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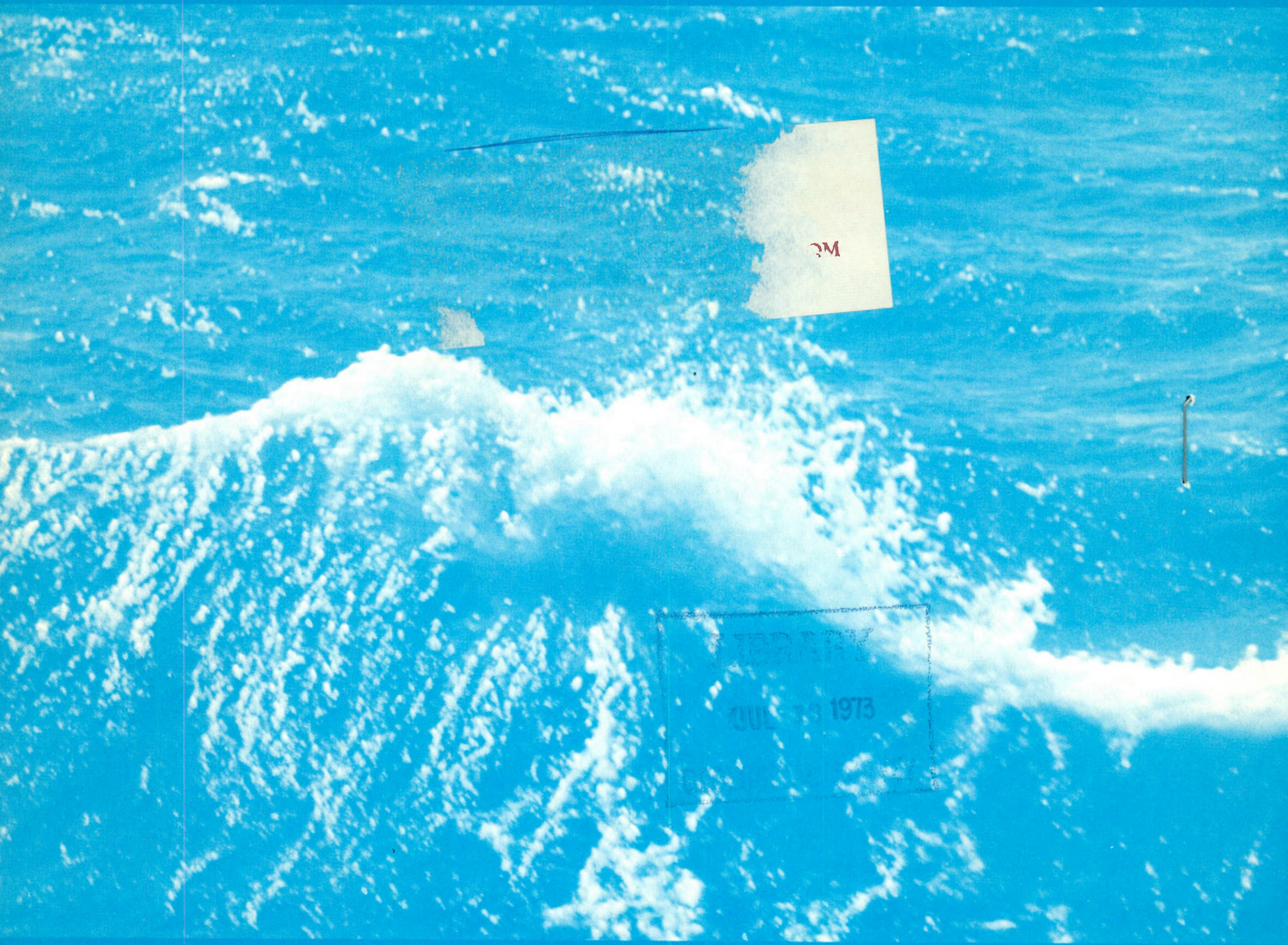
Report on the Surficial Sediment Distribution of the Great Lakes

Part 1 — Lake Ontario

R. L. Thomas, A. L. W. Kemp and C. F. M. Lewis



SCIENTIFIC SERIES NO. 10

GEOLOGICAL SURVEY OF CANADA
PAPER 72-17

(Résumé en français)

CANADA CENTRE FOR INLAND WATERS,
BURLINGTON, ONTARIO, 1972.

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Acknowledgments

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Abstract

Three major sediment units are recognized in the surficial sediments of Lake Ontario on the basis of extensive sampling and echo sounding: (1) glacial till and bedrock; (2) glaciolacustrine clay; (3) postglacial mud. Sand and silt are minor units in the Ontario surficial sediments. The sediment distribution pattern is essentially simple with a natural superposition of sediment units reflecting the glacial and postglacial history of the lake. The inshore region of Lake Ontario is composed of glacial till and bedrock. The till is overstepped in deeper water by glaciolacustrine clays which are themselves overstepped by postglacial muds. Two north-south sills, composed of glaciolacustrine clay, subdivide the main basin of Lake Ontario into three distinct basins of postglacial mud accumulation.

The surficial sediments contain variable amounts of quartz, feldspar, clay minerals, organic carbon and calcite. Quartz and feldspar contents are greatest in the coarser inshore sediments while clay minerals and organic carbon contents are greatest in the finer offshore sediments. Carbonate content is generally low throughout the lake. Illite is the dominant clay mineral with lesser amounts of chlorite and kaolinite. Mean rates of sedimentation ranging from 114 to 309 $g/m^2/y$ = ea = r are estimated for the basins of modern mud accumulation.

The primary source of detrital material is believed to be the extensive glacial deposits of southern Ontario and northern New York State. An estimated 55% of this material is derived from the drainage basin while the remaining 45% is the result of shoreline and lake bottom erosional processes. The textural characteristics, defined by moment measures, of the modern sediments can be interpreted as resulting from the varying degrees of mixing between a sand-and a clay-size end member population; the former occurring in the nearshore zone and the latter in the offshore basin deposits. Both end member populations are leptokurtic and skewed due to the introduction of silt-size material in the form of $CaCO_3$ probably as the product of lake-wide precipitation. Mean grain size and standard deviation, predictably show trends from nearshore to offshore, with decreasing grain size, related to increasing water depth and hence to decreasing energy from a wave- and current-active nearshore region to an offshore region of quiet water with sedimentation from suspension. In addition, skewness and kurtosis show trends relative to mean grain size and standard deviation which can be explained in terms of increasing distance from shore. Variations in the compositional phases of the sediment in terms of quartz, clay and organic carbon, and also variations in the redox potential can in turn be related directly to textural characteristics of the sediment and consequently to the depositional environment.

Résumé

Sur la base d'un échantillonnage extensif et d'une investigation par écho-sondage, on a pu reconnaître trois unités sédimentaires importantes dans les sédiments superficiels du Lac de l'Ontario: (1) les dépôts glaciaires; (2) de l'argile glacio-lacustre; (3) et des vases post-glaciaires. Sables et silt constituent des unités d'importance mineure dans les sédiments superficiels du Lac de l'Ontario. Le modèle de distribution sédimentaire est essentiellement simple. Il se compose d'une superposition naturelle d'unités sédimentaires reflétant l'histoire glaciaire et post-glaciaire du Lac. La région de bordure lacustre est formée de la roche en place et de dépôts glaciaires sur lesquels reposent dans les eaux plus profondes, des argiles glacio-lacustres. Ces dernières sont à leur tour recouvertes par des vases post-glaciaires au fond du bassin. Deux seuils d'allongement Nord-Sud, formés d'argiles glacio lacustres, subdivisent le bassin principal du lac en trois bassins distincts où des vases post-glaciaires se sont accumulées.

Les sédiments superficiels contiennent du quartz, des feldspaths, des minéraux argileux, du carbone organique ainsi que de la calcite, en quantités variables. La teneur en quartz et en feldspaths est plus élevée dans les sédiments grossiers des bordures lacustres à faibles profondeurs d'eau; celle des minéraux argileux et du carbone organique devient plus forte dans les sédiments fins des grandes profondeurs. La teneur en carbonates est généralement faible partout à travers le lac. L'illite constitue le minéral argileux le plus dominant, tandis que la chlorite et la Kaolinite se trouvent en moindres quantités. On estime entre 114 et 309 g/m^2/an les taux moyens de sédimentation dans les bassins d'accumulation récente de vases.

On croit savoir que la source primaire du matériel détritique est constituée par les larges dépôts glaciaires situés au sud de l'Ontario et à la partie nord de l'État de New York. Cinquante-cinq pour-cent de ce matériel sont estimés provenir du bassin de drainage; les autres 45 pour-cent étant le résultat des processus d'érosion des rivages et du fond du lac. Les caractéristiques texturales des sédiments récents, telles que déterminées par des mesures de «moment», peuvent être interprétées comme résultant des degrés variables de mixtion entre des populations de «fin-de-membre» dont la taille des grains est de l'ordre du grain de sable (zone de bordure) et celles dont la taille des grains est de l'ordre de la particule argileuse (zones des grandes profondeurs). Les deux populations sont leptocurtiques et se caractérisent par une distorsion dûe à l'intrusion de matériel très fin sous forme de $CaCO_3$, probablement à la suite de précipitations chimiques généralisées qui se seraient produites dans le lac. Taille moyenne des grains et courbe de déviation standard montrent des tendances à la réduction dans la taille des grains en allant des zones de rivage aux zones des grandes profondeurs. Ces tendances sont dûes à la dimunition d'énergie en partant des zones de rivage caractérisées par une activité intense des vagues et des courants aux régions de grandes profondeurs caractérisées par des eaux plus tranquilles et où la sédimentation est le résultat de décantation du matériel en suspension. De plus, distorsion, kurtosis, montrent des tendances relatives à la taille moyenne des grains et à la déviation standard. Ces tendances peuvent s'expliquer en termes de variations croissantes de la distance à partir du rivage. Les variations affectant les phases de composition des sédiments en ce qui concerne le quartz, l'argile et le carbone organique, ainsi que les variations affectant le «potentiel redox», peuvent en retour être attribuées directement aux caractéristiques texturales des sédiments et par conséquent au milieu de sédimentation.

CHAPTER 1

Introduction

The Laurentian Great Lakes of North America are a unique global feature and comprise the largest natural body of freshwater in the world. As a natural resource, they are without peer and have facilitated the economic and industrial growth of central North America. In view of their importance, it is surprising that little is known of the distribution of the bottom sediments. Geologists, to date, have been primarily concerned with the Quaternary history of the lakes and with the development of the regional physiography (Leverett and Taylor, 1915; Hough, 1958, 1963; Chapman and Putnam, 1966; Prest, 1970).

The first major study of Lake Ontario sediments was that of Kindle (1925). This excellent work was restricted to a series of cross-lake traverses and to a detailed study of three localized areas. Considering the equipment available to Kindle, his elucidation of the bottom sediments is remarkable. Lewis and McNeely (1967) compiled the results of a number of reconnaissance surveys of Lake Ontario sediments and recognized three major groups of surficial deposits: (1) complex nearshore sediments, (2) glaciolacustrine clays, (3) postglacial muds. In addition, a number of publications have been presented on sediment occurrence and distribution in localized areas of the lake; for example, Sutton, Rukavina and Towle (1965), Woodrow, Sutton and Rukavina (1967), Kemp and Lewis (1968), Kemp (1969), Rukavina (1969, 1970), Sly (1969a) and Sutton, Lewis and Woodrow (1970).

The prime objective of the present study is to describe the distribution, composition and characteristics of the surficial Lake Ontario sediments and to relate these to modern lacustrine processes. To this end, samples of the top three cm of sediment were collected at 287 locations throughout the lake. The composition and characteristics of the sediment are described by the particle-size distribution, clay mineralogy, organic carbon, carbonate carbon, quartz, feldspar and by pH and Eh measurements on each sample. In addition, a detailed visual description of each sediment sample was maintained in order to produce a comprehensive map of the sediment distribution in Lake Ontario. Echo-sounding profiles carried out from 1966 to 1970 were utilized to define accurately contacts between major sediment types and to determine the thickness of postglacial muds throughout the lake. These measurements were corroborated by a number of piston cores and used to estimate mean sedimentation rates for the main depositional basins.

The sediment sampling was carried out in 1968 on the C.S.S. LIMNOS and the C.S.L. LEMOYNE, vessels of the Canada Department of Energy, Mines and Resources. Samples were taken at the intersections of a polyconic grid with a north to south line separation of 8 km and an 8 km east to west separation on the grid baseline on latitude 43° 30.0′ N (Figure 1). Positioning was carried out by a Decca 416-radar with a variable range marker. Dead reckoning was used on many cross-lake traverses between reliable radar fixes. The accuracy of the positioning is not known but is estimated as being better than ± 200 m in mid-lake positions.

The grid comprised 287 sampling stations and sufficient sediment for analytical purposes was recovered from 262 locations. Sample recovery was poor or nil at the remaining locations due to a bedrock or boulder lake bottom.

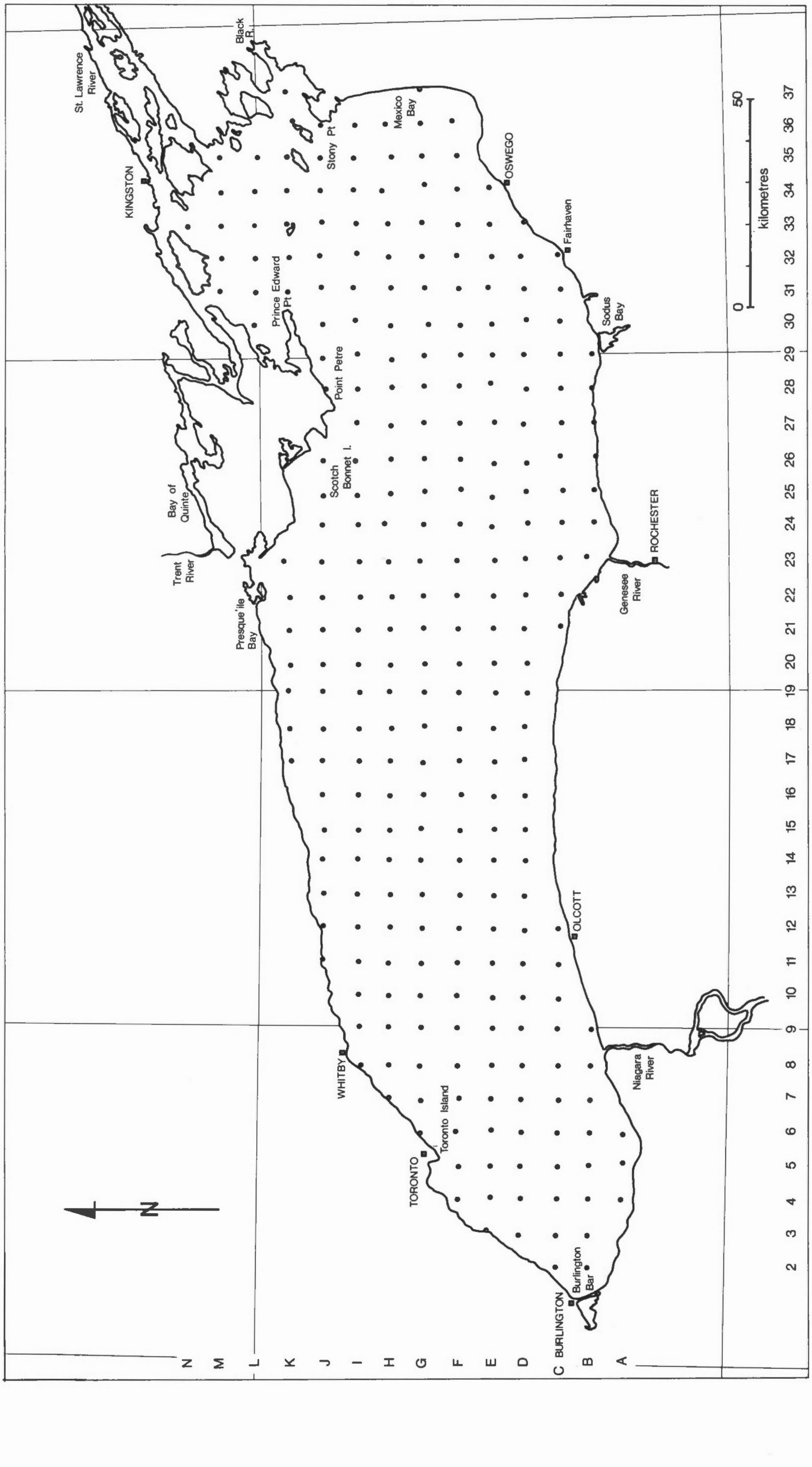

Figure 1. Lake Ontario grid sampling plan, sample locations designated by letter for latitude and number for longitude, e.g., C3, E30 etc.

CHAPTER 2

Regional and Temporal Setting of Lake Ontario

GENERAL DESCRIPTION

Lake Ontario stands at the end of a chain of five Great Lakes, ranging in elevation from 600 ft to 245 ft a.s.l. These lakes drain the southern portions of the Precambrian Shield and its adjacent borderlands composed of marine sedimentary strata eastward to the Atlantic Ocean via the St. Lawrence River. The lake basins appear to be intimately related to bedrock structure and lithology through the effects of preglacial and glacial differential erosion.

Modern Lake Ontario is situated on the regional slope of Ordovician limestones and shales which dip southward into the Appalachian geosyncline. The greater part of the lake basin is excavated in soft Upper Ordovician shale (Queenston Formation). A prominent cuesta of Middle Silurian (Niagaran) dolomite forms the southern margin of the lake basin. The lake axis, trending east to west, is displaced southward because the basin is asymmetric having a gentle-shelving, structurally-controlled, north shore and a steeply-sloping south shore (Fig. 2).

The lake has a maximum length of 306 km and a maximum width of 84 km with a surface area of 19,190 km^2 in a drainage basin having a total area of 69,655 km^2. The maximum depth is 244 m with a mean depth of 91 m.

The shoreline is composed predominantly of unconsolidated glacial sediments, in particular till, glaciolacustrine laminated sediment and in places sandy ice-marginal deposits. Coastal bedrock outcrops composed of Middle Ordovician Trenton limestone occur nearly continuously along the water-line in the northeast. In the west and south, Upper Ordovician shales are exposed at the shoreline in several places. The southern shore in northern New York State is composed of glacial materials throughout with spectacular truncated drumlins occurring in the vicinity of Sodus Bay and Fairhaven. Modern sand accumulation forms the shoreline in a few regions, particularly along the extreme eastern shore near Mexico Bay, along the extreme western shore on Burlington Bar, at Toronto Island and in Presqu'ile Bay on the northern shore.

Lake Ontario discharges 6,620 m^3s^{-1} (233,900 cfs) on the average down the St. Lawrence River. Approximately 83% of this water is received from the upper Great Lakes via the Niagara River entering Lake Ontario in the southwest. The major stream inputs from the local drainage basin are Genesee River with 77 m^3s^{-1} (2,726 cfs) entering from the south at Rochester, Oswego River with 169 m^3s^{-1} (6,200 cfs) entering from the southeast at Oswego, Black River with 106 m^3s^{-1} (3,828 cfs) entering from the east, and Trent River with 118 m^3s^{-1} (4,170 cfs) entering from the north into the Bay of Quinte and northeast Lake Ontario. Both the Black and Trent Rivers drain, in part, portions of the Precambrian shield whereas most streams drain glacial sediments over a Palaeozoic rock terrain. The remaining water input to Lake Ontario is comprised of numerous minor short streams, groundwater discharge and direct precipitation.

GEOLOGICAL HISTORY

The development of the Lake Ontario bedrock basin in Palaeozoic rocks is not fully deciphered but is believed to have resulted from preglacial (Tertiary) river valley erosion in a mature continental drainage system followed by differential glacial scour during the Pleistocene (Hough, 1958). The bedrock basin was certainly in existence during the last major glaciation, the Wisconsin, judging from its influence upon local ice-movements, the lobation of major ice advances, and the circum- and intra-basin distribution of terminal moraines (Chapman and Putnam, 1966).

Lake Wisconsin ice flowed westward through the Ontario basin into the Erie basin. Ablation by melting and stagnation caused the active terminus to retreat northeastward. The retreat was oscillatory with periods of rapid wastage alternating with episodes of increased flow resulting in small advances and deposition of morainic debris. Throughout retreat, the ice-front lay in deep proglacial lake water which deposited fine-grained glacial sediments throughout much of the basin as varved or laminated clay.

Lake Iroquois, with a prominent shoreline around the western Ontario basin, came into being about 126,000 years B.P. during the northeastward glacial retreat when an outlet via the Mohawk and Hudson Valleys was opened to the Atlantic Ocean. Continued retreat permitted the glacial lake waters to drain through a succession of lower lake phases as discharge passed down the St. Lawrence Valley. Final opening of this valley allowed sea water to interchange with fresh; the resulting Champlain Sea extended westward to Brockville, Ontario. Ontario basin waters fell

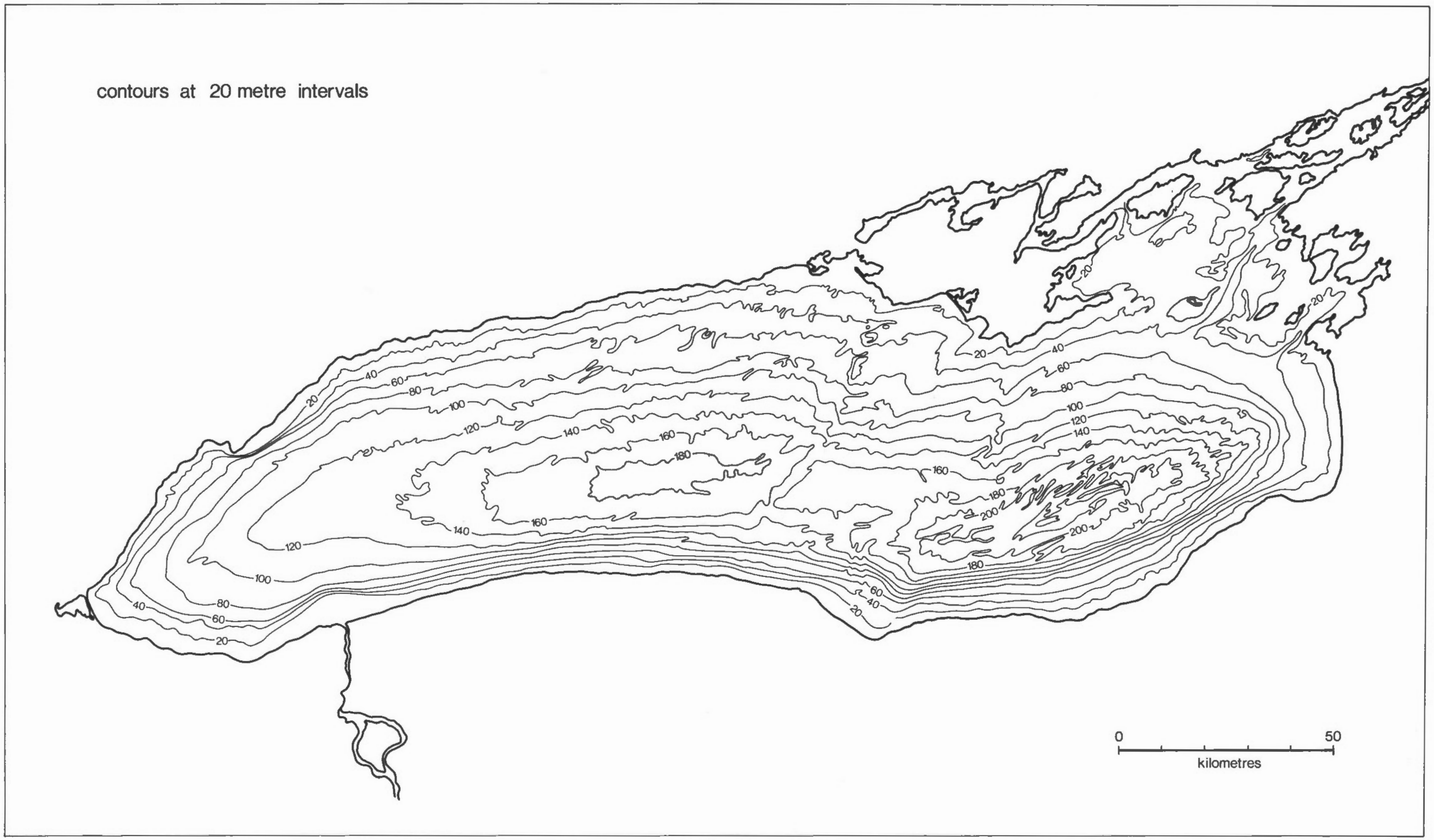

Figure 2. Bathymetric plan of Lake Ontario with a 20-m contour interval.

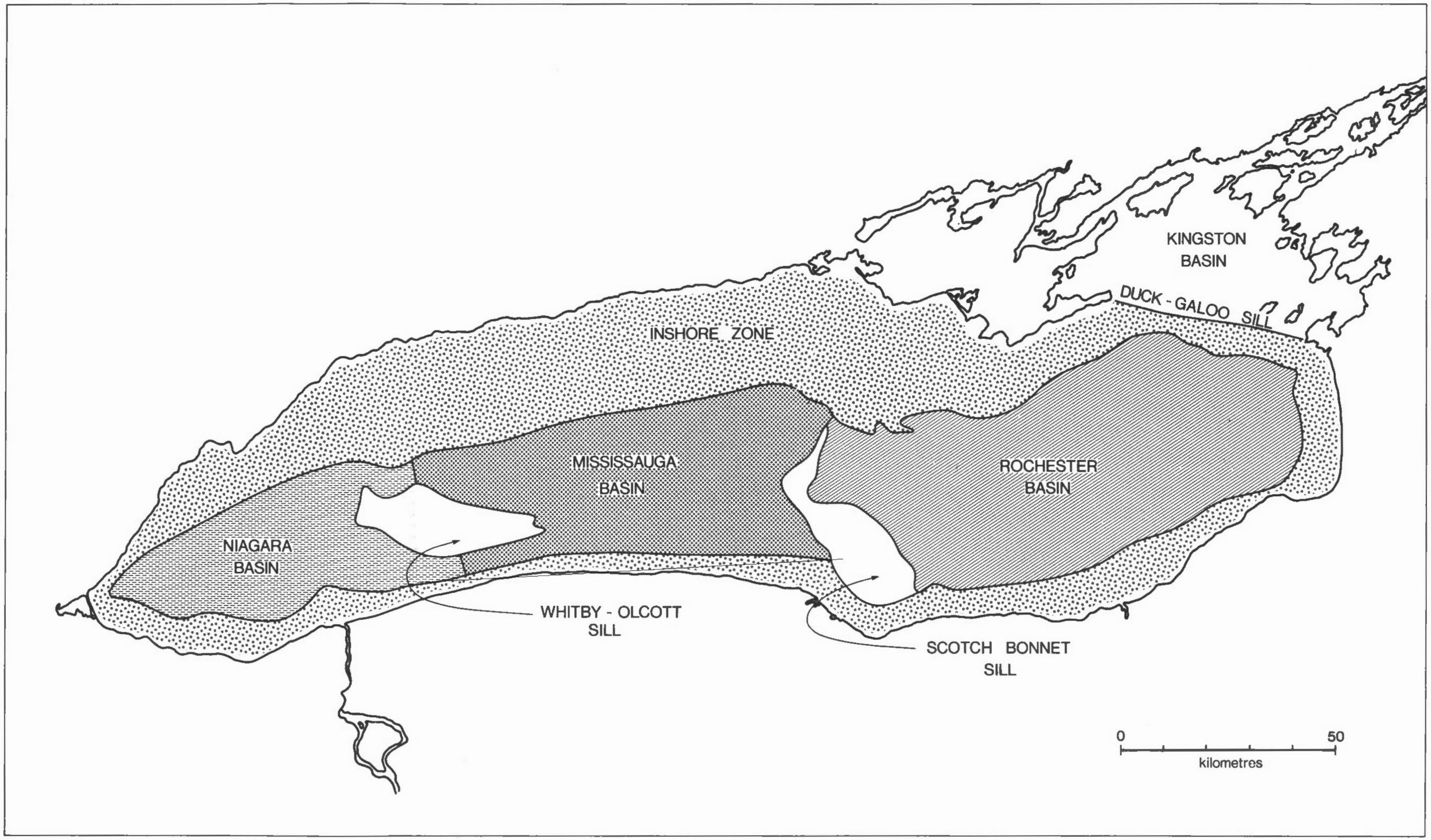

Figure 3. Nomenclature for major zones and depositional regions in the basin of Lake Ontario.

to the low-level Admiralty phase (early Lake Ontario) which is believed to have been maintained slightly above the Champlain sea level by a sill in the upper St. Lawrence River (Prest, 1970).

Radiocarbon dates on lagoon and shoreline sediments in the Burlington-Hamilton area led Karrow *et al.* (1961) to place the drainage of Lake Iroquois and inception of early Lake Ontario at about 11,000 years B.P. Prest (1970), in a recent review of Quaternary events in the Great Lakes area, inferred that the Champlain Sea and early Lake Ontario were in existence shortly after 12,000 B.P.

Throughout the postglacial period, the Ontario basin has been uplifted by isostatic rebound consequent to prior removal of ice and glacial lake water loads from the earth's crust. The uplift is differential with the fastest rates occurring in the northeast where the basin outlet is located. Uplift has thus induced basin tilting and water levels have risen accordingly (Karrow *et al.,* 1961). Since the low level Admiralty phase, the tilt has amounted to about 84 m between the outlet and the western end. Modern lake-level gauge observations indicate the tilt is continuing at 23 cm/century (0.75 feet/century) (Clark and Persoage, 1970).

LAKE BASIN MORPHOLOGY

For the purpose of this paper, Lake Ontario is considered in two parts, the main lake and that part of Lake Ontario to the northeast occupying an area termed the *Kingston Basin.* These are separate sedimentary entities divided by a sill formed by outcropping limestone marked by a line of limestone islands and trending WNW to ESE from Prince Edward Point, Ontario to Stony Point, N.Y. This dividing shallow water region has been named the *Duck-Galloo Sill* after two of the islands (Fig. 3).

Main Lake Ontario occupies a simple asymmetrical basin though the bathymetry of the lake suggests some complication introduced by two cross-lake low-amplitude ridges (Fig. 2). These ridges are formed of glacial sediments and subdivide the main lake into three depositional basins. These have been named from west to east, the *Niagara, Mississauga* and *Rochester* basins respectively (Fig. 3). Since the intervening ridges appear to form natural partitions between major depositional basins, they have been designated as sills and have been named the *Whitby-Olcott Sill* to the west and the *Scotch Bonnet Sill* to the east (Fig. 3).

CHAPTER 3

Shipboard Procedures

SAMPLING

Surficial lake bottom samples were taken using a Shipek grab sampler (Hydroproducts Ltd., San Diego). Trials of grab samplers, undertaken by the Canada Centre for Inland Waters, demonstrated the ability of the Shipek to take relatively undisturbed surface samples of most sediment types occurring in the Great Lakes (Sly, 1969a). Other than in areas of bedrock outcrop or large boulder accumulations, satisfactory samples were recovered. On recovery of each sample, the state of the surface sediment in the sampler bucket was examined, and if evidence of disturbance of the surface layers was seen, the sample was retaken until satisfactory. To ensure horizontal orientation of the top sediment layers, sample buckets were taken to the shipboard laboratory and placed in a stand. The following procedures were then undertaken:

(1) The sample was photographed.

(2) Electrodes were inserted to a depth of 1.5 cm below the sediment surface to measure pH and Eh.

(3) Temperature at a depth of 1.5 cm was recorded for pH measurements (see below).

(4) Subsamples were taken (see below).

(5) A visual description of the sediment profile was recorded.

Eh-pH Measurements

The hydrogen ion concentrations (pH) and the oxidation-reduction potentials (Eh) were measured with a Metrohm E-208A pH meter using combination glass/AgCl and platinum/AgCl electrodes. The electrodes were placed in clamps supported by a stand over the sample bucket and were inserted into the sediment to a depth of 1.5 cm. The sediment temperature was recorded at a depth of 1.5 cm immediately after electrode insertion. The pH measurements were taken between 30 and 60 sec. after insertion into the sediment. The values did not drift after this time indicating that the samples were well buffered. The Eh was measured after 10 min. when the drift, initially rapid, had either ceased or was very slow, indicating that equilibrium or quasi-equilibrium had been established.

Subsampling

To ensure uniform subsampling of the sediment in the Shipek bucket, a box subsampler was constructed of stainless steel, 5 cm square by 3 cm deep, capable of retaining 75 ml of sediment. The subsampler was pressed gently to its full extent into the sediment in the Shipek bucket. A slide was then placed into the sediment and gently eased into horizontal slots cut at exactly 3 cm in the subsampler. In this way, an undisturbed sample of the top three cm of sediment was obtained. Four such subsamples were removed from a Shipek bucket taken at each station locality. Two subsamples were transferred to a Virtis freeze-dry flask which was rotated for 10 to 20 min. in methanol at -50°C to freeze the sediment as a shell on its inner periphery. The flask was then placed on a Virtis freeze drier under high vacuum (approximately 0.02 mm of mercury) until dry. The drying process took from 6 to 12 h, depending on the grain size of the sediment. Coarse materials dried faster than finer clay muds. The dried powder was transferred to a plastic vial and stored for geochemical analysis. The third and fourth subsamples were transferred wet into plastic bags, heat sealed and stored at 4°C for sedimentological and mineralogical analysis.

Coring

Piston cores were taken with a 1200 lb Alpine piston corer. The location of the cores and the subsampling methods have been previously described (Kemp, 1969). Water content and bulk density were determined at intervals down each core in order to estimate the weight of sediment in the core column. The postglacial-glacial sediment contact was noted visually in each core and correlated with the sediment thickness from the echo-sounding profiles.

Echo Sounding

Conventional echo-sounding equipment has been used successfully in many previous studies to determine sediment types and their distribution (Allen, 1964; King, 1966; Belderson, 1964; Lewis and McNeely, 1967). During the present work, a zig-zag track around the periphery of the lake and across the *Scotch Bonnet* and *Whitby-Olcott Sills,* together with a series of cross-lake traverses, was followed in order to map the gross distribution of the major sedimentary units. A Kelvin Hughes M.S. 26B sounder operating at 14.25 KHz was used throughout. A high degree of penetration of fine-grained sediments with excellent resolution of reflecting horizons was achieved. The correlation between the piston cores and the echograms in the fine-grained muds indicated that the acoustic velocities in the modern muds are similar to that of the overlaying waters.

Laboratory Procedures

In addition to standard particle-size analysis, a number of geochemical and mineralogical parameters were determined. These include Eh and pH (see Shipboard Procedures above), organic carbon, inorganic or carbonate carbon, clay minerals, quartz and feldspar. Methods used are described below. The station locations, geochemical and sedimentological data are detailed in the Appendix.

SAMPLE PREPARATION

The freeze dried samples were sieved through a 20 mesh screen, hand picked for shell and animal fragments, then lightly pulverized and homogenized.

CARBON

Total carbon was measured by heating the freeze-dried sample at about 1300°C in a Leco induction furnace carbon analyzer. Organic carbon was measured in the same apparatus after carbonate removal by sulphurous acid at room temperature (Rittenberg and others, 1963; Shaw, 1959).

QUARTZ AND FELDSPAR

Total quartz plus feldspar was determined, gravimetrically, to be the residue after fusion with potassium pyrosulphate (Trostel and Wynne, 1940). A qualitative estimate of the feldspar composition was undertaken by dissolving the fusion residue with a hydrofluoric, perchloric acid mixture and determining the feldspar end member cations K, Na and Ca (Kiely and Jackson, 1965; Thomas, 1969a). K and Na were determined by flame photometry using a strong lithium buffer to suppress interference effects and Ca was measured by EDTA photo-electric titration using murexide indicator. Confirmation of the feldspar suite as inferred from the K, Na, and Ca analyses was undertaken using a Philip's X-ray diffractometer and by microscope examination of the fusion residues.

TOTAL MINERAL CLAY

The total mineral clay content of the sediment was calculated geochemically as follows: Per cent clay = 100 - (per cent organic matter + per cent $CaCO_3$ + per cent quartz). Organic carbon was converted to organic matter by multiplying by 1.72 and carbonate carbon to calcium carbonate by multiplying by 8.3. All the carbonate carbon was assigned to calcium carbonate since no quantitative data is, as yet, available on the distribution of dolomite and other carbonates in the lake sediments.

PARTICLE-SIZE ANALYSIS

The wet samples were sieved through a 4 phi screen. The coarser than 4 phi material was then dried and sieved at 0.5 phi intervals from -4 to +4 phi. The material finer than 4 phi was analysed by standard pipette techniques (Krumbein and Pettijohn, 1938) at 1.0 phi intervals from 4 to 9 phi after dispersing the sediment in a 0.5% wt/vol Calgon solution and homogenizing for 15 min. with an electric mixer. In the case of a few samples, high in clay and organic matter, a double concentration of Calgon was required to achieve effective particle dispersion. All size classes were then combined and movement measures calculated for mean grain size, standard deviation, skewness and kurtosis after the method of Krumbein and Pettijohn (1938) using a computer programme developed by Coakley and Beal (1969).

CLAY MINERALOGY

X-ray diffractograms were prepared from the <2 μm grain-size fractions for selected samples. The dry sample was dispersed in aqueous solution in a beaker partially immersed in an ultrasonic water bath for 50 min. The suspension was then allowed to settle for 35 min. and an aliquot withdrawn at the 1 cm level using a micropipette. The pipetted suspension containing <2 μm material, was placed onto four glass slides and air dried. Diffractograms were run for air-dried, glycolated and heat-treated (450°C and 550°C) slides. The instrument used was a Philip's diffractometer with a curved LiF crystal monochrometer, run at Kv 40, Ma 20, divergence slit 1°, exit slit 0.1 mm, scan rate 1° 2 θ min, recorder speed 600 mm/h, time constant 4, and a rate meter setting of 4 x 10^2. Semi-quantitative estimation of the clay content was carried out after the method of Johns *et al.*, (1954) using the 10 Å illite peak as an internal standard. Sixty-two samples were analysed, comprising east to west lines, F, L, M, N and north to south lines 6, 18 and 27 (Fig. 1).

TOTAL MINERALOGY

Diffractograms of total dried sample were run using the instrumentation described above. The samples selected were those used for clay mineral analysis. The dried powders were lightly pulverized in an agate mortar and packed in a Philip's fixed sample holder and run from 4° to 40° 2 θ using the instrument-operating parameters described above.

CHAPTER 5

Distribution of Bottom Materials

A number of sedimentary units were recognized and characterized on echograms. These are shown in Plate 1 A-G and are tabulated as follows:

1. Bedrock (Plate 1 A), characterized by irregular relief and high reflectivity.

2. Glacial till (Plate 1 B), difficult to differentiate from bedrock but characterized by a less irregular surface.

3. Glaciolacustrine clays (Plate 1 C). This unit has unique characteristics that make it readily identifiable by echo sounding. It is readily penetrated acoustically and shows consistently a large number of closely-spaced reflecting horizons often contorted into slump-like structures. Where this unit outcrops, it is normally covered with a thin layer of sand which shows up as a smooth, more intense reflection on the echogram.

4. Postglacial muds (Plate 1 D). These represent accumulations ranging in age from early Lake Ontario to the present time. In offshore regions, they are pre-

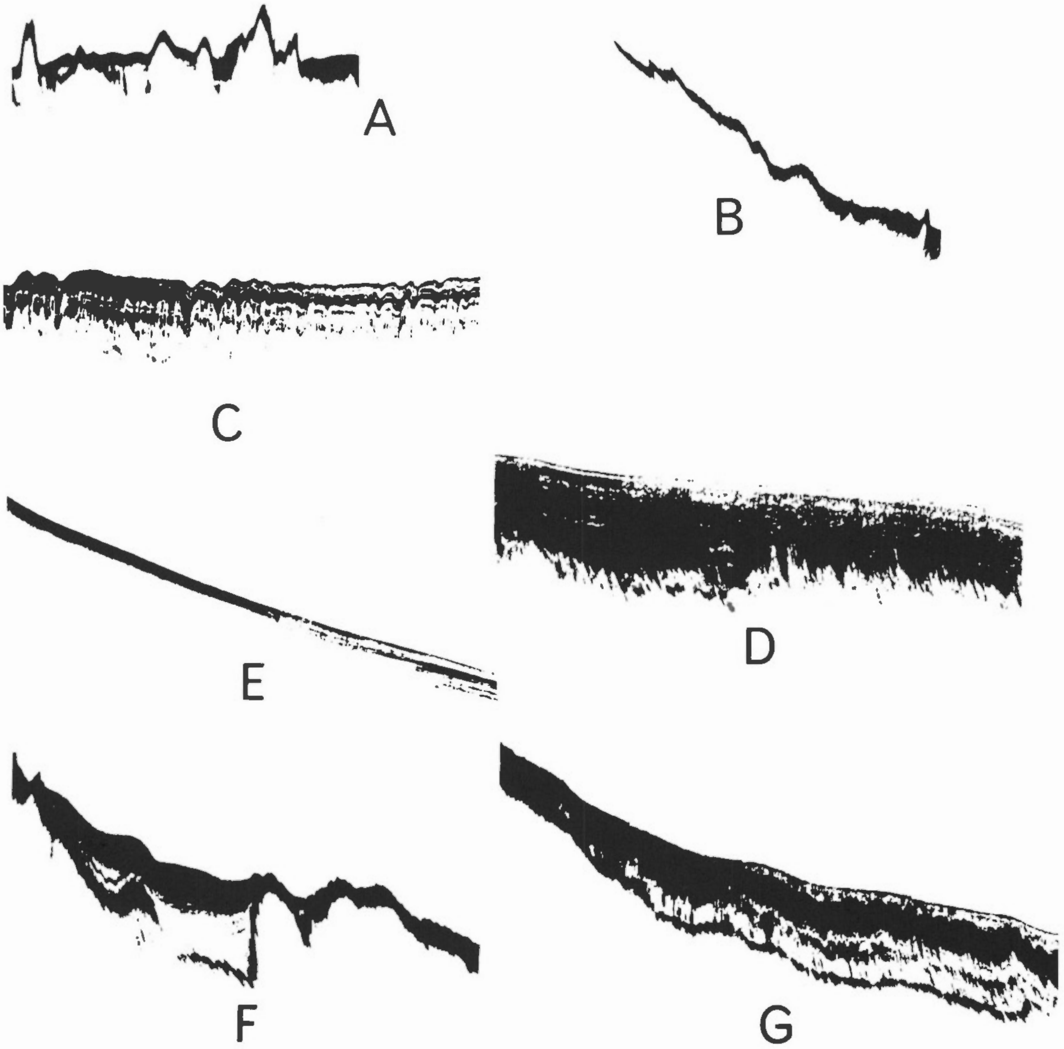

Plate 1. Echograms. A–bedrock with irregular relief and high reflectivity; B–glacial till; C–glaciolacustrine clays; D–postglacial muds; E–sand.

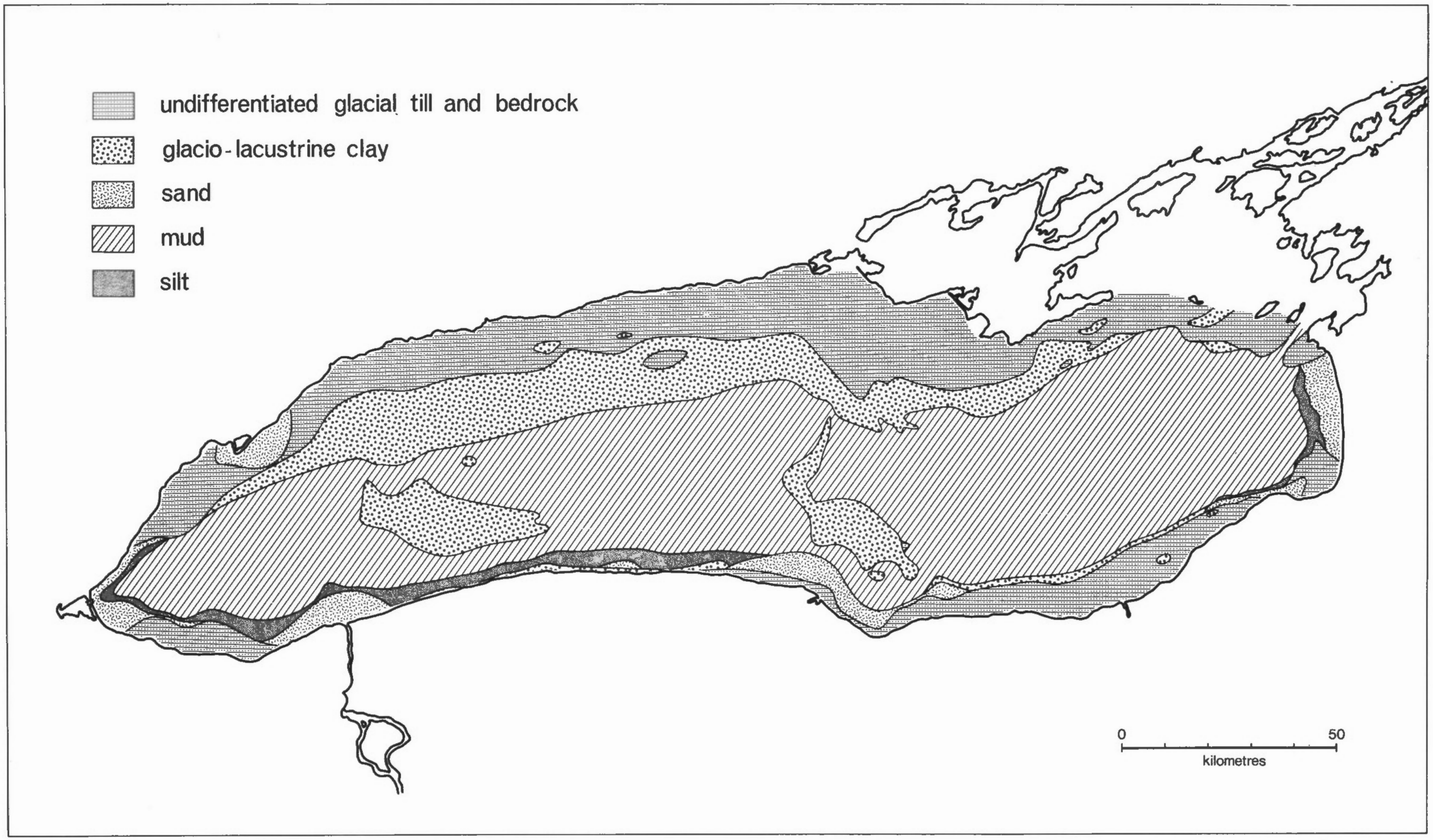

Figure 4. The distribution of glacial and postglacial sediment units based upon echo sounding profiles of Lake Ontario.

dominantly fine-grained, and are readily penetrated acoustically through to the underlying glaciolacustrine clays. Variations in grain size occur with the muds becoming increasingly silty towards regions of glacial outcrops. Such variations, i.e. increasing size, are recognized on the echograms by the increasing intensity of the bottom reflection. Postglacial muds are characterized also by a smooth bottom relief.

5. Sand (Plate 1 E). Sand shows, always, an intense black bottom return with no penetration and is characterized by its smooth surface. Fining grain size is indicated by decreasing reflectivity and greater penetration as is well shown in Plate 1 E.

The regional distribution of major sedimentary units throughout the main lake basin is shown in Figure 4. The pattern is basically simple with a natural superposition of sediment units reflecting the glacial and postglacial history of the lake.

The glacial tills were deposited as debris from the last ice advance and retreat and outcrop discontinuously around the periphery of the lake (Fig. 4). In some areas, particularly between Burlington and Toronto, and the region around Scotch Bonnet Shoals, the tills have been removed exposing bedrock. The nearshore zone from Niagara westwards around the lake to Presqu'ile Bay has been described in detail by Rukavina (1969 and 1970). Overlying glaciolacustrine clays have been observed in many deep hollows in the till surface (Plate 1 F). The tills overlie the bedrock base of the lake basin and dip inwards from the lake periphery beneath the overlying glaciolacustrine clays which outcrop immediately offshore of the tills (Fig. 4). That the outcrop surface of the glaciolacustrine sediments is erosional, is indicated by the occurrence of till outliers in a few places and the truncation of successively shallower reflecting horizons from inshore to offshore. The glacial sediments are almost everywhere overlain by thin sands or gravels formed as lag deposits by winnowing of the finer materials by current and wave activity. This is discussed subsequently. Both the *Whitby-Olcott* and *Scotch Bonnet Sills* occur as slightly elevated ridges of glacial sediment, largely glaciolacustrine clay, which are being overstepped by modern mud accumulations.

Recent sediments deposited in Lake Ontario are found predominantly in the offshore deep-water basin areas of the lake. They are fine-grained muds characterized by deep penetration and low intensity on the echograms. The echogram records clearly demonstrate the unconformable overstepping of the glacial materials by the recent muds (Plate 1 G).

CHAPTER 6

Sediment Description

The sediment distribution, based on a visual observation of samples during collection, is given in Figure 5. The sediment described in Figure 5 refers to the immediate surficial material which varies in part from the acoustic sediment distribution given in Figure 4. The acoustic sediment distribution, however, is the basic framework over which the superficial materials are superimposed with the result that the sediments fall into three zones related to the distribution of a nearshore zone of till and bedrock, intermediate glaciolacustrine clays and offshore basin muds.

TILL ZONE

The inshore zone is defined by the distribution of glacial tills and bedrock. The surficial deposits are complex, comprising coarse lag gravels with some finer sandy gravel. Accumulations of sand occur particularly in the west at the Burlington Bar, in the east in Mexico Bay and in large quantities at Toronto Island. Other sand accumulations are confined to embayments restricting longshore transport such as at Presqu'ile Bay and in embayments west of Point Petre. Other sandy accumulations occur on the south shore of the lake, particularly in the Niagara Bar and in the vicinity of Rochester.

The gravels overlie till occurrences in the inshore zone and range in size from fine to extremely coarse. Diver observations have recorded boulders up to 5 ft. in size. The gravels are primarily composed of limestone, granitic gneiss and amphibolite. The till, when exposed, varies in colour from medium grey to brown and is composed of cobbles and pebbles in a very stiff, often crumbly, silty clay matrix which may frequently be sandy. The bedrock distribution is not described here but in the limestone region, south of Kingston, the surface is irregular with well-developed pot-holing, very often covered with a thin veneer of sandy gravel.

GLACIOLACUSTRINE ZONE

The distribution of this zone can be seen from the acoustic diagram in Figure 4. Exposures of clay are few and occur primarily in the *Scotch Bonnet* and *Whitby-Olcott Sills* (Fig. 5). In almost all other cases, the glaciolacustrine clays are overlain by a thin fine sand up to 6 cm thick. The sand appears to be well-sorted at the surface but becomes more clayey downwards grading into the underlying glaciolacustrine clays. This decrease in sorting downwards suggests that the sands have originated as lag deposits formed by the winnowing of the fine materials from the glaciolacustrine outcrop by current and wave activity. Along the north shore, these sands are characterized by a coating of black ferromanganese oxides on individual sand particles. Analyses of the acid extractable component of these manganiferous sands give an average content of Fe 20.6% and Mn 17.0% (Cronan and Thomas, 1970). As reported by Cronan and Thomas (1970), however, the northern part of the ferromanganese deposit does extend over the southern part of the till zone.

The glaciolacustrine clays are dark grey to light brown silty clays, occasionally sandy and enriched in calcium carbonate. They are moderately stiff and greasy, frequently laminated and occasionally contain ice-rafted pebbles (Lewis and McNeely, 1967).

For statistical purposes, quoted subsequently, both the till and the glaciolacustrine zones have been incorporated into a single zone called the inshore zone.

OFFSHORE BASIN ZONES

The offshore basin zone occupies approximately 60% of the total Lake Ontario basin and represents the prime region of modern sediment accumulation. The basin sediments are composed of soft, fluid, fine-grained, silty clays and clays, grey to grey black in colour. They are often black-speckled in appearance and normally contain subsurface black laminations (a few mm thick), both of which are believed due to amorphous iron sulphides. A thin oxidized microzone of reddish-brown to olive-green ooze, varying in thickness from 0.1 to 2 cm was observed at the surface of all mud samples. This interfacial microzone is believed to consist predominantly of hydrated iron oxides (Gorham, 1958) and organic detritus (Burns, personal communication).

A distinctive feature of the lake sediment is a thin hard crust of yellowish-brown amorphous iron oxide. The iron oxide layer occurs at many localities, usually where a thin veneer of mud overlays glaciolacustrine clay. The layer occurs usually at a depth between 2 and 5 cm. The Ambrosia horizon (circa 150 years B.P.) has been found at several locations below the iron oxide layer, indicating that at these locations, the layer is of recent origin. At some locations, the layer is of soft consistency and at other locations shows a segregation into a black Mn layer and a

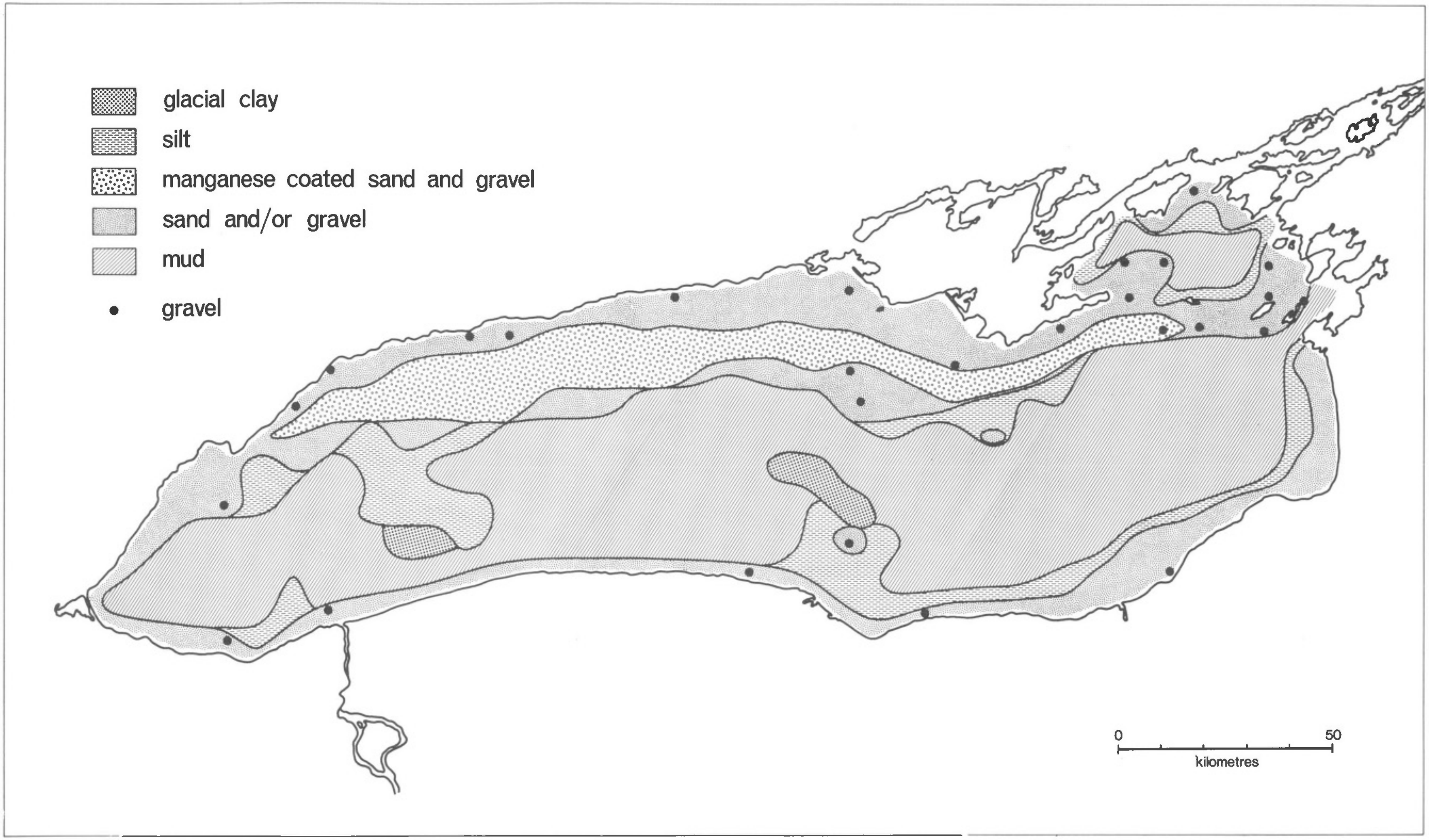

Figure 5. Lake Ontario distribution of surface bottom materials as described by visual observation during collection.

yellow brown Fe layer. Analysis of the iron oxide layer at station E23 yields an Fe content of 15.3% and an Mn content of 0.34%. The origin of the layer is as yet not understood but it is believed due to precipitation of iron oxide originating from the upward diffusion of ferrous ions from the more reduced sediments below. The redox potential was measured at centimetre intervals down to 10 cm at station E6 and was found to be greater than +0.300 V to 1 cm below the iron oxide layer and then decreased to -0.100 V at 10 cm.

Rates of Sedimentation

Mean sedimentation rates were calculated from the bulk density, water content and postglacial mud thickness of the sediment, assuming that sediment accumulation has been constant throughout the postglacial history of the lake. The estimated present-day sedimentation rates for the main basin of Lake Ontario are shown in Figure 6; contouring for this diagram was based on the echo sounding profiles mentioned previously. The greatest sedimentation rates are found in the Rochester and Niagara basins. Average sedimentation rates of 114, 139 and 309 g/m^2/year were calculated for the Niagara, Mississauga and Rochester basins. The thickness of sediment accumulating each year ranges from 0 at the fringes of each basin to a maximum of 3.6 mm in the Rochester basin. The estimated sedimentation rate at a sample station in the Niagara basin was determined by an alternate method. The *Ambrosia*[1] horizon, which is between 140 and 150 years B.P. in the Ontario region, was located between 15 and 16 cm below the surface. Our estimates predicted 15 cm of sedimentation at this location. Lake Ontario sedimentation rates are in a similar range to those of the central basin of the Caspian Sea where an average of about 360 g/m^2/year was estimated (Bordovskiy, 1969) and a station in Lake Victoria where a rate of 200 g/m^2/year was obtained (Kendall, 1969). It is estimated that 2.28 million tons of fine-grained sediment accumulate in the main part of Lake Ontario each year with 1.64, 0.41 and 0.22 million tons accumulating in the Rochester, Mississauga and Niagara basins respectively (Table 1).

Table 1. Annual basin sedimentation for Lake Ontario

Basin	Total area of basin (km^2)	Average rate of accumulation (g/m^2/yr)	Range of values (g/m^2/yr)	Average thickness of sediment (mm/yr)	Range of values (mm/yr)	Weight of sediment accumulated (tons)
Rochester	4,715	309	0-821	1.4	0-3.6	1,644,250
Mississauga	2,706	139	0-489	0.6	0-2.1	414,780
Niagara	1,726	114	0-620	0.4	0-2.2	217,540
Total	9,147	221	–	1.0	–	2,276,570

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[1] *Ambrosia* is the generic name given to the pollen of the common ragweed which developed rapidly in the region with the deforestation associated with the initial settlement and cultivation by European man.

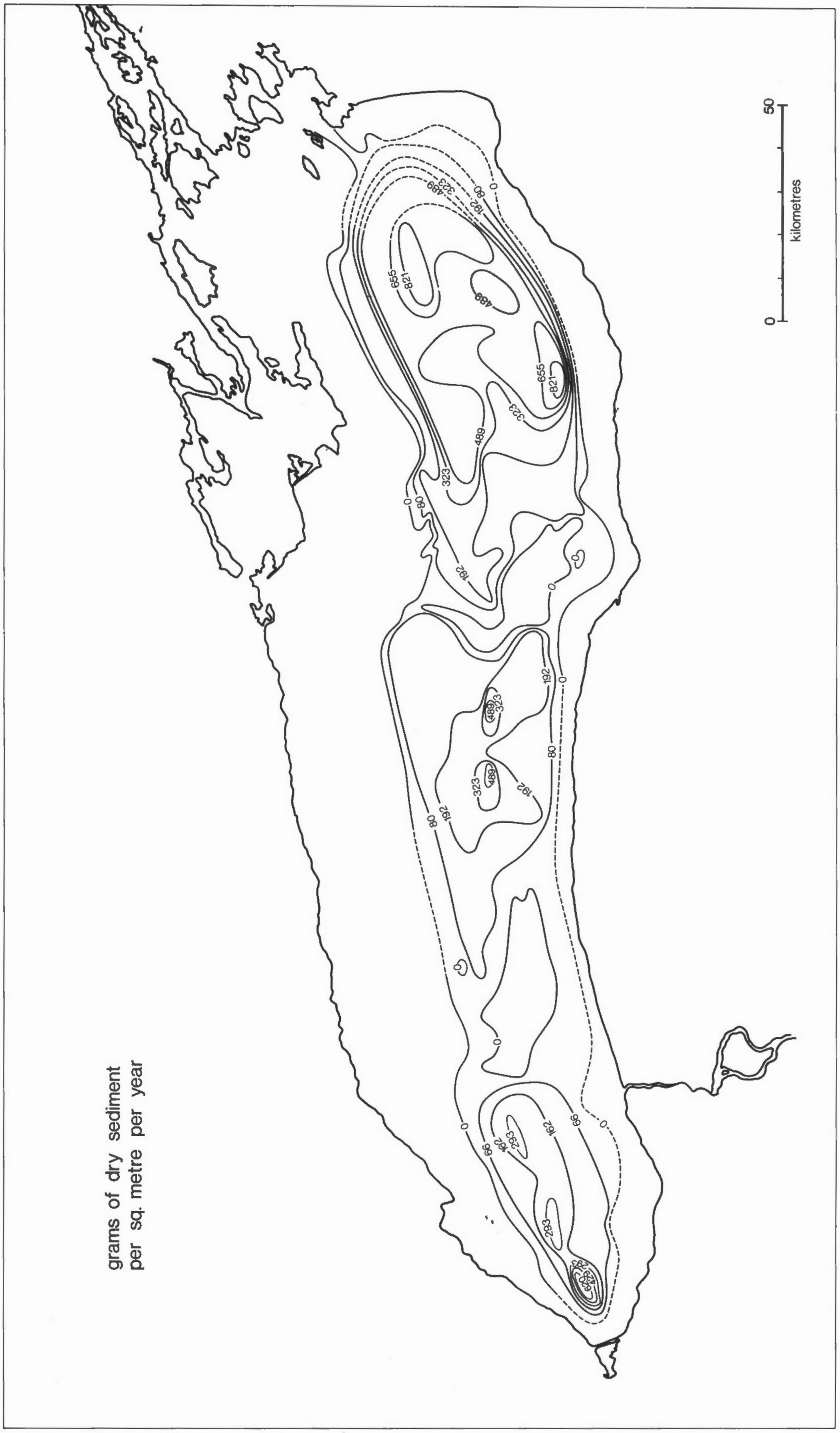

Figure 6. Contour diagram showing estimated present day accumulation rates in the basins of Lake Ontario.

Hydrogen Ion Concentration and Redox Potential

The hydrogen ion concentration (pH) was measured at each sample station at a depth of 1.5 cm below the sediment-water interface and the results are shown in Figure 7. The pH ranged from 6.5 to 8.18 and was generally between 7.0 and 8.0 throughout the lake. At the centre of the three main basins of mud accumulation, values greater than 8.0 were recorded. The general distribution of pH shows no obvious pattern. The pH ranged from an average of 7.6 in the sands to 7.8 in the clay muds. The values are lower than the average of 7.9 for Lake Ontario waters (Weiler and Chawla, 1969). The pH was shown to be generally uniform in the top 6 cm of sediment at 7 stations along the main axis of Lake Ontario (Kemp and Lewis, 1968). The range of values found in Lake Ontario is similar to that recorded in surface marine sediments off the coast of California (Emery and Rittenberg, 1952). Biogenetic transformations of organic and inorganic compounds are the most likely processes to affect changes in sediment pH. The principle processes are:

1. Mineralization of organic compounds with the formation of carbon dioxide.
2. Microbial reduction of sulphates to form hydrogen sulphide;
3. Microbial decomposition of proteinaceous compounds to produce ammonia.

Lower pH values will be expected for the former processes and higher values for the latter. The processes will depend also on the redox potential of the environment and will be discussed below.

The redox potential is a quantitative measure of the state of oxidation or reduction of a reversible oxidation - reduction system and is termed Eh when referred to a standard hydrogen half cell. The Eh was measured at a depth of 1.5 cm at each station and the results are shown in Figure 8. As can be seen, considerable variation is observed from station to station with values ranging from +0.458 V to -0.217 V. The silty clay muds in the main lake basins usually have a potential of less than +0.100V with the centre of mud accumulation having negative potentials. An area of extremely negative values was observed in the deep part of the lake off Rochester, suggesting a zone of stagnation (e.g., lack of bottom water circulation and utilization of oxygen from the interstitial water in the decomposition of organic matter). The nearshore zones and the cross-lake sills are characterized by potentials greater than +0.100 V. The lake-bottom water generally has a potential of about 0.500 V and this is reflected in many of the water-saturated sand samples. The Eh ranged from an average of +0.321 in the sands to +0.061 in the clay muds. The Eh was found to decrease sharply from the surface down to 6 cm at 7 main basin stations (Kemp and Lewis, 1968). It must be remembered that the distribution shown in Figure 8 represents Eh values at 1.5 cm and that more positive potentials usually exist above this level and more negative values below. Positive potentials are characteristic of well-oxygenated sediments, poor in organic matter whereas negative potentials are associated with bottom materials rich in organic matter (Zobell, 1947). This pattern is followed in Lake Ontario, where the regions of negative potential (Fig. 8) are those that have the highest organic carbon values (Fig. 11). Reducing conditions are mainly brought about by the decomposition of organic matter by bacteria and allied microorganisms.

Certain features of the Lake Ontario surface sediments can be explained in terms of the Eh and pH observed for the various subenvironments.

1. The reddish-brown surface ooze underlain by the dark grey muds in each of the Ontario basins is paralleled by a change from positive to negative potential. The reddish-brown ooze is in contact with lake waters which are usually saturated with oxygen. The lowest values recorded to date are 50 to 60% saturation (Dobson, 1967). The reddish colour and the positive potentials again suggest oxidized iron compounds at the surface.
2. The dark grey muds underlaying the ooze are in a zone of negative potential and the colouration suggests reduced iron sulphides. Exposure of the fresh muds to air changes the colour from grey to brown in about 30 min.
3. The black laminations and specs observed at many of the mud stations are often accompanied by the odour of hydrogen sulphide and very low Eh values. Black laminations in Lake Michigan sediments were found to consist predominantly of iron sulphides (Hough, 1958) and a similar situation is believed to exist in Lake Ontario.
4. The zones of manganese deposition and iron oxide crust formation were in regions where the Eh was always greater than +0.300 V which is consistent with the Eh-pH requirements for manganese and iron deposition (Garrells and Christ, 1965; Cronan and Thomas, 1970).
5. Ammonia concentrations in the surface sediments have been measured in our laboratories and range from 20 ppm in the sands to 250 ppm in the clay muds. The high pH values observed at many of the reduced mud stations are probably due to decomposition of proteins to ammonia with an accompanying rise in pH.

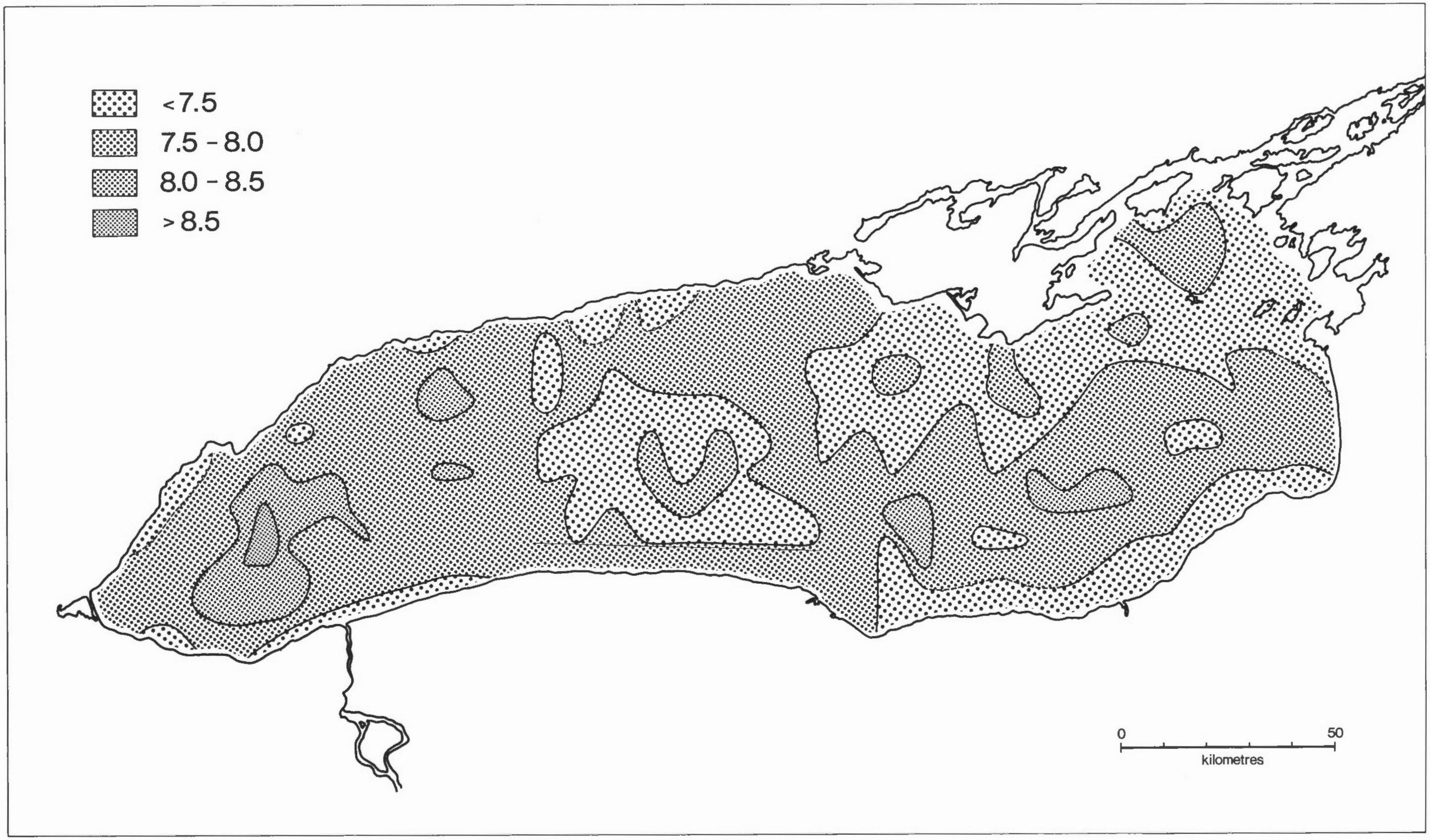

Figure 7. Lake Ontario regional distribution of pH values at a sediment depth of 1.5 cm.

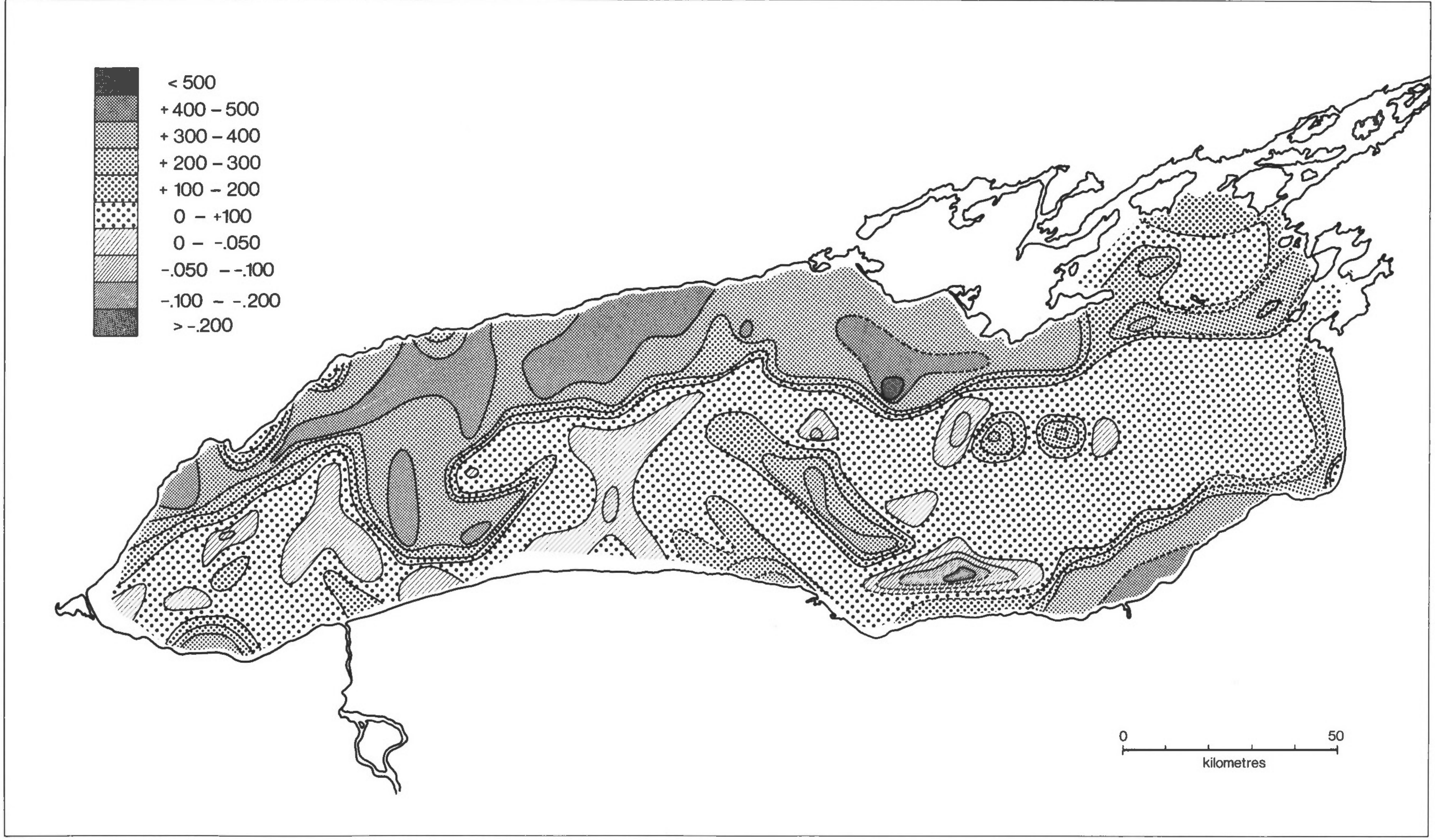

Figure 8. Lake Ontario regional distribution of Eh values at a sediment depth of 1.5 cm.

CHAPTER 9

Sediment Composition

MINERALOGY

The sediments of Lake Ontario show little variation in gross composition and comprise variable amounts of quartz, feldspar, clay, organic carbon and calcite. Small amounts of amphibole, probably tremolite, also have bee recognized on diffractograms though no heavy mineral separations or concentration techniques have been undertaken in the present study. Amorphous ferromanganese oxides (Cronan and Thomas, 1970) and iron monosulphide occur, the former in the nearshore oxidizing environment and the latter in the offshore basin muds

Quartz

Quartz occurs as a major constituent in all samples ranging from 24.6 to 94.9% with a lake average of 50.8%. The lakewide distribution of quartz is given in Figure 9 which shows that quartz decreases offshore into the fine basin sediments. The effect on quartz content of the *Whitby-Olcott* and *Scotch Bonnet Sills* is also evident in Figure 9. An eastward and westward decrease in quartz from the two sills into the basins may imply erosion and transportation from the sills which thus may serve as mid-lake sources of detrital materials

Feldspars

Total feldspar content in Lake Ontario sediments has been estimated as ranging from 4 to 20% and includes orthoclase, microcline, albite, and labradorite with a possible trace of andesine in some samples (Thomas, 1969a). The total feldspar content varies proportionally to the quartz content. In the nearshore zone, a poor positive correlation of feldspar to quartz ($r = 0.51$) is believed to be the result of poor mixing of sediments in a coarse traction load, whereas an excellent correlation of 0.90 in the basin muds reflects natural sorting by sedimentation from a suspended load. Thomas (1969a) demonstrated variation in the composition of the feldspars on a regional basis in the surficial lake sediments with the feldspar suite becoming enriched in orthoclase and microcline relative to plagioclase from inshore to offshore. This was interpreted as being a manifestation of chemical weathering related to length and time of transportation with a progressive partial loss of the plagioclase feldspars. The influence of the sills was also evident with the occurrence of a fresher more plagioclase rich suite. This again suggests that the sills are actively contributing detrital materials to the depositional basins

Clays

X-ray diffractometry of the <2 micron-size fraction has demonstrated a consistent suite of clay minerals throughout Lake Ontario, consisting of illite, chlorite and kaolinite. Montmorilonite was only observed at station M33 in the Kingston basin. Semi-quantitative estimation of the clay mineralogy was carried out after the method of Johns, Grim and Bradley (1954) using the 10 Å illite peak as an internal standard. On this basis, illite ranges from 54 to 88% with an average for the lake of 66%, kaolinite 6 to 27% with a mean of 15% and chlorite from 1 to 30 with a mean of 18% of the total clay mineral content.

The total *mineral* clay was calculated by difference from geochemically determined phases (see methods) and its distribution is given in Figure 10. The distribution of the clay is naturally inverse to the quartz distribution showing increasing clay concentrations offshore into the three basins. The *mineral* clay ranges from 2.75 to 70.08% with a mean of 42.3%.

Organic Carbon

The organic carbon distribution for the topmost 3 cm of sediment in Lake Ontario is given in Figure 11. Values range from 0% to 5.27% with a lake average of 1.98%. From Figure 11 the trend in organic carbon is similar to the mineral clay, increasing outwards into the basin muds. Again, low organic carbon values are associated with the higher energy sediments of the sills. The average value of organic carbon for the inshore zone sediments is 0.96% and 3.01% in the silty clay basin muds. These values are greater than the 1-3% generally observed in marine fine-grained sediments (Emery and Rittenberg, 1952 and Bordovskiy, 1965) and are lower than the 10-40% found in numerous smaller lakes in southern Ontario (Kleerekoper, 1957). Organic carbon was found to decrease about 30% in the top 6 cm of sediment in seven stations along the axis of Lake Ontario\(Kemp and Lewis, 1968).The decrease is attributed to mineralization of the organic matter together with an increase in organic carbon input to the sediment in recent years.

Carbonate Carbon

The distribution of carbonate carbon in the Lake Ontario is shown in Figure 12. Carbonate carbon is generally low throughout the lake ranging from 0 to 4.97%. No general trends are observable but higher carbonate values occur along the southern shore from Hamilton to

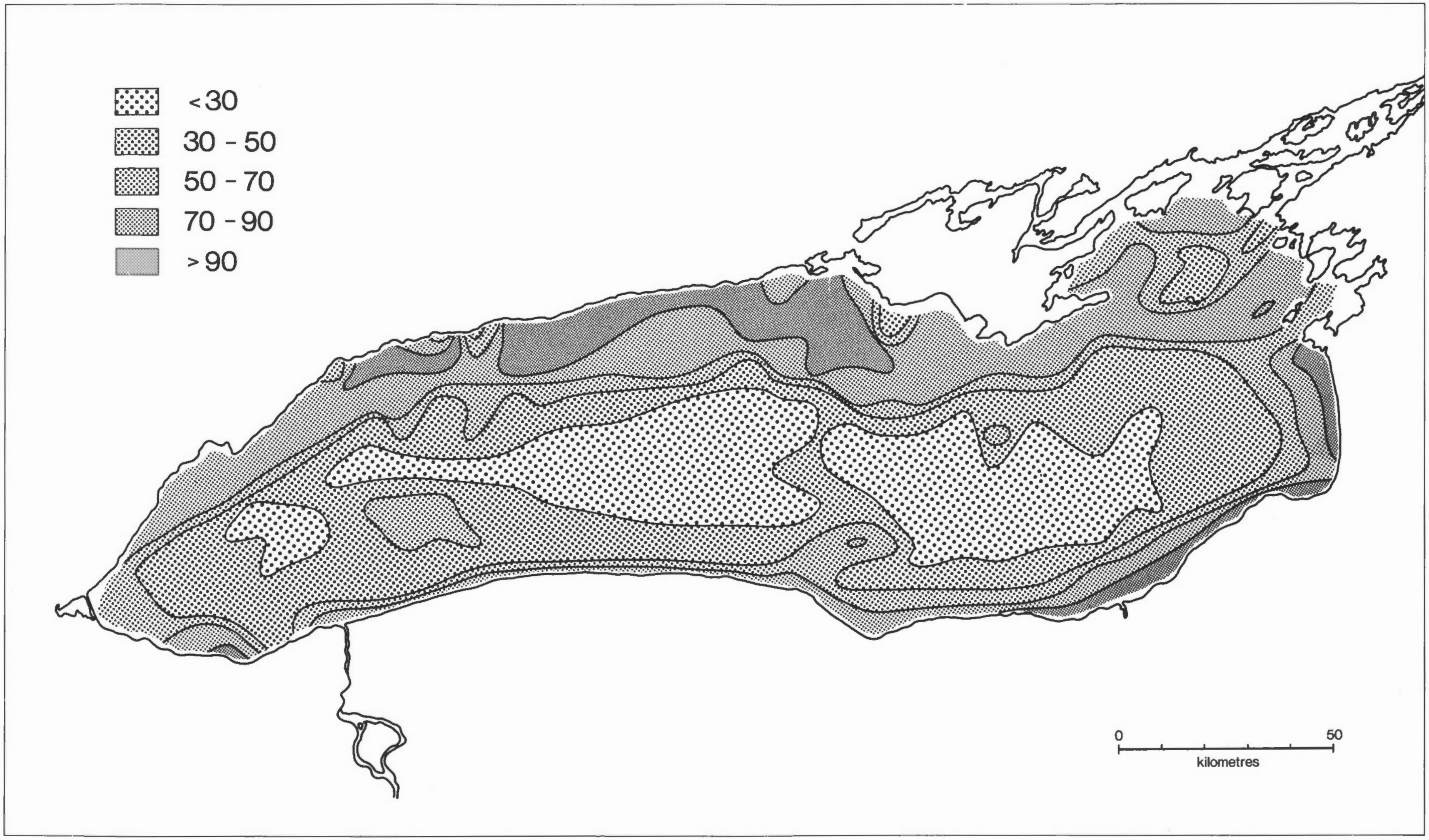

Figure 9. Lake Ontario quartz distribution (%).

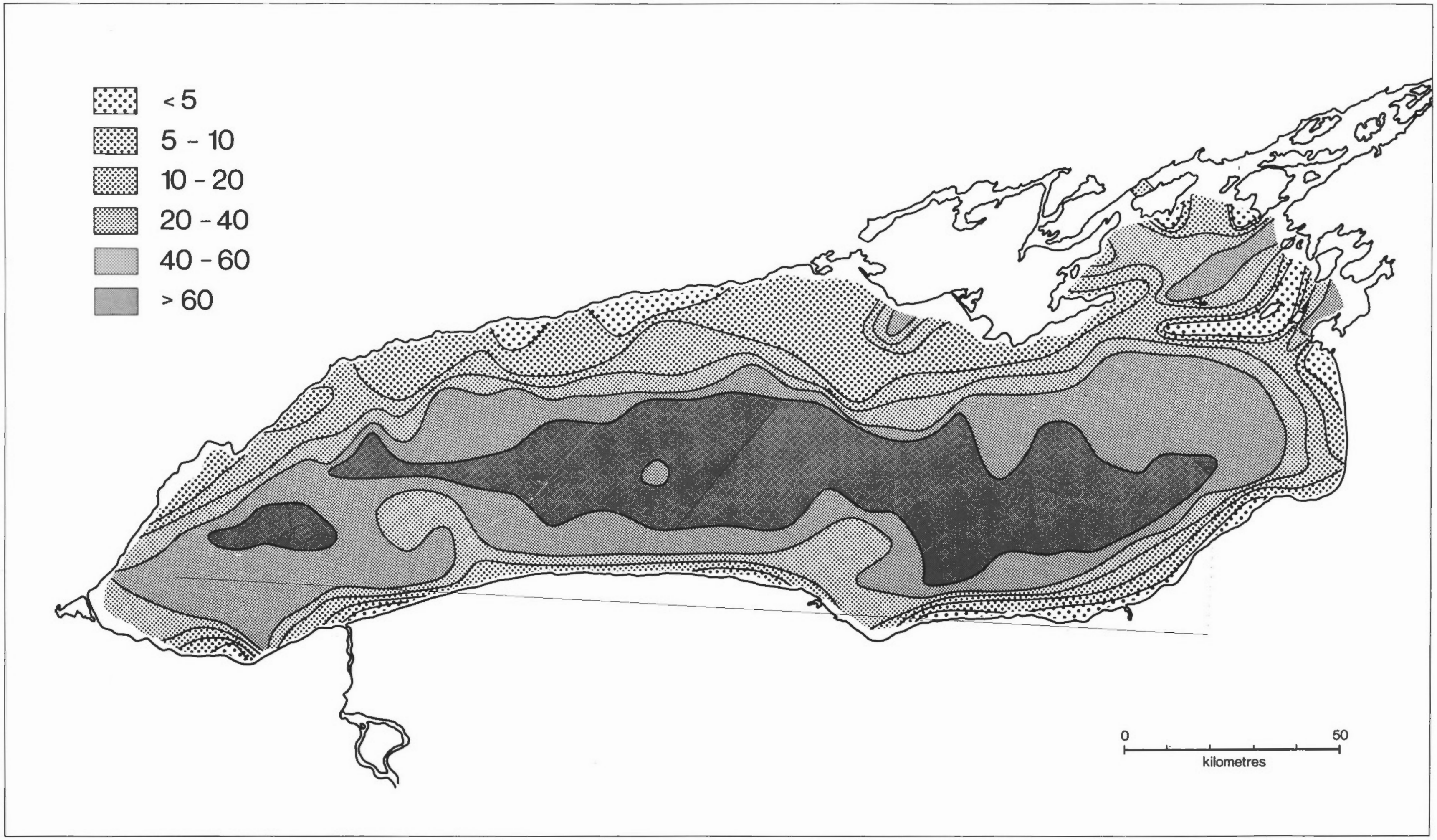

Figure 10. Lake Ontario distribution of mineral clay (%).

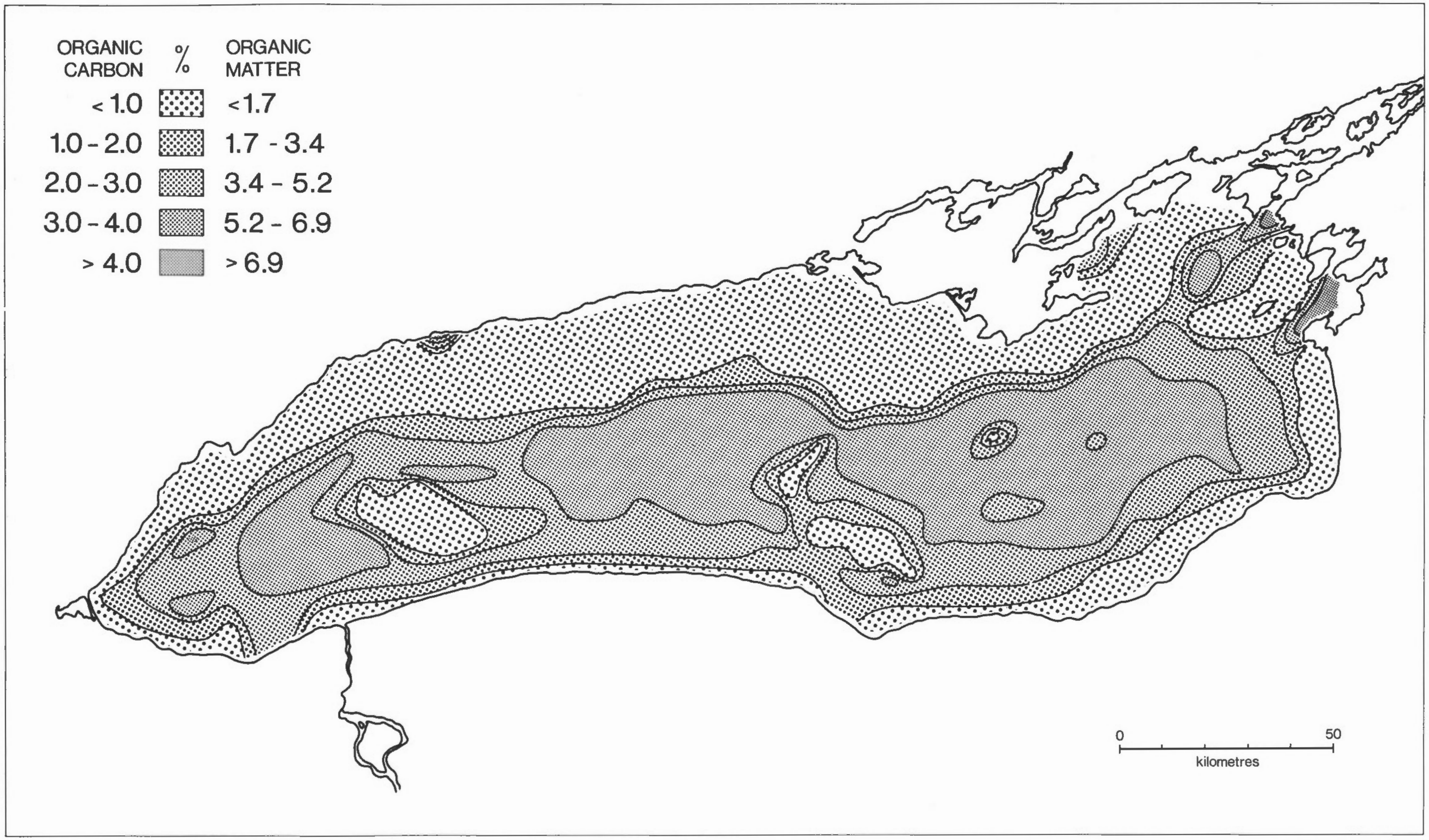

Figure 11. Lake Ontario distribution of organic carbon (%).

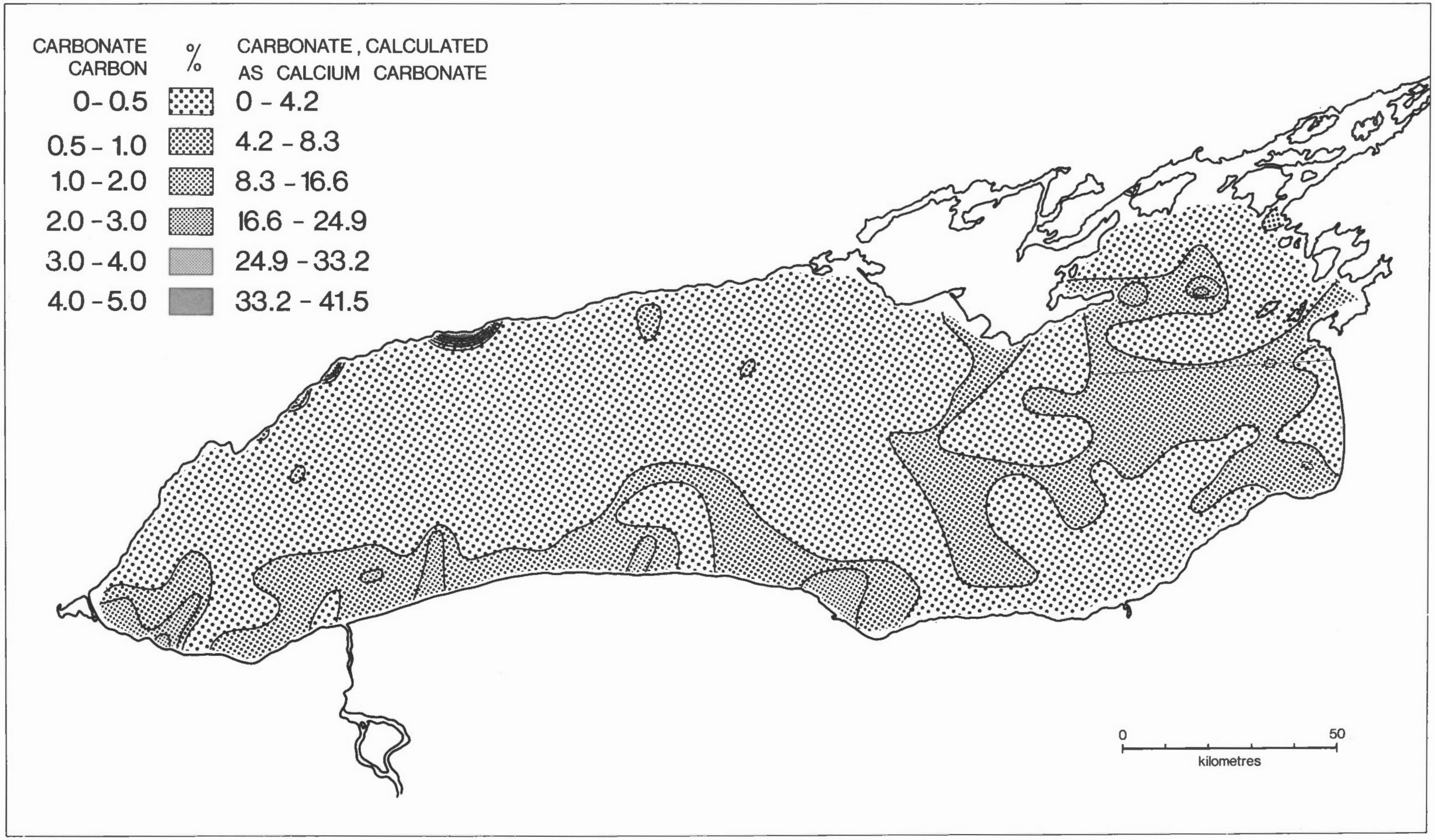

Figure 12. Lake Ontario distribution of carbonate carbon (%).

Table 2. Mean values and standard deviations for the compositional phases

	Quartz		Mineral Clay		Organic C		Inorganic C	
	mean %	std. dev. %	mean %	std. dev. %	mean %	std. dev. %	mean %	std. dev. %
Total lake	50.8	23.7	42.3	21.4	1.98	0.33	0.43	0.44
Inshore zone	68.5	20.3	26.2	17.8	0.96	1.05	0.40	0.55
Total basin	32.4	7.3	58.4	8.1	3.01	0.55	0.46	0.29
Rochester basin	33.6	8.4	57.0	19.2	2.96	0.50	0.54	0.23
Mississauga basin	30.0	6.2	62.0	6.2	3.08	0.63	0.33	0.25
Niagara basin	34.7	5.2	56.2	6.4	3.02	0.55	0.48	0.38

Rochester. These are probably due to the local input of carbonaceous sediment from the south shore rivers together with wave eroded materials from the shoreline exposures of glacial materials. From X-ray diffraction studies, all the carbonate appears to bound as calcium carbonate with no observable dolomite or siderite.

The statistical breakdown of the compositional phases, outlined above for individual basins and the nearshore zone, are given in Table 2.

CHAPTER 10

Sediment Textural Properties

SEDIMENT SOURCES

The sediments of Lake Ontario are derived from a number of sources which include river input, coastal erosion, and bottom erosion by wave and current activity. The relative quantitative importance of these forms of material input is not known at the present time, however, a very crude estimate of the input of rivers relative to lake erosional processes can be made. It is estimated that 2,276,570 tons of fine-grained sediment accumulate in the basin regions of Lake Ontario (Table 1). This value excludes the sand accumulations of the nearshore zone for which no value can be quoted. The mean composition of Lake Ontario sediment, derived from grain-size analysis (Table 3), comprises 0.5% gravel, 31.5% sand, 26.1% silt and 43.3% clay, which must, to some extent, represent the original composition of the source material. Since sand is not significant in the basin sediments, then some 32.0% (sand and gravel) of the total sediment input must be remaining in the nearshore zone. If silt is discounted from the calculation in the nearshore zone, then a rough total annual sediment input from all sources to the lake would be 3,328,320 tons of which 1,051,750 tons are of sand and gravel and 2,276,570 tons are of silt and clay. The total estimated annual input of sediment from rivers is 1,829,000 tons (Jonys, personal communication) which represents 55% of the total lake budget, suggesting that approximately 45% is derived from lake erosional processes. It should be observed that these calculations do not take into account output of sediment to the St. Lawrence River. However, this is not considered to be significant, insofar as the main lake is concerned, due to the effect of the *Duck-Galloo Sill* as a major topographical barrier impeding direct sediment transport to the *Kingston Basin* region.

The predominant materials serving as the sediment source to the lake are the variety of glacial materials occurring in southern Ontario and northern New York State. Other than in the possible case of the regional limestone outcrops, direct bedrock erosion is not considered to be of significance as a source of detrital materials. The nature of the source material and the mechanisms of derivation give rise to sediment characteristics which show strong similarities to those reported from the Irish Sea (Belderson, 1964; Cronan, 1969), Cardigan Bay (Moore, 1968) and with deposits of the Scotian Shelf (King, 1966, 1967).

SEDIMENT TEXTURAL CLASSIFICATION

The percentage composition of each sample for sand plus gravel, silt and clay has been determined from the sieve and pipette analyses using the Wentworth classification. The regional distribution of these three fractions is summarized in Figures 13, 14 and 15. Sand and gravel (Fig. 13) predominate in the nearshore zone, decreasing uniformly outwards from the lake periphery into the three basins of the lake. The *Whitby-Olcott* and *Scotch Bonnet Sills* also show high sand content with decreasing concentrations around their margins into the depositional basins (Fig. 13). Clay (Fig. 14) shows an inverse relationship to the sand fraction with increasing clay outwards into the basins. Again the cross-lake sills are marked by decreasing concentrations in the clay-size fraction. The trends in the silt concentrations (Fig. 15) are less pronounced than the sand and clay and show a more uniform regional distribution. In general, the highest silt concentrations occur in the southern parts of the basins decreasing northwards across the lake. Additionally, higher silt concentrations occur in association with river inputs, in particular the Black River and the Genesee. A general similarity in the silt distribution to the carbonate carbon distribution (Fig. 12) can be observed. This is discussed subsequently.

The sediment distribution, based upon the nomenclature of Shepard (1954) and derived from a ternary diagram comprising sand plus gravel, silt and clay as end members is given in Figure 16. This diagram shows very well the complex distribution of coarse sediments in the nearshore zone fining outwards to the predominantly clays and silty clays of the three basins. The diagram also demonstrates the coarser nature of the sediments of the cross-lake sills and their probable significance in relation to sediment deposition in Lake Ontario.

GRAIN-SIZE DISTRIBUTIONS

Folk and Ward (1957), Spencer (1963) and Davis and Ehrlich (1970) interpret statistical measures defining grain size distribution curves to be a summation of the degree of mixing of a number of modal populations. Spencer (1963) suggested that all sediments are comprised of three or less such populations of modal grain sizes, each displaying a log normal grain size distribution. This hypothesis was used by

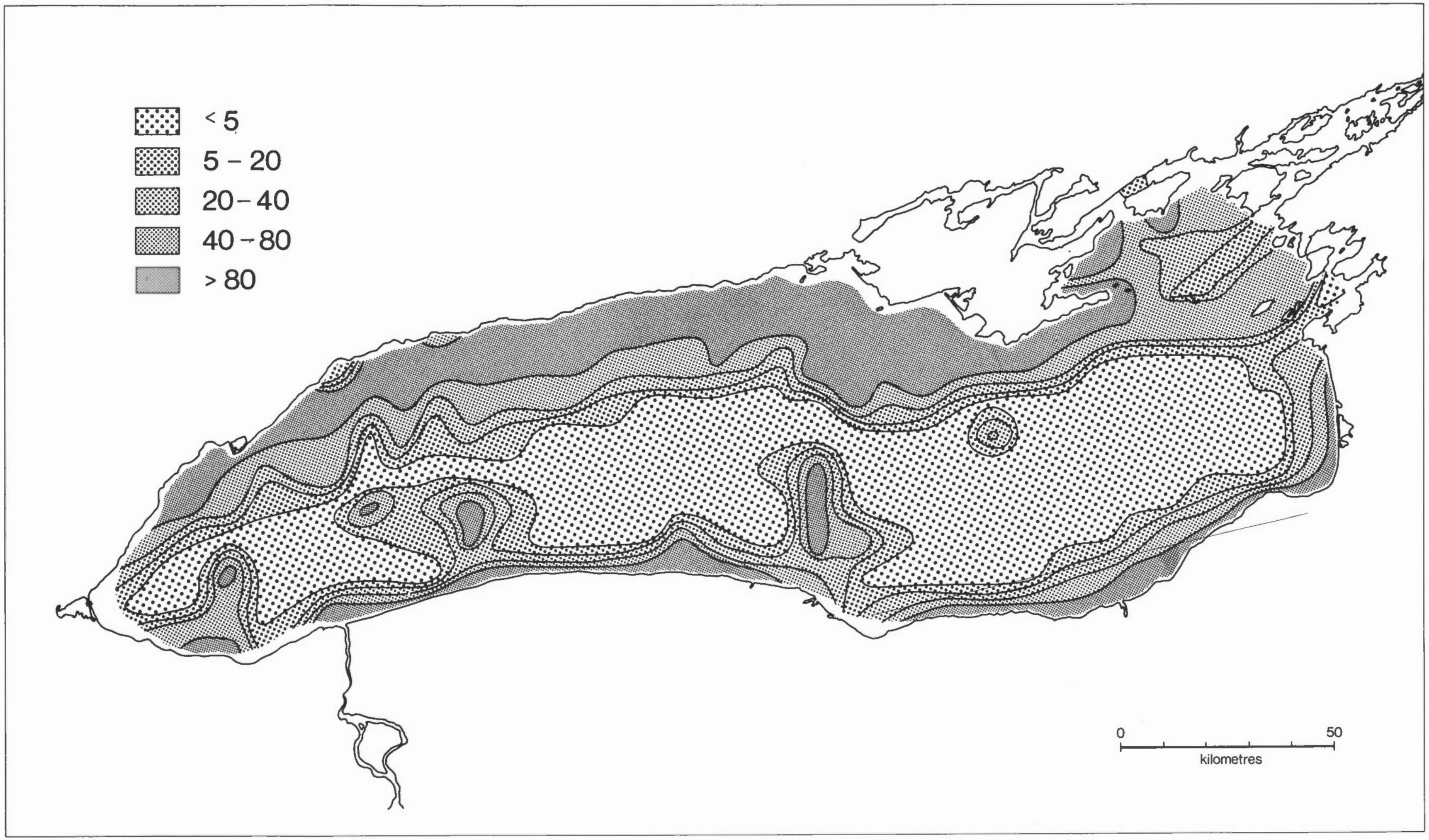

Figure 13. Lake Ontario distribution of the sand and gravel fractions (%).

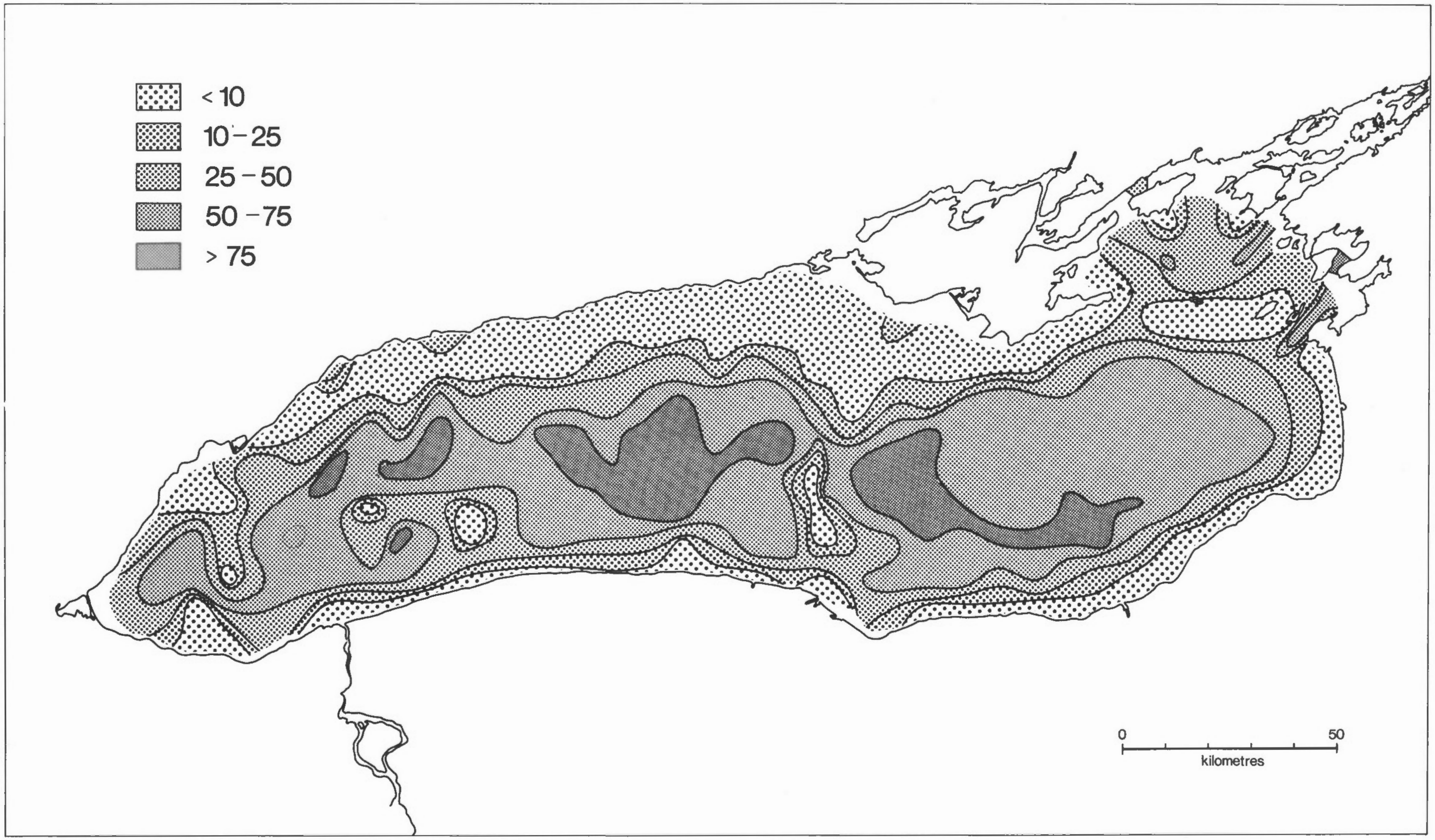

Figure 14. Lake Ontario distribution of the clay size fraction (%).

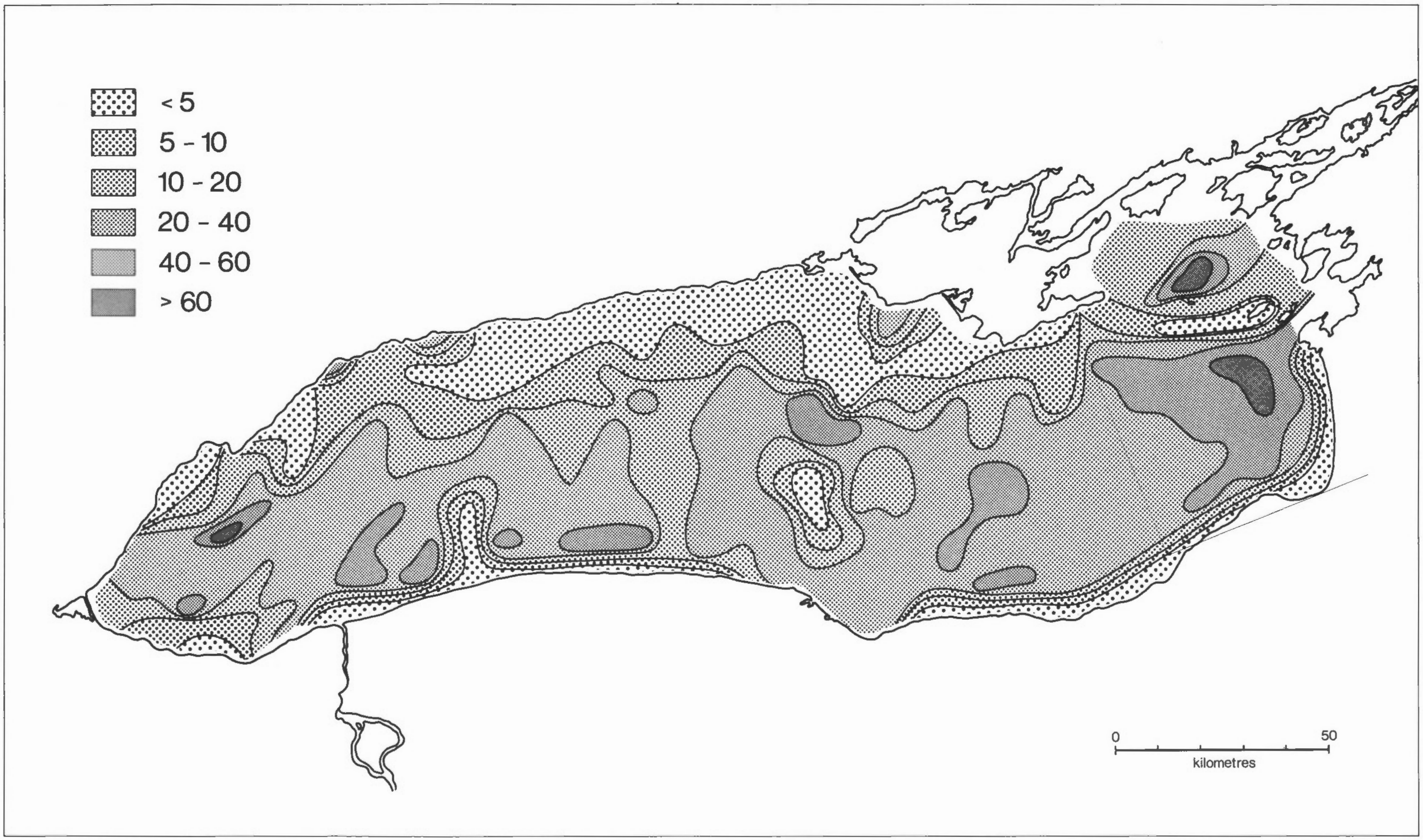

Figure 15. Lake Ontario distribution of the silt size fraction (%).

Figure 16. Lake Ontario distribution of sediment types based on the classification of Shepard, 1954.

Table 3. Mean values and standard deviations for mean grain size and per cent gravel, sand, silt, clay fractions

	Mean grain size		Gravel fraction		Sand fraction		Silt fraction		Clay fraction	
	mean phi	std. dev. phi	mean %	std. dev. %	mean %	std. dev. %	mean %	std. dev. %	mean %	std. dev. %
Total lake	6.3	2.6	0.5	1.7	31.5	37.8	26.1	19.5	43.3	34.9
Inshore zone	4.4	2.2	0.8	2.2	57.9	34.6	18.6	19.7	23.1	22.4
Total basin	8.1	1.1	0.1	0.5	4.5	14.6	33.8	16.0	64.1	33.3
Rochester basin	8.2	0.8	0.1	0.2	1.9	3.6	36.9	15.4	61.2	16.7
Mississauga basin	8.4	1.4	0.2	0.8	7.0	20.0	25.7	12.0	67.1	18.9
Niagara basin	7.8	1.3	0.0	0.0	6.5	19.3	39.5	18.7	54.0	21.4

Cronan (1969) to describe the sedimentological characteristics of sediments in the central, northeastern Irish Sea, and is equally applicable to the interpretation of the grain-size data from Lake Ontario.

The original or primary source of material to Lake Ontario is the glacial till. This, together with glacial outwash, supplied the sediment to Lake Iroquois, forming the glaciolacustrine clays of the region. Both tills and reworked tills, in the form of glaciolacustrine clay are the primary source of the recent deposits in Lake Ontario. The general textural characteristics of glacial till are well known (Pettijohn, 1957) and comprise three modal populations in the gravel, sand and clay sizes. Gravels derived from glacial till are common on the bed of the nearshore regions of Lake Ontario, yet due to sampling and subsampling techniques, do not play a significant role in defining the grain-size characteristics of the sediments as described in this paper. Hence, the statistical measures used here define sediment fundamentally characterized by two modal populations in the sand-and-clay size ranges. Variations in the numerical values are related to the varying proportions of the end member size populations which show trends in Lake Ontario related to the depositional environment.

MEAN GRAIN-SIZE AND STANDARD DEVIATIONS

The relationship of mean grain size to standard deviation is shown in Figure 17*. The trend in this figure is in good agreement with the modal of Folk and Ward (1957) showing that part of the sinusoidal trend in the sand-to-clay size ranges. Additionally, the values shown for both mean and standard deviation are in good agreement with the sand and clay populations of Spencer (1963). From the scatter diagram (Fig. 17), the ranges of values suggested for the end member populations related to those of Spencer (1963) are:

Sand: This study: mean 1.5-3.5 phi, standard deviation 0.3-2.3 phi
Spencer: mean 1.5-4.0 phi, standard deviation 0.4-1.0 phi

Clay: This study: mean 7.0-9.5 phi, standard deviation 1.4-2.7 phi
Spencer: mean 7.0-9.0 phi, standard deviation 2.0-3.0 phi

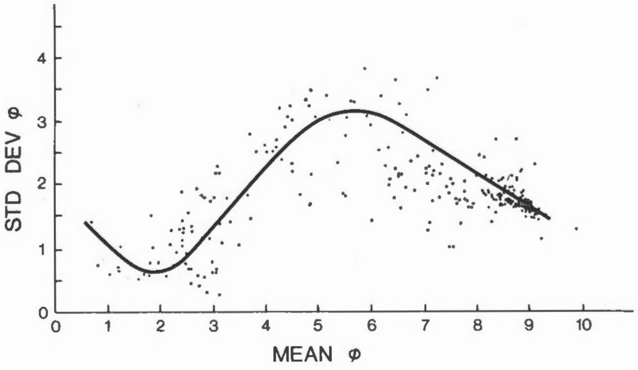

Figure 17. The relationship of mean grain size to standard deviation.

The trend shown in the relationship of mean size to standard deviation (Fig. 17), displays predominantly well-sorted sands in the size range 1.5 to 3.5 phi, the standard deviation increases as the mean grain size decreases to a phi value of about 5.5. Here, the trend reverses with

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*The phi (φ) scale is commonly used by sedimentologists in discussing grain size of sediments (Krumbein and Pettijohn, 1938, p. 84). Phi units = $-\log_2$ (diameter in mm).

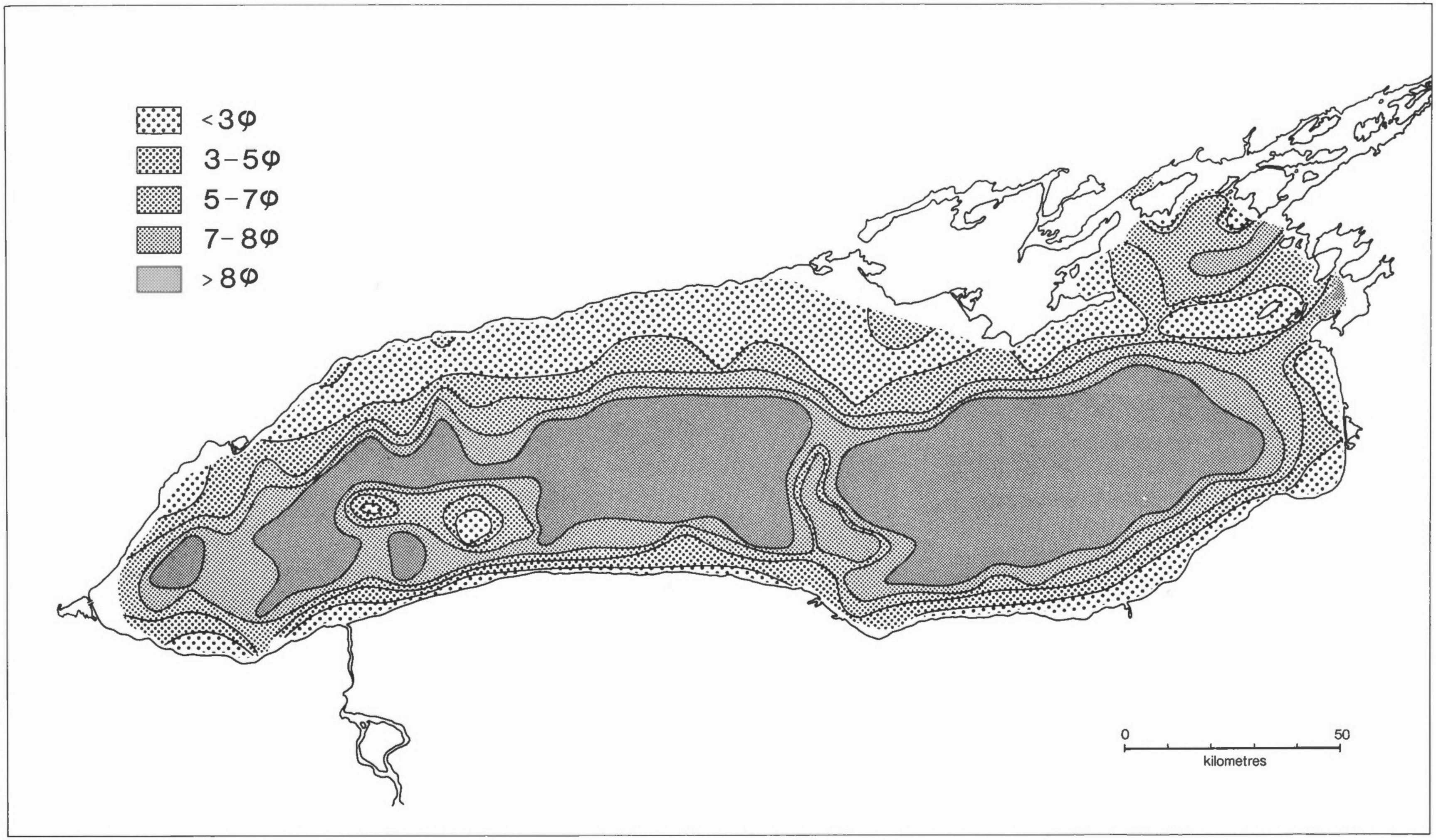

Figure 18. Lake Ontario distribution of mean grain size values (in phi).

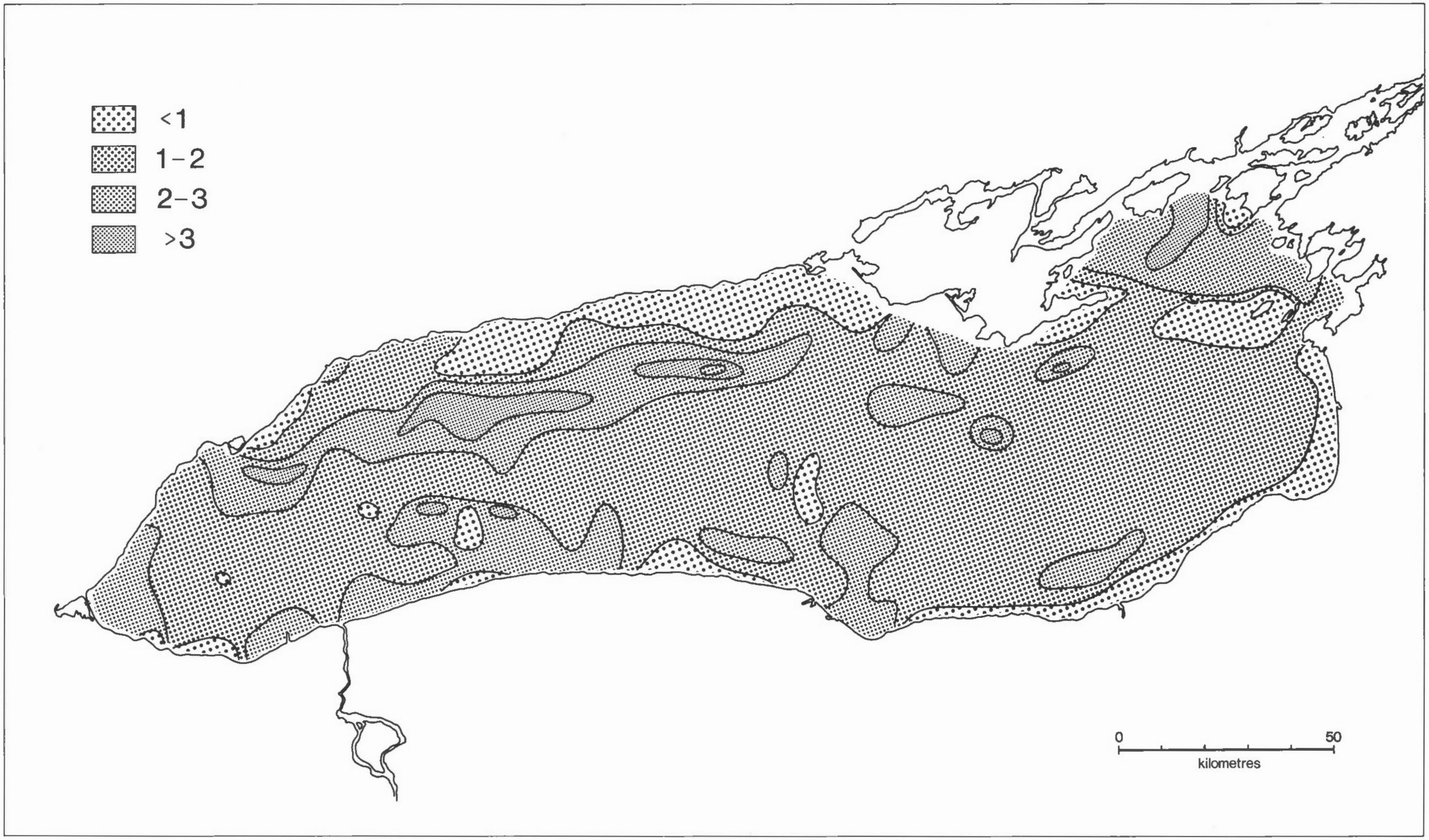

Figure 19. Lake Ontario distribution of standard deviation (in phi).

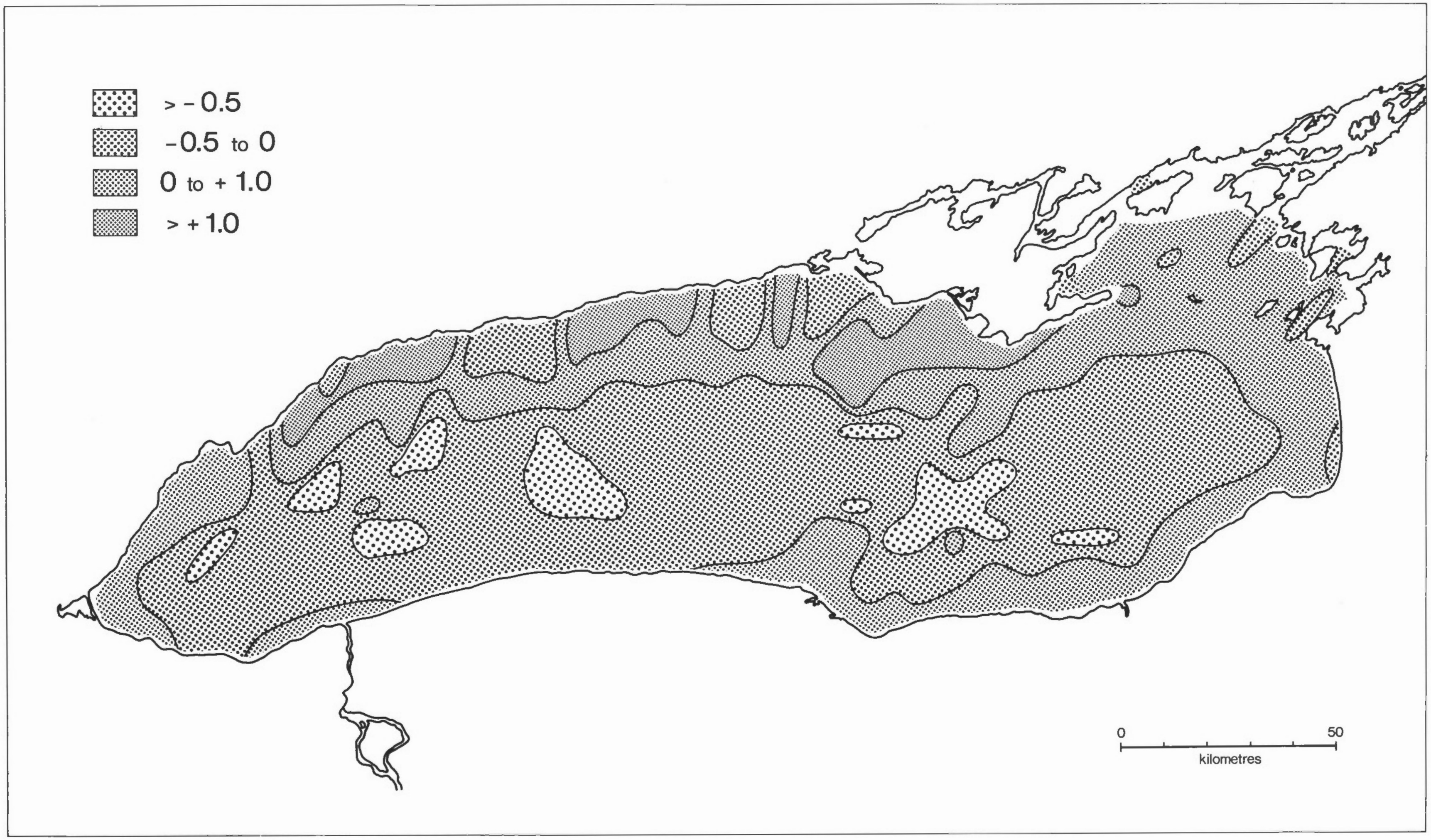

Figure 20. Lake Ontario distribution of skewness values.

the standard deviation decreasing with decreasing mean grain size to the fine-grained clay end member populations which is less well-sorted than the sands.

A contour plan of the mean grain-size distribution is shown in Figure 18. The trends are pronounced and demonstrate a decreasing mean grain size from inshore out into the three depositional basins. This diagram (Fig. 18) also shows a marked increase in the mean grain size of samples taken on the *Whitby-Olcott* and *Scotch Bonnet Sills,* suggesting a possible higher energy environment.

The regional variation in the standard deviation is shown in Figure 19. This shows that the regions displaying the best-sorted sediments are confined to the nearshore zones of the lake in the regions of coarser sediment (Fig. 18), though again some samples on the cross-lake sills also show a high degree of sorting. Poor to very poor sorting is seen in a zone parallel to the north shore of the lake and in parts of the cross-lake sills. It should be noted that these regions are very closely related to the regions of glaciolacustrine clays as indicated by the acoustic map (Fig. 4). It has been suggested previously that the thin sand veneer covering the glaciolacustrine clay outcrop has originated as a lag deposit. Indeed on close visual observation, the clay content of the sand can be seen to increase with depth with the sand grading down into the underlying clay. The high standard deviation of these sands can thus be attributed in part to the combination of a sand and clay population with the degree of combination related to some extent with the thickness of the sand veneer relative to the 3 cm subsampling. The bulk of the remainder of the lake is composed of sediment with a standard deviation ranging from 1 to 3 phi which includes the main depositional basins and parts of the nearshore zone.

Evaluation of the data for mean grain size relative to standard deviation suggests that Lake Ontario sediments show a natural trend in values related to the degree of mixing of two end member populations. The sand end member population is well sorted and confined to the immediate nearshore zone which comprises the high energy environment in the lake. The clay population end member (>7 phi mean grain size) is confined to the offshore deep water environment and must represent low energy conditions with sedimentation from suspension. The remaining regions represent an offshore decrease or prograding of mean grain size related to increasing clay content relative to sand in a continuous series of sediment with varying mixtures of the end member populations.

SKEWNESS

The regional distribution of skewness values shown in Figure 20 demonstrates that the nearshore coarser sediments are positively skewed whereas the offshore basin sediments are negatively skewed. This suggests that the end member populations do not fully demonstrate a normal distribution as suggested by Folk and Ward (1957).

Lake Ontario sediments comprise substantial quantities of material in the silt-size range with an average silt content of 18.6% and 33.8% in the inshore and basin samples respectively (Table 3). It is shown later that the bulk of this silt material consists of calcium carbonate.

Folk and Ward (1957) note that a second minor mode has a pronounced effect on the symmetry of the primary modal populations. In Lake Ontario, the introduction of a silt component has skewed the end member populations with the sand becoming positively skewed and the offshore clays becoming negatively skewed. The relationship of skewness to mean grain size is well illustrated in the scatter diagram in Figure 21. Here, a linear antipathetic relationship is observed from a mean grain size of 2 phi to 9 phi with normal distribution occurring in the region 6 to 7 phi in samples with high values of standard deviation as indicated by Figure 17. Normal distribution of grain size frequency, as indicated by skewness, in Lake Ontario sediments, thus represents poor sorting in a mixture comprising two populations with skewed distribution curves.

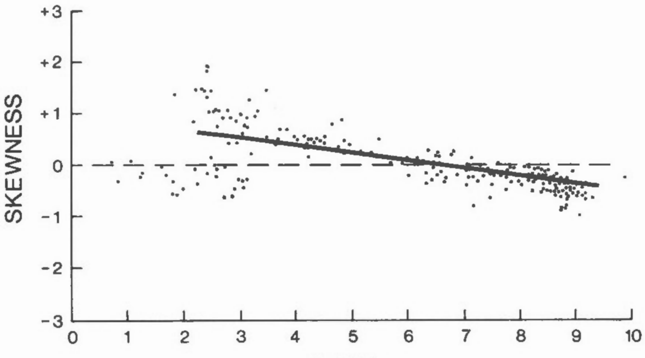

Figure 21. The relationship of mean grain size to skewness ($y = 0.78 - 0.13x$)

KURTOSIS

Folk and Ward (1957, p. 20) state: "The addition of very small amounts (3 to 10 per cent) of another mode means that the sorting in the tails is worsened while the sorting in the central part remains good; hence, the curves become strongly leptokurtic....." We have already suggested that the end member populations have been modified by the occurrence of silt-size material. Using the above argument of Folk and Ward (1957) this would suggest that the sand and clay populations in Lake Ontario should be leptokurtic. This is illustrated in Figure 22, which shows the relationship of kurtosis to mean grain size. The diagram (Fig. 22) is again very different from the model of Folk and Ward (1957) and the variation can again be attributed to the silt-size material. Samples with a mean grain size coarser than 4 phi and finer than 8 phi are leptokurtic whereas samples between 4 and 8 phi are generally moderately platykurtic. The sand population is markedly more liptokurtic than the clay population which probably represents the greater silt content of the basin sediments over the nearshore sand (Table 3) and the lesser sorting of the fine-grained sediments (Fig. 17).

The platykurtic region of the 4 phi to 8 phi region in Figure 22 represents the wide range of grain sizes represented in a poorly sorted mixture which varies in a sinusoidal trend relative to the degree of mixing of the end member populations (Folk and Ward, 1957).

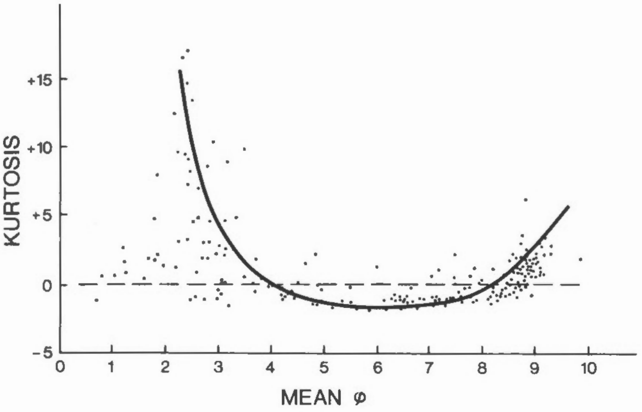

Figure 22. The relationship of mean grain size to kurtosis.

RELATIONSHIP OF SKEWNESS TO KURTOSIS

The relationship of skewness to kurtosis in Lake Ontario sediments is shown in the scatter diagram in Figure 23. This diagram summates the characteristics of the grain-size distribution curves in sediments composed of variable amounts of two populations, each with an asymmetric grain-size distribution. Starting at point A (Fig. 23), the sand end member population is markedly leptokurtic and positively skewed with a tail into the silt size. Proceeding along the curve, there is a continuous addition of a clay size population which is moderately leptokurtic and negatively skewed as in zone D. Zones B and C consist of platykurtic samples comprising a mixture of the populations in A and D and transitional between the two. The sorting is poor in zones B and C but the dominant population is suggested by the sign of the skewness. Zone B is positive with dominant sand whereas zone C has a negative sign suggesting the dominance of the clay-size population.

The trend shown in Figure 23 from A through B and C to D represents the changes occurring in the sediment textural characteristics from a nearshore environment through a zone of mixing associated with decreasing energy to an offshore zone in which the sediments are derived predominantly from suspension.

Again the pattern displayed in Figure 23 shows similarities to the proposed model of Folk and Ward (1957) but differs in that a completely circular trend is not seen. In Folk and Ward's (1957) model, the pure end member populations have a symmetrical distribution curve with zero skewness. In Lake Ontario, this condition is not seen and the end member population are asymmetric with opposing signs.

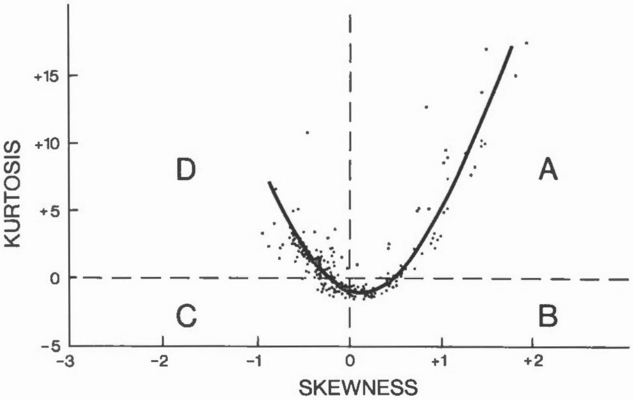

Figure 23. The relationship of skewness to kurtosis.

The regional distribution of zones A, B, C and D in Lake Ontario are shown in Figure 24. The postulation outlined previously that these zones represent decreasing energy from nearshore to offshore environments is verified by the contour plan. Zone A represented by the regions of highest energy in the lake occur around the periphery of the lake in the nearshore zone. This zone predominates in the northern and eastern shores of the lake and, within the confines of the sample grid interval, but is absent from the southern shore. This is probably due to two factors: (1) the higher angle slope of the southern shore relative to the northern shore which forms a larger northern nearshore zone and (2) the predominating westerly and southwesterly winds of the region. Such winds have a long fetch to the northern and eastern shorelines and will create high energy conditions to greater depths than on the southern shore. Zones B and C occur generally as transitional zones in an offshore sequence related to increasing water depth and decreasing energy to the offshore basin sediments of zone D. Figure 24 also shows that the sill sediments are of zone-B and zone-C types suggesting higher energy than observed in the deeper basins. This fact would tend to corroborate earlier suggestions that the *Scotch Bonnet* and *Whitby-Olcott Sills* are still actively supplying sediment eastward and westward into the depositional basins.

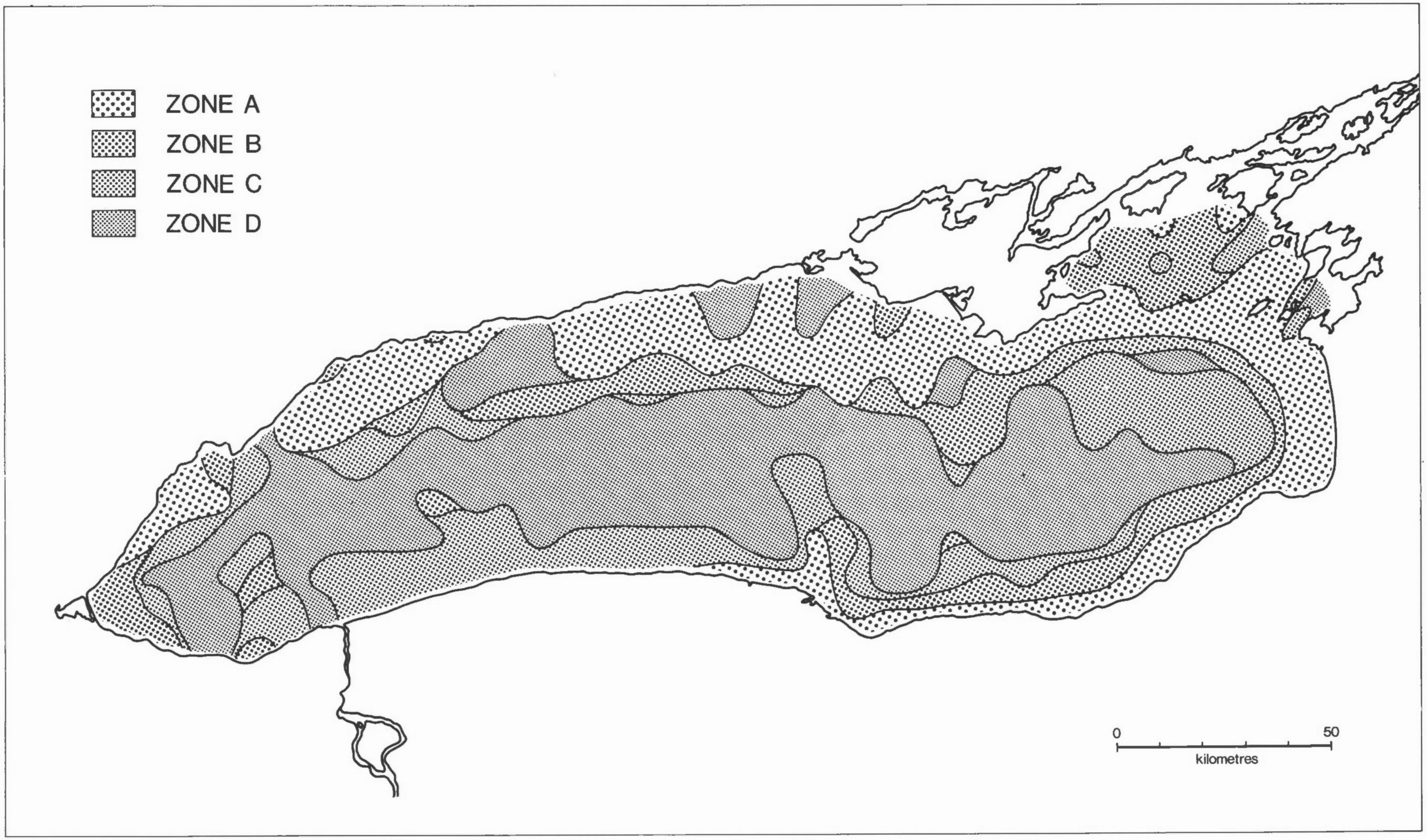

Figure 24. Lake Ontario distribution of zones A, B, C and D derived from the relationship of skewness to kurtosis given in Figure 23.

Discussion

The foregoing description of the grain-size distribution characteristics of Lake Ontario sediments demonstrates similar trends to the models of Folk and Ward (1957). In Lake Ontario, however, the sediments consist of finer sizes incorporated in the models, whereas the Brazos River Bar samples are composed of gravel and sand end member populations. This is undoubtedly a reflection of the higher energy regimes operative in a fluvial, unidirectional river system as distinct from the lacustrine current and wave situation existing in Lake Ontario. An additional and perhaps more significant difference can be directly related to the relatively high-silt concentration in Lake Ontario sediments inducing asymmetry in the end member populations. The fact that this silt consists predominantly of calcium carbonate suggests that a pretreatment of the sample with acid would give results in direct agreement with the data of Folk and Ward (1957) and Spencer (1963). This, in turn, would result in trends that might well be universal in application. However, the silt component, be it detrital or a chemical precipitate, is a product of the natural Lake Ontario environment and should not be discounted in the numerical description of the grain-size characteristics of the lake sediments. The trends observed are thus unique to the lake and greatly assist in the interpretation of the origin, movement, and deposition of Lake Ontario sediment relative to increasing or decreasing energy regimes due to wave and current activity.

Spencer (1963) states that a Ternary diagram of the type used by Shepard (1954) utilizing silt as one end member is of no genetic significance because sediment material in the silt-size fraction does not appear to be a natural constituent in sediments (Hough, 1942; Pettijohn, 1957). The importance of silt-size modes in determining the grain-size characteristics of Lake Ontario sediments has been emphasized earlier. Since this silt appears to be a natural phenomenon associated predominantly with the carbonate phase of the sediment, then a ternary diagram, as proposed by Shepard (1954), will be meaningful in assessing a potential relationship between the sediment and the depositional environment. The scatter of sample values in such a ternary diagram is shown in Figure 25. Sector A of this diagram, within the dashed line, represents samples with compositions low in silt, comprising variable mixtures of sand plus gravel and clay. The visual descriptions of these samples, made during collection, show that within sector A the samples are contaminated, to a greater or lesser extent, by glacial sediment. These are samples generally taken at localities where lag sands <3 cm thick overlie glacial clays. As such, these samples are not truly representative of recent sedimentation in Lake Ontario. The remaining samples show a general trend which may be related to sedimentation processes in the present lake environment. Point B represents the sand end member population and point D, the clay end member population discussed previously. A line drawn from point B through point C to point D represents the natural nearshore to offshore prograding of the lake sediments related to mixing of populations B and D. As one proceeds along the trend line from B to C, there is a progressive increase in silt and clay. From point C to D there is a continued but slower decrease in sand; a more marked decrease in silt with increasing clay. The clay population at D still shows a greater silt content than that of the sand population at B which satisfactorily explains the higher leptokurtic values and lower values for standard deviation of the sand population relative to the clay end member population as discussed earlier. This trend, B, C and D is again a manifestation of the size frequency distribution of the lake sediments and is probably a direct function of decreasing energy from shallow nearshore regions to the deeper offshore basins (Pelletier, personal communication).

So far, this paper has been concerned primarily with a descriptive account of the regional distribution of a large number of compositional and textural properties of the sediments of Lake Ontario. These properties and their variations are the net product of sedimentation in a series of three large lake basins.

A sediment is the result of the agents which bring about its denudation, transport, and deposition. A sediment thus maintains the essential characteristics of the source material modified by the agents of transportation. The final texture and composition of the sediment is a reflection of the overall conditions existing at its point of deposition. As such, the sediment must be regarded as the result of a complex series of interrelated variables, the trends of which give an insight into the regional conditions controlling its sedimentation.

INTERRELATIONSHIPS BETWEEN VARIABLES

A correlation-coefficient matrix summating the relationships between variables is given in Table 4. With 250 samples used in the analysis, a correlation-coefficient greater than 0.3 is significant at the 0.01% confidence level.

A number of types of covariation can be seen in the matrix diagram (Table 4). In order to facilitate the

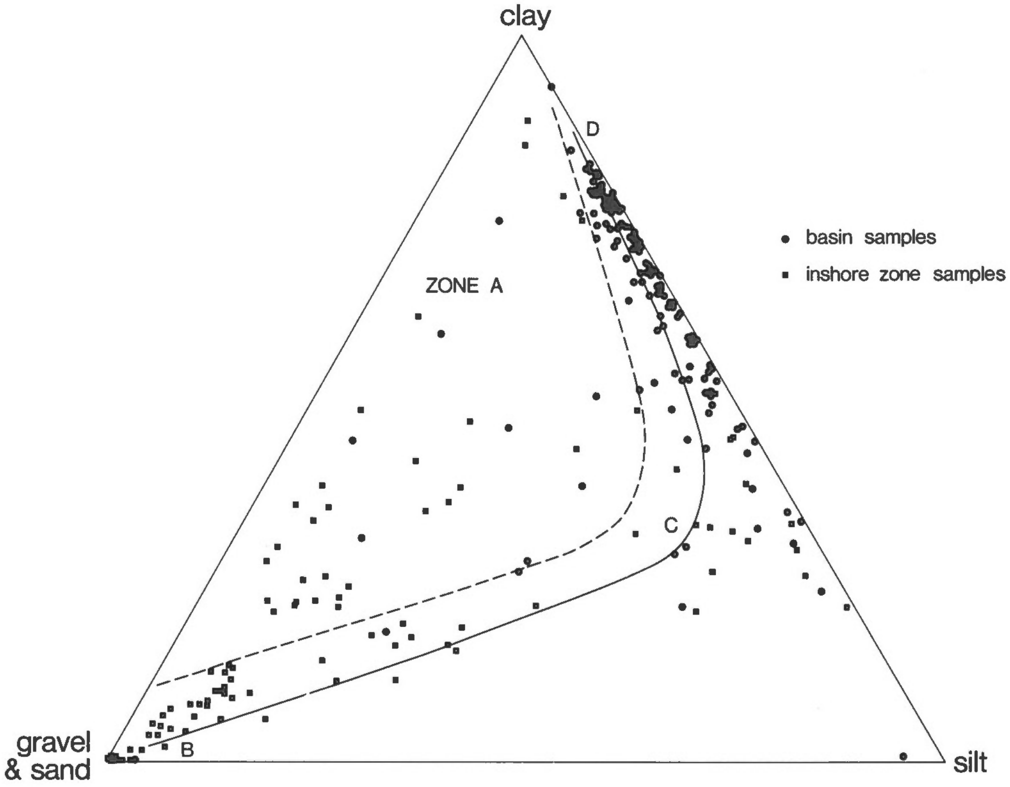

Figure 25. Sand plus gravel, silt and clay ternary diagram.

discussion of these interrelations, a number of terms may be used to classify the relationships to be observed. Firstly, a *primary* relationship is one in which there is a direct interaction between the two variables, e.g., two variables associated with a mineral or compositional phase of the sediment. Secondly, a *secondary* relationship, defined as a variable related indirectly to but controlled by a *primary* relationship and finally an *indirect* relationship where the two variables are covariant but do not have a direct association. Only the relationships which are considered to be of value in understanding the sediments and their deposition in Lake Ontario are considered further in this discussion.

Since, as has been previously discussed, the sediment textural properties are controlled by the degree of mixing of a sand and clay population modified by a silt mode, then the major compositional features of the sediments, in their turn, must also be related to the same phenomena. To this end, the relationships are discussed relative to the percentage composition of the sediment in terms of sand, silt, and clay.

RELATIONSHIPS WITH THE SAND FRACTION

Figure 26 shows a scatter diagram illustrating the relationship of sand to quartz. This is a *primary* relationship in that the quartz is a direct reflection of the detrital silicates which are predominantly in the sand-size fraction. It should be noted that the term, quartz, as used here includes the feldspar content of the sediment (Thomas, 1969a). Since the sand fraction represents one end member population, the addition of increasing quantities of the clay end member population will demonstrate an effect upon the mean size of the sediment resulting in a *secondary* correlation of mean grain size to both quartz and sand which represent the *primary* relationship. This is illustrated

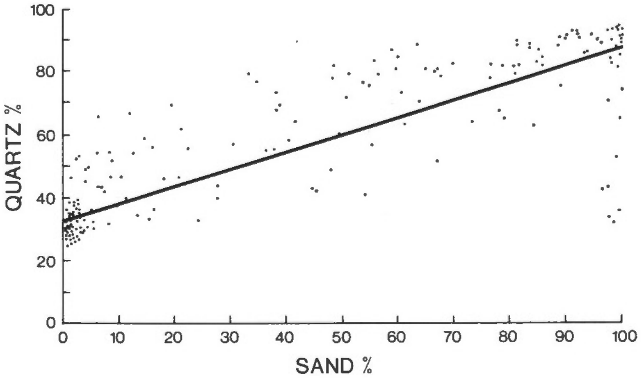

Figure 26. The relationship of sand to quartz (r = 0.869, y = 32.5 + 0.64x).

Table 4. Correlation coefficient matrix

	Eh	pH	Quartz	Organic carbon	Inorganic carbon	Mean	Mineral clay	Gravel fraction	Sand fraction	Silt fraction	Clay fraction
Water depth	−0.275	0.304	−0.692	0.539	−0.209	0.637	0.752	−0.237	−0.531	0.066	0.678
Eh		−0.138	.701	−0.745	−0.373	−0.657	−0.637	0.101	0.696	−0.535	−0.548
pH			−.256	0.190	−0.152	0.242	0.292	−0.098	−0.171	−0.028	0.270
Quartz				−.900	−0.196	−0.897	−0.982	0.247	0.869	−0.500	−0.831
Organic carbon					0.215	0.834	0.859	−0.253	−0.825	0.501	0.757
Inorganic carbon						0.144	0.022	−0.024	−0.257	0.446	0.026
Mean							0.886	−0.284	−0.963	0.520	0.957
Mineral clay								−0.243	−0.835	0.420	0.844
Gravel fraction									0.224	−0.203	−0.222
Sand fraction										−0.690	−0.880
Silt fraction											0.303

in Figures 27 and 28 where mean grain size shows good correlation with both sand (r = -0.963) and quartz (r = 0.897). The high degree of relationship between mean grain size and quartz in Great Lakes sediments was demonstrated and discussed previously by Thomas (1969b). The present data confirms the results obtained by Thomas (1969b). Examination of the correlation matrix (Table 4) shows that both the *primary* and *secondary* relationships with sand have an *indirect* relationship with water depth. The correlations show that with increasing water depth there is a decrease in sand, quartz and mean grain size. This is discussed subsequently.

RELATIONSHIPS WITH SILT

Table 4 shows that silt correlates directly with organic carbon and mean grain size and indirectly with quartz.

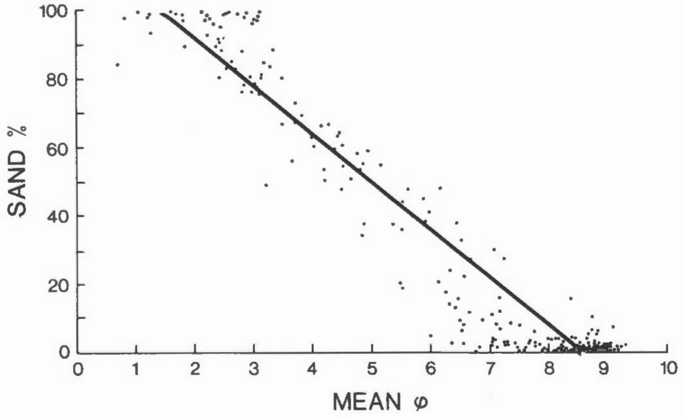

Figure 27. The relationship of mean grain size to sand (r = −0.963, y = 120.5 − 14.2x).

Additionally, a poor but significant correlation of silt to $CaCO_3$ (r = 0.446) can be seen from Table 4. This suggests a *primary* relationship in which a considerable proportion of the silt content is in the form of a carbonate. This relationship has also been recognized in Lake St. Clair (Thomas, unpublished data), in Lake Geneva (Vernet, personal communication) and in Wisconsin lakes (Williams, personal communication). The origin of the carbonate is uncertain at the present time and may well represent denudation of the regional Silurian and Ordovician limestones. X-ray diffraction, however, has failed to reveal the occurrence of dolomite in the lake sediments and the carbonate appears to be wholly in the form of calcite. This fact would suggest that the calcium carbonate is derived by precipitation from the lake waters as is the case in Lake Geneva (Vernet, personal communication). The regional distribution of the carbonate (Fig. 12) and the silt (Fig. 15) demonstrates associations with river inputs and higher values along the south shore of the lake. Other than these regions, the distribution is relatively uniform. It may

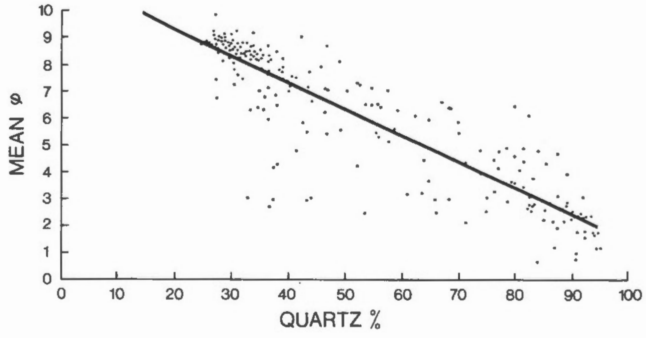

Figure 28. The relationship of quartz to mean grain size (r = −0.897, y = 11.2 − 0.10x).

well be that minor precipitation is occurring on a lake-wide basis with increased concentrations occurring in regions where input of carbonate-rich waters is taking place.

RELATIONSHIPS WITH CLAY

The clay fraction of the sediment shows positive correlation with mean grain size, organic carbon and Eh (Table 4). From Table 4, the degree of correlation between computed *mineral* clay and the clay fraction is r = 0.844. The clay fraction, here, is based upon the Wentworth classification and is composed of materials less than 4 micron in diameter. The correlation should improve with the utilization of a less than 2 micron-size fraction as suggested by Thomas (1969b). Since a *primary* relationship of organic carbon to clay is a function of the *mineral* clay content rather than a function of a clay defined by grain size, the correlation of organic carbon to *mineral* clay is somewhat better than with the clay fraction (Table 4). The scatter diagram illustrating the *primary* relationship between *mineral* clay and organic carbon is given in Figure 29.

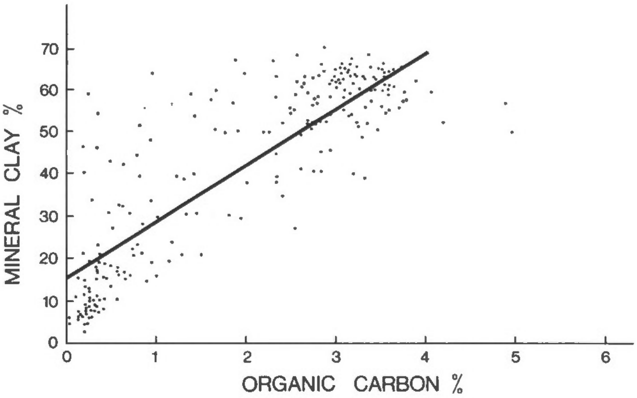

Figure 29. The relationship of organic carbon to mineral clay ($r = 0.859, y = 15.8 + 13.5x$).

The absence of *chlorophyll b* in the surface sediments of Lake Ontario suggests that the organic matter is mainly of autochthonous origin (Gray and Kemp, 1970). Phyto- and zooplankton are the main precursor materials and the organic matter can be expected to have similar sedimentation properties to that of fine clay particles. Illite, the most abundant clay mineral in Lake Ontario, reacts with organic ions up to its exchange capacity (Grim *et al.*, 1947) with neutral organic molecules and microorganisms probably absorbed on the illite surface sites. The positive correlation between mineral clays and organic carbon is believed to be mainly due to the clay-organic interactions and the settling properties of the decomposing plankton.

The relationship of Eh with both organic carbon and clay is a *secondary* relationship derived from the *primary* relationship of organic carbon to clay with the sediment oxygen demand or consumption and hence the redox potential being a direct function of the chemical and bacterial oxidation of organic matter. A linear relationship between organic carbon and sediment particle size has been observed in marine and lacustrine sediments by many workers since the pioneer work of Trask (1932). This *secondary* relationship between organic carbon and mean grain size is seen in the high correlation coefficient of 0.834 (Table 4). The relationship is due to the decreasing mean grain related to the increasing clay fraction offshore into the basin muds. Additionally, the high degree of correlation might well be due to enhancement of the organic matter with the increasing surface area of the clay particles available for organic absorption as the grain size decreases (Bader, 1962; Thomas, 1969b).

From Table 4, similar yet inverse *indirect* relationships can be seen between water depth and organic carbon, *mineral* clay and the clay-size fraction as were seen for the sand relationships.

In order to simplify and clarify the interrelationships discussed above, r-mode factor analysis (Cameron, 1967, 1968, 1969) was utilized in an effort to relate the relationships to comparatively simple environmental mechanisms. This analysis is not reported in detail but demonstrated satisfactorily that the prime cause of the sediment variation in Lake Ontario is water depth which, in turn, is a function of distance from shoreline. Thus, from inshore to offshore there is a progressive deepening of the lake leading to a decrease in sand, quartz and mean grain size and an associated increase in clay and organic carbon. These variations in composition are due to variation in the degree of mixing of a sand and clay population relative to decreasing energy as water depth increases from the nearshore zone around the periphery of the lake outwards into the three depositional basins. Factor loadings additionally emphasize the relationship of the silt to carbonate carbon discussed previously.

Conclusions

The basic textural trends and the compositional variations related to them are summarized in Figure 30. The distribution of sediments in Lake Ontario conforms to an inshore to offshore prograding associated with declining energy as water depths increase. The recent sediment material is derived from a predominant or primary source of glacial till and glaciolacustrine clays deposited in glacial Lake Iroquois. The eroded glacial sediment is introduced by the rivers and tributaries entering the lake (55%) and is also derived by lake erosion mechanisms involving the shoreline and shallow water regions (45%). This primary material consists of a poly-modal mixture of gravel, sand, and clay of which the latter two play a significant role in determining both the textural and compositional properties of the recent sediment. These sand and clay end member populations show asymmetric grain-size distribution curves skewed towards the silt size due to the introduction of substantial quantities of silt materials probably in the form of chemically-precipitated calcium carbonate. The silt-size material, in addition to skewing the size-distribution curves of the two populations, results in the populations becoming leptokurtic. The variation in the textural characteristics of

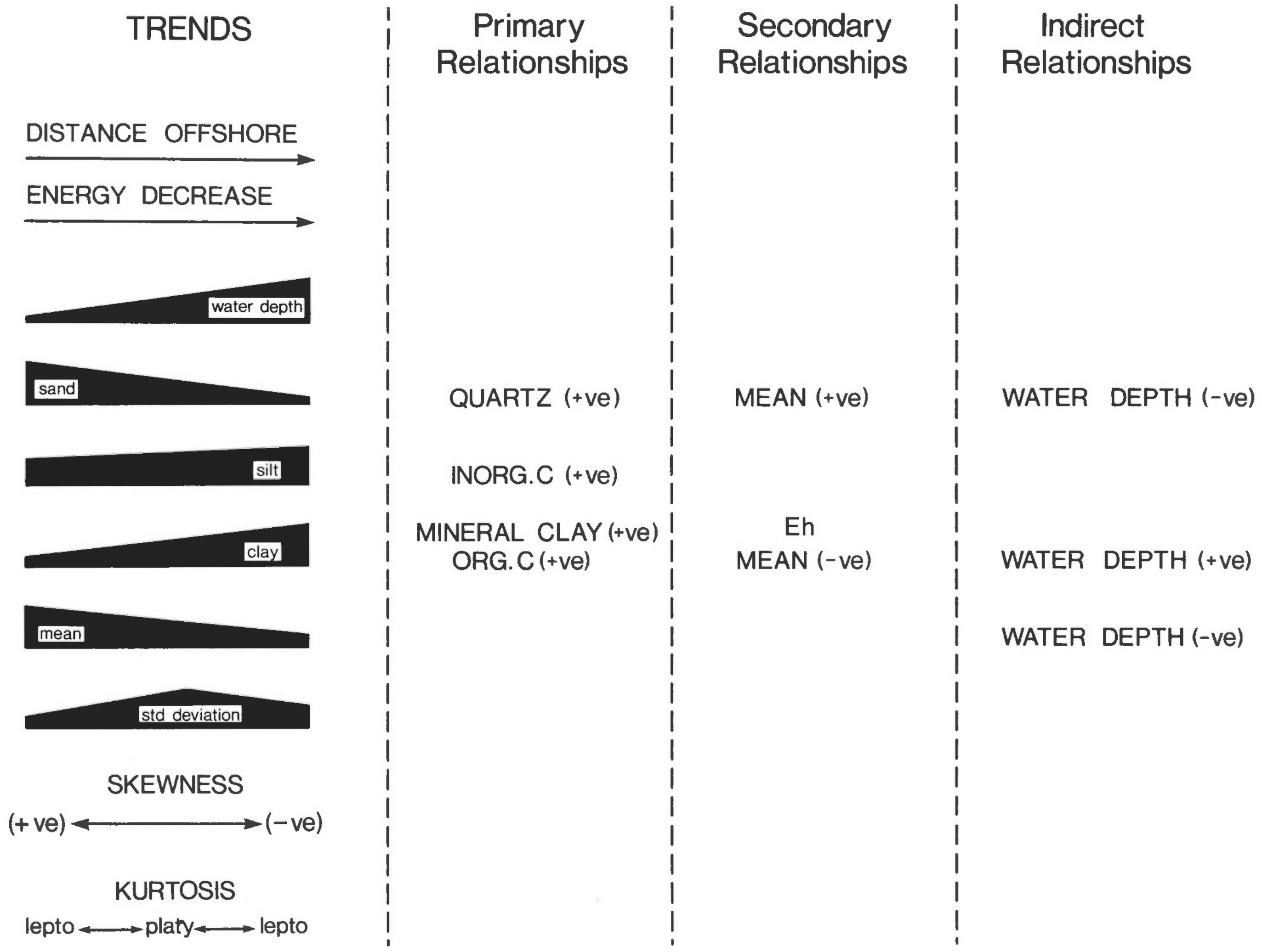

Figure 30. Schematic diagram summarizing the textural trends in Lake Ontario sediments and their relationship to compositional variations with the postulated controlling mechanisms.

the sediment from inshore to offshore, from the sand to the clay population through all intermediate mixtures, is summarized graphically in Figure 30. The degree of mixing and the predominating end member population is indicated by the standard deviation, skewness, and kurtosis. The composition of the sediment is also a direct function of the textural properties with quartz, mineral clay, and organic carbon, showing direct *primary* relationships with the end member size populations. Compositional variations, related to textural mixing, results in secondary relationships of sediment composition with mean grain size and Eh, and ultimately to an indirect relationship with water depth and declining energy (Fig. 30).

The pattern that emerges from the study of Lake Ontario sediments is essentially simple yet its understanding is a basic requirement to the future interpretation of geochemical data leading to an understanding of man's role on the geochemical modification of the sediments of the Great Lakes.

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APPENDIX

Lake Ontario Station Locations Sedimentological and Geochemical Data

	Station Location					Percent[1]											
Station	Lat. N.	Long. W.	Depth m	pH	EH Volts	Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size[2]	Standard Deviation[2]	Skewness[2]	Kurtosis[2]
B–2	43°17.2′	79°42.2′	28	7.8	–.010	54.4	30.3	1.32	1.53	0.0	6.1	61.9	32.0	6.5	2.2	+0.2	–0.9
C–2	43°21.3′	79°42.0′	33	7.8	+.165	55.7	42.2	0.62	0.13	0.3	37.8	36.1	25.8	5.3	2.3	+0.2	–1.0
A–3	43°12.8′	79°35.8′	6	7.0	+.045	60.8	19.2	0.24	2.36	5.7	49.3	28.0	17.1	3.2	3.6	+0.2	–1.4
B–3	43°17.2′	79°36.0′	46	7.9	+.005	52.3	37.9	2.00	0.77	0.0	2.2	47.9	49.9	7.3	2.2	0.0	–1.2
C–3	43°21.4′	79°36.2′	76	7.9	+.005	37.7	55.6	2.48	0.29	0.0	1.8	34.0	64.2	8.5	1.9	–0.3	+0.2
D–3	43°25.8′	79°36.2′	55	7.5	+.210	76.1	22.2	0.73	0.06	0.1	54.8	26.1	19.0	4.5	2.2	+0.6	+0.4
A–4	43°13.0′	79°29.8′	17	7.7	+.380	86.7	10.0	0.29	0.34	4.8	93.6	0.7	0.0	1.2	1.0	–0.2	+1.0
B–4	43°17.2′	79°30.1′	73	8.0	–.010	36.3	48.6	3.29	1.15	0.1	5.0	94.3	0.6	6.0	1.4	–0.2	+1.5
C–4	43°21.4′	79°30.0′	87	7.9	+.015	34.9	52.3	2.88	0.95	0.1	1.6	31.3	67.1	8.6	1.9	–0.5	+2.5
D–4	43°25.8′	79°30.0′	94	7.6	+.055	32.2	59.4	4.06	0.17	0.0	0.4	38.2	61.4	8.3	1.6	–0.2	–0.4
E–4	43°30.2′	79°30.0′	60	7.7	+.415	82.4	15.5	0.12	0.24	0.9	81.2	8.4	9.4	3.1	1.4	+0.7	+4.9
A–5	43°13.0′	79°23.7′	14	7.8	+.355	90.5	4.4	0.02	0.61	1.9	98.0	0.0	0.0	0.8	0.7	–0.3	+0.7
B–5	43°17.1′	79°23.8′	75	8.2	+.015	45.5	50.1	1.90	0.14	0.0	3.9	43.6	52.5	8.0	2.1	–0.3	+0.6
C–5	43°21.3′	79°24.0′	97	8.2	+.150	43.1	52.0	2.68	0.04	0.0	96.6	3.5	0.0	3.0	0.8	–0.3	–0.9
D–5	43°25.7′	79°24.3′	109	7.9	–.050	30.0	62.9	2.74	0.29	0.0	2.9	73.7	23.4	7.0	1.3		
E–5	43°30.1′	79°24.2′	85	8.0	+.215	68.0	30.6	0.70	0.03	0.0	78.0	16.1	6.0	3.0	2.2	+0.6	+0.5
F–5	43°34.4′	79°24.0′	62	7.9	+.375	85.2	13.4	0.47	0.07	1.1	59.7	16.8	22.3	4.4	2.9	+0.5	–0.3
A–6	43°13.0′	79°18.0′	18	7.5	+.095	46.1	44.8	2.33	0.61	0.0	17.8	53.7	28.5	6.3	2.3	+0.1	–0.8
B–6	43°17.2′	79°18.0′	87	8.1	+.025	38.8	54.3	2.49	0.32	0.0	1.0	40.8	58.2	8.3	1.8	–0.1	–0.9
C–6	43°21.5′	79°18.1′	102	8.2	+.050	30.9	57.5	3.78	0.61	0.0	1.7	52.7	45.6	7.6	1.7	+0.1	–1.1
D–6	43°26.0′	79°18.1′	121	8.8	+.040	30.0	60.7	3.64	0.37	0.0	0.7	31.8	67.5	8.6	1.7	–0.2	–0.3
E–6	43°30.2′	79°18.1′	114	8.7	+.020	31.7	63.2	2.97	0.00	0.0	8.1	43.6	48.3	7.5	2.1	–0.4	+0.4
F–6	43°34.4′	79°17.6′	98	8.1	+.395	79.5	18.9	0.93	0.00	0.0	33.0	20.3	46.8	6.5	3.3	–0.2	–1.5
G–6	43°39.0′	79°17.8′	10	7.6	+.055	82.0	11.3	0.19	0.77	0.0	99.2	1.9	0.0	2.7	0.6	–0.6	+3.2
B–7	43°17.3′	79°12.1′	76	8.0	+.060	46.7	41.1	2.60	0.93	0.0	8.4	47.5	44.1	7.1	2.3	–0.1	–0.9
C–7	43°21.4′	79°12.0′	100	8.1	–.020	33.2	54.4	3.55	0.76	0.1	1.0	30.5	68.5	8.7	1.9	–0.4	+0.2
D–7	43°26.0′	79°12.0′	123	7.8	–.005	28.2	63.6	3.20	0.33	0.0	0.5	23.7	75.8	8.9	1.7	–0.5	+1.6
E–7	43°30.2′	79°12.0′	135	7.8	+.030	30.3	61.2	3.54	0.30	0.0	5.6	31.0	63.5	8.7	2.0	–0.5	+1.6
F–7	43°34.5′	79°11.6′	120	7.8	+.155	41.3	50.0	2.19	0.59	0.7	54.1	15.3	30.0	4.8	3.2	+0.3	–1.2
G–7	43°39.0′	79°12.0′	86	7.4	+.455	86.4	12.1	0.25	0.13	0.0	93.1	3.4	3.6	2.2	1.3	+1.5	+9.9
H–7	43°43.2′	79°11.8′	10	7.7	+.395	84.1	5.8	0.32	1.11								
B–8	43°17.2′	79°06.0′	6	7.5	+.005	83.7	12.8	0.24	0.38	14.5	84.5	0.5	0.0	0.7	1.4	+0.1	–1.1
C–8	43°21.4′	79°06.0′	96	7.8	+.125	34.3	53.9	3.16	0.77	0.0	1.0	37.2	61.8	8.4	1.8	–0.1	–0.6
D–8	43°26.1′	79°06.6′	125	7.7	–.020	30.3	61.3	3.03	0.38								
E–8	43°30.2′	79°06.6′	145	8.1	–.015	36.8	58.4	2.33	0.10	0.0	2.3	30.6	67.1	8.2	1.6	–0.5	+1.4
F–8	43°34.4′	79°06.0′	125	8.0	–.045	29.9	61.0	3.59	0.35	0.2	2.2	20.0	77.6	8.9	1.8	–0.6	+1.9
G–8	43°39.0′	79°06.0′	108	7.8	+.460	82.1	17.2	0.33	0.02	0.9	80.4	6.3	12.4	3.1	2.2	+0.9	+2.8
H–8	43°43.2′	79°06.0′	131	7.4	+.375	89.1	10.1	0.36	0.02	0.3	83.3	8.1	8.3	2.5	1.6	+1.0	+4.8
I–8	43°47.4′	76°06.0′	11	7.8	+.010	54.5	20.8	1.49	2.67	0.0	8.2	61.5	30.3	6.6	2.2	0.0	–0.7
C–9	43°21.4′	79°00.0′	87	7.7	–.010	34.9	51.8	2.76	1.03	0.0	2.1	45.5	52.5	7.0	2.2	–0.1	–1.3
D–9	43°26.0′	79°00.0′	117	8.0	–.025	34.4	55.6	3.70	0.44	0.3	3.7	58.6	37.4	7.7	1.4		
E–9	43°30.2′	79°00.0′	137	7.7	+.300	53.3	44.5	0.77	0.11	0.0	98.8	0.1	0.0	2.5	0.8	+0.1	–1.0
F–9	43°34.2′	79°00.0′	128	7.7	+.330	28.7	66.9	2.28	0.04	0.0	1.0	26.9	72.1	8.6	1.9	–0.4	0.0
G–9	43°39.6′	79°00.0′	118	7.8	+.335	33.0	61.4	2.64	0.13	0.1	3.7	25.7	70.6	8.0	2.5	–0.4	–0.1

	Station Location					Percent[1]											
Station	Lat. N.	Long. W.	Depth m	pH	EH Volts	Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size[2]	Standard Deviation[2]	Skewness[2]	Kurtosis[2]
H–9	43°43.2′	79°00.0′	91	7.8	+.425	82.3	14.6	0.19	0.34	0.0	78.5	8.7	12.8	2.8	1.8	+0.9	+3.2
I–9	43°47.4′	79°00.0′	27	7.7	+.395	92.1	5.7	0.35	0.20								
C–10	43°21.4′	78°54.0′	83	7.8	+.005	35.3	52.3	2.82	0.90	0.0	0.9	38.3	60.8	8.4	1.8	–0.2	–0.2
D–10	43°25.8′	78°53.8′	126	7.7	+.450	65.8	33.6	0.28	0.01	0.0	6.2	16.1	77.7	8.8	2.2	–0.8	+2.1
E–10	43°30.2′	78°54.3′	145	7.7	+.405	66.7	32.2	0.62	0.00	0.0	11.8	56.0	32.2	6.6	1.9	–0.3	0.0
F–10	43°34.4′	78°54.0′	137	7.8	+.405	29.6	65.2	3.05	0.00	0.0	0.9	17.1	82.0	9.2	1.6	–0.5	+2.5
G–10	43°38.8′	78°53.8′	119	7.7	+.400	63.6	30.1	1.81	0.39	0.1	60.9	13.7	25.3	4.5	3.0	+0.4	–0.7
H–10	43°43.2′	78°54.0′	94	7.9	+.405	89.0	10.6	0.26	0.00	0.1	81.1	9.7	9.1	2.9	1.2	+0.8	+5.0
I–10	43°47.4′	78°54.2′	44	7.6	+.445	90.8	7.3	0.35	0.16	0.3	89.7	5.6	4.5	1.8	1.5	+1.4	+8.2
C–11	43°21.4′	78°48.0′	57	7.5	–.040	39.6	45.6	2.93	1.17	0.0	2.6	52.8	44.6	7.4	2.0	–0.1	–0.8
D–11	43°26.0′	78°48.0′	127	7.8	+.345	43.4	46.3	0.33	1.17	0.0	6.2	41.6	52.2	7.7	2.0	–0.5	+0.9
E–11	43°30.2′	78°48.0′	147	7.7	+.375	69.7	28.1	0.85	0.09	0.0	38.6	23.7	37.7	5.9	3.1	0.0	–1.5
F–11	43°34.3′	78°48.0′	147	8.1	+.360	27.8	65.1	3.47	0.14	0.0	2.3	22.1	75.6	8.9	1.7	–0.5	+1.3
G–11	43°39.0′	78°48.0′	120	7.8	+.350	42.0	53.8	1.42	0.21	0.0	7.3	8.1	84.7	9.1	2.3	–1.0	+3.2
H–11	43°43.2′	78°47.8′	97	8.3	+.395	40.0	59.0	0.23	0.08	4.2	27.7	7.0	61.2	7.2	3.7	–0.3	–1.1
I–11	43°47.4′	78°48.0′	57	8.1	+.425	93.2	5.9	0.25	0.06	0.0	91.8	3.0	5.2	2.4	1.0	+1.9	+17.4
J–11	43°51.9′	78°48.1′	6	7.4	+.235	37.9	13.4	5.27	4.78	0.0	57.2	26.7	16.1	4.3	2.4	+0.4	–0.5
C–12	43°21.4′	78°42.0′	27	7.5	+.025	74.7	16.0	0.70	0.98	0.0	99.9	0.0	0.0	2.6	0.7	–0.1	–0.8
D–12	43°26.0′	78°42.2′	127	7.7	+.415	65.8	32.7	0.57	0.06	0.0	99.4	0.2	0.0	2.5	0.7	0.0	–0.8
E–12	43°30.2′	78°42.2′	158	7.8	+.380	43.9	53.7	1.42	0.00	0.0	97.4	0.1	0.0	3.0	0.6	–0.5	+0.3
F–12	43°34.4′	78°42.0′	156	8.0	–.010	28.2	65.6	3.22	0.09	0.0	0.4	28.9	70.7	8.8	1.7	–0.3	+0.5
G–12	43°39.0′	78°42.0′	128	7.2	+.430	57.3	39.3	1.21	0.16	0.0	30.4	10.9	58.7	7.1	3.5	–0.2	–1.4
H–12	43°43.2′	78°42.1′	103	8.0	+.425	51.9	46.3	0.17	0.18	0.0	67.0	5.5	27.5	4.2	3.2	+0.5	–0.7
I–12	43°47.4′	78°42.1′	66	7.6	+.425	84.7	14.7	0.19	0.03	0.7	97.9	3.5	0.0	2.2	0.7	–0.4	+3.3
J–12	43°51.8′	78°41.8′	8	7.8	+.415	49.5	8.6	0.38	4.97								
D–13	43°26.0′	78°36.0′	123	7.7	+.065	37.6	57.7	1.60	0.24	0.1	9.5	43.1	47.3	6.9	2.4	–0.2	–0.9
E–13	43°30.2′	78°36.0′	166	7.6	+.335	44.0	50.5	1.65	0.32	1.2	27.6	25.3	45.9	6.7	3.1	–0.3	–1.1
F–13	43°34.4′	78°36.6′	160	7.6	+.050	27.3	68.2	2.55	0.01	0.0	1.0	25.5	73.5	8.5	2.1	–0.5	+0.4
G–13	43°38.8′	78°36.3′	130	7.8	+.015	39.8	56.9	1.85	0.01	0.5	11.1	48.2	40.2	7.0	2.2	–0.4	+0.9
H–13	43°43.2′	78°36.0′	98	7.9	+.360	42.4	54.3	0.34	0.33	0.1	45.3	6.3	48.3	5.9	3.8	0.0	–1.7
I–13	43°47.4′	78°35.5′	75	7.7	+.395	92.0	7.6	0.20	0.00	0.0	100.0	0.0	0.0	1.6	0.5	0.0	+0.6
J–13	43°52.0′	78°36.0′	25	7.6	+.385	94.4	2.8	0.19	0.31	0.7	99.0	0.1	0.0	1.8	0.6	–0.6	+5.0
D–14	43°26.0′	78°30.0′	116	7.8	–.005	34.3	58.3	2.80	0.31	0.0	3.4	37.0	59.7	8.2	2.1	–0.3	+0.3
E–14	43°30.2′	78°30.0′	173	7.7	+.055	32.8	63.7	1.97	0.01	0.3	2.5	31.4	65.8	8.5	1.9	–0.5	+2.0
F–14	43°34.2′	78°30.0′	172	8.1	+.150	26.4	64.2	3.54	0.40	0.0	0.9	28.9	70.2	8.7	1.7	–0.5	+3.3
G–14	43°39.0′	78°30.0′	141	8.1	+.060	28.7	64.8	3.64	0.03	0.0	1.4	19.9	78.9	9.0	1.7	–0.5	+1.8
H–14	43°43.2′	78°30.0′	107	7.3	+.420	57.2	39.5	0.81	0.23	0.0	55.1	7.1	37.8	5.1	3.4	+0.3	–1.5
I–14	43°47.4′	78°30.0′	76	7.4	+.425	92.1	6.7	0.14	0.12	2.7	94.5	4.7	0.0	1.8	1.0	–0.6	+2.3
J–14	43°51.8′	78°29.8′	30	7.5	+.385	93.5	6.2	0.17	0.00	0.5	97.5	4.3	0.0	1.8	0.8	–0.3	+1.9
D–15	43°26.0′	78°24.0′	87	8.0	–.010	36.3	50.8	2.64	1.00	0.0	2.8	46.6	50.6	7.7	1.9	–0.2	0.0
E–15	43°30.2′	78°24.0′	173	8.5	+.045	31.6	61.4	3.19	0.18	3.8	1.3	23.0	71.9	8.8	1.8	–0.6	+2.4
F–15	43°34.4′	78°23.8′	175	8.0	+.005	26.6	66.2	3.06	0.24	0.0	1.6	19.7	78.7	9.0	1.6	–0.6	+2.6
G–15	43°39.6′	78°23.8′	149	8.1	–.025	27.8	65.4	3.38	0.12	0.0	1.7	18.6	79.7	9.0	1.7	–0.6	+2.5
H–15	43°43.2′	78°24.0′	115	7.9	+.295	49.0	48.0	0.93	0.17	0.0	47.9	10.4	41.7	5.6	3.3	+0.2	–1.6

Station	Station Location					Percent^1											
	Lat. N.	Long. W.	Depth m	pH	EH Volts	Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size^2	Standard Devia-tion^2	Skew-ness^2	Kurt-osis^2
I–15	43°47.4′	78°24.0′	76	7.7	+.430	88.1	8.7	0.24	0.34	0.0	83.3	10.9	5.8	2.7	1.9	+0.9	+2.1
J–15	43°52.0′	78°24.0′	52	8.0	+.415	92.0	7.6	0.27	0.00	0.0	90.0	3.9	6.2	2.3	1.3	+1.4	+9.7
D–16	43°25.8′	78°17.8′	78	7.8	+.015	41.1	49.8	2.25	0.64	0.0	3.8	48.4	47.9	7.5	2.0	–0.2	–0.3
E–16	43°30.2′	78°18.4′	175	7.9	–.045	29.3	60.1	3.58	0.54	0.3	3.5	21.0	75.2	8.7	2.1	–0.8	+3.9
F–16	43°34.4′	78°18.0′	184	8.1	–.045	25.5	65.4	3.72	0.33	0.0	1.4	22.3	76.3	8.9	1.7	–0.5	+1.1
G–16	43°39.0′	78°18.0′	156	8.2	–.035	26.8	63.9	3.52	0.40	0.0	2.8	24.0	73.2	8.8	1.8	–0.5	+1.6
H–16	43°43.7′	78°18.0′	116	8.1	+.375	46.5	51.5	0.81	0.08	0.0	10.2	6.7	83.1	8.7	2.7	–0.9	+2.3
I–16	43°47.4′	78°18.0′	82	8.0	+.425	80.6	18.8	0.35	0.00	0.4	66.3	11.8	21.6	4.1	2.5	+0.6	+0.1
J–16	43°52.0′	78°18.0′	61	8.1	+.415	93.2	4.5	0.23	0.23	0.0	91.0	3.5	5.6	2.4	1.1	+1.8	+15.0
D–17	43°26.0′	78°12.0′	78	8.1	–.015	36.2	50.8	2.72	1.01	0.0	2.8	48.2	49.0	7.6	1.7	–0.2	–0.1
E–17	43°30.2′	78°11.8′	172	8.1	+.020	24.7	70.1	2.86	0.04	0.0	0.5	21.7	77.8	8.9	1.6	–0.4	+1.4
F–17	43°34.4′	78°12.0′	184	7.7	+.010	28.1	59.2	3.76	0.75	0.0	2.6	19.5	77.9	9.0	1.5	–0.4	+1.9
G–17	43°38.3′	78°11.8′	159	7.8	–.025	28.6	64.6	3.13	0.17	0.0	0.4	19.0	80.6	9.1	1.5	–0.3	+1.2
H–17	43°43.2′	78°12.0′	129	8.2	+.035	31.1	62.2	3.02	0.18	0.0	1.2	34.9	64.0	8.3	2.1	–0.3	–0.5
I–17	43°47.9′	78°12.0′	87	7.6	+.395	81.3	17.8	0.32	0.04	0.0	64.7	5.9	29.4	4.4	3.2	+0.5	–0.9
J–17	43°52.0′	78°12.0′	53	7.5	+.405	71.0	21.2	0.17	0.90	1.7	97.5	2.7	1.8	2.2	1.1	+0.8	+12.7
D–18	43°26.0′	78°05.8′	95	8.0	+.115	36.5	55.2	2.52	0.47	0.0	99.5	0.0	0.0	2.7	0.7	–0.1	–1.0
E–18	43°30.2′	78°06.0′	182	7.7	+.045	26.6	67.4	3.17	0.06	0.0	0.4	18.3	81.3	9.2	1.4	–0.3	+1.0
F–18	43°34.4′	78°05.5′	183	8.1	+.005	26.4	61.9	3.89	0.60	0.0	2.1	13.9	84.0	9.3	1.5	–0.6	+3.1
G–18	43°38.3′	78°06.1′	168	8.2	+.025	26.6	64.7	3.62	0.30	0.0	1.1	17.6	81.3	9.1	1.6	–0.6	+3.0
H–18	43°43.2′	78°06.0′	134	8.3	–.015	27.7	66.3	3.52	0.00	0.0	2.0	19.5	78.5	9.0	1.7	–0.6	+2.3
I–18	43°47.4′	78°06.0′	85	7.7	+.395	87.2	10.3	0.42	0.22	0.0	58.6	8.4	33.0	4.8	3.3	+0.3	–1.3
J–18	43°51.5′	78°06.0′	68	7.7	+.405	84.9	13.2	0.20	0.18	0.3	85.6	6.2	7.9	2.6	1.3	+1.1	+7.3
D–19	43°26.0′	77°79.8′	112	8.0	+.095	33.2	57.8	2.75	0.52	0.0	24.2	38.0	37.8	6.3	2.6	–0.4	–1.0
E–19	43°30.1′	78°29.8′	173	8.4	+.130	27.0	63.2	3.22	0.52	0.0	0.9	28.2	70.9	8.6	1.7	–0.5	+2.3
F–19	43°34.4′	78°00.2′	196	7.9	+.060	27.2	62.8	3.33	0.52	0.2	0.2	24.1	75.6	8.8	1.7	–0.3	+0.2
G–19	43°39.0′	78°00.0′	186	7.9	+.155	27.1	66.0	3.15	0.18	0.0	0.3	33.0	66.7	8.6	1.8	–0.2	–0.4
H–19	43°43.2′	78°00.0′	152	8.2	+.065	28.7	62.1	3.43	0.39	3.1	1.0	22.2	73.6	8.9	1.7	–0.5	+2.1
I–19	43°47.4′	78°00.0′	108	7.5	+.275	65.6	29.8	1.01	0.34	0.0	78.7	8.3	13.0	3.0	1.8	+1.0	+3.0
J–19	43°52.0′	78°00.0′	78	7.6	+.265	88.4	11.0	0.33	0.00	0.1	98.9	0.9	0.0	2.2	0.7	–0.1	+1.4
K–19	43°56.2′	78°00.0′	21	7.9	+.355	94.9	4.8	0.00	0.04	0.6	99.4	0.0	0.0	1.2	0.6	–0.2	+1.8
D–20	43°26.0′	77°54.0′	113	8.0	+.155	32.5	58.2	2.78	0.54	0.0	5.4	19.2	75.4	8.8	2.2	–0.7	+2.3
E–20	43°30.2′	77°54.0′	171	8.0	+.025	26.6	63.9	3.06	0.51	0.0	0.3	32.3	67.4	8.6	1.7	–0.1	–0.7
F–20	43°34.4′	77°54.0′	197	8.0	+.055	25.4	68.5	3.36	0.04	0.0	1.2	24.6	74.2	8.8	1.7	–0.5	+1.9
G–20	43°39.0′	77°54.0′	168	8.2	+.150	27.5	63.1	3.54	0.41	0.0	0.6	23.3	76.0	8.9	1.6	–0.4	+1.3
H–20	43°43.2′	77°54.0′	131	7.9	+.075	28.9	62.6	3.44	0.32	0.0	1.5	28.0	70.5	8.7	1.6	–0.4	+1.4
I–20	43°47.4′	77°54.0′	113	8.0	+.035	43.1	49.7	1.76	0.51	0.3	44.6	21.0	34.2	5.5	3.0	+0.2	–1.4
J–20	43°51.8′	77°54.5′	62	7.8	+.405	94.0	4.2	0.19	0.17	1.5	98.2	0.0	0.0	1.2	0.7	–0.3	+2.9
K–20	43°56.2′	77°54.5′	41	7.7	+.375	93.7	6.1	0.12	0.00	0.3	99.5	0.2	0.0	1.7	0.6	–0.2	+2.1
C–21	43°21.4′	77°48.1′	39	7.7	+.305	79.6	15.3	0.43	0.53	3.4	56.2	29.1	11.3	3.6	1.8	+0.4	+0.3
D–21	43°26.0′	77°48.0′	135	8.1	+.045	33.2	56.9	2.78	0.61	0.1	3.6	30.4	65.9	8.4	2.1	–0.5	+1.0
E–21	43°30.2′	77°48.0′	175	8.3	+.025	28.1	63.3	3.16	0.38	2.2	0.8	23.1	73.9	8.9	1.6	–0.5	+1.8
F–21	43°30.2′	77°48.0′	186	7.7	+.290	33.8	63.9	0.94	0.08	0.0	15.5	10.1	74.4	8.4	2.7	–0.5	–0.2
G–21	43°39.0′	77°48.0′	168	7.8	+.085	27.5	62.8	3.42	0.46	0.0	0.8	19.9	79.3	9.1	1.6	–0.4	+1.0

	Station Location					Percent[1]											
Station	Lat. N.	Long. W.	Depth m	pH	EH Volts	Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size[2]	Standard Devia-tion[2]	Skew-ness[2]	Kurt-osis[2]
H–21	43°43.2′	77°48.0′	132	7.9	+.015	28.8	62.8	3.31	0.33	0.0	0.4	26.0	73.6	8.9	1.5	–0.1	–0.5
I–21	43°47.4′	77°48.0′	98	7.8	+.365	83.0	15.1	0.65	0.10	0.0	69.6	8.4	22.0	3.8	2.5	+0.7	+0.6
J–21	43°52.0′	77°48.0′	68	7.6	+.325	92.3	6.0	0.27	0.15	0.0	92.0	6.1	1.9	2.4	1.4	+1.3	+7.5
K–21	43°56.2′	77°48.0′	38	7.7	+.335	89.6	10.0	0.25	0.00	0.1	96.2	2.3	1.5	2.3	0.9	+1.5	+16.9
C–22	43°21.2′	77°42.0′	59	7.8	+.045	64.5	23.8	1.17	1.17	0.0	73.1	22.1	4.8	3.7	1.5	+0.7	+2.1
D–22	43°26.0′	77°42.0′	139	8.0	+.055	63.6	33.6	0.93	0.15	0.0	84.0	8.3	7.6	3.3	1.8	+0.9	+2.8
E–22	43°30.2′	77°42.0′	176	7.7	+.305	37.2	58.9	1.38	0.18	0.0	97.7	0.4	0.0	3.0	0.6	–0.3	–0.2
F–22	43°34.4′	77°42.0′	197	7.6	+.300	32.6	63.3	2.33	0.01	0.0	98.6	0.0	0.0	3.1	0.7	–0.3	–0.6
G–22	43°39.0′	77°42.0′	165	7.7	–.055	30.3	64.2	3.13	0.02	0.0	2.3	47.4	50.4	7.8	1.6	–0.3	+1.4
H–22	43°42.2′	77°42.0′	128	7.6	+.010	30.0	61.6	2.99	0.39	0.0	3.7	70.8	25.5				
I–22	43°47.4′	77°42.0′	73	7.3	+.380	90.7	8.1	0.40	0.06	2.6	95.4	2.4	0.0	2.4	1.3	+1.0	+9.4
J–22	43°51.8′	77°42.0′	36	7.7	+.375	90.1	8.9	0.19	0.08	14.1	80.9	3.6	1.3	2.4	1.9	–0.2	+3.5
K–22	43°56.2′	77°42.6′	40	7.5	+.395	93.9	5.5	0.12	0.06	0.0	99.8	0.1	0.0	2.1	0.6	–0.2	+0.7
B–23	43°17.4′	77°36.0′	19	7.7	+.095	56.0	33.2	1.35	1.02	0.0	15.8	54.6	29.7	6.4	2.2	+0.1	–0.9
C–23	43°21.4′	77°36.0′	67	7.9	+.040	43.3	40.7	2.83	1.35	0.0	6.8	50.3	43.0	7.2	2.2	–0.1	–0.8
D–23	43°26.0′	77°36.0′	176	7.9	+.325	71.0	27.1	0.50	0.13	0.0	63.7	11.3	25.0	4.4	3.1	+0.5	–0.8
E–23	43°30.2′	77°36.0′	166	7.8	+.205	36.1	59.8	1.66	0.15	0.0	6.5	20.1	73.4	8.7	2.1	–0.6	+1.1
F–23	43°35.4′	77°36.0′	165	8.0	+.005	28.4	62.5	3.32	0.41	0.0	0.1	21.7	78.2	9.1	1.5	–0.3	+0.3
G–23	43°39.0′	77°36.0′	139	7.5	+.045	27.1	64.8	3.51	0.25	0.0	0.9	77.9	21.2	7.5	1.0	–0.6	+2.5
J–23	43°52.0′	77°36.0′	49	7.9	+.435	91.4	7.6	0.30	0.06	0.0	92.3	3.2	4.5	2.5	0.9	+1.4	+13.7
K–23	43°56.3′	77°36.0′	25	8.0	+.335	89.8	7.4	0.12	0.31	0.0	99.8	0.2	0.0	2.6	0.5	–0.3	+1.0
B–24	43°17.2′	77°29.9′	37	7.4	+.075	73.5	20.7	0.74	0.55	0.0	37.9	40.6	21.5	4.9	2.2	+0.5	+0.1
C–24	43°21.4′	77°30.0′	128	7.3	–.095	33.8	55.1	3.08	0.70	0.0	2.9	35.9	61.2	8.5	1.9	–0.4	+0.5
D–24	43°25.8′	77°29.6′	180	7.3	+.395	54.4	43.0	0.47	0.22	0.0	12.4	39.5	48.0	7.2	2.1	–0.8	+1.4
E–24	43°30.3′	77°30.3′	172	8.1	.000	28.5	63.4	2.80	0.40	0.0	0.6	18.9	80.5	9.1	1.5	–0.4	+1.5
F–24	43°34.6′	77°30.0′	165	7.5	+.035	26.9	64.4	3.58	0.31	0.0	0.1	7.2	92.7	9.9	1.3	–0.2	+2.1
G–24	43°39.0′	77°30.0′	118	7.4	+.020	29.7	59.7	3.51	0.55	0.3	1.6	24.8	73.4	8.8	1.7	–0.6	+2.8
H–24	43°43.2′	77°30.0′	84	7.5	+.555	79.1	18.8	.42	0.17	2.2	67.5	9.9	20.4	3.7	2.8	+0.5	–0.4
I–24	43°47.3′	77°30.0′	62	7.8	+.425	91.4	7.3	.34	0.09	0.3	88.9	4.1	6.8	2.4	1.3	+1.0	+8.5
J–24	43°52.0′	77°30.0′	36			37.3	62.2	.31	0.00	18.3	41.2	23.2	17.3	4.2	2.9	+0.2	–0.9
C–25	43°21.4′	77°24.0′	156	7.9	–.135	32.6	60.6	2.61	0.27	0.0	0.5	27.3	72.3	8.8	1.7	–0.3	+0.1
D–25	43°26.0′	77°24.0′	200	8.4	+.035	27.1	65.1	3.09	0.30	0.1	2.5	21.8	75.5	8.8	1.9	–0.7	+2.9
E–25	43°30.3′	77°24.9′	185	8.3	–.015	27.6	64.8	2.98	0.30	0.0	1.4	21.0	77.6	9.0	1.7	–0.6	+2.1
F–25	43°34.7′	77°23.9′	166	7.6	+.025	24.6	62.2	3.44	0.88	1.0	0.8	23.1	75.1	8.8	1.8	–0.8	+6.5
G–25	43°39.0′	77°24.0′	129	7.5	+.025	28.2	61.4	3.46	0.54	0.0	0.6	22.6	76.8	8.9	1.6	–0.4	+0.9
H–25	43°43.3′	77°24.0′	78	7.5	+.325	74.7	23.3	0.34	0.18	3.9	75.8	8.2	12.2	3.1	2.3	+0.7	+2.3
I–25	43°47.5′	77°24.0′	30	7.5	+.405	88.8	8.9	0.31	0.22	0.2	88.4	4.3	7.1	2.8	1.2	+1.1	+8.9
J–25	43°51.8′	77°23.8′	48	7.3	+.330	87.2	10.5	0.56	0.17	0.1	84.9	7.4	7.7	3.2	1.1	+1.2	+9.2
C–26	43°21.6′	77°18.0′	143	7.7	+.215	32.1	59.1	2.68	0.50	0.0	1.4	36.3	62.4	8.4	1.8	–0.2	–0.7
D–26	43°25.5′	77°18.0′	206	7.6	–.005	27.1	61.3	2.93	0.79	0.0	0.4	55.6	44.0	6.7	2.4	+0.2	–1.5
E–26	43°30.0′	77°18.0′	192	7.6	+.065	25.9	59.9	3.42	1.00	0.0	2.1	21.6	76.3	8.8	1.8	–0.6	+2.8
F–26	43°34.4′	77°18.2′	169	7.6	+.035	28.3	61.5	2.91	0.63	0.0	1.3	31.8	66.9	8.1	2.1	–0.2	–1.2
G–26	43°39.0′	77°18.0′	124	7.6	–.085	28.0	65.6	3.10	0.13								
H–26	43°43.3′	77°18.0′	91	7.5	–.020	30.7	58.4	2.93	0.71	2.4	4.1	24.2	69.3	8.6	2.1	–0.6	+1.4

Station	Station Location		Depth m	pH	EH Volts	Percent[1]											
	Lat. N.	Long. W.				Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size[2]	Standard Devia-tion[2]	Skew-ness[2]	Kurt-osis[2]
J–26	43°51.8′	77°18.1′	29	7.1	+.385	87.2	8.2	0.21	0.52	1.3	98.7	0.0	0.0	2.0	0.8	–0.5	+1.5
C–27	43°21.4′	77°12.0′	112	7.5	–.070	35.5	54.0	2.93	0.65	0.0	2.8	67.3	29.9	6.3	2.1	+0.3	–0.9
D–27	43°22.1′	77°12.1′	220	7.4	+.105	28.6	61.6	3.04	0.55	0.0	1.7	17.1	81.1	9.2	1.6	–0.7	+3.7
E–27	43°30.0′	77°12.1′	206	7.9	+.050	30.1	63.2	2.64	0.26	0.0	0.3	45.9	53.8	8.1	1.9	0.0	–0.8
F–27	43°34.7′	77°12.0′	160	7.5	+.005	29.8	59.9	3.09	0.61	0.0	0.3	66.7	33.0				
G–27	43°39.0′	77°11.9′	124	7.5	+.315	58.4	40.3	0.19	0.12	2.0	40.4	16.4	41.2	5.7	3.3	+0.1	–1.5
H–27	43°43.3′	77°12.0′	97	7.5	+.005	33.6	60.0	3.38	0.44	0.0	1.6	17.2	81.2	9.2	1.1	+0.7	–4.5
I–27	43°47.8′	77°11.8′	50	7.7	+.400	76.1	14.6	0.88	0.94	0.0	88.9	7.5	3.6	3.3	1.4	+1.1	+5.1
C–28	43°21.4′	77°06.0′	103	7.8	–.025	38.4	52.1	2.40	0.65	0.0	2.7	46.4	51.0	7.8	1.7	–0.1	–1.1
D–28	43°26.0′	77°06.1′	220	7.5	+.035	28.2	63.1	2.97	0.43	0.0	0.3	21.7	78.0	8.9	1.6	–0.4	+0.9
E–28	43°30.1′	77°05.0′	234	8.0	+.020	29.5	66.9	1.87	0.04	0.0	0.5	38.4	61.2	8.3	1.4	–0.1	–0.6
F–28	43°34.8′	77°05.8′	171	8.1	+.040	28.4	62.3	2.95	0.51	0.0	0.9	36.1	63.0	8.4	1.6	–0.1	+0.1
G–28	43°39.0′	77°05.4′	128	7.3	+.015	29.5	65.3	3.04	0.00	0.0	1.3	33.5	65.2	8.5	1.7	–0.2	+0.7
H–28	43°43.2′	77°05.6′	86	7.6	+.005	30.8	57.2	3.74	0.67	0.0	1.2	34.0	64.9	8.5	1.8	–0.3	+0.6
I–28	43°43.3′	77°06.0′	48	7.4	+.335	82.6	15.2	.32	0.20	0.9	85.5	7.5	6.1	2.6	1.3	+0.7	+5.1
C–29	43°21.5′	77°00.0′	77	7.6	+.305	55.3	40.0	1.42	0.28	0.0	36.2	36.5	27.3	5.5	2.8	+0.2	–1.1
D–29	43°26.1′	77°00.0′	190	7.6	+.065	27.6	63.2	3.29	0.43	0.4	1.5	21.6	76.6	8.9	1.8	–0.5	+1.8
E–29	43°30.4′	77°00.0′	219	8.1	+.055	28.3	59.1	3.15	0.87	0.0	1.5	21.3	77.2	8.9	1.7	–0.5	+1.3
F–29	43°34.8′	77°00.0′	192	7.7	+.035	29.2	60.5	3.00	0.57	0.0	3.0	25.5	71.5	8.8	1.6	–0.3	+0.8
G–29	43°39.0′	77°00.0′	152	7.7	+.330	30.9	62.4	3.02	0.19	0.0	3.0	27.9	69.2	8.7	1.8	–0.4	+1.1
H–29	43°43.3′	77°00.1′	96	7.4	+.025	30.5	57.2	3.39	0.77	0.0	4.3	36.5	59.3	8.4	1.8	–0.2	+0.1
I–29	43°47.3′	76°59.9′	63	7.4	+.335	81.2	17.8	0.55	0.00	0.0	59.5	10.0	30.5	4.9	3.1	+0.4	–1.0
K–29	43°56.3′	77°00.0′	8	7.7	+.065	83.1	8.5	0.33	0.94	0.2	98.1	2.0	0.0	2.8	0.5	–0.6	+4.8
C–30	43°21.7′	76°53.9′	68	7.4	+.305	78.2	21.2	0.36	0.00	0.2	48.2	33.2	18.5	4.5	2.3	+0.4	–0.2
D–30	43°25.8′	76°53.5′	190	7.6	+.065	29.1	62.2	3.00	0.42	0.0	1.5	20.0	78.5	8.9	1.9	–0.6	+1.4
E–30	43°30.4′	76°53.9′	222	8.1	+.045	26.7	63.1	3.52	0.50	0.0	2.8	22.2	75.0	9.0	1.7	–0.5	+1.2
F–30	43°34.8′	76°48.0′	189	8.1	+.050	28.3	62.7	3.07	0.45	0.0	0.3	27.0	72.7	8.8	1.6	–0.2	0.0
G–30	43°38.9′	76°54.0′	168	7.3	–.040	32.3	58.8	2.54	0.55	0.0	0.4	36.7	62.9	8.5	1.7	–0.1	–0.6
H–30	43°43.3′	76°54.0′	105	7.6	+.045	33.7	55.8	3.51	0.54	0.0	0.3	23.8	75.9	8.7	1.6	–0.3	–0.1
I–30	43°47.8′	76°53.8′	74	7.5	+.075	35.1	52.2	3.22	0.86	0.0	0.8	47.0	52.2	7.9	1.6	–0.1	–0.9
J–30	43°52.0′	76°54.2′	37	7.4	+.175	78.4	16.2	.57	0.53	1.4	76.4	12.7	9.5	2.9	1.7	+0.4	+2.4
L–30	44°00.8′	76°54.0′	30	7.2	+.085	48.8	45.3	2.83	0.13	0.0	3.9	35.7	60.5	8.1	2.4	–0.3	–0.7
C–31	43°21.5′	76°48.1′	36	7.4	+.455	90.6	9.1	.20	0.00	0.1	99.8	0.1	0.0	1.0	0.6	+0.1	+0.8
D–31	43°26.2′	76°48.1′	114	7.5	+.305	55.5	38.7	1.30	0.43	0.0	22.1	34.9	42.9	6.6	2.8	–0.1	–1.1
E–31	43°30.6′	76°47.8′	208	7.9	+.085	27.2	66.1	2.83	0.23	0.0	0.6	23.8	75.5	8.9	1.6	–0.3	+0.8
F–31	43°34.5′	76°48.0′	209	7.7	+.045	29.5	60.1	3.26	0.58	0.0	0.5	28.3	71.2	8.8	1.7	–0.3	+0.5
G–31	43°38.9′	76°47.4′	165	7.8	+.065	27.4	58.7	3.58	0.94	0.3	0.5	33.9	65.4	8.6	1.7	–0.3	+1.2
H–31	43°43.3′	76°48.0′	113	7.7	+.060	33.6	55.7	3.32	0.60	0.0	0.2	41.9	57.9	8.3	1.8	–0.1	–0.7
I–31	43°47.6′	76°48.0′	73	7.5	+.040	36.6	53.7	3.13	0.52	0.0	0.5	45.6	53.9	8.1	1.8	0.0	–0.8
J–31	43°52.0′	76°48.0′	42	8.0	+.315	82.8	13.4	0.49	0.36	3.0	76.4	9.3	11.3	2.8	1.8	+0.4	+2.1
K–31	43°56.4′	76°48.2′	14	7.3	+.115	79.6	6.9	0.20	1.59	0.0	80.7	9.2	10.1	3.5	1.0	+1.4	+10.1
L–31	44°00.6′	76°48.1′	30	7.3	+.175	76.7	21.1	0.83	0.09	4.1	53.6	24.4	18.0	4.2	2.6	+0.4	–0.6
M–31	44°05.2′	76°48.1′	24	7.6	+.095	64.5	29.5	1.94	0.32	0.0	41.3	23.0	36.7	6.0	2.9	+0.2	–1.5
N–31	44°05.3′	76°48.1′	35	7.8	+.275	58.9	18.0	0.48	2.68	0.0	14.4	59.5	26.1	6.3	2.0	–0.2	–0.5

	Station Location					Percent[1]											
Station	Lat. N.	Long. W.	Depth m	pH	EH Volts	Quartz	Clay Minerals	Organic Carbon	In-organic Carbon	Gravel	Sand	Silt	Clay	Mean phi size[2]	Standard Deviation[2]	Skewness[2]	Kurtosis[2]
D–32	43°26.3′	76°42.2′	75	7.5	+.360	81.3	16.7	0.33	0.19	0.0	66.9	22.2	10.9	3.5	1.8	+0.5	+0.8
E–32	43°30.3′	76°42.1′	180	7.8	+.035	30.8	60.4	3.01	0.44	0.0	1.0	27.6	71.4	8.8	1.7	–0.4	+0.9
F–32	43°34.8′	76°41.8′	212	7.5	+.030	31.3	62.0	2.55	0.28	0.0	0.8	30.9	68.4	8.7	1.7	–0.3	+0.4
G–32	43°39.2′	76°42.0′	157	7.5	+.065	31.4	58.1	3.08	0.63	0.0	0.6	36.6	62.8	8.4	1.7	–0.1	–0.1
H–32	43°43.6′	76°42.0′	105	7.8	+.030	36.5	50.5	3.46	0.86	0.0	0.6	41.0	58.5	8.3	1.7	–0.1	–0.6
I–32	43°47.5′	76°41.6′	67	7.5	+.055	38.8	52.2	2.73	0.52	0.0	1.1	45.5	53.4	7.9	1.7	–0.2	+0.4
K–32	43°56.1′	76°42.1′	37	7.3	+.065	46.5	27.2	2.54	2.65	0.0	20.7	58.2	21.1	5.5	1.9	+0.5	0.0
L–32	44°00.6′	76°42.2′	34	7.8	+.285	68.1	30.9	0.46	0.03	0.2	38.1	10.9	50.9	6.4	3.6	–0.1	–1.6
E–33	43°34.2′	76°30.4′	118	7.1	+.355	62.1	30.5	1.44	0.59	0.1	21.0	47.6	31.3	6.1	2.5	+0.1	–0.9
F–33	43°34.4′	76°36.5′	183	7.8	+.055	29.2	64.4	2.87	0.18	0.0	2.9	33.3	63.8	8.4	1.8	–0.4	+1.0
G–33	43°39.2′	76°35.8′	148	6.5	+.030	33.2	55.1	3.59	0.66	0.0	0.9	41.8	57.3	8.2	1.9	–0.2	–0.3
H–33	43°43.5′	76°36.2′	96	7.8	+.030	36.3	51.3	3.24	0.83	0.0	0.5	45.2	54.3	8.1	1.8	0.0	–0.7
I–33	43°47.5′	76°36.2′	59	7.4	+.050	39.0	52.2	2.69	0.51	0.3	1.8	55.5	42.3	7.5	1.9	–0.2	+0.7
K–33	43°56.3′	76°36.0′	27	7.5	+.065	37.8	39.1	3.32	2.10	0.0	9.4	59.1	31.5	6.5	2.1	+0.2	–1.0
L–33	44°00.6′	76°36.0′	36	7.6	+.060	46.4	40.2	3.19	0.95	0.0	1.3	64.4	34.3	7.1	1.7	+0.1	–0.7
M–33	44°04.9′	76°36.2′	34	7.6	+.175	82.1	16.8	0.63	0.00	0.0	48.4	7.4	44.2	6.2	3.4	+0.1	–1.7
N–33	44°09.1′	76°35.9′	20	7.3	+.085	83.8	15.5	0.40	0.00	0.2	55.6	9.3	35.0	4.8	3.5	+0.2	–1.3
F–34	43°34.6′	76°30.2′	132	7.5	+.025	34.5	51.9	3.34	0.94	0.0	1.3	41.3	57.4	8.2	1.9	–0.2	+0.1
G–34	43°38.5′	76°28.9′	132	7.8	+.055	35.1	56.6	2.73	0.44	0.0	0.8	41.4	57.8	8.3	1.8	–0.1	–0.5
H–34	43°44.2′	76°30.3′	83	7.5	+.055	40.4	49.2	2.60	0.72	0.1	0.9	53.1	46.0	7.6	1.8	0.0	–0.7
I–34	43°47.8′	76°30.1′	51	7.6	+.005	53.4	38.0	2.33	0.56	0.0	2.8	68.0	29.2	6.5	1.6	+0.2	–0.6
K–34	43°56.3′	76°29.7′	40	7.5	+.095	73.5	20.9	1.28	0.41	1.0	60.5	19.8	18.8	4.0	2.5	+0.5	0.0
L–34	44°00.4′	76°29.9′	30	7.2	+.085	51.9	40.8	2.75	0.32	0.0	8.6	39.7	51.7	7.3	2.3	–0.2	–0.8
F–35	43°34.6′	76°24.0′	68	7.6	+.035	50.0	39.3	2.34	0.80	0.0	4.5	57.3	38.2	7.1	2.0	0.0	–0.8
G–35	43°38.9′	76°24.0′	93	7.7	+.035	38.6	52.6	2.68	0.51	0.0	1.8	47.6	50.7	7.8	1.8	–0.1	–0.7
H–35	43°42.9′	76°23.9′	56	7.6	+.085	35.6	34.6	2.40	0.68	0.0	1.6	65.5	32.8	6.8	1.9	+0.3	–0.9
I–35	43°47.8′	76°23.9′	46	7.7	+.045	69.8	19.3	1.31	1.05	0.0	19.2	60.1	20.7	5.5	1.8	+0.5	0.0
L–35	44°00.5′	76°24.0′	22	7.5	+.105	88.9	10.7	0.24	0.00	0.6	63.2	14.0	22.2	4.0	2.6	+0.5	0.0
M–35	44°04.9′	76°23.9′	22	7.4	+.105	36.2	52.3	4.19	0.52	0.1	16.1	33.6	50.2	7.2	2.5	–0.2	–0.9
F–36	43°35.1′	76°17.9′	37			67.7	20.1	1.90	1.08								
G–36	43°39.0′	76°18.1′	45	7.9	+.050	79.6	16.7	0.56	0.33	0.0	51.1	33.0	15.8	4.6	1.8	+0.8	+1.7
H–36	43°43.6′	76°18.1′	38	7.7	+.115	76.8	15.9	1.00	0.67	0.0	34.3	50.4	15.3	4.8	1.7	+0.9	+2.4
J–36	43°51.9′	76°18.1′	43	7.1	+.065	34.4	50.0	4.96	0.86	0.0	13.1	54.4	32.5	6.4	1.8	–0.3	–0.7
K–36	43°55.3′	76°18.0′	23	7.4	+.045	72.2	23.2	0.78	0.39	10.8	50.7	17.0	21.6	4.2	2.7	+0.3	–0.1
F–37	43°34.4′	76°12.1′	5	7.9	+.050	85.8	10.8	0.09	0.39	0.1	99.6	0.5	0.0	2.9	0.3	–0.5	+10.7
G–37	43°39.1′	76°12.0′	5	8.0	+.235	91.8	5.8	0.02	0.29	0.0	99.7	0.6	0.0	3.1	0.3	–0.3	+0.3
K–37	43°56.3′	76°12.0′	23	7.2	+.050	30.3	56.8	4.88	0.55	0.0	2.9	53.6	43.5	7.3	1.8	0.0	–1.4
L–37	44°00.6′	76°12.0′	14		+.080	30.7	59.7	4.86	0.15	0.3	0.4	15.1	84.2	9.3	1.6	–0.6	+2.5

1. Contents given as percentages of dry weight of sediment.
2. Defined by Coakley, J.P. and Beal, G.S. (in press). SEDAN – a computer program for sediment particle analysis. Inland Waters Branch Tech. Rept. Series, Dept. of Environment, Ottawa.