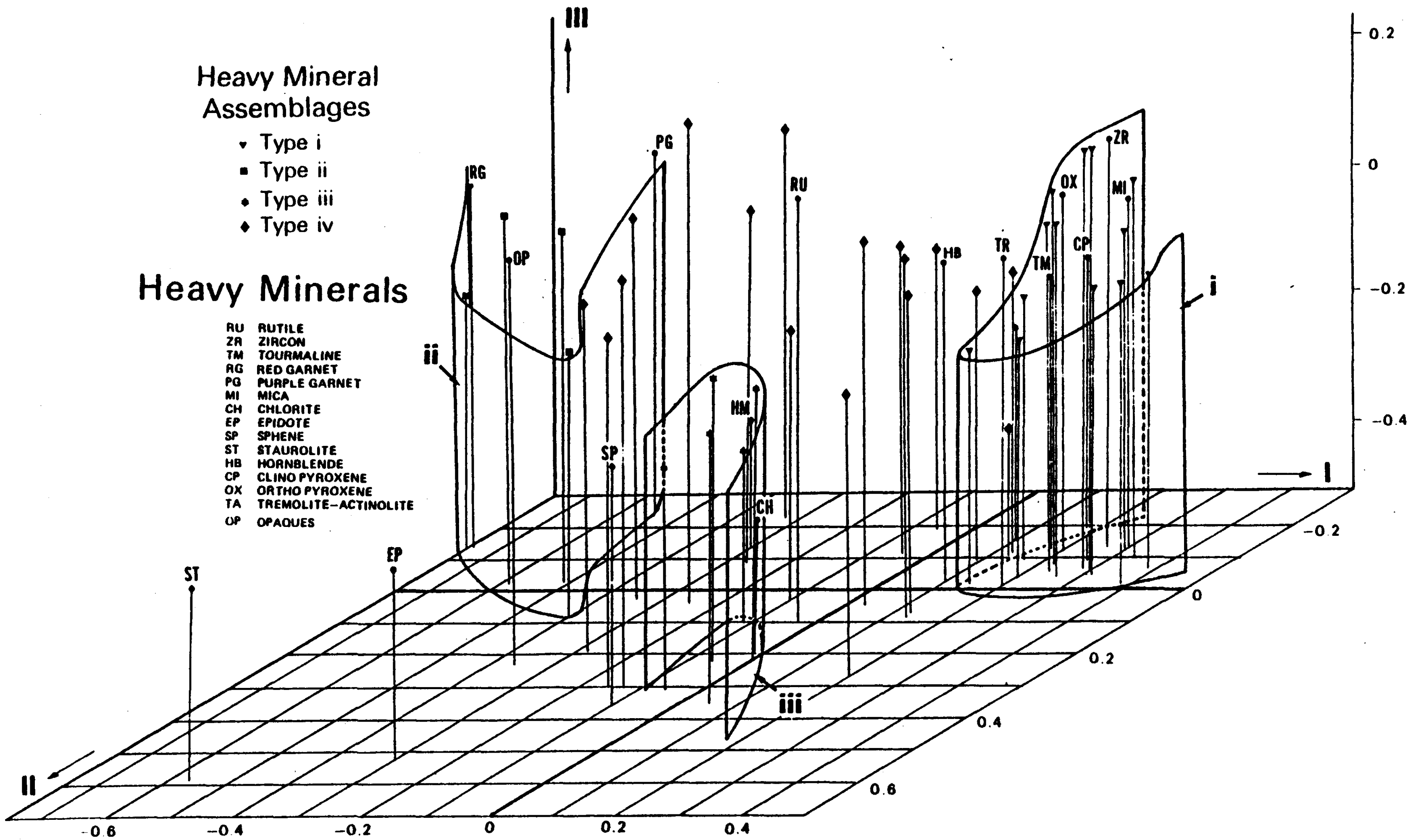


Figure 17. Simulated three dimensional diagram showing the relative loadings of heavy minerals (variables) and samples on the three principal factors, determined by correspondence analysis. The envelopes indicate the preferred field of occurrence of types of heavy mineral assemblages.

analysis (Figs. 16, 17). This assemblage is dominated by garnets and has high concentration of opaques.

Type iii is based on the weaker loadings (greater than 0.500) of few samples on the ill-defined oblique Q-Factor III. Correspondence analysis confirms the loose relationship of the components of this type as they plot on a loose scatter at one side of the diagram (Fig. 17). The characteristic components of this type are chlorite, sphene, epidote, and staurolite. The extreme sample has also the highest tourmaline and termolite-actinolite content of the samples treated (Fig. 16).

Type iv has a variety of compositions, some particularly rich in rutile. It represents a mixed collection of samples belonging mostly to Clusters 2 and 3, and plotting toward a central zone in the correspondence analysis diagram (Fig. 17).

Vertical and Areal Variations of Heavy Mineral Types

a. Vertical variations

The heavy mineral types of the top 1-2 cm of the vial-cores generally differ from the types found in the underlying 2-3 cm. However, no consistent vertical trend has been observed, except for three samples from the Presqu'ile area. They show a consistent change from type iv assemblage at the bottom, to type iii at the top (Fig. 18).

All samples from the two Wellers Bay long cores (62 and 82 cm) belong to type i. To detect whether minor variations occur, depth plots were made of samples loadings on oblique Factor I, of available grain sizes, and of standard deviations (Fig. 19). The plots show a slight correlation between upward weakening of the loadings, coarsening of the sand, and decrease in sorting, except for the topmost part of core 43. This core was

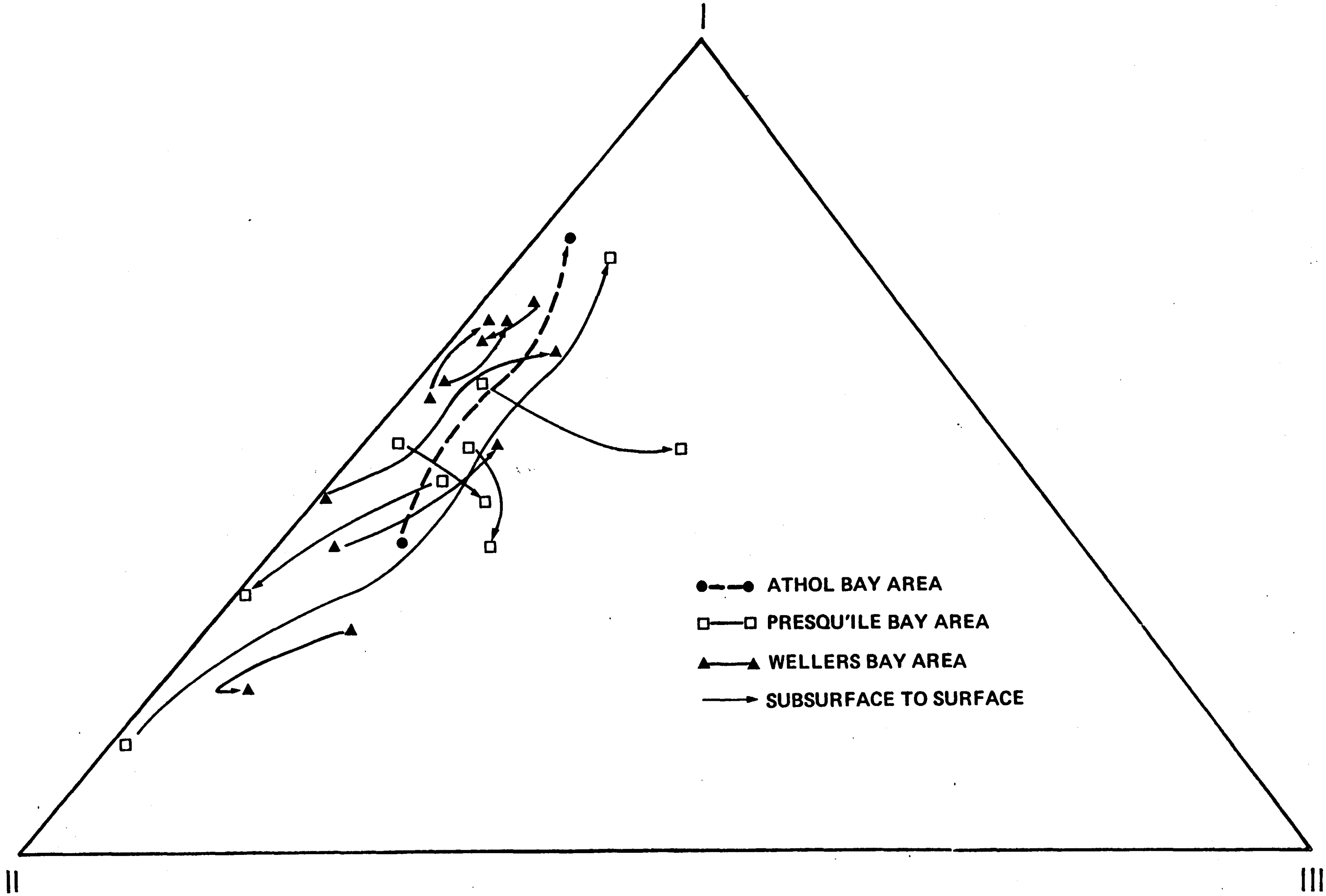


Figure 18. Triangular loading diagrams of the samples on the three principal Q-Factors. The arrows indicate the variations of samples from a lower to the top stratigraphic horizon in the short vial cores.

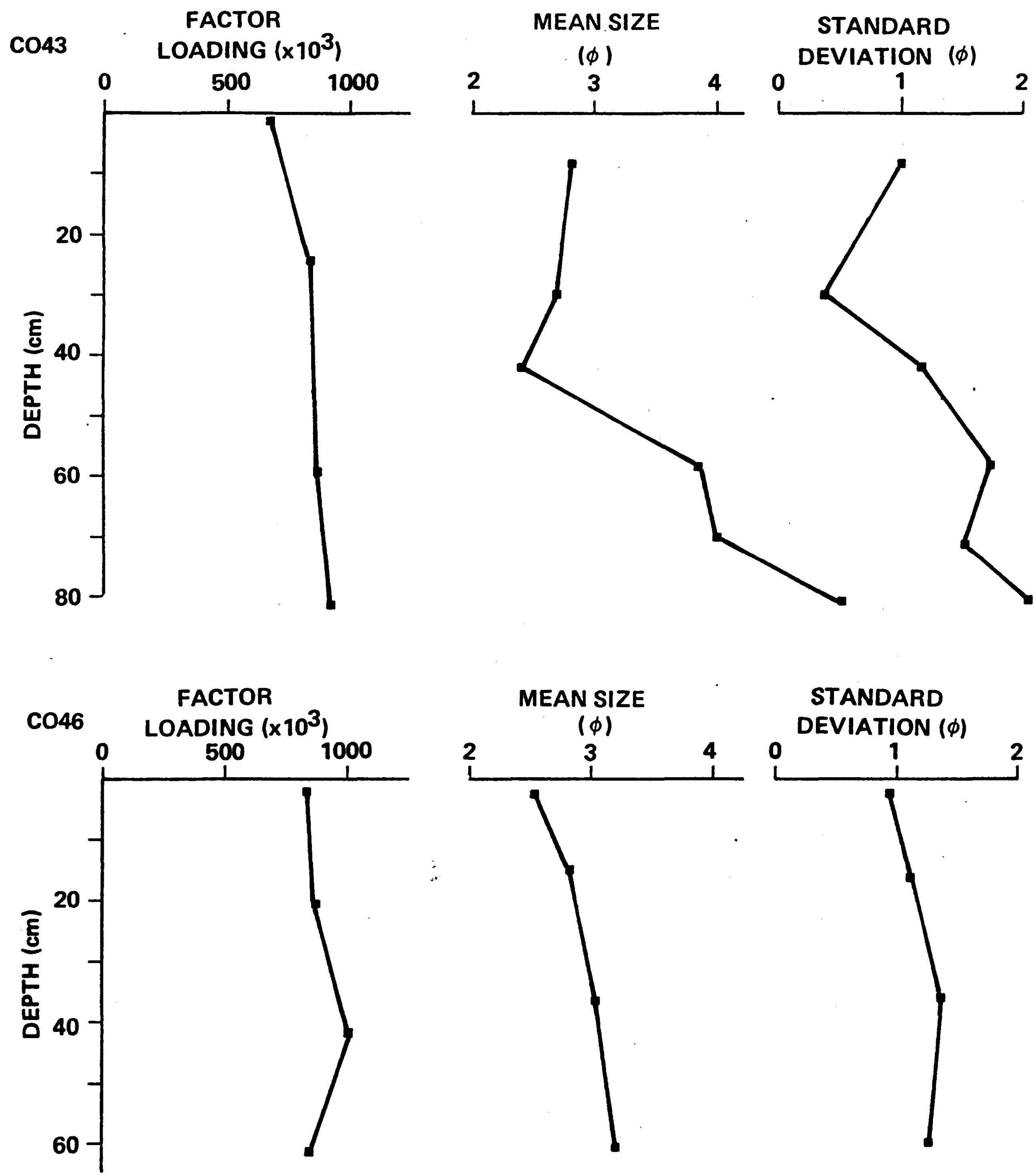


Figure 19. Vertical variation of the normalized loadings of the samples on Q-Factor I in two deep piston cores, compared with the vertical variation of the average and standard deviation (phi values) of the whole sample grain size).

taken in shallow water (3 m). It shows a uniform average grain size in the top 40 cm, perhaps indicating reworking and mixing by waves. However, the topmost 2 cm of this core shows different concentration of heavy minerals. With respect to the sample taken at 23 cm depth, the surficial sample is enriched in total heavy minerals (13.0% vs. 5.6%) and total garnet (7.9% vs. 5.7%), and it has less horneblende (35% vs. 40%).

b. Areal variation

Only the surficial samples are considered in the areal variation of the heavy mineral types, as they characterize the present bottom conditions of the lake. The surficial samples of Wellers, Wellington and Athol Bays collected in water shallower than 18 m have, consistently, a type i assemblage (Fig. 20). Both type i and type iii assemblages are found in the shallower portions of Presqu'ile. The samples collected from water deeper than 18 m derived from a variety of hard substratum, lag deposits and reworked sands, and they show types ii, iii, and iv assemblages.

Relationship Between Heavy Mineral Assemblages and Grain Size

Results of the heavy minerals analyses suggest that hydraulic sorting may have played a role in the formation of the assemblages. Selleck (1972, 1974) in a study of the south shore of Lake Ontario found that sorting had affected significantly the distribution of heavy minerals, perhaps destroying any information about the source area of the sands. However, Selleck used a wider than normal sediment fraction ($2\ \phi - 4\ \phi$) in his study.

To determine whether the heavy mineral assemblages determined in the fine ($2 - 3\ \phi$) sand fraction are affected by the sample grain size

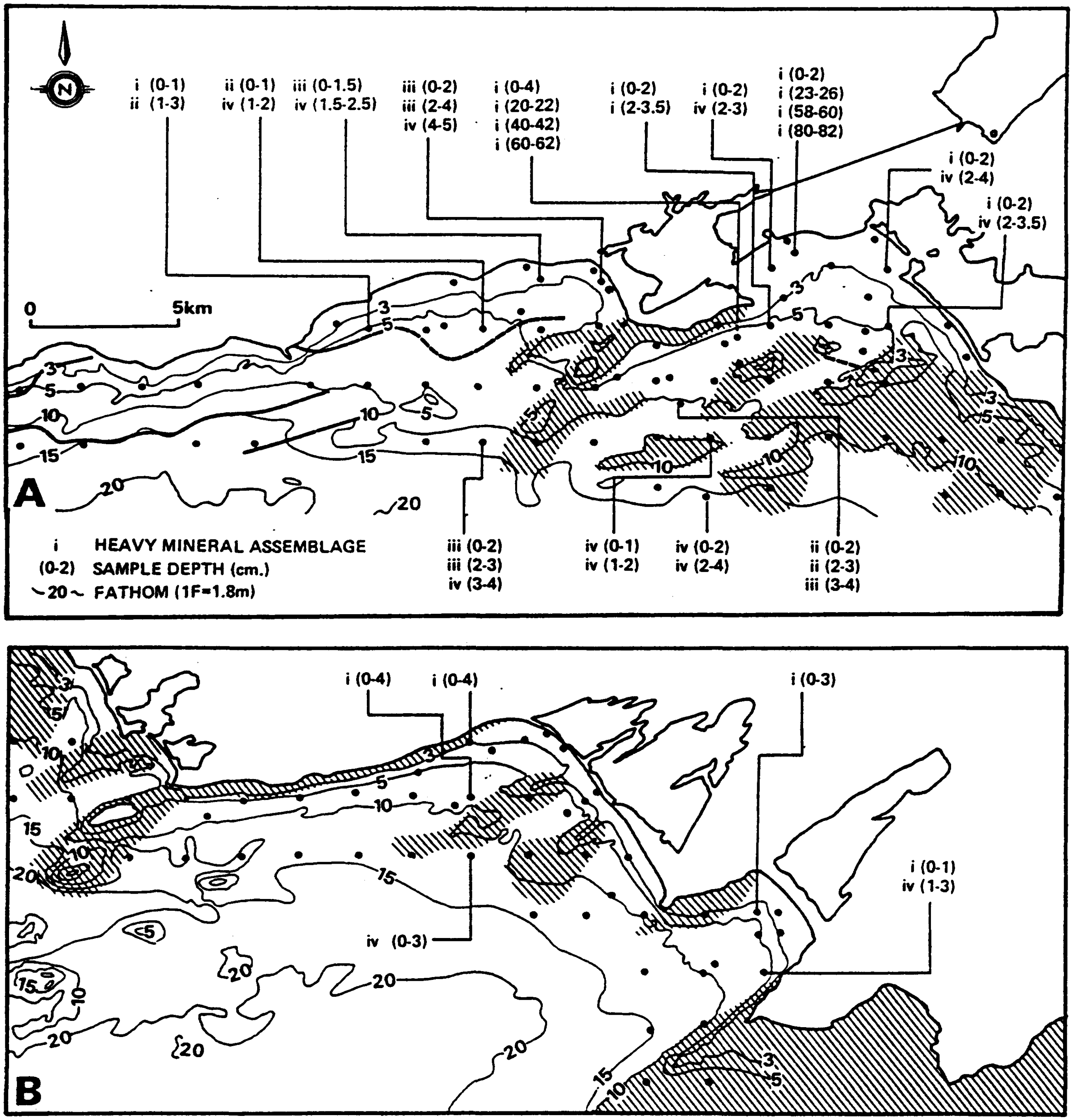


Figure 20. Distribution of the types of heavy mineral assemblages measured at different depths.

distribution, correspondence factor analysis was run on samples containing the complete set of information. The resultant diagram indicates that the previously found heavy mineral types ii (garnet dominated) and in minor measure type iii (staurolite dominated) define a strong axis heavily weighted upon respectively by the finer medium sand (G4) and the coarser medium sand and coarse sand (G3-G2-G1)(Fig. 21). This axis contrasts with a weaker one characterized by silt (G9), very fine sand (G8-G7), and zircon, mica, and pyroxenes. Another weak association is found between rutile (type iv assemblage) and the coarser half of the fine sand fraction (G5)(Fig. 21).

The results of this analysis indicate that processes that influence the overall grain size distributions in different environments, affect somewhat the concentrations of heavier and flatter minerals in the fine sand fraction. However, the relationships between the heavy minerals and the grain size are weak, and the behaviour of some species such as purple and red garnets is not affected. Their ratios may retain information about the source areas of the sands.

REGIONAL VARIATION IN HEAVY MINERALS IN THE LAKE ONTARIO BASIN

The regional variation in heavy minerals was analyzed using the Q-mode and correspondence factor analyses on the assemblages determined by this study, Gwyn and Dreimanis (1979), and also by comparing different types of ratios, primarily between red to purple garnet from all other available data sets (Fig. 22).

The data set of Gwyn and Dreimanis (1979) was suitably modified to correspond to those that are prepared specifically for this study. The best solutions were found discarding the total heavy mineral concentration,

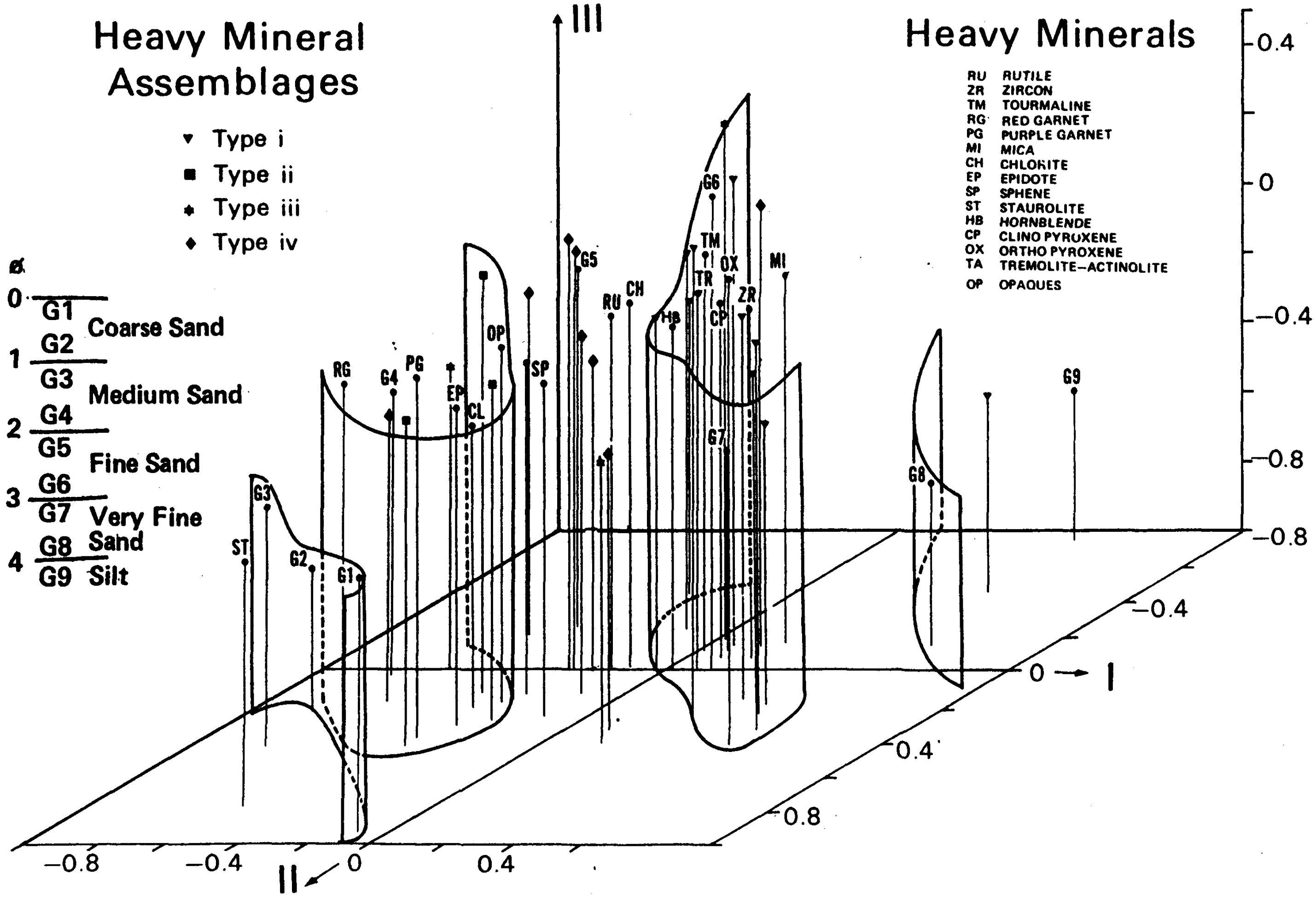


Figure 21. Simulated three dimensional diagram showing the relative loadings of heavy minerals, sand and silt concentrations (variables) and surficial samples on the three principal factors determined by correspondence analysis. The envelopes indicate the preferred occurrence of types of heavy mineral and grain size assemblages.

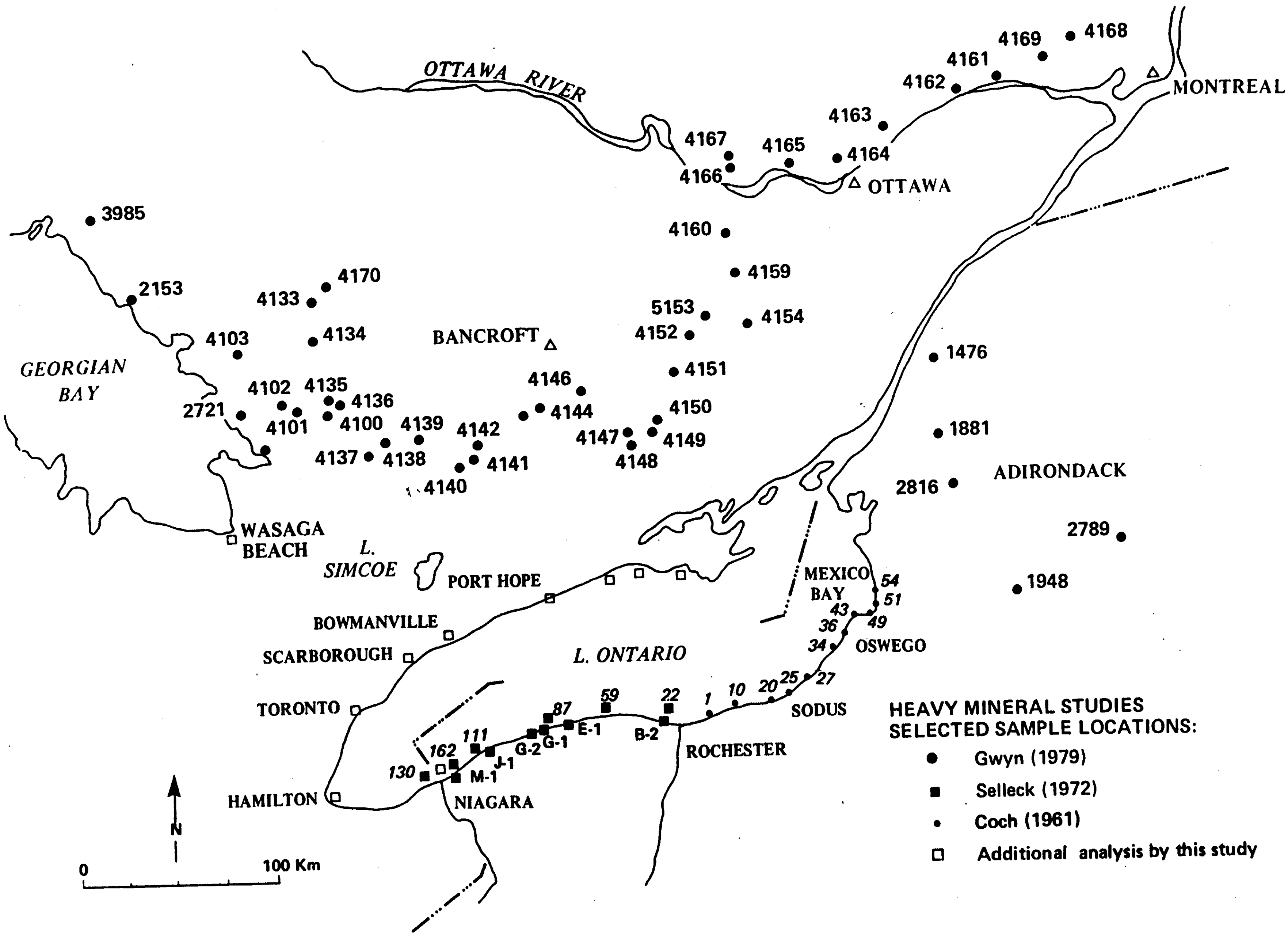


Figure 22. Location of samples utilized to compare heavy mneral assemblages in the Lake Ontario area.

opaques, rutile, zircon, horneblende and orthopyroxene from the analyses.

A four factor solution was retained and diagrammatically depicted in figure 23. For convenience the samples in the triangular diagram are placed according to the normalized varimax matrix for the three factors solution, and the fields are designated on the basis of the prevalent loadings of the samples on the obliquely rotated axis of the four factors solution.

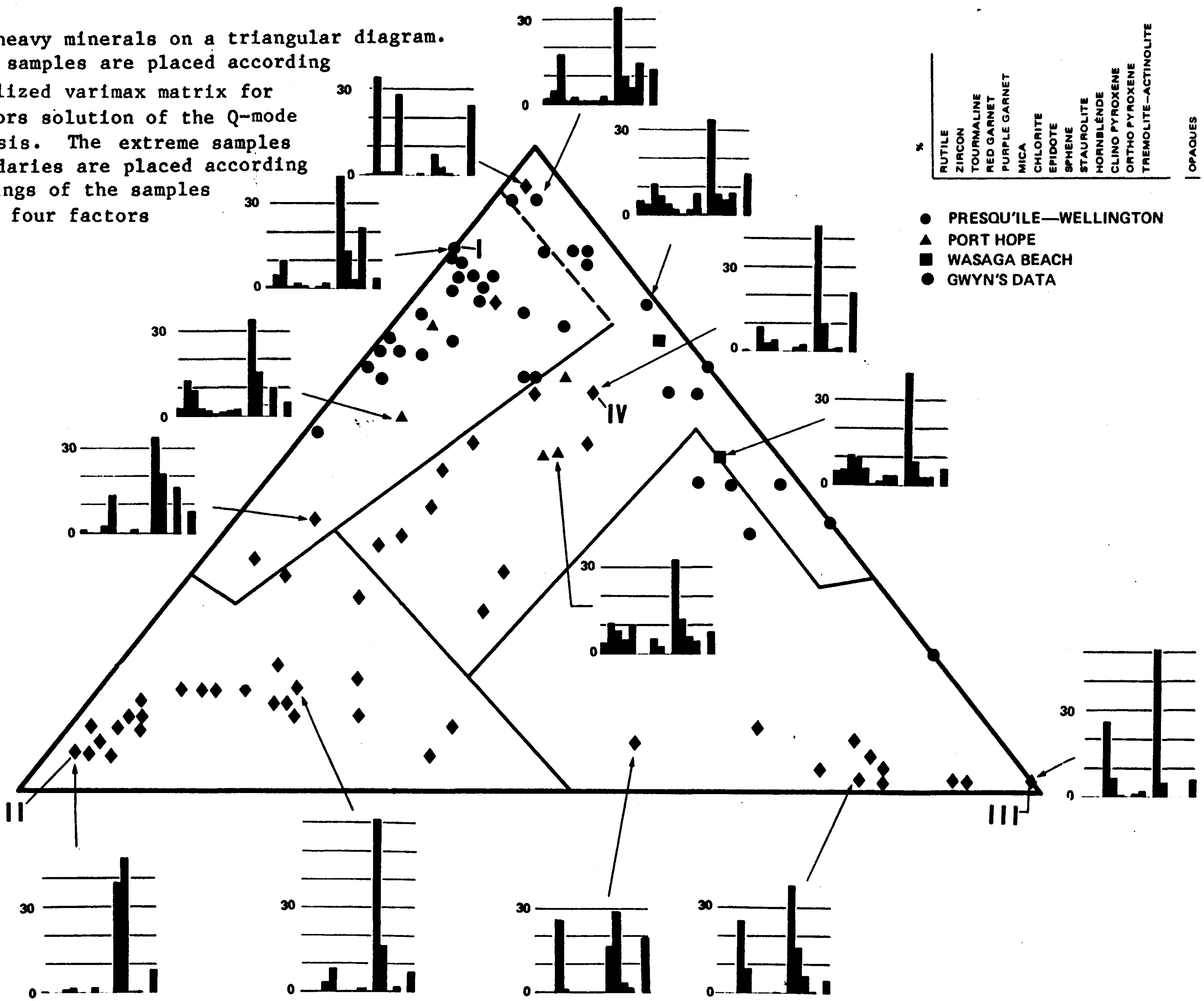
A strong overall difference was found in the heavy mineral distributions measured in tills (Gwyn and Dreimanis, 1979) (Factors II, III; Fig. 23), and those measured from water and wind reworked sands (Factors I, IV; Fig. 23).

A great variety of heavy mineral ratios have been used in studies on the Lake Ontario Basin, to try to detect hydraulic sorting, effect of weathering on minerals, and source areas of the sands.

Samples collected from water less than 18 m deep in the Wellington-Athol Bay area are compared with those of Presqu'ile and Wellers Bay according to some of those ratios. Samples from Wellens, Wellington and Athol Bay have a lower concentration of total heavy minerals, opaques and garnets. In general it has higher horneblende/opaque ratios (a hydraulic sorting indicator), pyroxene + tremolite/tourmaline (a weathering indicator), and purple garnet/red garnet (a source area indicator (Gwyn and Dreimanis, 1979)). This suggests that within the fine sand fraction the flatter and coarser horneblende is preferentially concentrated in lower energy environments such as in parts of Athol Bay, where overall finer grain sizes (Type i sand) are found. The weathering indicators are somewhat inconclusive, particularly as no visible strong weathering features were observed during microscopic examinations of the mineral grains. The

Figure 23.

Loadings of heavy minerals on a triangular diagram. Locations of samples are placed according to the normalized varimax matrix for a three factors solution of the Q-mode factor analysis. The extreme samples and the boundaries are placed according to the loadings of the samples based on the four factors solution.



purple/red garnet ratio is generally higher in the Welington-Athol Bay than in the Presqu'ile-Wellers Bay and most deposits of the Pleistocene terrains along the northshore of Lake Ontario (Fig. 24). Similar high garnet ratios have been found by Gwyn and Dreimanis (1979) in parts of the till in northwestern Ontario, the Montreal area and from an area just north of the Adirondack (Fig. 24). Similar high ratios were found along the southern coasts of Lake Ontario (Coch, 1961; Selleck, 1972, 1974). In the Rochester region of New York State, Connally (1959, 1960, 1964) separated tills interpreted to have been deposited from ice lobes moving westwards from the southern Adirondack areas, from tills with high purple/red garnet ratios moving across Lake Ontario and skirting the northern flank of the Adirondack.

DISCUSSION

The concept that suggests that the major nearshore sandy deposits of Lake Ontario have been formed by longshore drift has been long established (Berg and Duane, 1968; Rukavina, 1969, 1970, 1976; Rukavina and St. Jacques, 1972; Hands, 1970; Lewis and Sly, 1971; Sly, 1969, 1973a, 1973b, 1977; Sly and Thomas, 1974; Thomas et al., 1972). Even part of the bar that has developed at the mouth of the Niagara River is considered to have formed by interception of an eastward longshore drift by the fluid groin of the Niagara River plume (Sly, 1983a, 1983b). Perhaps the sandy deposit of the shelf off Toronto is the best documented example of longshore drift. The material has been brought there from the inferred source of the eroding Scarborough Bluffs, about 18 km to the east (Lewis and Sly, 1971).

Some difficulties are encountered in accepting the long-range longshore drift as the only or prime mechanism for the formation of all nearshore sand bodies. It has been observed that only a small percentage of

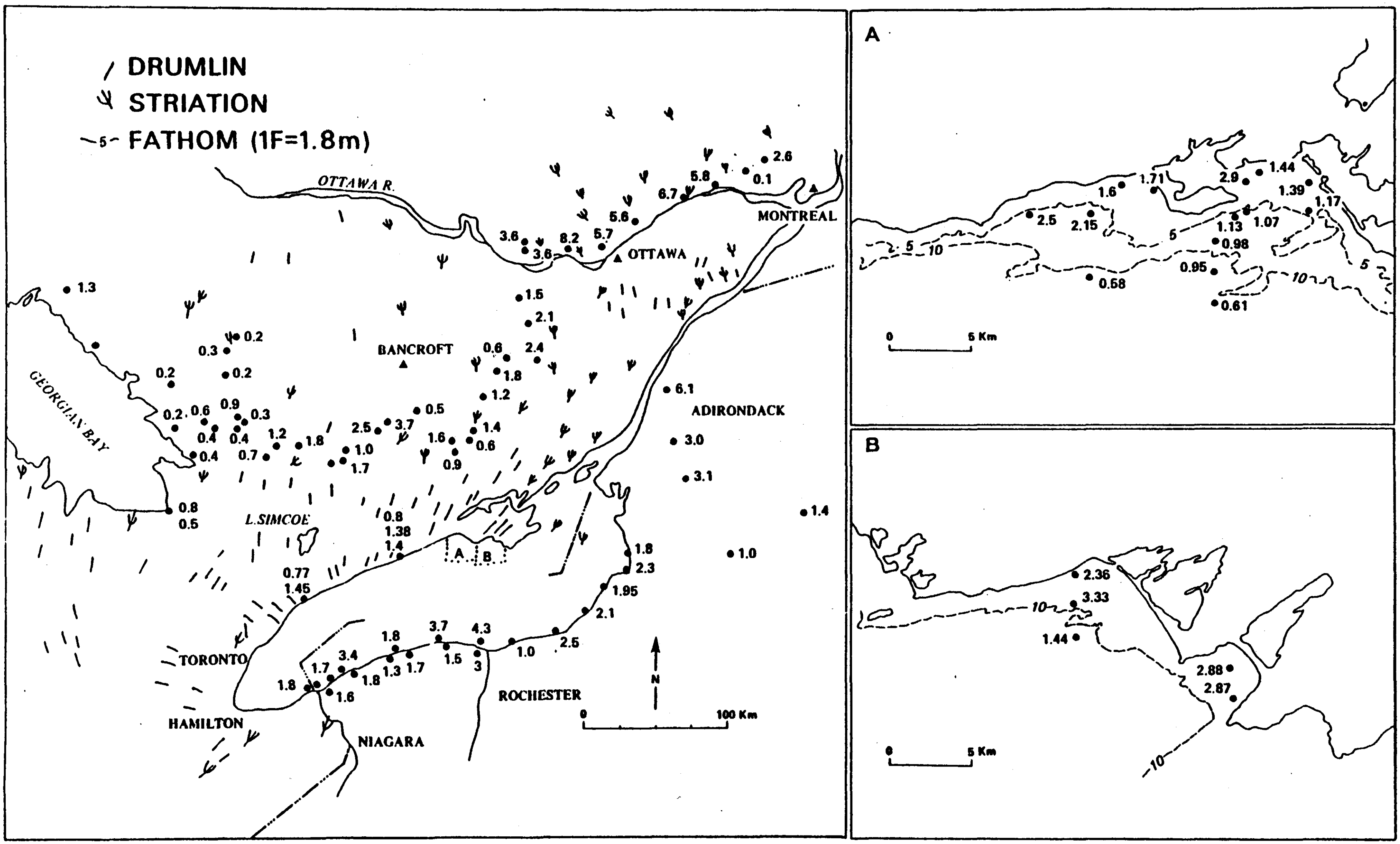


Figure 24. Distribution of the purple to red Garnet ratios in the Lake Ontario area. Data from Gwyn, 1971; Selleck, 1972; Coch, 1961 and this study.

the material eroded from the coastal bluffs are coarse enough to be retained in the nearshore zone. Most (94%) of the material is fine and is dispersed offshore (Fricbergs, 1970). Consequently the submerged tills are an important alternative source for some of the nearshore sediments (Rukavina, 1969; Selleck, 1972, 1974; Sly and Thomas, 1974). Indeed, recent measurements of vertical erosion of submerged till reveal that up to 8 cm per year are locally removed from the shelf (Davidson-Arnott and Askin, 1980). However, only a small (coarser) portion of this material is considered to contribute to the nearshore deposits. Furthermore the subaqueous source can become rapidly armoured by pebble and boulder lags, as observed by underwater television (Rukavina, 1970).

Coakley (1970) suggested that perhaps parts of the sand bodies of Hamilton and Toronto have local origin. Such an idea was later reinforced by the small amount of longshore drift that could be measured along the southern shores (Coakley, 1970; Nurul-Amin, 1982). Along the American shores of Lake Ontario, it was found that instead of long-range longshore drift, the mapable textural parameters of the longshore sediments indicate local drift cells. Similar and perhaps smaller cells were mathematically derived for the Toronto area by Greenwood and McGillivray (1978).

Another series of observations are related to the development of large baymouth bars in drowned valleys. Although they were never properly drilled and studied, it is believed that these bars moved slightly lagoonward during the Lake Ontario transgression.

In analyzing the Pleistocene exposures both along the coastal bluffs and inland, it is apparent that till is only a small portion of such deposits. Lacustrine clays, sands and gravels make up the bulk of the deposits. Those materials were locally dissected by large valleys and later refilled by till or sandy sequences. Undoubtedly similar sequences were deposited on the presently submerged shelf of Lake Ontario during Pleistocene time. Some of the sandy deposits may have been completely removed by wave erosion from exposed promontories. However, similar deposits may have been retained in sheltered areas, only slightly reworked during the lake transgression and are able to provide sufficient local material to build up the present nearshore sand bodies (Sly and Thomas, 1974; Sly and Prior, 1984). This interpretation appears particularly well fitting with regard to the Presqu'ile-Wellington case.

The multiple source of the deposits of Presqu'ile-Wellington Bay is supported by several evidences, some associated with the geology of the area, some associated with the characteristics of the deposits themselves.

First and foremost, recent mapping of the inland Pleistocene terrain (Leyland, 1982, 1983) has confirmed that two major glacial lobes have affected the region. The largest lobe has carried materials southward from the Precambrian Shield and has deposited them onto the northshore area of eastern Lake Ontario. Those Pleistocene tills, sands, and gravels have been reworked first by Lake Iroquois and later by Lake Ontario waters. Beaches, tombolos and other coastal features of both lakes are strongly imprinted on the landscape (Chapman and Putnam, 1966; Mirynech, 1962; Leyland, 1982). A second glacial lobe was diverted through the St. Lawrence-Kingston channel and prograded southwestward through the Prince Edward peninsula. Thin clay tills of this second lobe have been mapped in the Presqu'ile area, but the bulk of the deposits of this lobe are restricted to the southwesterly trending graben between Picton and Wellington-Athol Bay (Fig. 25). There, the Pleistocene deposits have developed good sequences of drumlins, eskers, outwash sand, and gravel (Peat, 1973; Leyland, 1982). Some of these drumlins are found along the coast modified by wave cut benches. Anomalous localized subaqueous highs made up of fines rich (23.8% silt and clay) material have been mapped by echosoundings and have been jetted into, in relatively deep waters along the northshore of Wellington Bay. They may be associated to Pleistocene drumlins (Figs. 11, 25). Leyland (1982) interpreted some of the Pleistocene sands of the graben as subaqueous outwash. There is no reason not to believe that Pleistocene tills and sands were deposited also on the shelf of Lake Ontario (Peat, 1973). The glacial lobes that crossed the area carried slightly different materials, and the reworking of the sands by lacustrine processes have not completely obliterated their textural and mineralogical characteristics such that the multiple sources of the recent nearshore deposits can be recognized.

Longshore drift exists in the Presqu'ile-Wellington Bay area, but it is limited to individual embayments, perhaps with the exception of some long-range drift along the nearshore into Presqu'ile and sediment over-spilling from the Presqu'ile tombolo into the Wellers Bay area. The local longshore drift has been detected by the southeastward decrease in average grain sizes, both along the beaches of Presqu'ile and Wellington Bay (Ernstring, 1976; Peat, 1973) and in the shallower portion of the subaqueous bar. Longshore drift has not been recorded along the beaches of the baymouth bar in the deep and narrow Athol Bay (Mitchell, 1976). The sands do not form a continuous transport pathway from Presqu'ile to Athol Bay. They are separated by barriers in the form of shoals, wide expanses of dissected barren bedrock, and by steep barren nearshore shelf along the northshore of Wellington Bay.

The sands in parts of the various embayments are adjusted to the local hydraulic factors, such that the narrower Athol Bay develop finer

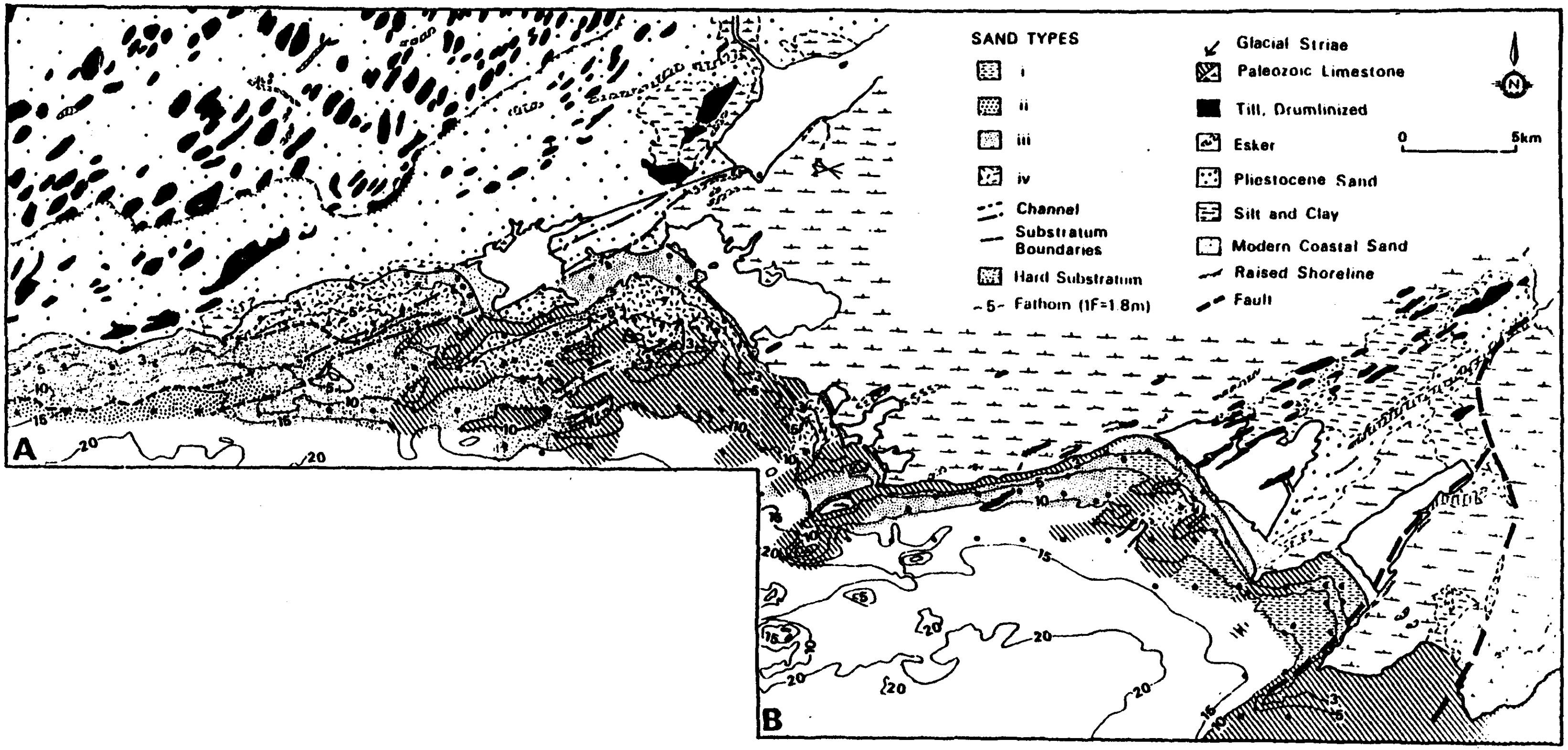


Figure 25. Generalized surficial geological map of the Presqu'ile-Wellington Bay area.

surficial material (Type i sand) showing fine laminations and occasional ripple marks. The presence of numerous shoals protects local areas from significant reworking. For instance the fine grain sizes of the surficial samples in the northern corner of Wellington Bay are believed to be associated with the input of fines from the outlet of the lagoon.

The relatively close relationship between the modern deposits to the Pleistocene sands is perhaps best illustrated by the distribution of Type ii sand which follows preferentially the partially buried valleys of the Presqu'ile and Wellers Bay area. Peat (1973) reported some textural similarities between the inland Pleistocene outwash and the sands of the coastal deposits of Wellington Bay.

The mineralogy of the subaqueous sands do not differ greatly from bay to bay. However, some differences do occur, such as the presence of only Type i heavy mineral assemblage in the surficial samples of Wellers, Wellington and Athol Bays and the variable composition of similar samples from Presqu'ile. Furthermore, whereas differences in concentrations of total heavy minerals, opaque and perhaps total garnet may be, in part, associated with sorting processes, the ratio between purple and red garnet is not affected significantly by hydraulic sorting (Fig. 21) and retains useful information about the source of the materials. Gwyn and Dreimanis (1979), Dreimanis (1960), Dreimanis et al., (1957), Connally (1964) were able to establish that different parts of the Precambrian Shield and of the Adirondack have provided different amount of purple and red garnet to the Pleistocene tills. The high purple to red garnet ratios of the Wellington-Athol Bay indicate that these deposits differ from those of the Presqu'ile-Wellers Bay. They are considered to have derived from material transported by the southwestward flowing glacial lobe which had crossed source areas north of Montreal and skirted the northern part of the Adirondack (Fig. 24; Gwyn and Dreimanis, 1979).

When and how did the baymouth bars developed? No deep cores are available from baymouth bars in Lake Ontario. The baymouth bars of the study area were probably formed during the last stages of the rapid transgression of Lake Ontario and have been molded in approximately the same position in the last 10,000 years. These baymouth bars are located at different distances inland from the mouths of the drowned valleys, and are perpendicular to the prevailing wind direction, indicating that they are hydraulically adjusted to the strong storm conditions of eastern Lake Ontario. These nearshore areas show a quasi-equilibrium profile with multiple longshore bars and a smoothed out deeper slopes. There is no evidence to indicate that the baymouth barriers were formed at lower lake levels and have migrated in their present position (Mitchell, 1976; Sly and Thomas, 1974). Some landward migration of the barrier and their widening is associated with local landward migration of subaerial sand dunes reactivated by deforestation (Peat, 1973; Martini, 1981).

The baymouth bars in the study area have been designated as recreational Provincial Parks. They are protected from deforestation and reactivation of dunes by careful management. However, the increasing demands for building materials in the Province of Ontario has required an assessment of the economic potential of the nearshore sands. The sands in the study area are too fine to satisfy the requirements for concrete aggregates (National Standard of Canada, 1977; AASHTO, 1974), unless they are blended with coarser material from other sources (Appendix 1; Martini et al., 1983). These sands could however be used as highway subgrade material or general purpose sand. Should these deposits be dredged their local origin implies that any material extracted cannot be readily replenished by long-range longshore drift. In the Presqu'ile-Wellington Bay area as well as in other similar settings in the Great Lakes, removal of subaqueous material may very well trigger erosion of adjacent beaches and dunes to restore the altered offshore profile to quasi-equilibrium conditions.

CONCLUSIONS

The main conclusions of this study are:

1. Large amount of information has been gathered concerning the geology and sediments of the Great Lakes. Although the data sets require complementary work such as mineralogical determinations and definition of stratigraphic controls for the analysis of vertical and lateral facies associations, they provide sufficient input for a sedimentological analysis of various lacustrine environments.
2. In most instances the analysis of grain size distributions and heavy mineral concentrations may lead to trivial and erroneous conclusions if standard statistical techniques are not used. Even the results of careful statistical analyses must be used in conjunction with good geological knowledge of the basin in order to treat 'noisy' data and to arrive at reasonable sedimentological interpretations.
3. Recent lacustrine sediments of Lake Ontario are derived from erosion and sorting of Pleistocene sands, clays, gravels and tills exposed along the coastal bluffs and in the drowned shelf. A smaller amount of material is derived through frost shattering of the thinly bedded carbonates exposed along some shores. Little material is derived from the non-graded streams discharging into the lake. Only a small portion of all these

materials are retained in the nearshore area. Most of the fines are carried offshore into the deeper lacustrine basins.

4. The nearshore deposits are redistributed by longshore drift toward depositional sinks, generally associated with valleys drowned during the early Holocene transgression of Lake Ontario.
5. Long-range longshore drift has occurred, but the nearshore sands in Lake Ontario form relict deposits and their surficial cover was formed by reworking of Pleistocene or early Holocene materials. This dual origin of the recent deposits is particularly well demonstrated in the Presqu'ile-Wellington Bay area. Those various embayments have different types of sands, and different heavy mineral assemblages which can be related to material transported in the area by different lobes of late Wisconsin glaciers.
6. Surficial grain size distributions in Presqu'ile-Wellington Bay are adjusted to the prevalent environmental conditions. Accordingly, a nearshore zone where local longshore drift occurs can be distinguished from offshore less frequently reworked areas. Similarly, apparently anomalous grain size distributions such as fine materials nearshore or well sorted sands offshore, can be related to local processes such as discharge from a lagoonal outlet or offshore turbid return flows during heavy storms.
7. The main applied result of this study is the realization that the nearshore sand bodies of Presqu'ile-Wellington Bay and other parts of the lake are reworked local Pleistocene relict bodies, and should they be dredged, materials removed cannot be readily replenished by long-range longshore drift and the bottom profile can only be re-established by removing sand from adjacent beaches and coastal dunes.

FUTURE WORK

This report attempts to demonstrate that there are grounds for opening the key question of local source versus long-range longshore drift for some of the sand bodies in the Presqu'ile-Wellington Bay area. There is no doubt that longshore drift contributes significantly to the distribution of sediments in the Great Lakes. However, complacent acceptance of such concept everywhere would obscure the fact that there are also relict sand bodies of Pleistocene and early Holocene times. The study of how much drift material is supplied to various sand bodies is of particular urgent importance if any dredging of those offshore deposits is contemplated.

There is no sufficient data to allow quantification of longshore drift in many critical parts of Lake Ontario. Long term monitoring of shore and shelf erosion and of longshore drift is requried. Similarly, long term field monitoring of the rates of sedimentation in critical areas is needed.

For shorter and relatively much less expensive studies, a considerable amount of information can be obtained with a detailed analysis of the stratigraphy of coastal areas and the shelf. The water line should not be a boundary for geological investigations. The Great Lakes are essentially large glaciated valleys with thin Holocene to recent sedimentary drapes. Stratigraphic drilling of the coastal zones and the shelf will not be prohibitively expensive and would contribute to a significant advance in the understanding of the Pleistocene Geology of North America.

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Appendix 1

Resource Potential of Lake Ontario Nearshore Deposits

by

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INTRODUCTION

Concern about future reserves of sand and gravel in southern Ontario has prompted an analysis of existing data on the nearshore deposits of Lake Ontario to determine whether the deposits have the appropriate textures and volumes to be useable as an aggregate resource. A more detailed study was made of the Presqu'ile-Wellington deposit to establish methods for distinguishing relict and modern deposits, identifying the sediment source, and estimating the sedimentation/replacement rate.

DATA

Data used were obtained by the Hydraulics Division, NWRI during nearshore surveys of Lake Ontario from 1968 to 1974 (Rukavina, 1976) and include:

1. Surface grab samples (Shipek sampler) collected on a 1-km grid west of Whitby and a 2-km grid east of Whitby.
2. Shallow cores (average length of 1 m) x-radiographed and subsampled for grain-size analysis.
3. Sediment thickness measurements obtained by jetting to refusal (Rukavina and LaHaie, 1977).
4. Echo-sounding traverses at 1-km intervals used to establish the boundary of the unconsolidated deposits.
5. Grain-size data for surface samples and cores from analyses by the NWRI Sedimentology Laboratory (Duncan and LaHaie, 1979; Sandilands and Duncan, 1980).

ANALYSIS AND RESULTS

Major deposits of unconsolidated sediment have been identified in the nearshore zone of Lake Ontario (Rukavina, 1976) at Niagara, Hamilton, Toronto and Presqui'ile-Wellington (Fig. 1). For each deposit, grain-size data for surface samples were used to establish the surface area of the sand and gravel component. Size data from shallow cores showed no major change in grain size with depth, and surface values were assumed to apply throughout the thickness of the deposit. The estimated quantities of sand and gravel are shown in Table 1. Only limited data are available on the quality of these sediments in terms of their mineralogy and petrology. Samples from Presqu'ile-Wellington showed no significant amounts of deleterious minerals in the sand fraction. However, organic matter and glass have been reported from some samples in the other deposits.

Figure 2 shows a plot of representative grain-size distributions from each area overlaid with envelopes delimiting the requirements for coarse and fine aggregates for concrete (National Standard of Canada, 1977).

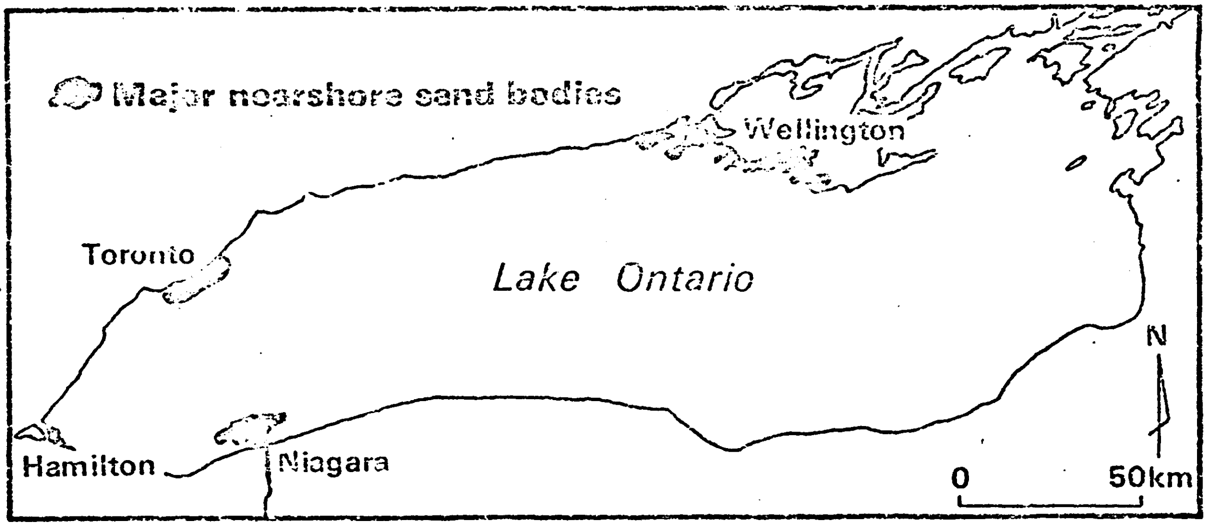

Figure 1. Major sand deposits of Lake Ontario.

Table 1. Sand and Gravel Volumes

	Deposit	Surface Area*, m^2	Average Thickness**, m	Volume, m^3
1.	Niagara	3.8×10^7	3.2	1.2×10^8
2.	Hamilton	3.0×10^7	7.0	2.1×10^8
3.	Toronto	5.7×10^7	3.8	2.2×10^8
4.	Presqu'ile/ Wellington	9.7×10^7	4.8	4.7×10^8

* % sand + gravel > 50% in surface samples   ** based on jetting to refusal

The requirements for bituminous paving mixtures (ASTM:D 1073-63) are similar to those for fine aggregates for concrete (AASHTO, 1974; National Standard of Canada, 1977). The results indicate that both the Toronto and the Niagara deposits have suitable material for concrete and bituminous paving mixtures. The deposits of Hamilton and the Wellington areas are too fine for such purposes unless blended with coarser materials but could be used as highway subgrade material or general purpose sand.

Sediments in the Presqu'ile-Wellington area occur as a series of isolated deposits within protective embayments or depressions in the bedrock surface (Rukavina, 1970; 1972). Multivariate analysis of grain-size data revealed three major sand types. Downdrift trends in grain size were observed within each of the isolated deposits but there was no consistent downdrift textural trend for the area as a whole. This is unexpected since there is evidence of extension of the Wellington Bay deposits at an accumulation rate of 0.2-1.0 cm/year since Kindle's original survey of the area in 1915-1916 and littoral drift from the west was presumed to be the source material (Kindle, 1926; Rukavina, 1970; 1972). Recent mapping by Leyland (1982) shows the presence of onshore drumlins and glacio-fluvial/lacustrine deposits adjacent to some of the nearshore deposits. Some of the textural anomalies may result from the reworking of offshore extensions of these deposits. Alternatively longshore trends in texture may be masked by local differences in exposure and wave energy along an irregular coast with a complex nearshore bathymetry. Further assessment of these suggestions is underway in an attempt to develop generally useful procedures for identifying source materials and determining sedimentation rates.

FURTHER RESEARCH

This pilot study has established that sediment of grain size suitable for aggregate use occurs in the Toronto and Niagara nearshore deposits. Decisions on whether to exploit the deposits will require further data on their composition and their variability with depth, and a careful consideration of the environmental impact of their removal. Key questions to be resolved include:

1. Will extraction steepen the slope and promote local shore erosion?
2. Will removal of material deplete the supply of sediment available for littoral drift and cause downdrift erosion problems?
3. Are the deposits relict or still accumulating? If modern, what is the time required to replace extracted material by transport from updrift sources?
4. Will the process of extraction mobilize finer sediments and attached contaminants and create local water quality problems?

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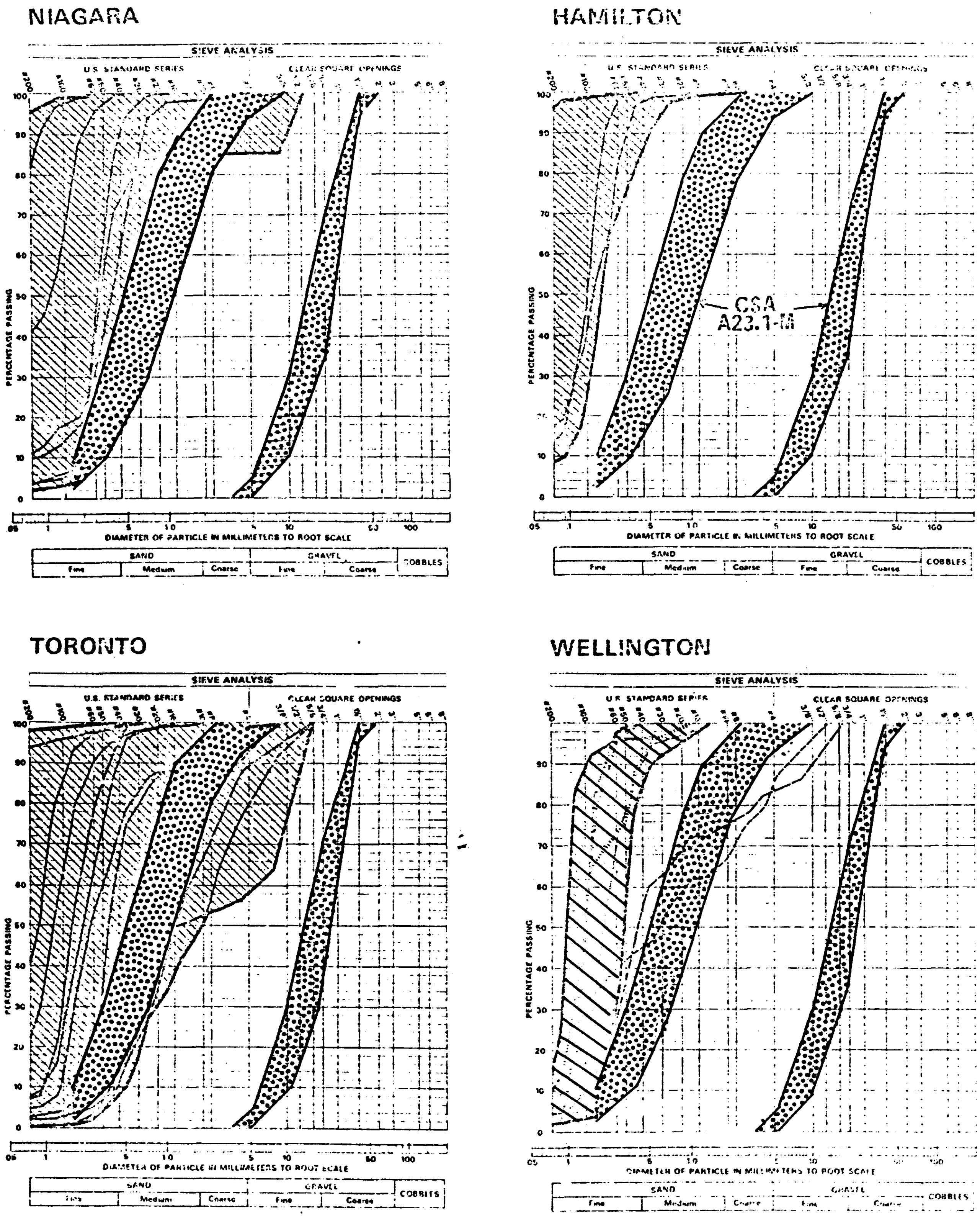
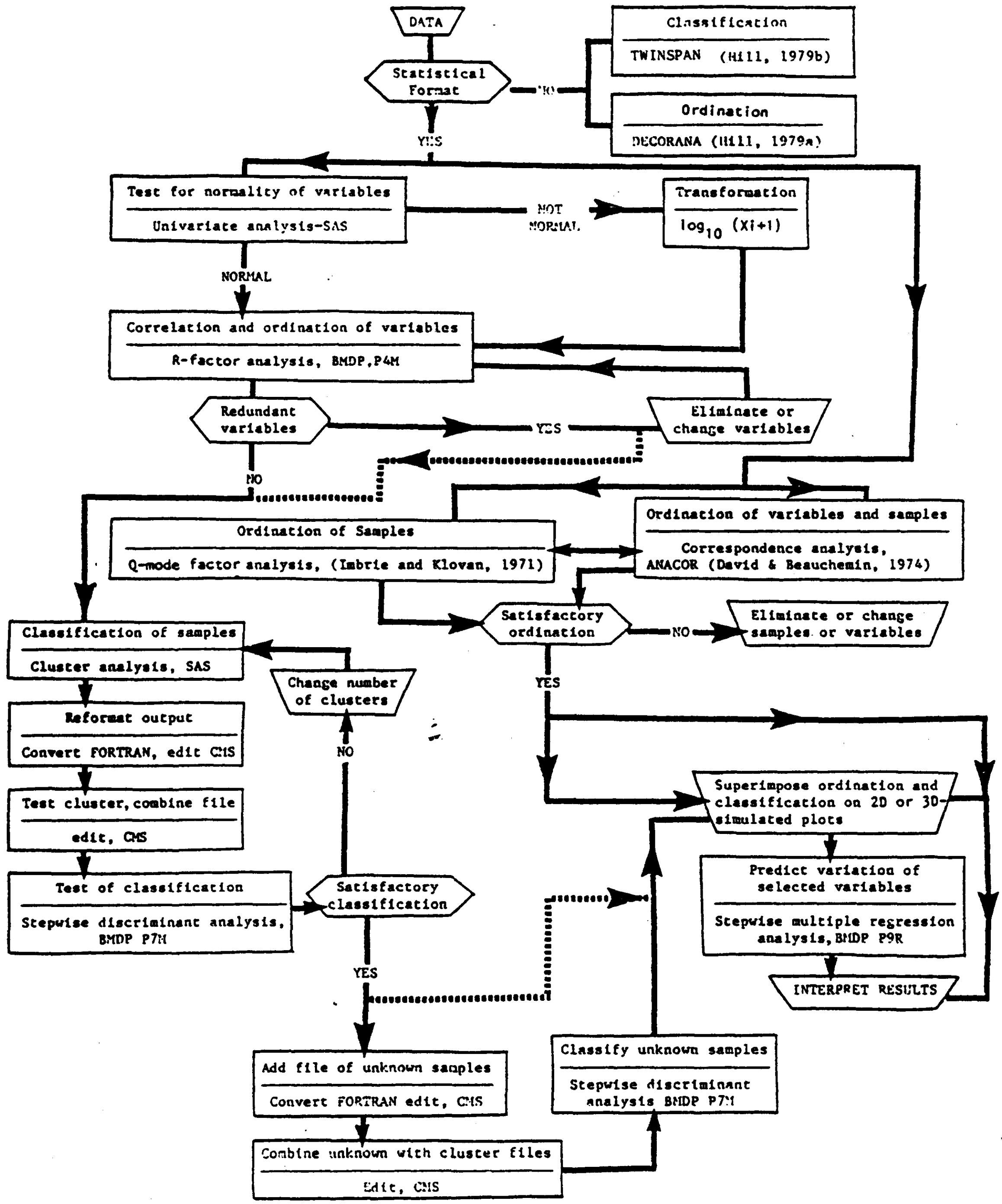


Figure 2. Representative grain size curves and envelopes depicting requirement limits for fine and coarse aggregates for concrete (CSA-A 23.1 M).

Appendix 2

Statistical analytical strategy and computer programs used.



Appendix 3

PROCEDURE FOR PETROGRAPHIC ANALYSIS OF HEAVY MINERALS

by Ralph H. Krueger
Dept. Land Resource Science, University of Guelph

- Sampling, Sieving and Splitting of Samples collected in small Plastic Vial Cores

A. SAMPLING

1. Obtain undisturbed sample in vial.

2. If sample is dry, add a small amount of water to the vial to give the grains some consistency.

3. Place a cardboard crescent to cover roughly half the cross-sectional area of the sediment. Holding the cardboard gently in place over the sample which is to be left undisturbed, carefully remove the exposed sediment, with a spatula.

4. Remove enough of the sample to ensure that there will be at least 2 grams in the size range to be examined. If laminations or heavy mineral concentrations exist, it may be necessary to sub-sample the sediment, thereby avoiding the mixing of strongly different materials.

5. Once the sample has been removed from the disturbed half, place sample in foil dish, put in an oven to dry. If the sample appears to be fine textured it should be wet sieved to remove the silt and clay.

6. With the undisturbed half still in tact, fill the space from the cardboard crescent to mouth of the vial with cotton batten and cap the vial.

7. The undisturbed half may be impregnated for further study. Note that the plastic vial will be dissolved with acetone polyester based resin mixtures.

B. SIEVING

8. Place oven dry samples in standard geology sieve nest and leave in the shaker for 5 minutes. Use small diameter sieves.

9. Carefully remove sediment from their respective sieves and place into their corresponding (labelled) vials.

C. SPLITTING

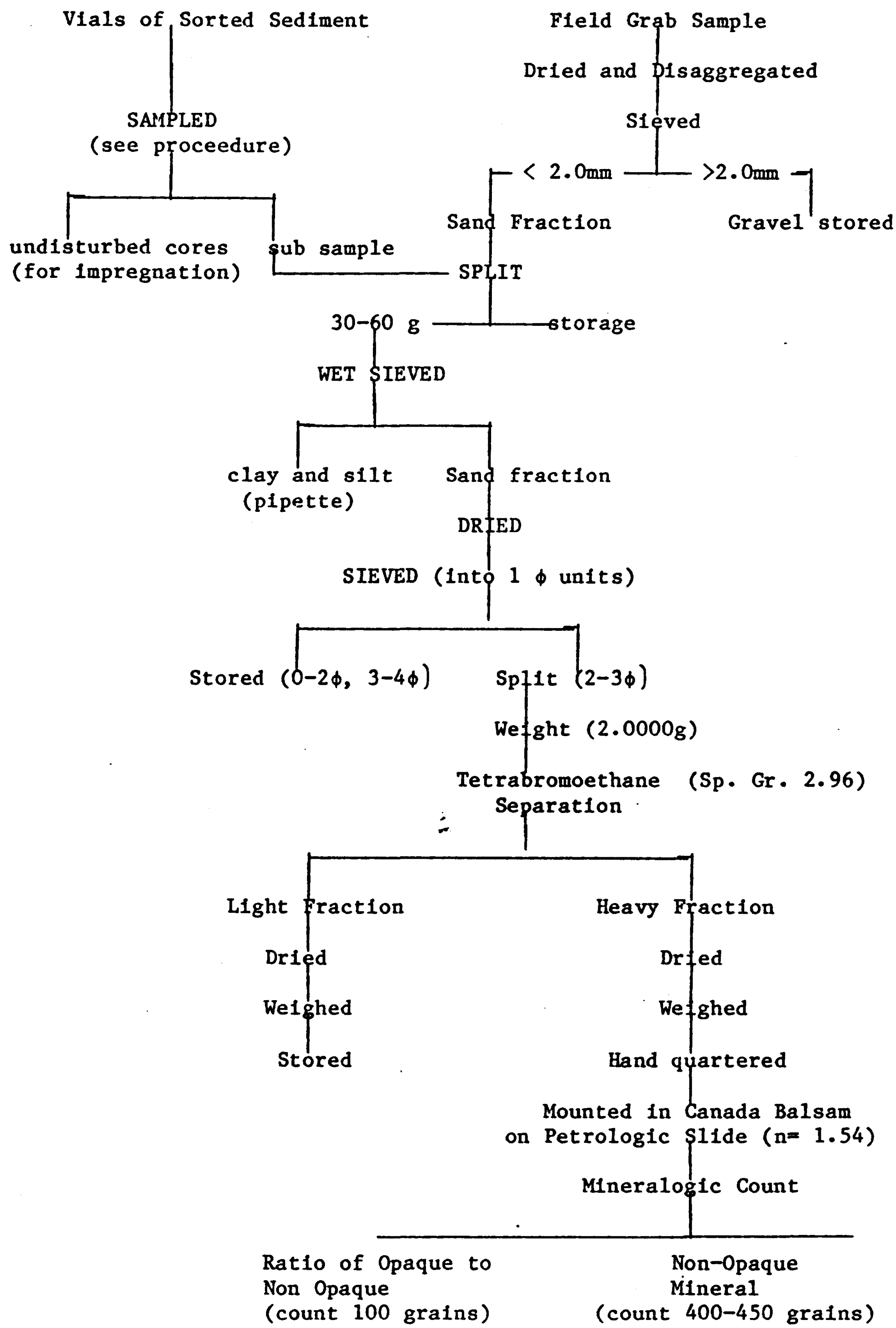
10. Take desired size fraction (in this study; 2-3ϕ) and pour into micro-splitter.

11. Collect sample from either right or left hand side box and pour it into the chute, then return the box to its proper position.

12. Repeat this proceedure until approximately 2 grams have been collected in one of the boxes.

13. Transfer the sample to a weight plastic boat and record the weight.

PROCEDURE FOR HEAVY MINERAL ANALYSIS



- Sampling, Sieving and Splitting of Field Grab Samples

1. The field sample undergoes preliminary disaggregation into smaller aggregates, which are dried and split into test samples in order to obtain a representative sample, caution should be exercised in the splitting procedure. Physical properties such as size, shape, density etc. may produce significant selective errors when heavy mineral analysis is applied to medium and coarse grain sediments. The effect of such errors is reduced with very fine grain sediments.

2. The test samples are further disaggregated and then sieved. The portion greater than 2mm is stored while the remainder is wet sieved to remove the silt and clay fractions. The sand fraction is dried and split according to steps 8 to 13.

D. HEAVY MINERAL SEPARATION USING TETRABROMOETHANE (Sp. Gr. 2.96)

Equipment:

4 separatory funnels
6 concial funnels
8 filter papers (per run)
4 250 ml. beakers (for heavy liquid)
4 100 ml beakers (for acetone)
1 1000 ml beaker (for waste acetone)
2 squeeze bottles (one for acetone & one for tetrabromoethane).
2 retort stands
3 funnel racks
several clamps
1 stirring rod
1 pair rubber gloves

Procedure:

1. Oven dry filter papers and weigh

2. Set up apparatus, pour tetrabromoethane into separatory funnels, fill to about 3/4 full.

3. Pour sample into separatory funnel and stir vigourously for 1 minute. Allow grains to settle for 15 minutes (Repeat this step 3 time). Stirring ensures that the heavy grains are completely wetted. Failure to do so will prevent the grain from sinking due to surface tension effects. Wash any grains that adhere to the sides of the seperatory funnel with a stream of heavy liquid from a wash bottle.

4. Fifteen minutes after last stirring, check the heavy liquid for clarity. If clear, decant approximately half the heavy liquid. Upon opening the stopcock of the seperatory funnel, the heavy liquid will collect on the filter paper placed immediately below and will eventually filter through to the collecting beaker, thereby trapping the heavy minerals on the filter paper.

5. The filter paper & heavy minerals are washed with acetone; once the heavy liquid beaker is replaced by the acetone collecting beaker. The filter paper is then removed from the funnel and placed on a separate funnel rack to air dry, and then is placed overnight in a dessicator. Once dry, the filter paper and heavy mineral's combined weight is recorded.

6. A new filter paper is placed in each funnel. The remaining heavy liquid and light minerals are decanted using the heavy liquid collecting beaker. Once the heavy liquid has been decanted, the heavy liquid collecting beaker is removed and replaced by the acetone beaker, so that the walls of the separatory funnel may be washed with acetone to remove the remaining light minerals. Repeat the application steps in step 4 for the filter papers containing the light minerals.

E. RECLAIMING USED HEAVY LIQUID

1. Add washings of used tetrabromeoethane to 1 gallon (approx.) of cold water and place in a large stoppered flask.

2. Shake vigourously, then allow liquids to separate. Decant most of the water. Repeat this step two more times.

3. After the last decantation, pour remaining water and tetrabromoethane into a large separatory funnel. Draw tetrabromoethane down (by opening stopcock), allowing it to run into a funnel fitted with several thicknesses of filter paper. (Whatman No. 41-fast type).

4. Collect tetrabromethane filtrate in a beaker. If the filtrate is not clear, repeat steps 1 to 3 using a second funnel and filter paper, (N.B. the filter paper will absorb any dispersed water and any wax that may have formed).

5. Calculate the density (for pure tetrabromoethane the specific gravity is 2.96 at 20°C). If it is acceptable, put heavy liquid in a brown bottle labelled "Used Tetrabromoethane". If it is not then the above procedure should be repeated until a satisfactory density value can be obtained.

F. MAGNETIC SEPARATION

a) By Hand Magnet

The heavy mineral fraction is placed on a thin clean, piece of paper. A hand magnet is placed underneath the paper and passed under the sample, thus separating the highly magnetic grains (specifically magnetite) from the less magnetic grains. The magnetic and non-magnetic fractions, are weighed and collected in labelled vials. In several test runs, it was found that the sample contained very little magnetite. The actual weights of highly magnetic constituents were very small relative to the total weight of the heavy minerals and therefore could be considered as unreliable data. For this reason, the removal of highly magnetic constituents by hand magnet was not considered with the exception of when the sample was to be placed in a magnetic separator. It is necessary to remove the highly magnetic fraction of the heavy minerals prior to placement in a magnetic separator, in order to prevent clogging of the metal chute.

b) By Franz Magnetic Separator

The Franz magnetic separator will sub-divide a sample according to the different magnetic susceptibility of minerals. It is essentially an electromagnet, whose field strength can be altered by changing the amount of direct current applied. An inclined non-magnetic shute vibrates between the poles of the magnet. Many magnetic susceptibility tables have been published and these should be consulted when deciding on the most suitable settings for the Franz separator. After the highly magnetic minerals are removed by hand magnet, the remaining heavy minerals can be divided into moderately magnetic and weakly magnetic categories using the following settings:

Horizontal slope	30°
Side Tilt	20°
Field Strength	12 amps.

Two labelled vials are placed at the chute outlet; the vial farthest from the operator collects the weakly magnetic mineral, conversely the vial closest would contain moderately magnetic minerals. Grains should be gradually feed into the collecting hopper to prevent clogging and to ensure accurate separation. It may be necessary to raise the hopper by unscrewing it upwards, since prolonged vibration may cause the hopper to rotate downwards thereby closing the gap to the chute.

A visual observation of the minerals in the vials should give an indication of the effectiveness of the separation. It may be necessary to run the sample several times throught the separator to ensure an adequate separation.

Although use of a magnetic separator may be useful in heavy mineral identification, it was found that the proceedure was too time consuming in view of the results produced.

MAGNETIC SUSCEPTIBILITY TABLE*

HEAVY MINERAL SEPARATION

SAMPLE (up to 25 g)

Sieve

2.0ϕ and 3.0 ϕ FRACTIONS

HEAVY LIQUID (Specific Gravity - 2.96)

Sinks (>2.96)
Weigh

Float (<2.96)
Weigh

Hand Magnet (Wt. Magnetite)

Franz Magnetic Separator -

Side Inclination 20°

Side Inclination 5°

0.35 AMPS	0.8 AMPS	1.2 AMPS	1.2 AMPS
Ilmenite	Garnet Hornblende Pyroxene Biotite Olivine Epidote	Spinel Diopside Hornblende Pyroxene Tremolite Muscovite Tourmaline	Sphere Zircon Rutile Anatare Brookite Apatite Monozite Leucoxene

Methylene Iodine
(Specific Gravity 3.3)

Sink (3.3)	Float (3.3)
Garnet Hornblende	Amphibole Pyroxine Epidote

Methylene Iodine
(Specific Gravity 3.3

Sink (3.3)	Float (3.3)
Zircon Sphere	Qtz. Impurities Apatite Zoisite

* Courtesy of the laboratory of the Canadian Inland Water Research Directorate (Burlington)

The groups of minerals separated by the apparatus could be visually identified under the microscope in a lesser amount of time and therefore the magnetic separator was abandoned.

G. MOUNTING

To obtain a representative sample prior to mounting the heavy minerals, the sample was quartered by hand using 4 pieces of paper. The mounting medium, Lakeside 70 (R.I. 1.54) was heated to 100°C on a hot plate so that it could be spread evenly over a glass slide.

The grains are carefully sprinkled laterally across the width of the slide to reduce the amount of sorting and clustering in an attempt to achieve a random distribution of grains.

Once the grains are mounted, the slide is removed from the hot plate to be properly labelled.

H. COUNTING

A "modified" ribbon count employed by Gwyn (1979) was used. In this method, regularly spaced traverses are used, with only the grains completely within the field of view being identified and counted. The field of view is moved at 2mm intervals in a traverse down the length of the slide and 2mm over to begin a new traverse, once the end of the slide has been reached.

Slides were examined with a Vickers petrographic microscope, both in transmitted and reflected light (supplied by a binocular light source). The occular lens magnification was 10 X while the objective lens magnification was 10 X which provided a combined magnification of 100 X. The slides were moved by Vickers point counter and the counts were recorded on a Swift counter.

Since information on the non-opaque minerals are most useful for interpretation purposes, it is practical to make a preliminary count to determine the ratio of non-opaque to opaque minerals using aforementioned counting proceedure. Subsequently only the non-opaque minerals are identified in the grain counts.

Between 400 and 450 grains non-opaque grains were counted per sample, as this seems to be the number at which the percentage values stabilize for constituents less than 10%. Tables were set up with percentage values for the most prevalent minerals.

AID IN MICROSCOPIC IDENTIFICATION OF MINERALS

The following is a list of useful parameters in mineral identification

(i) Colour & luster
(ii) Pleochroism
(iii) Cleavage and fracture
(iv) Habit
(v) Refractive Index
(vi) Inclusions
(vii) Interference Colours
(ix) Alteration

It is often useful to examine a set of index or reference slides of heavy minerals in order to familiarize oneself with the mineralogy of sand-sized grains. The characteristics of unknown grains should be noted when counting and may be referred to as unknown 1,2,3, etc. If later on they are identified, then these counts can be included rather easily. Making sketches of prevalent minerals is also helpful in the beginning. Often dark hornblende may be confused with opaque minerals, however a thin band of interference colours around the edge of the hornblende grain usually gives it away. It is often best to examine garnets under reflected light to determine the true colour of the grain. One should be careful of what is the colour of the mineral and what may be a coating. It should be noted that for some minerals the form is cleavage controlled, but for others it may not be.

Characteristics of Common Minerals found in Sediments

Apatite
- colourless, white or green; often transparent
- ends may be fractured
- well rounded oval or elongate grains
- moderately high relief
- inclusion common
- gray to pale yellow interference colours
- straight extinction

Biotite
- brown translucent flakes, green biotite rare
- non pleochroic
- tabular, platy cleavage flakes vary from hexagonal to rounded irregular; jagged edges
- low to moderate relief
- inclusions common with characteristic dark halos
- commonly altered
- extinction from 0-9°, wavy

Opaque Minerals

1. Ilmenite
   - brownish to purplish black in reflected light
   - opaque in transmitted light
   - high refractive index
   - irregular to well rounded
   - may be altered
2. Hematite
   - dark red to black with metallic lustre in reflected light (may appear translucent)
   - opaque in transmitted light
   - high refractive index
   - may occur as irregular powdery aggregates, as inclusions or as grain coatings

3. Limonite
   - dull yellow/orange, brown to brownish black in reflected light
   - opaque in transmitted light
   - has earthy to metallic lustre
   - high refractive index
   - may occur as irregular grains or powdery aggregates

4. Magnetite
   - bluish-black in reflected light
   - opaque in transmitted light
   - has metallic lustre
   - angular and well rounded grains
   - difficult to distinguish from magnetite
   - strongly magnetic

5. Muscovite
   - colourless
   - occurs in thin transparent flakes or in tabular, scaly and aggregate forms
   - low relief
   - low order interference colours
   - biaxial negative
   - extinction 1-3°

6. Ortho-pyroxene
   - colourless (enstatite) to pale pink & green (hyperstene) to brown (bronzite variety)
   - highly variable pleochroism from pink to green
   - elongate to stubby cleavage fragments (prismatic, anhedral-subhedral)
   - striations occur parallel to cleavage
   - high refractive index
   - numberous tiny inclusions produce schiller structure
   - low briefringence
   - biaxial positive
   - straight extinction

7. Rutile
   - yellow, reddish brown, red
   - faint pleochroism
   - irregular grains, elongate with well rounded ends, may be prismatic, acicular or as reticulate network

- extremely high relief, produces dark bands around edges
- numerous inclusions common
- very high briefringence
- uniaxial, positive
- parallel extinction

8. Sphene (titanite) pale yellow to light brown.
   - may be faintly pleochroic (colourless to pale green to yellow brown)
   - form ranges from diamond shaped euhedral grains to subangular irregular grains
   - poor cleavage
   - high relief
   - high birefringenece
   - incomplete extinction in white light due to high dispersion
   - may have dusky alteration products in its interior

9. Staurolite
   - straw yellow gold, brown & colourless
   - marked pleochroism (colourless to pale yellow to golden yellow)
   - cleavage is not readily noticeable
   - short prismatic grains determined by cleavage, either by hackly or subconcoidal fracture
   - irregular, platy grains
   - high relief
   - numerous inclusions (usually quartz) - gives porous appearance
   - bright interference colours
   - parallel, symmetrical extinction

10. Tourmaline
    - yellow, brown, dark brown to black
    - strongly pleochroic (dark brown to honey yellow)
    - cleavage lacking
    - usually occurs as irregularly fractured grains, sometimes as elongate prismatic grains or well rounded oval grains
    - moderate relief
    - inclusions are common
    - extinction parallel to length (and to striations)

11. Tremolite
    Actinolite
    - colourless (tremolite) to pale green (actinolite)
    - weakly pleochroic
    - cleavage occurs at 56° and 124°
    - prismatic, elongate grains, with ragged ends
    - moderate relief
    - inclined extinction
    - biaxial negative

12. Zircon
    - colourless, yellow, pink & purple
    - pleochroic in strongly coloured varieties
    - prismatic grains with pyramidal terminations
    - usually rounded
    - may be zoned or have inclusions
    - straight extinction

13. Clinopyroxenes

a) Augite

- brownish grey and grayish green - (both pale), lavender
- only lavender variety is pleochroic - cleavage at 90°
- occurs as elongate grains or worn cleavage fragments
- poorly rounded to irregular
- high refractive index
- may have dark platy inclusions
- biaxial positive
- 45° extinction angle
- may show cloudy alteration

b) Diopside

- lacks colour, may be pale green
- non pleochroic
- two cleavages at 87°
- occurs as prismatic grains, moderately, well rounded to irregular
- may be coated with greenish yellow alteration products
- biaxial positive
- extinction angle 38°

14. Chlorite

- pale green to dirty yellow green
- form ranges from tabular, radiating, pseudomorphs
- micaceous platy appearance
- low to moderate refractive index
- very low birefringence
- biaxial, negative and positive
- may contain pleochroic haloes
- extinction angle 0-9°

15. Epidote

- pale greenish yellow to lemon yellow distinct weak pleochroism (colourless to greenish yellow to colourless)
- partly rounded to irregular grain, sometimes prismatic
- high refractive index
- biaxial negative
- high order interference colours
- small extincton angle, ranges from 0-15°

16. Hornblende

- mostly green also brown or very dark (nearly opaque)
- prismatic fragments which are irregular and poorly rounded
- pleochroic from pale green to dark green
- moderate to high refractive index
- cleavages at 56° and 124°
- moderate interference colours
- inclined extinction from 4° - 24°

17. Garnet

- brown green, purple, colourless, pink, red
- non-pleochroic
- very angular, irregular transparent grains
- characterized by conchoidal fractures
- very high relief
- may have anisotropic inclusions
- anisotropic

I. PRETREATMENT

The heavy minerals were not cleaned with stannous chloride or hydrochloric acid so that the more solube minerals such as apatite would not be destroyed. The carbonates would have been removed, had provenance been the object of the study.

Appendix 4

Mineralogical Composition (in percentage) Determined by Model Analysis of Thin Sections.

	Presqu'ile Bay Area		Wellington-Athol Bay Area		
Sample No.	0568	0575	0625	0628	0646
Total count	335	311	303	382	307
Quartz	49.3	49.2	51.82	45.8	56.4
Feldspars	11.27	8.7	10.56	8.62	3.26
Carbonates	7.16	28.0	7.08	23.31	30.94
Mica (MI)	0.9	--	0.33	--	--
Orthopyroxene (OX)	2.99	2.3	1.65	1.05	1.3
Clinopyroxene (CP)	7.67	3.86	0.33	4.19	1.3
Rutile (RU)	0.3	--	--	--	--
Epidote (EP)	0.6	0.96	0.33	0.52	0.65
Opaque (OP)	7.16	0.96	2.97	2.09	0.65
Garnet (PG & RG)	3.66	0.96	2.97	2.36	1.3
Horneblende (HB)	5.1	2.25	1.65	7.07	0.65
Tremolite-Actinolite (TR)	2.39	0.96	1.0	1.8	1.3
Sphere (SP)	--	0.65	0.33	0.26	--
Tourmaline (TM)	trace	0.64	0.66	1.3	.98
Unknown	0.9	--	0.33	1.05	1.3
Sum of Percentage	99.4%	99.4%	100%	99.42%	100%
% Light mineral	68.63	85.92	87.8	77.73	90.6
% Heavy mineral	31.28	13.44	11.2	21.05	8.1

Appendix 5:
Heavy mineral concentrations used for analysis.

WB = Wasaga Beach; BB = Bowmanville Bluffs; WBY = Presqu'ile-Wellington Bay area; GWY = data from Gwyn's Ph.D. Thesis (1971) modified to fit the classes measured in WBY. Gr. si. = grain size; Tot. Hvy = total heavy mineral; No. Cts = number of counts; Unkn = Unknown; Wt. HVY(g) = weight of heavy mineral in grams; Spl. wt. (g) = weight of sample in grams.

The mineral species measured are:

HB Hornblende

TR Tremolite-Actinolite

CP Clinopyroxene

OX Orthopyroxene

RG Red Garnet

PG Purple Garnet (including colouress garnet)

EP Epidote

RU Rutile

SP Sphene

ZR Zircon

MI Mica

TM Tourmaline

ST Staurolite

CH Chlorite

OP Opaques

Samples	Gr.si. mm / MI · Wt. HVY (g) / TM · Tot. HVY% / ST · No. Cts / CH · HB · TR · CP · OX · RG · PG	EP / Unk. · RU / OP · SP / Spl.Wt(g) · ZR	Record no.
WB730201	125 40239.403.103.507.109.605.907.504.903.505.6		1
WB730201	00.71 .000.001.6	02.006.0	2
WB30180	125 40034.300.305.504.029.813.502.500.702.700.7		1
WB30180	00.005.500.000.0	02.012.0	2
WB30205	125 40047.303.007.504.806.006.300.601.303.009.0		1
WB30205	00.013.000.000.0	08.011.0	2
WB40100	125 40011.000.500.800.052.031.802.001.300.800.8		1
WB40100	00.001.000.000.0	04.008.0	2
77BB00740002	1250.148607.440032.504.512.306.004.809.505.303.602.812.8		1
77BB00740002	00.008.000.000.0	05.008.002.0002	2
77BB00740013	1250.021404.640233.107.512.204.505.706.003.703.002.711.2		1
77BB00740013	00.309.200.700.3	02.012.002.0004	2
77BB01910008	1250.132406.640636.506.211.103.406.407.103.405.703.907.6		1
77BB01910008	00.506.900.301.0	01.003.002.0008	2
77BB01980002	1250.382519.140629.108.918.006.904.403.902.002.702.710.3		1
77BB01980002	00.509.000.000.7	06.008.002.0000	2
77BB02000005	1250.058002.941636.110.111.208.402.203.103.802.902.211.8		1
77BB02000005	01.006.000.700.5	05.006.002.0005	2
77BB03160102	1250.288314.441134.110.015.604.102.902.002.002.702.412.4		1
77BB03160102	01.009.205.201.7	09.005.002.0004	2
WBYOSPL563A	00.001.01250.046302.340239.021.413.703.500.802.000.800.902.004.5		1
WBYOSPL563A	00.001.001.209.700.000.5	06.004.002.0001	2
WBYOSPL563A	01.003.01250.439621.941239.403.404.601.520.315.102.200.604.002.2		1
WBYOSPL563A	01.003.000.904.600.600.6	07.020.002.0004	2
WBYOSPL568A	00.001.01250.261613.141533.806.008.603.807.516.101.701.707.507.5		1
WBYOSPL568A	00.001.000.501.701.701.9	00.010.002.0003	2
WBYOSPL568A	01.002.01250.233311.740531.413.908.904.707.505.601.402.805.605.6		1
WBYOSPL568A	01.002.000.611.400.300.0	02.009.002.0007	2
WBYOSPL570A	00.002.01250.075703.341733.608.007.405.407.404.302.305.107.704.3		1
WBYOSPL570A	00.002.002.611.100.600.3	07.015.002.0015	2
WBYOSPL570A	02.003.01250.100605.040937.611.203.604.304.004.302.603.209.204.6		1
WBYOSPL570A	02.003.000.908.600.300.6	02.014.002.0005	2
WBYOSPL570A	03.004.01250.189509.540146.405.707.104.303.302.504.303.905.702.2		1
WBYOSPL570A	03.004.001.410.701.001.4	02.012.002.0001	2
WBYOSPL571A	00.001.51250.142507.140931.010.912.404.403.505.602.103.508.907.4		1
WBYOSPL571A	00.001.502.106.301.500.0	04.014.002.0004	2
WBYOSPL571A	01.502.51250.252314.840737.108.411.105.206.104.103.501.306.704.1		1
WBYOSPL571A	01.502.500.310.100.000.0	07.009.002.0003	2
WBYOSPL575B	00.002.01250.066703.341129.314.612.705.901.402.401.202.105.905.0		1
WBYOSPL575B	00.002.001.41 500.000.6	06.013.002.0007	2
WBYOSPL575B	02.004.01250.103105.240634.012.809.805.903.701.705.100.302.804.5		1
WBYOSPL575B	02.004.000.316.301.401.4	03.012.002.0015	2
WBYOSPL575B	04.005.01250.114605.741334.712.610.104.103.004.404.402.206.305.2		1
WBYOSPL575B	04.005.001.004.000.602.4	05.008.002.0004	2
WBYOSPL584C	00.002.01250.283714.240334.108.403.702.912.813.101.601.304.404.8		1
WBYOSPL584C	00.002.000.606.700.300.6	05.022.002.0001	2
WBYOSPL584C	02.003.01250.277811.940736.109.105.702.614.914.003.401.702.303.1		1
WBYOSPL584C	02.003.000.805.100.301.1	08.020.002.0002	2
WBYOSPL584C	03.004.01250.182209.140828.912.709.803.512.408.502.303.202.603.9		1
WBYOSPL584C	03.004.001.009.800.001.0	05.017.002.0004	2
WBYOSPL585B	00.001.01250.162708.140334.213.909.905.504.204.001.202.003.208.7		1
WBYOSPL585B	00.001.001.708.700.001.2	08.013.002.0007	2
WBYOSPL585B	01.002.01250.233211.740837.009.810.102.908.610.302.002.000.505.9		1
WBYOSPL585B	01.002.001.508.600.300.5	05.015.002.0006	2
WBYOSPL586A	00.002.01250.122926.141244.712.112.905.603.101.900.502.701.902.9		1

Samples — Gr.s.l. mm (MI) / Wt. HVY (g) (TM) / Tot. HVY % (ST) / No. Cts (CH) / HB / TR / CP / OX / RG / PG / EP (Unkn.) / RU (OP) / SP / ZR (Spl.Wt(g))	Record no.
WBYOSPL586A00.002.001.700.500.000.5 01.013.002.0007	2
WBYOSPL586A02.004.01250.132206.640133.710.717.405.502.704.001.703.202.205.3	1
WBYOSPL586A02.004.000.311.200.001.0 06.010.002.0008	2
WBYOSPL587A00.002.01250.131309.140339.113.815.103.501.704.901.501.203.504.2	1
WBYOSPL587A00.002.000.902.400.600.6 08.006.002.0007	2
WBYOSPL587A02.003.01250.141707.140533.612.614.604.008.406.901.002.503.203.0	1
WBYOSPL587A02.003.001.209.100.200.0 06.005.002.0001	2
WBYOSPL588B00.002.01250.303515.142137.311.415.902.902.903.100.701.404.305.2	1
WBYOSPL588B00.002.002.910.000.002.1 07.004.002.0004	2
WBYOSPL588B02.003.51250.159608.041142.613.113.102.403.201.901.001.502.704.1	1
WBYOSPL588B02.003.501.711.700.001.0 08.004.002.0010	2
WBYOSPL596B00.002.01250.181509.139837.915.015.703.701.802.500.602.702.517.0	1
WBYOSPL596B00.002.002.211.000.000.6 00.011.002.0004	2
WBYOSPL596B02.004.01250.177603.041437.008.908.903.111.110.901.004.102.703.1	1
WBYOSPL596B02.004.002.905.600.200.5 09.007.002.0001	2
WBYOSPL597A00.002.01250.199610.041433.814.714.301.204.805.600.601.702.703.9	1
WBYOSPL597A00.002.002.913.500.300.3 11.003.002.0002	2
WBYOSPL597A02.003.51250.153807.740335.211.613.602.706.908.700.003.902.005.7	1
WBYOSPL597A02.003.500.908.200.000.6 06.007.002.0003	2
WBYOSPL625 00.004.01250.159508.040638.413.311.804.202.505.901.501.203.005.9	1
WBYOSPL625 00.004.002.010.100.300.0 02.003.002.0002	2
WBYOSPL626 00.004.01250.078104.440541.713.311.107.401.204.000.701.203.204.7	1
WBYOSPL626 00.004.003.505.700.000.3 07.005.002.0001	2
WBYOSPL627 00.003.01250.164408.240230.710.010.603.010.214.701.503.002.507.0	1
WBYOSPL627 00.003.000.505.700.500.0 06.008.002.0004	2
WBYOSPL646 00.003.01250.131906.640039.013.816.004.000.802.300.001.802.809.8	1
WBYOSPL646 00.003.001.507.800.000.5 08.004.002.0003	2
WBYOSPL647A00.001.01250.081904.141541.515.417.303.400.202.200.501.202.208.0	1
WBYOSPL647A00.001.002.803.000.000.5 08.004.002.0003	2
WBYOSPL647A01.003.01250.700003.540537.212.305.703.110.208.701.602.503.106.7	1
WBYOSPL647A01.003.000.907.500.500.0 06.015.002.0002	2
WBYCORE004300.002.01250.262413.041035.609.812.006.103.204.600.702.902.209.5	1
WBYCORE004300.002.002.011.000.000.5 07.007.002.0003	2
WBYCORE004323.026.01250.111405.640140.009.011.205.002.003.201.002.502.010.2	1
WBYCORE004323.026.002.210.700.001.0 08.005.002.0001	2
WBYCORE004358.060.01250.036004.342140.111.215.405.501.401.900.501.402.907.6	1
WBYCORE004358.060.002.908.600.000.2 07.006.002.0002	2
WBYCORE004380.032.01250.018201.240244.509.012.405.201.003.700.502.202.208.7	1
WBYCORE004380.032.002.707.200.000.5 06.005.001.5783	2
WBYCORE004600.004.01250.202210.140736.911.114.005.203.904.401.001.702.008.4	1
WBYCORE004600.004.001.509.300.000.7 10.006.002.0007	2
WBYCORE004620.022.01250.036104.340534.613.315.306.401.004.000.301.501.510.9	1
WBYCORE004620.022.001.209.600.300.3 04.004.002.0004	2
WBYCORE004640.042.01250.050002.541042.410.217.304.601.501.500.701.002.708.0	1
WBYCORE004640.042.002.008.000.000.5 03.003.002.0005	2
WBYCORE004660.062.01250.033001.941244.409.214.104.401.502.900.302.401.508.7	1
WBYCORE004660.062.002.207.300.000.7 06.007.002.0006	2
GWY 4135 0.0 0.0125 1.2484 60.3 0.816.4 4.6 8.7 7.8 0.6 0.0 0.0 0.0	1
GWY 4135 0.0 0.0 0.6 0.2 0.0 0.0 0.0 1.4	2
GWY 4136 0.0 0.0125 1.148940.0 0.816.8 6.426.8 9.0 0.0 0.0 0.2 0.0	1
GWY 4136 0.0 0.0 0.0 0.0 0.0 0.0 0.0 4.5	2
GWY 4137 0.0 0.0125 3.149351.3 0.713.7 9.013.9 9.6 1.1 0.0 0.2 0.4	1
GWY 4137 0.0 0.0 0.0 0.0 0.0 0.0 0.010.4	2
GWY 4138 0.0 0.0125 0.2454 9.6 0.0 3.8 0.5 1.5 1.7 0.0 0.0 1.2 0.3	1
GWY 4138 0.0 0.026.744.7 0.0 0.0 0.024.0	2

Samples		Gr.si. mm / Wt. HVY (g) / Tot. HVY% / No. Cts / HB / TR / CP / OX / RG / PG — MI / TM / ST / CH	EP / RU / SP / ZR — Unkn. / OP / Spl.Wt(g)	Record no.
GWY	4139	0.0 0.0125 2.351067.2 0.027.2 1.5 0.9 1.5	0.0 0.4 1.1 0.0	1
GWY	4139	0.0 0.0 0.0 0.2 0.0 0.0	0.0 5.9	2
GWY	4141	0.0 0.0125 0.950452.8 5.419.6 0.3 5.6 9.4	0.8 1.8 3.3 0.5	1
GWY	4141	0.0 0.0 0.0 0.5 0.0 0.0	0.020.6	2
GWY	4142	0.0 0.0125 2.250757.3 1.920.4 0.4 7.2 7.2	1.5 1.5 2.4 0.0	1
GWY	4142	0.0 0.0 0.0 0.0 0.0 0.0	0.0 6.5	2
GWY	4143	0.0 0.0125 1.951865.9 1.317.7 0.2 3.6 8.8	0.4 0.0 1.1 0.2	1
GWY	4143	0.0 0.0 0.2 0.0 0.0 0.0	0.0 7.3	2
GWY	4144	0.0 0.0125 2.050642.7 4.838.7 0.0 2.1 7.9	0.4 1.7 1.7 0.0	1
GWY	4144	0.0 0.0 0.4 0.0 0.0 0.0	0.0 7.7	2
GWY	4145	0.0 0.0125 2.151449.0 3.838.4 0.0 0.4 2.1	0.0 1.7 3.8 0.2	1
GWY	4145	0.0 0.0 0.0 0.4 0.0 0.0	0.0 4.7	2
GWY	4146	0.0 0.0125 2.451966.7 3.615.3 0.9 6.7 3.4	0.7 0.2 1.5 0.0	1
GWY	4146	0.0 0.0 0.5 0.0 0.0 0.0	0.013.5	2
GWY	4147	0.0 0.0125 1.549154.5 7.122.9 0.5 4.5 6.9	2.2 0.0 0.7 0.0	1
GWY	4147	0.0 0.0 0.5 0.2 0.0 0.0	0.016.7	2
GWY	4148	0.0 0.0125 0.950851.611.620.0 0.4 4.5 3.9	3.8 2.2 1.1 0.0	1
GWY	4148	0.0 0.0 0.4 0.4 0.0 0.0	0.0 6.9	2
GWY	4149	0.0 0.0125 1.251553.9 6.123.3 0.6 6.5 4.1	3.5 0.0 1.5 0.0	1
GWY	4149	0.0 0.0 0.2 0.4 0.0 0.0	0.0 4.1	2
GWY	4150	0.0 0.0125 1.451453.1 5.826.1 0.9 4.6 6.2	1.3 0.4 1.7 0.0	1
GWY	4150	0.0 0.0 0.0 0.0 0.0 0.0	0.0 6.0	2
GWY	4151	0.0 0.0125 2.150457.9 6.919.1 0.4 5.4 6.5	0.8 0.8 1.7 0.0	1
GWY	4151	0.0 0.0 0.4 0.0 0.0 0.0	0.0 2.8	2
GWY	4152	0.0 0.0125 2.449253.7 4.622.0 0.0 5.6 9.9	0.0 1.1 1.9 0.0	1
GWY	4152	0.0 0.0 1.1 0.2 0.0 0.0	0.0 5.3	2
GWY	4153	0.0 0.0125 2.750448.7 7.130.7 1.1 4.0 2.5	1.3 1.5 1.5 0.2	1
GWY	4153	0.0 0.0 0.2 1.3 0.0 0.0	0.0 3.2	2
GWY	4154	0.0 0.0125 1.473651.9 3.117.5 0.9 3.0 7.0	3.1 0.6 2.3 0.1	1
GWY	4154	0.0 0.0 0.010.4 0.0 0.0	0.012.2	2
GWY	4155	0.0 0.0125 1.169356.3 1.920.1 1.5 3.9 4.3	1.1 0.4 1.5 0.1	1
GWY	4155	0.0 0.0 0.0 9.0 0.0 0.0	0.017.5	2
GWY	4156	0.0 0.0125 1.367451.3 2.716.6 1.1 5.1 4.9	1.5 2.0 1.6 0.5	1
GWY	4156	0.0 0.0 0.014.9 0.0 0.0	0.017.5	2
GWY	4157	0.0 0.0125 1.372857.3 1.913.2 1.4 4.2 5.3	1.9 0.4 3.0 0.0	1
GWY	4157	0.0 0.0 0.011.3 0.0 0.0	0.021.3	2
GWY	4158	0.0 0.0125 1.572464.2 2.214.8 1.0 2.5 3.5	0.7 0.5 2.3 0.0	1
GWY	4158	0.0 0.0 0.0 8.4 0.0 0.0	0.015.7	2
GWY	4159	0.0 0.0125 2.350362.0 3.717.8 0.6 4.3 9.1	1.0 0.0 1.2 0.0	1
GWY	4159	0.0 0.0 0.2 0.0 0.0 0.0	0.0 2.4	2
GWY	4160	0.0 0.0125 2.061261.6 2.218.2 2.1 5.0 7.3	0.5 0.7 2.1 0.0	1
GWY	4160	0.0 0.0 0.3 0.0 0.0 0.0	0.0 3.8	2
GWY	4161	0.0 0.0125 1.849627.331.315.2 1.8 3.118.1	0.7 0.2 1.8 0.0	1
GWY	4161	0.0 0.0 0.4 0.0 0.0 0.0	0.0 9.7	2
GWY	4162	0.0 0.0125 1.550258.817.614.3 1.3 0.6 4.2	0.6 0.6 0.8 0.0	1
GWY	4162	0.0 0.0 0.6 0.6 0.0 0.0	0.0 2.2	2
GWY	4163	0.0 0.0125 3.451038.8 4.542.0 1.3 1.8 9.6	0.2 0.9 0.0 0.4	1
GWY	4163	0.0 0.0 0.4 0.0 0.0 0.0	0.0 6.3	2
GWY	4164	0.0 0.0125 2.650037.017.623.7 0.4 2.614.8	1.1 1.1 0.9 0.0	1
GWY	4164	0.0 0.0 0.7 0.0 0.0 0.0	0.0 7.6	2
GWY	4165	0.0 0.0125 2.551352.213.820.3 0.0 1.310.1	1.6 0.4 0.2 0.0	1
GWY	4165	0.0 0.0 0.2 0.0 0.0 0.0	0.0 4.1	2
GWY	4166	0.0 0.0125 1.651848.3 3.924.8 1.6 4.315.4	0.0 1.0 2.4 0.0	1
GWY	4166	0.0 0.0 0.2 0.0 0.0 0.0	0.0 5.4	2
GWY	4167	0.0 0.0125 2.254361.7 2.817.0 1.0 3.211.5	0.8 0.8 0.2 0.2	1

Samples		Gr.s.l. mm / MI, Wt. HVY (g) / TM, Tot. HVY% / ST, No. Cts / CH	HB, TR, CP, OX, RG, PG	EP, RU, SP, ZR / Unkn., OP, Spl.Wt.(g)	Record no.
GWY	4167	0.0 0.0 0.0 0.0 0.0 0.0		0.0 7.9	2
GWY	4168	0.0 0.0125	1.250518.5 5.348.311.7 4.010.4	0.3 0.3 0.0 0.0	1
GWY	4168	0.0 0.0 0.3 0.0 0.0 0.0		0.020.0	2
GWY	4169	0.0 0.0125	2.051120.5 2.736.2 4.433.0 2.0	0.2 0.5 0.2 0.2	1
GWY	4169	0.0 0.0 0.0 0.0 0.0 0.0		0.019.4	2
GWY	4170	0.0 0.0125	2.051750.5 0.215.6 0.026.1 5.8	0.2 0.2 1.3 0.0	1
GWY	4170	0.0 0.0 0.0 0.0 0.0 0.0		0.0 6.8	2
GWY	4171	0.0 0.0125	0.958218.3 0.371.8 0.4 1.3 4.5	3.2 0.0 0.0 0.0	1
GWY	4171	0.0 0.0 0.0 0.3 0.0 0.0		0.030.8	2
GWY	1881	0.0 0.0125	.652737.9 0.726.0 3.2 3.610.9	1.7 0.0 1.4 0.8	1
GWY	1881	0.0 0.0 2.2 2.7 0.0 0.0		0.021.8	2
GWY	1948	0.0 0.0125	0.751136.514.032.8 2.9 6.0 6.0	0.3 0.0 1.2 0.3	1
GWY	1948	0.0 0.0 0.0 0.0 0.0 0.0		0.025.4	2
GWY	2153	0.0 0.0125	1.852063.0 0.415.4 0.2 7.9 4.2	5.5 0.6 2.6 0.0	1
GWY	2153	0.0 0.0 0.0 0.0 0.0 0.0		0.0 5.2	2
GWY	2196	0.0 0.0125	0.751942.3 0.451.8 0.4 1.1 1.9	1.9 0.2 0.0 0.0	1
GWY	2196	0.0 0.0 0.0 0.0 0.0 0.0		0.0 8.3	2
GWY	2199	0.0 0.0125	2.351155.6 0.0 5.7 0.027.7 7.0	1.1 0.0 2.4 0.0	1
GWY	2199	0.0 0.0 0.4 0.0 0.0 0.0		0.0 6.1	2
GWY	2816	0.0 0.0125	0.249739.610.117.1 3.3 4.915.2	0.8 1.1 1.1 0.0	1
GWY	2816	0.0 0.0 2.7 4.1 0.0 0.0		0.026.8	2
GWY	3961	0.0 0.0125	2.548553.7 0.414.9 1.120.3 7.9	0.4 0.4 0.0 0.0	1
GWY	3961	0.0 0.0 0.0 0.0 0.0 0.0		0.0 4.8	2
GWY	3985	0.0 0.0125	1.251140.5 0.052.7 0.2 1.8 2.3	1.8 0.2 0.5 0.0	1
GWY	3985	0.0 0.0 0.0 0.0 0.0 0.0		0.011.7	2
GWY	4100	0.0 0.0125	2.954754.1 0.713.0 1.720.2 8.5	0.8 0.0 1.2 0.0	1
GWY	4100	0.0 0.0 0.0 0.0 0.0 0.0		0.0 9.0	2
GWY	4101	0.0 0.0125	2.450746.9 1.714.6 0.924.7 9.1	0.9 0.2 0.2 0.0	1
GWY	4101	0.0 0.0 0.0 0.0 0.0 0.0		0.0 5.7	2
GWY	4102	0.0 0.0125	2.150751.0 0.410.6 0.622.612.8	0.6 0.0 0.8 0.0	1
GWY	4102	0.0 0.0 0.0 0.4 0.0 0.0		0.0 3.9	2
GWY	4103	0.0 0.0125	2.350774.4 0.0 6.3 0.213.9 2.3	0.8 0.2 1.9 0.0	1
GWY	4103	0.0 0.0 0.0 0.0 0.0 0.0		0.0 3.2	2
GWY	4104	0.0 0.0125	1.251840.1 0.251.2 0.7 4.6 1.7	1.1 0.0 0.4 0.0	1
GWY	4104	0.0 0.0 0.0 0.0 0.0 0.0		0.010.2	2
GWY	4105	0.0 0.0125	0.353015.1 0.074.9 0.0 2.2 4.1	3.7 0.0 0.0 0.0	1
GWY	4105	0.0 0.0 0.0 0.0 0.0 0.0		0.0 3.0	2
GWY	4128	0.0 0.0125	1.369458.7 0.332.1 0.5 2.2 3.8	1.3 0.0 0.1 0.4	1
GWY	4128	0.0 0.0 0.0 0.0 0.0 0.0		0.0 9.7	2
GWY	4129	0.0 0.0125	1.951372.0 0.222.1 0.2 1.5 0.8	2.8 0.0 0.2 0.0	1
GWY	4129	0.0 0.0 0.0 0.2 0.0 0.0		0.0 2.5	2
GWY	4130	0.0 0.0125	1.549670.0 0.224.1 0.0 0.4 0.4	4.0 0.2 0.6 0.0	1
GWY	4130	0.0 0.0 0.0 0.0 0.0 0.0		0.0 4.2	2
GWY	4131	0.0 0.0125	0.951271.5 0.415.6 0.0 0.7 1.1	8.0 0.2 2.3 0.0	1
GWY	4131	0.0 0.0 0.0 0.2 0.0 0.0		0.0 6.9	2
GWY	4132	0.0 0.0125	1.149852.2 0.513.8 0.019.2 7.6	4.1 0.7 1.8 0.0	1
GWY	4132	0.0 0.0 0.0 0.0 0.0 0.0		0.012.0	2
GWY	4133	0.0 0.0125	2.151342.7 1.514.1 0.232.8 8.2	0.4 0.0 0.0 0.0	1
GWY	4133	0.0 0.0 0.0 0.0 0.0 0.0		0.0 7.4	2
GWY	4134	0.0 0.0125	2.349341.0 0.214.3 1.733.5 7.7	0.2 0.4 0.0 0.0	1
GWY	4134	0.0 0.0 0.8 0.0 0.0 0.0		0.0 5.7	2

Appendix 6

Mean Concentrations of Indicator Minerals and Heavy Mineral Ratios.

For the nearshore samples only the topmost layer was considered. Gwyn's (1971) data have the magnetic opaques (MG) measured as percentage by weight of the total sample prior to splitting the sample. The percentage opaques (OP) was obtained by point counting. Coch (1961) has the percentages calculated only for the most common seven heavy minerals in the 1 to 4 ϕ grain size fraction. The percentage magnetics is by weight, and the percentage opaque is by point count.

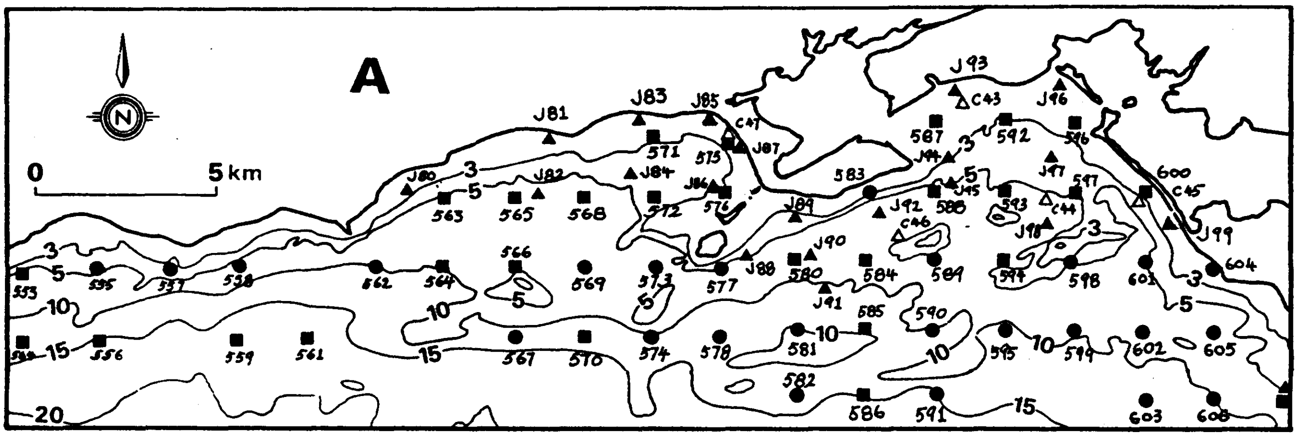
Area	No. of Samples	Assemblages Types	% Total Heavy Minerals	% PG+RG	PG/RG	% OP	% HB	HP/OP	% metastable minerals (OX+CP+TR)	% ultrastable minerals (RT+ZR+TM)	OX+CP+TR/TM
This Study											
a. Presqu'ile nearshore											
<5 m water depth	2	iii	5.2	6.45	1.65	13.5	30.0	2.2	30.5	21.2	3.0
<5 m, <18 m water depth	2	i&ii	7.7	7.0	2.32	7.0	36.5	6.6	28.5	12.4	20.4
<18 m water depth	1	iii	3.18	11.7	0.58	15.0	33.6	2.24	20.8	20.5	1.9
Mean of all samples	5		8.3	8.2	1.71	11.2	33.3	4.85	27.7	17.5	9.7
b. Wellers nearshore											
<18 m water depth	6	i	11.05	7.23	1.52	6.2	35.85	6.97	30.9	20.7	2.9
>18 m water depth	3	iv	9.47	13.0	0.85	16.0	37.7	2.6	28.9	15.8	3.9
Total	9		9.84	9.2	1.17	9.44	37.4	5.52	30.2	19.0	3.2
c. Wellington-Athol nearshore											
<18 m water depth	4	i	5.8	5.0	2.86	4.0	40.15	10.3	36.6	16.4	4.7
>18 m water depth	1	iv	8.2	24.9	1.44	8.0	30.7	3.84	23.5	3.0	4.1
Total	5		6.26	9.0	2.58	4.8	38.26	8.0	34.0	13.2	4.6
d. Port Hope (Bluffs)											
Proximal sand	2	--	16.75	6.6	0.79	6.5	31.6	3.25	31.8	23.6	2.8
Distal sand	3	--	6.2	13.2	1.38	7.7	34.0	6.4	22.5	22.0	3.3
Deep lacustrine	1	--	2.9	5.3	1.4	6.0	36.1	6.0	29.7	20.7	5.0
e. Scarborough Bluffs											
Bedded sand	2	--	12.2	25.0	0.77	13.5	24.6	2.28	22.2	22.8	2.5
Rythmites	2	--	9.9	19.5	1.45	7.5	37.9	7.8	23.0	18.5	2.5

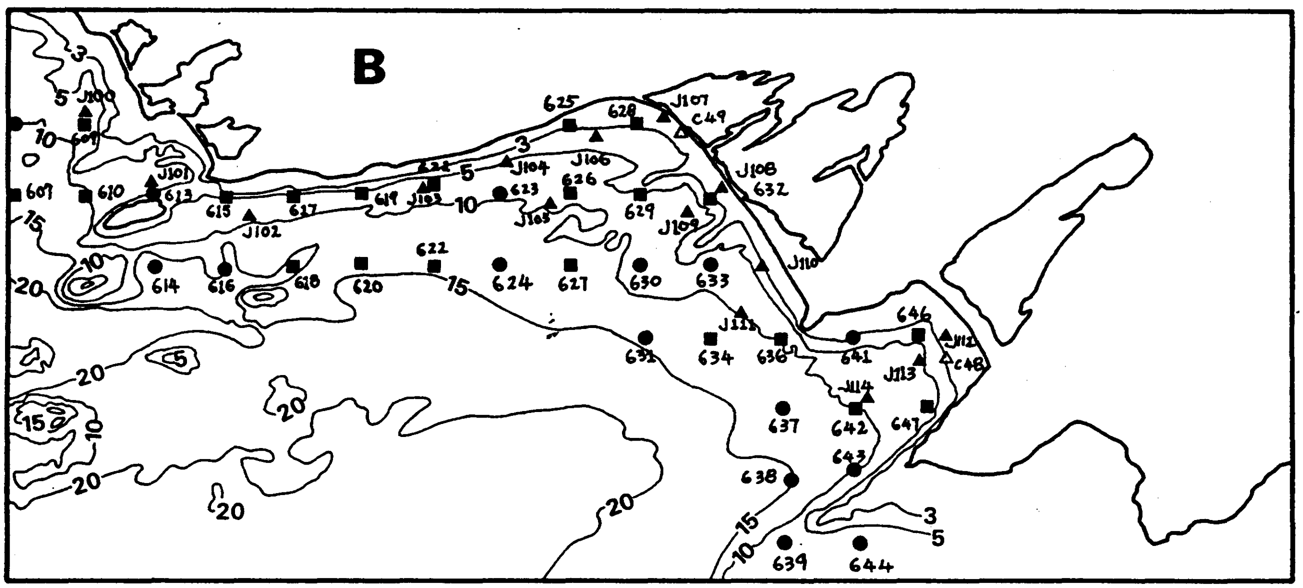
Appendix 6: Cont'd

Area	No. of Samples	Assemblages Types	% Total Heavy Minerals	% PG+RG	PG/RG	% OP	% HB	HP/OP	% metastable minerals (OX+CP+TR)	% ultrastable minerals (RT+ZR+TM)	OX+CP+TR/TM
f. Wasaga Beach											
Dune	2	--	--	13.9	0.83	8.5	43.4	5.4	15.0	21.7	1.3
Beach	2	--	--	62.5	0.55	10.0	22.9	2.1	5.6	5.0	1.6
						MG / OP					
Gwyn (1971): Inland											
a. Georgian Bay	13	--	2.0	25.8	0.45	2.1 / 5.9	48.3	--	17.36	0.24	--
b. East Grenville:											
Karwatha	9	--	1.64	9.9	1.63	5.7 / 12.5	45.8	--	21.4	4.6	--
Madoc	9	--	1.82	10.42	1.39	3.9 / 5.2	51.7	--	26.4	2.0	--
Quebec	8	--	2.09	24.7	5.2	4.6 / 7.9	40.0	--	36.4	0.76	--
Adirondack	4	--	0.71	10.2	2.1	12.8 / 35.6	24.4	--	24.1	1.67	--
Coch (1961): Beach											
a. Rochester - Sodus	9	--	4.3	19.6	1.6	14.7 / 28.6	42.9	--	--	--	--
b. Sodus - Mexico Bay	9	--	4.4	25.2	1.96	22.7 / 9.3	42.2	--	--	--	--
c. Mexico Bay	5	--	6.2	23.8	1.4	10.2 / 24.7	33.0	--	--	--	--
Selleck (1972)											
a. "lake" samples "nearshore"											
Niagara area	8	--	--	18.4	2.06	23.5	18.0	0.8	--	--	--
Between Niagara&Rochester	5	--	--	20.3	3.34	26.1	17.7	0.78	--	--	--
Rochester area	8	--	--	13.1	4.3	26.7	21.9	1.2	--	--	--
b. "Shore" samples											
Niagara Area	6	--	--	14.0	1.68	11.9	15.6	1.66	--	--	--
Between Niagara&Rochester	8	--	--	14.9	1.8	16.9	17.3	1.53	--	--	--
Rochester Area	5	--	--	11.6	3.4	15.1	15.1	2.0			

Appendix 7

Sample Locations





J= Jetting C= Core