Sedimentology of the Sixteen Mile Creek Lagoon, Niagara Peninsula, Ontario, Canada

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

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September, 1983

ABSTRACT

The effects of relative water level changes in Lake Ontario were detected in the physical, chemical and biological characteristics of the sediments of the Fifteen, Sixteen and Twenty Mile Creek lagoonal complexes. Regional environmental changes have occurred resulting in the following sequence of sediments in the three lagoons and marsh. From the base up they are; (1) Till,(2) Pink Clay, (3) Bottom Sand, (4) Gyttja, (5) Orange Sandy Silt, (6) Brown Clay and (7) Gray Clay. The till was only encountered in the marsh and channel; however, it is presumed to occur throughout the entire area. The presence of diatoms and sponge spicules, the vertical and longitudinal uniformity of the sediment and the stratigraphic position of the Pink Clay indicate that it has a glacial or post-glacial lacustrine origin. Overlying the Pink Clay or Till is a clayey, silty sand to gravel. The downstream fining and unsorted nature of this material indicate that it has a fluvial/deltaic origin. Water levels began rising in the lagoon 3,250 years ago resulting in the deposition of the Gyttja, a brown, organic-rich silty clay probably deposited in a shallow, stagnant environment as shown by the presence of pyrite in the organic material and relatively high proportions of benthic diatoms and grass pollen. Increase in the rate of deposition of the Gyttja on Twenty Mile Creek and a decrease in the same unit on Sixteen Mile Creek is possibly the result of a capture of the Sixteen Mile Creek by the Twenty Mile Creek. The rise in lake level responsible for the onset and transgression of this

unit may have been produced by isostatic rebound; however, the deposition also corresponds closely to a drop in the level of Lake Huron and increased flow through the lower lakes. The Orange Sandy Silt , present only in the marsh, appears to be a buried soil horizon as shown by oxidized roots, and may be the upland equivalant to the Gyttja.

Additional deepening resulted in the deposition of Brown Clay, a unit which only occurs at the lakeward end of the three lagoons. The decrease in grass pollen and the relatively high proportion of pelagic diatoms are evidence for this. The deepening may be the result of isostatic rebound; however, the onset of its deposition at 1640 years B.P. is synchronous in the three lagoons and corresponds to the end of the subAtlantic climatic episode. The effects of the climatic change in southern Ontario is uncertain. Average deposition rates of the Brown Clay are similar to those in the upper Gyttja on Sixteen Mile Creek; however, Twenty Mile Creek shows lower rates of the Brown Clay than those in the upper Gyttja. The Gray Clay covers the present bottom of the three lagoons and also occurs in the marsh. It is interlaminated with sand in the channels. Increases in the rates of deposition, high concentrations of Ca and Zn, an Ambrosia rise, and an increase in bioturbation possibly due to the activities of the carp, indicate that this unit is a recent deposit resulting from the activities of man.

ACKNOWLEDGEMENTS

The author would like to extend gratitude and appreciation to Dr. R. Dalrymple and Dr. J.J. Flint for their assistance and support towards the completion of this thesis. Both provided advise and technical assistance throughout the research. Financial support was provided to Dr. Dalrymple by the Ontario Research Grant No. 78. Appreciation is also expressed to the following: Dr. J. Terasmae for his assistance and the arrangement for the determination of the 14 C dates by Howard Melville, Dr J.Smol, Queens University who prepared and identified the diatom assemblages, Dr. S.R. Brown, Queens University who suggested the carp as the probable bioturbator of the Gray Clay and Dr. M. Dickman for his determination of the beetle larvae.

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INTRODUCTION

Purpose of Study

The water levels of the lower Great Lakes have been rising throughout the past 12,400 years as a result of differential isostatic readjustment (Hough, 1963; Lewis, 1969) and changes in post-glacial drainage patterns (Hough, 1963, 1969; Lewis, 1969; Prest, 1970). The present rates of uplift for the Ontario Basin are discussed by Price (1954) (Figure 1). Uplift is greater to the northeast therefore streams flowing into Lakes Erie and Ontario have become flooded at their mouths forming small lagoons. These lagoons, with their aesthetic and wildlife qualities, act as harbours for boating and fishing. Despite their socioeconomic value, studies of historical or modern day processes and sedimentation patterns have not been conducted with the exception of the one recently completed by Warwick (1980). These natural settling basins offer an underutilized opportunity to study the sediments, interpret their origin and thereby determine man's influence on the environment.

More specifically, this study has the following main objectives: (1) to conduct a detailed analysis of biological, physical and geochemical characteristics of the sediments from the lagoons on the Sixteen Mile Creek; (2) to examine adjacent lagoons to determine regional stratigraphic correlations; and (3) to examine the historical development of the lagoons including the influences of isostatic readjustment,

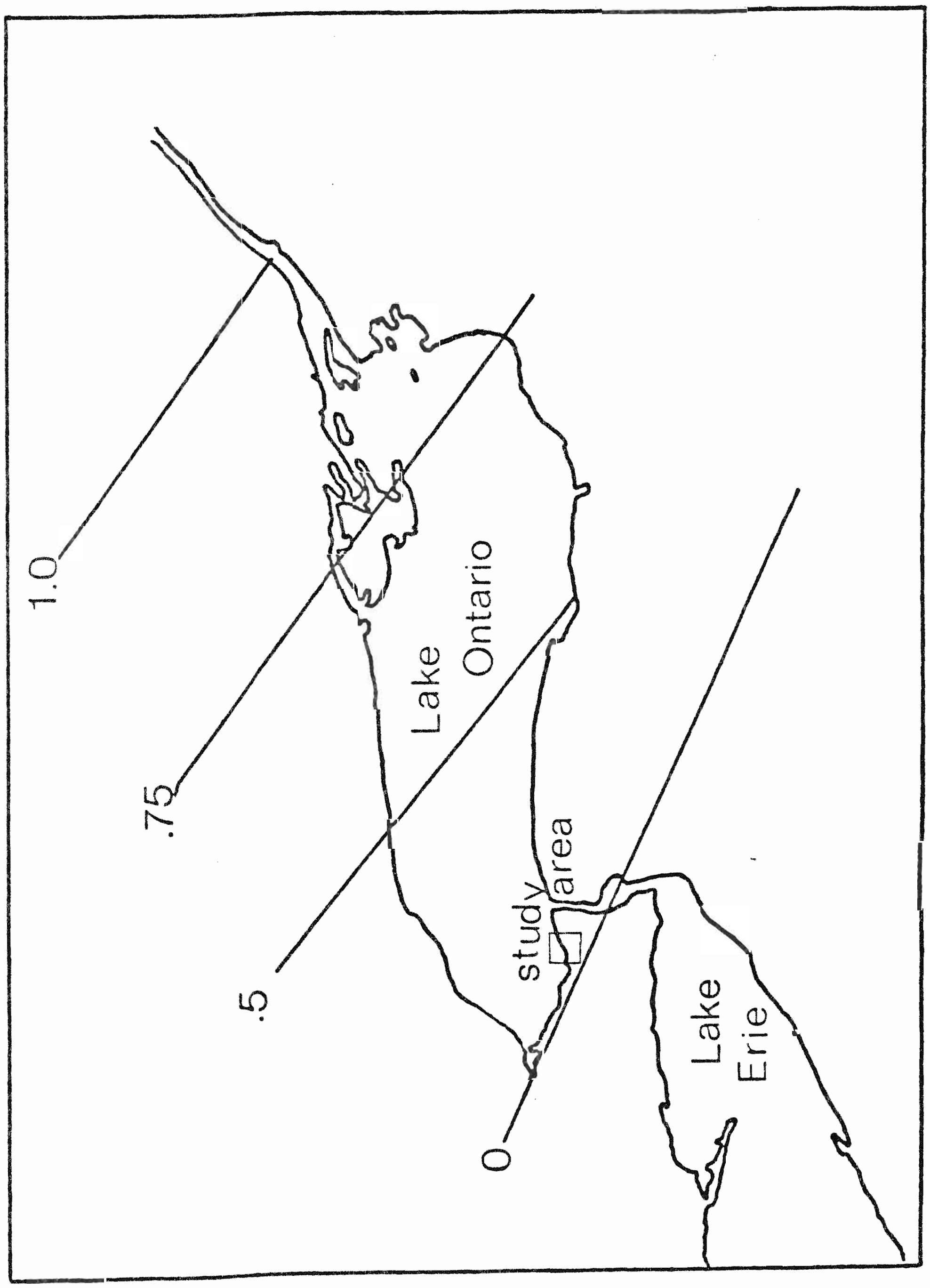


Figure 1. Rates of isostatic rebound of the Ontario Basin in in m/century. (Price, 1954)

climatic variations and lake-level fluctuations. It has previously been determined by Flint (1980, personal communication) that the drainage basin of Sixteen Mile Creek was reduced by one half when it was captured by the Twenty Mile Creek (1500±2200 years ago). The affect of this capture on the sediment in the lagoon will also be examined.

The location of the study area is in the Niagara Penninsula (Figure 2). The Sixteen Mile Creek lagoon, studied in the greatest detail, is located 5 km west of St. Catharines. This open water environment meanders in a north to south direction for approximately 2.5 km. Depths range up to 2.5 m. A shallow subaqueous delta occurs at the head and a barrier bar separates the lagoon from Lake Ontario at the mouth. The channel of Sixteen Mile Creek is surrounded by a low lying marsh subject to frequent flooding. The adjacent Fifteen and Twenty Mile Creek Lagoons were also investigated at a reconnaissance level to determine if a regional correlation could be made and to assess how representative the data from the Sixteen Mile Creek are.

Geology

Morphology

The study area is located in the Niagara Penninsula within the Lake Ontario drainage basin. The Fifteen, Sixteen, and Twenty Mile Creeks have their headwaters above the Niagara

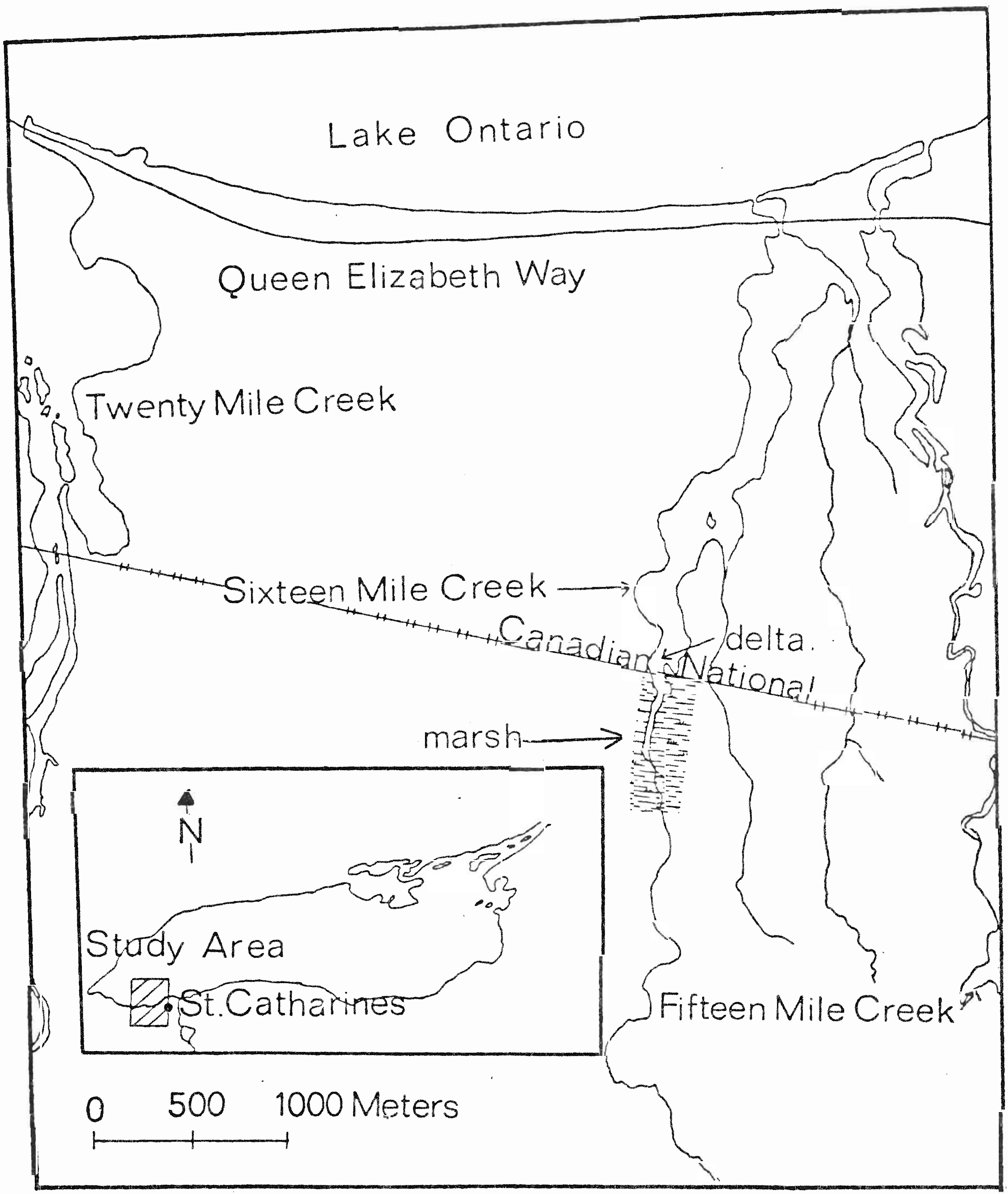


Figure 2. Location map of the study area.

Escarpment and flow over the escarpment through incised gorges. The escarpment reaches a maximum height of 150 feet in this vicinity. Below the escarpment, they flow over the Lake Iroquois Plain (Chapman and Putman, 1966) to Lake Ontario. The incised valley walls below the escarpment indicate a time of degradation. Fifteen, Sixteen and Twenty Mile Creeks have similar physical parameters (Table 1) although the size of their basins differ significantly.

Bedrock Geology

The drainage basins of Fifteen, Sixteen, and Twenty Mile Creeks are situated on Silurian limestone, dolostone, sandstone and shale which dip gently to the south. The stratigraphy of the Niagara Escarpment is described in Table 2 (American Falls International Board, 1974). Below the escarpment, bedrock beneath the lagoons is Upper Ordovician red shale from the Queenston Formation but generally it does not outcrop. The regional geology of the Niagara Pennunsula as mapped by Bolton and Liberty (1975) is shown in Figure 3.

Surficial Geology

The surficial sediments of the study area are composed of Late Wisconsin sediments (Feenstra, 1972). A lacustrine silty sand overlies a clay till in the vicinity of the lagoons. The Halton Till, deposited during the Port Huron Advance about 13,200 years ago, has been described as brown silty clay till.

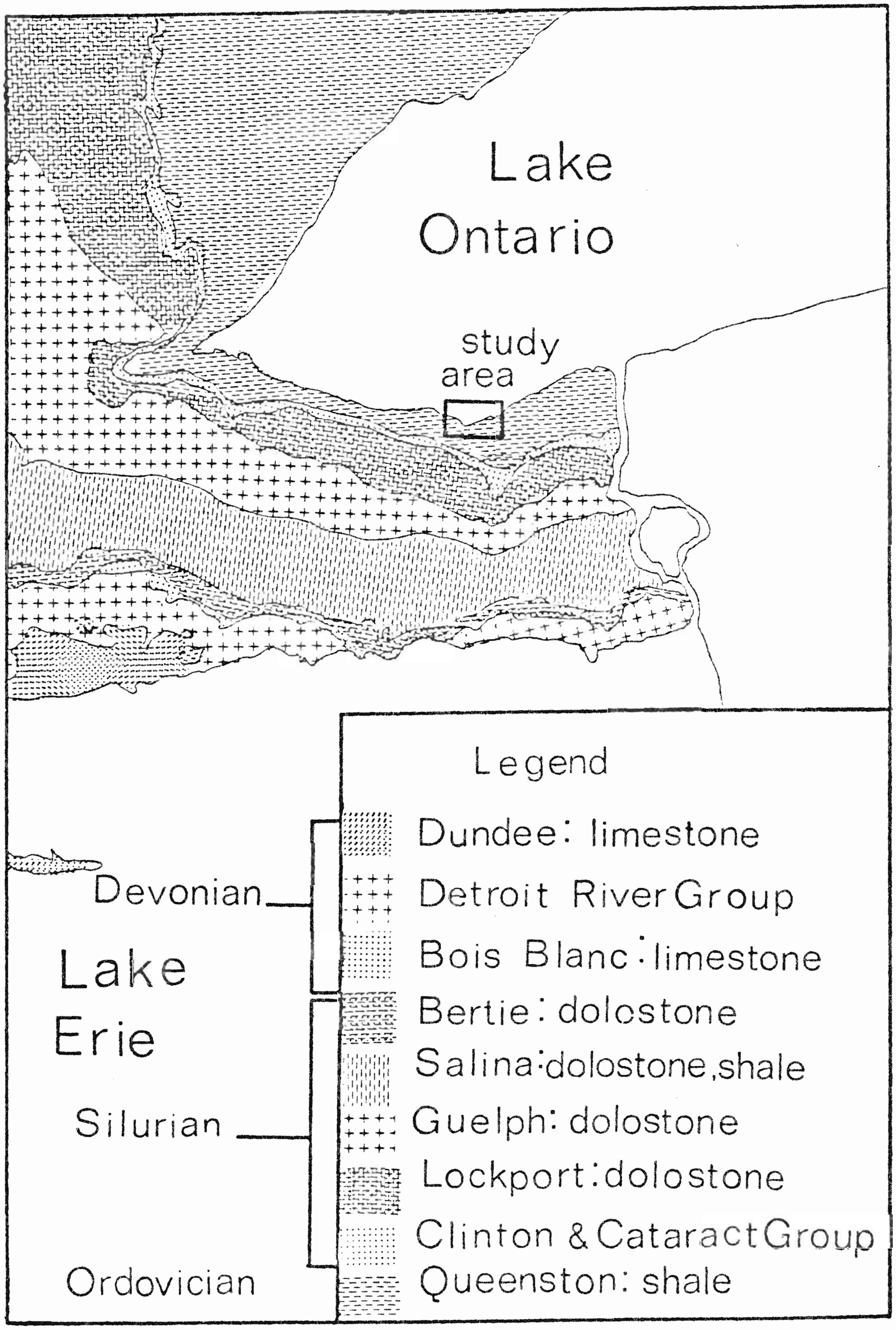


Figure 3. Regional bedrock geology map showing location of the study area (from Capman and Putnam, 1954).

Table 1. PHYSICAL PARAMETERS OF FIFTEEN, SIXTEEN AND TWENTY MILE CREEK LAGOONS.

Lagoon	Basin Area km^2	N/S Length km	E/W Width km	Area km^2	Max Depth m
Fifteen	69	1.o	0.25	0.2	1.5
Sixteen	40	2.6	0.20	0.5	2.5
Twenty	301	2.3	1.00	1.0	3.0

Table 2. GENERAL STRATIGRAPHY OF THE NIAGARA ESCARPMENT (from American Falls International Board, 1974, Table C2).

System	Formation	Thickness	Lithology
Silurian			
	Lockport	110'	Dolomite, dark brown, light brown and blue gray. Limestone, blue, gray.
	Clinton Group		
	Amabel	14'	Dolomite, dark brown or black, bituminous.
	Decew	10'	Dolomite, gray.
	Rochester	55-66'	Shale, dark gray with inter- bedded limestone
	Irondequoit	16-20'	Dolomite, gray. Limestone.
	Reynales	2-3'	Dolomite, gray and blue gray.
	Neagha	6'	Shale, gray.
	Medina Group		
	Thorold	9'	Sandstone, greenish. Shale.
	Grimsby	51'	Sandstone, red. Shale, red.
	Power Glen	34'	Shale, gray and green. Limestone.
	Whirlpool	18'	Dolomite, grayish brown, argillaceous.

Ordovician			
	Queenston	100+	Shale, red.

The Lake Iroquois sediments were deposited approximately 11,800 years ago (Prest, 1970) and consist of stratified silty fine sand (Feenstra, 1972). The detailed stratigraphy of the Lake Ontario bluffs near the Sixteen Mile Creek has been described by van der Laan (1979) and from the base up is as follows (Table 3): (1) gray clayey silt till; (2) gray clay; (3) glaciolacustrine gray silt and clay; (4) sand and gravel wedge; and (5) glaciolacustrine brown sand, silt and clay. The till has been identified as Halton Till. Overlying this unit are sediments of glaciolacustrine origin. The sand and gravel wedge is a glaciofluvial deposit.

Table 3. LOCAL BLUFF STRATIGRAPHY NEAR SIXTEEN MILE CREEK LAGOON (from van der Laan, 1979).

Unit	Description	Thickness (m)
Glaciolacustrine Brown Sand, Silt	Brown clayey silty till, massive with some stratification, no pebbles, cobbles or bolders.	2.25
Glaciolacustrine Gray Silt and Clay	Interbedded gray silt and clay, stratified, thickness of lamina range between 5-15 cm.	0.75
Sand and Gravel Wedge	Sequence of a loose, well stratified, coarse brown-gray sand and gravel that interfinger with gray lacustrine sediments. Gravel is coated with black precipitate which may appear rusty.	
Glaciolacustrine Gray Silt and Clay	Same as gray silt and clay above.	2.0
Gray Clay	Gray clay, massive, soft no pebbles samd or silt.	0.5
Gray Clayey Silt Till	Gray clayey silt till, contains red shale, limestone, Precambrian pebbles, cobbles and bolders. Lenses of yellowish-brown silt.	?

History of the Ontario Basin

The post-glacial history of the Ontario Basin (Table 4) began during the Carey Substage approximately 14,000 years ago (Prest, 1970). At that time, what is now known as the Ontario Basin was filled with ice. Evidence for this ice stand is the Valley Heads Moraine located at the southern end of several of the Finger Lakes in New York State (Hough, 1953) and the Vinemont Moraine situated just above the Niagara Escarpment in the Niagara Penninsula (Hough, 1969). During the Carey Port Huron Interval (13,000-13,600 years ago) the ice retreated from the southern edge of the Ontario Basin. The other Great Lakes continued to drain west through an outlet at Lake Arkona which encompassed portions of Lakes Huron and Michigan. Ice filled the Ontario Basin again during the Port Huron Readvance which produced the Halton Till (13,200 years ago, Hough, 1953; Prest, 1970).

Following this readvance, the ice retreat of the Two Creeks Interval produced a low water stage in three of the four lower lakes (Erie, Ontario and Huron). The extent and time of this retreat is not specifically known; however, it did occur before the Valders Substage which is dated at 12,900 B.P. (Prest, 1970; Hough, 1953). During the Valders Substage, the entire Ontario Basin was again blocked by ice preventing drainage to the east. The water continued to discharge westward to the Erie Basin. As the ice began to retreat following the maximum extent of the Valders advance, an outlet to the east occurred near Syracuse, New York, producing the earliest Lake Iroquois Stage (ancestral Lake Ontario) in the southwestern

Table 4. GLACIAL HISTORY OF ONTARIO BASIN (from Prest, 1969)

Event	Age (Years B.P.)	Deposit
Carey Substage	14,000	Valley Heads Moraine
Carey-Port Huron Interval	13,000-13,600	
Port Huron Advance	13,200	Halton Till
Two Creeks Interval	13,000	
Valders Substage	12,900	
Early Lake Iroquois	12,500	Shore deposits and deep water clays.
Ellenburg Phase	12,500-12,400	
Sidney Phase		
Admirality Phase of Early Lake Ontario	11,800	

portion of the basin at an elevation of about 102.0 m (Prest, 1970). The main stage of Lake Iroquois occurred as a result of additional ice retreat with the outlet discharging through Rome and down the Mohawk and Hudson Valleys to the Atlantic. This main Lake Iroquois Stage has been referred to as the Ellenburg Phase (12,500-12,400 years B.P. Prest, 1970; Figure 4). As the glacial recession continued water levels dropped 22.86 m below the Ellenburg Phase, forming Glacial Lake Frontenac (12,200 years B.P.; Prest, 1970). Further retreat of the ice caused an additional drop of 38 m in lake level. This short stand has been called the Sydney Phase (Mirynech, 1962). The continued recession of ice created the junction of Glacial Lake Vermont, located in northeastern New York State, with early Lake Ontario. The water discharged southward along a previously established route to the Hudson River. Water levels dropped an additional 12-15 m (Mirynech, 1962) when the ice retreated further up the St. Lawrence Valley. Remnant shorelines from this phase suggest a temporary halt in falling lake levels.

The lake drained through an outlet close to sea level as the ice sheet continued its recession. This is known as the Admirality Phase. Marine waters combined with the upper St. Lawrence Valley water forming the Champlain Sea west of the Ontario Basin (11,800 years ago; Prest, 1970). Marine sediments overlying till are evidence for this (Hough, 1953). As uplift continued to rise faster than sea level, this low water stage of the Ontario Basin ended when isostatic rebound brought the northeastern rim above sea level.

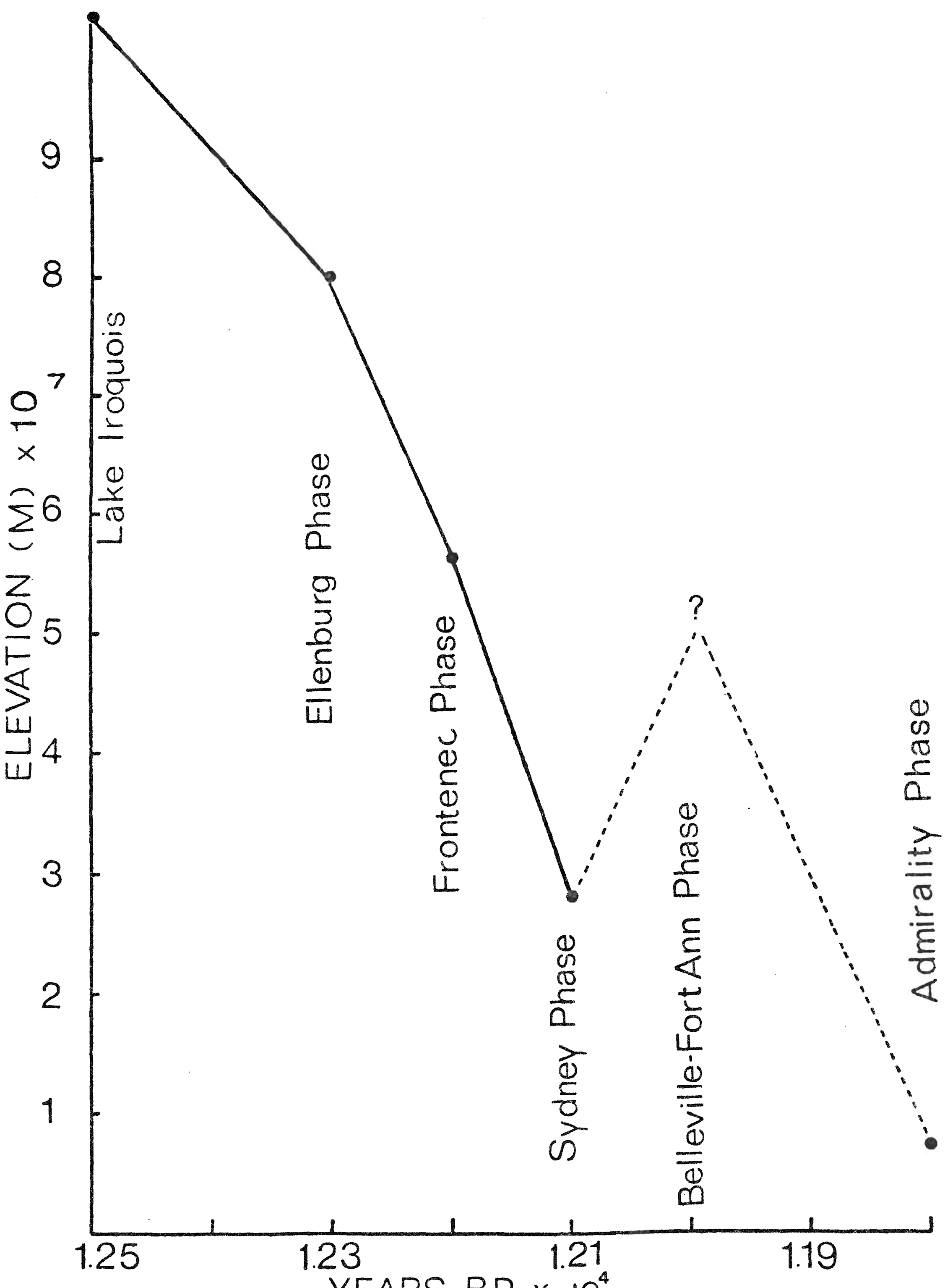


Figure 4. Pre- historic lake levels of the Ontario Basin. Elevations shown in meters. (from Prest, 1970).

Between 11,800 years ago and 9,000 years ago, the level of Lake Ontario continued to rise. Drainage of the upper Great Lakes went into the northernmost portions of Lake Ontario through the North Bay and Kirkfield Outlets, bipassing Lake Erie from 11,200 years ago until the Nippising Great Lakes. The affect of the upper Great Lakes drainage on Lakes Erie and Ontario are discussed by Hough (1953), Lewis (1969) and Prest (1970). Lewis (1969) found that the level of Lake Erie was inversely affected by changes in Lake Huron. It is presumed that similar changes in Lake Ontario water levels have occurred.

The Nippising Great Lakes Phase is characterized by three outlets: North Bay, Chicago and St.Clair (Prest, 1969, Figure 5). Their changes through time have affected the level of the lower lakes. As isostatic rebound progressed, the North Bay Outlet was the first to be abandoned and the Nippising Great Lakes were reduced to a two outlet system, the Chicago and the St. Clair (5,500 Years ago; Prest, 1970; Hough, 1963). All the drainage was transferred to the south causing the water level of Lake Nippising to rise to 184 m (Lewis, 1969). This has been called the Nippising Great Lakes Phase II by Prest (1970). It has been presumed that the same approximate elevations were maintained from 4700 years until 3800 years B.P. (Lewis, 1969). Drainage continued through the two southern outlets; however, because the Chicago Outlet was in bedrock and the St. Clair Outlet was in till, faster downcutting occurred in the St. Clair Outlet (Hough, 1963). This rapid erosion of the St. Clair Outlet caused the eventual abandonment of the

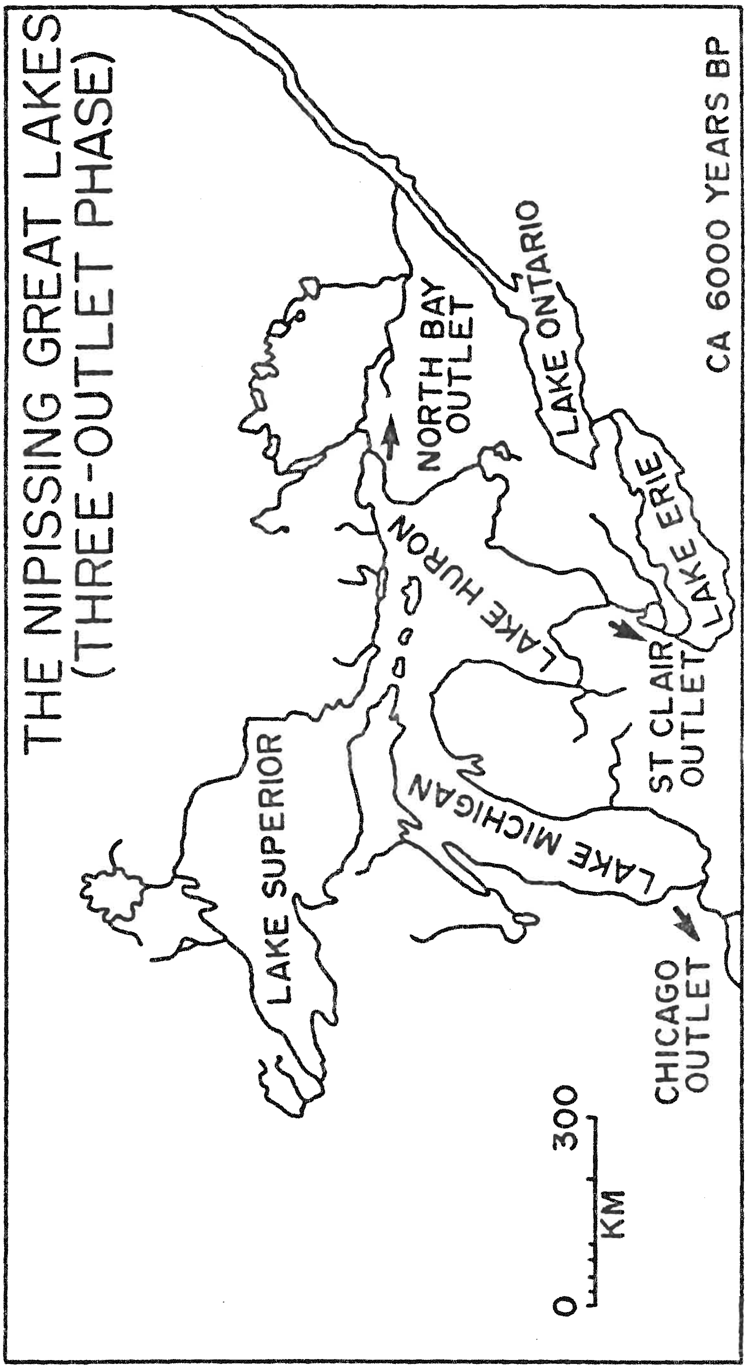


Figure 5. The Nippising Great Lakes drainage
from (Lewis, 1969).

Chicago Outlet and also produced a low lake level which is known as the Algoma Phase (Lewis, 1969; Hough, 1963). During the Algoma Phase, continuous downcutting of the St. Clair Outlet resulted in an additional lowering of Lake Huron. The end of the Algoma Phase is characterized by a steady drop in elevation until the present Lake Huron elevation of 176.8 m was reached at about 2500 years B.P. (Lewis, 1969). The ultimate effect of these changes in drainage during the Nippising Great Lakes was to allow more water to flow through Lakes Erie and Ontario by reducing the number of outlets from three to one.

Previous studies suggest that after the Admirality Phase, Lake Ontario rose exponentially to its present level (Prest, 1970; Hough, 1953). It is apparent from Lewis' (1969) findings that some of these rises may have been sudden rather than gradual (Figure 6).

The water levels of the lower Great Lakes are affected by differential isostatic rebound as well as changes in upper Great Lakes drainage (Lewis, 1969; Prest, 1970; Hough, 1963, 1963). Studies by Spencer (1894), Moore (1922, 1948), Price (1954), Terasmae and Hughes (1960), Macdonald (1968), Farrand (1969), and Harrison (1970) have examined isostatic rebound in the Great Lakes region. Spencer (1894) found that beach ridges of Lake Iroquois were not horizontal but occurred at an elevation of 1030 feet or 313.9 m at the northeastern end and at 110.3 m along the southern margin of the lake. Historic water levels have also been used to determine crustal movement surrounding Lake Ontario (Clark et al.,1970). They found that rates of uplift were higher on the northeastern shore of Lake

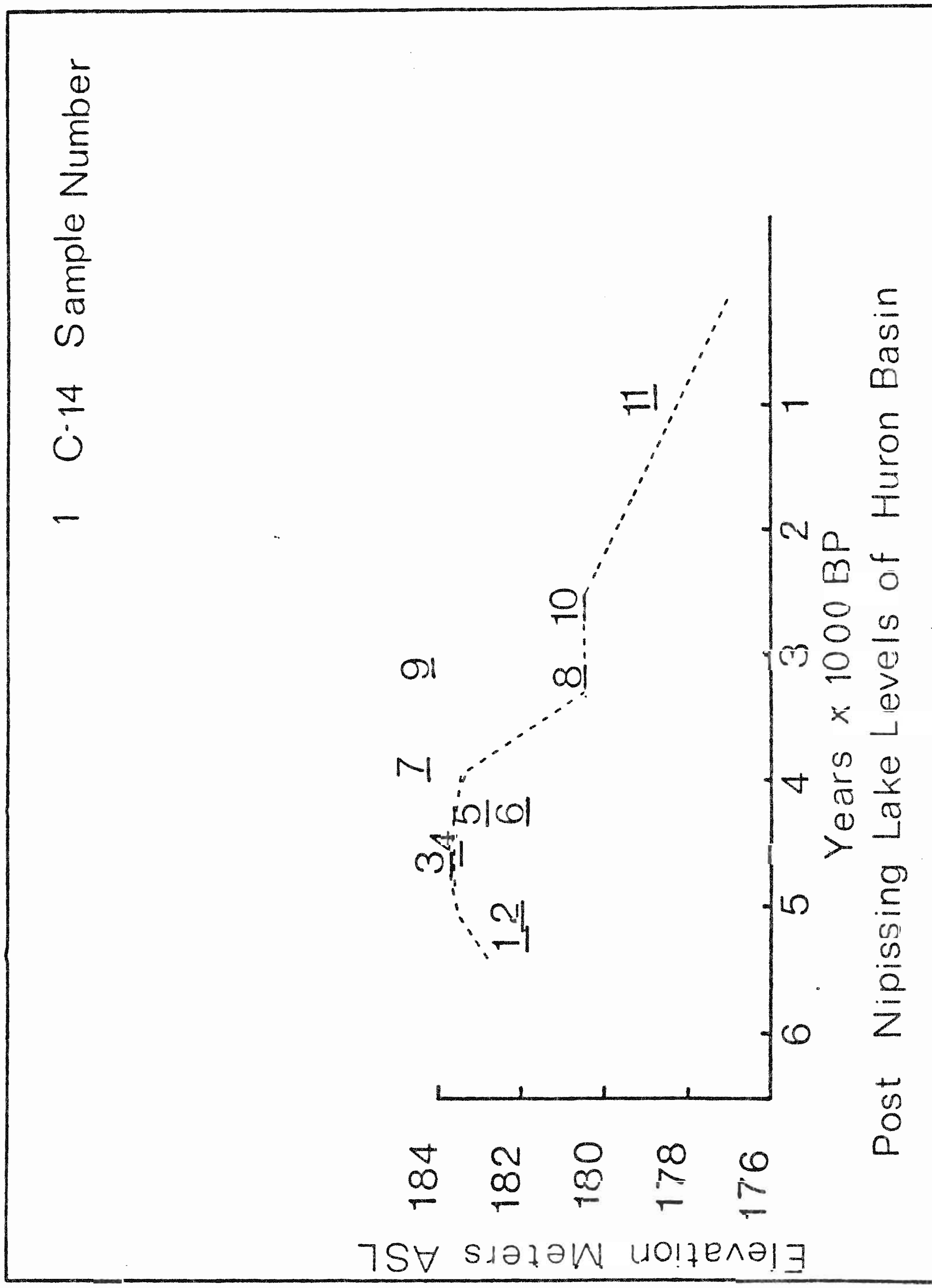


Figure 6. Lake levels of the Huron Basin (Lewis, 1969).

Ontario. The common axis line, which runs between locations of similar uplift, has an orientation of 0° N 50° W (Price, 1954; Figure 1). In a study in the Lake Superior Basin, Saarnisto (1975) found that rates of uplift were very rapid immediately following deglaciation, then decrease exponentially.

The long term variations in lake level have been discussed above as primarily a result of changes in drainage patterns produced by differential isostatic rebound. Similar variations in lake levels may also be produced by climatic changes. Figure 7 shows that historically, Lake Ontario levels may vary by as much as 1.2 m in one year as a result of variations in precipitation, evaporation, climate, river input and temperature. Figure 7, for example, shows periods during the early 1950's and 1970's when the level of the Great Lakes was higher than average. Evidence for longer term climatic changes have been documented in studies by Denton (1973), Wendland (1974), and Bryson et al.(1970). It has been suggested that post-glacial time can be subdivided into several climatic episodes. The Blytt-Sernander nomenclature, shown by Goodwin (1966), was adopted for this study. Table 5 summarizes the episodes and corresponding dates. Each climatic episode is characterized by a complex set of precipitation and or evaporation changes. Details of these conditions have been studied for local areas in the midwestern United States, but different responses may have occurred at the same times elsewhere. Additional studies are required to determine the affect these changes had on southern Ontario.

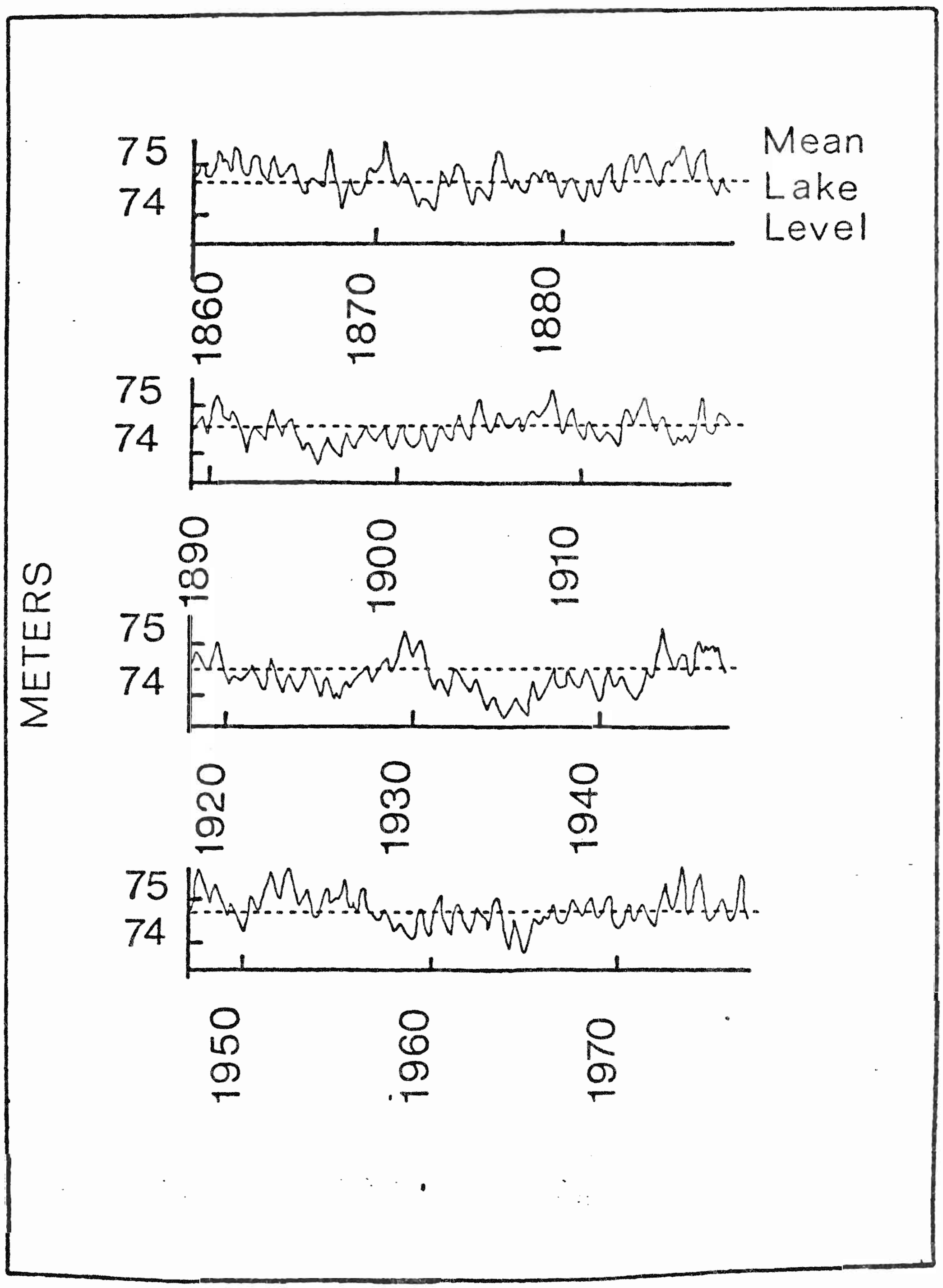


Figure 7. History of Ontario Water Levels (National Ocean SUrvey United States Great Lakes Hydrograph of mean levels of Great Lakes).

Table 5. CLIMATIC EPISODES (from Bryson, Baerreis and Wendland, 1970)

Episode	Date B.P.	Subepisode Division Dates	
Late Glacial			
	10,500		
Pre-Boreal			
	9650		
Boreal		9140	
	8450		
Atlantic		7730	5980
	4680		
Sub-Boreal		3970	3480
	2890		
Sub-Atlantic			
	1690		
		760	

GENERAL FIELD AND LABORATORY METHODS

Field work began in the fall of 1979 and extended to the fall of 1981. Sediment cores were obtained to collect stratigraphic, geochemical, palynological and textural data. Hydraulic data and suspended sediment were also obtained.

Hydraulics and Suspended Sediment

A bridge was constructed across the channel of the Sixteen Mile Creek 500 m upstream from the railroad bridge to measure discharge and collect suspended sediment samples of water entering the lagoon. Water discharge was obtained with a cup-type current-meter. Samples of suspended sediment were collected with a Standard United States Depth-Integrating, hand-held, suspended sediment sampler (U.S.DH-48) with a .32 cm intake nozzle. The suspended sediment and discharge measurements were obtained at 10 cm intervals across the bridge. The equal transit method was used for collecting the suspended sediment samples. This method, described by Guy and Norman (1970), consists of raising and lowering the sampler at a uniform rate so that the intake of suspended sediment is proportional to the flow velocity.

Measurements of discharge and suspended sediment were obtained during most significant rainstorms and/or snowmelts during January through April of 1980. Channel width, depth and velocity were also measured. From these values, hydraulic radius, wetted perimeter and cross sectional area were calculated. In addition, plastic sewer pipes were buried in holes adjacent to the channel at two stations 150 m apart to obtain water surface slope each time the discharge was measured.

Eighteen samples of suspended sediment were collected. The samples were stored in a controlled environment at $4^{o}C$. One drop of 10% HCl was added to prevent algal growth. The filtration method was used for the determination of suspended sediment concentration. Gooch Crucibles with .45 millipore membrane filter paper connected to an aspirator and vacuum system was utilized. Details of this method are discussed by Guy (1969).

Sedimentology, Palynology and Geochemistry

Core Locations and Sampling

Coring was conducted in the lagoon, delta, channel and marsh of the Sixteen Mile Creek during the two year period of 1980 and 1981. In the lagoon, thirteen shallow cores were taken with a 3 m plastic tube. The diameter of the cores was about 7.5 cm. Sixteen deep cores were later collected with a modified Livingston Piston Corer. The diameter of the cores was about 6 cm. Metal casing was used to provide convenient reentrance to the hole. Core sediments ranged from 10 cm to 1 m. In the channel, four shallow cores were obtained with a 3 m plastic tube and two deep cores with a vibracorer. The aluminum pipes used with the vibracorer were 10.2 cm in diameter and cores with lengths ranging from 2.0-2.3 m were obtained. The vibracorer was also used to obtain 4 deep cores from the marsh area. Core locations are shown in Figure 8.

Reconnaissance coring was conducted in the Fifteen Mile Creek Lagoon in the winter of 1981. Three short cores were obtained through the ice with the plastic tube corer. Core locations are shown on Figure 9A. Figure 9B also shows the location of two long cores and one short core obtained on Twenty Mile Creek (Jordan Harbour). The purpose for collecting these data on Fifteen and Twenty Mile Creeks was to determine if a regional correlation existed between the three lagoons.

Cores were wrapped and returned to the laboratory for X-ray photography, grain size, geochemistry and pollen analyses and determination of organic content, moisture content and compaction. All samples were stored in a controlled environment room at 4 ^{o}C. until the analyses were conducted. Samples were also obtained at suitable locations in the cores for 14 C dating. The laboratory methods for the analyses conducted in this study are summarized below.

X-Ray Photography

Six representative cores were photographed with a Faxitron X-ray unit to reveal structures in the sediment not visible

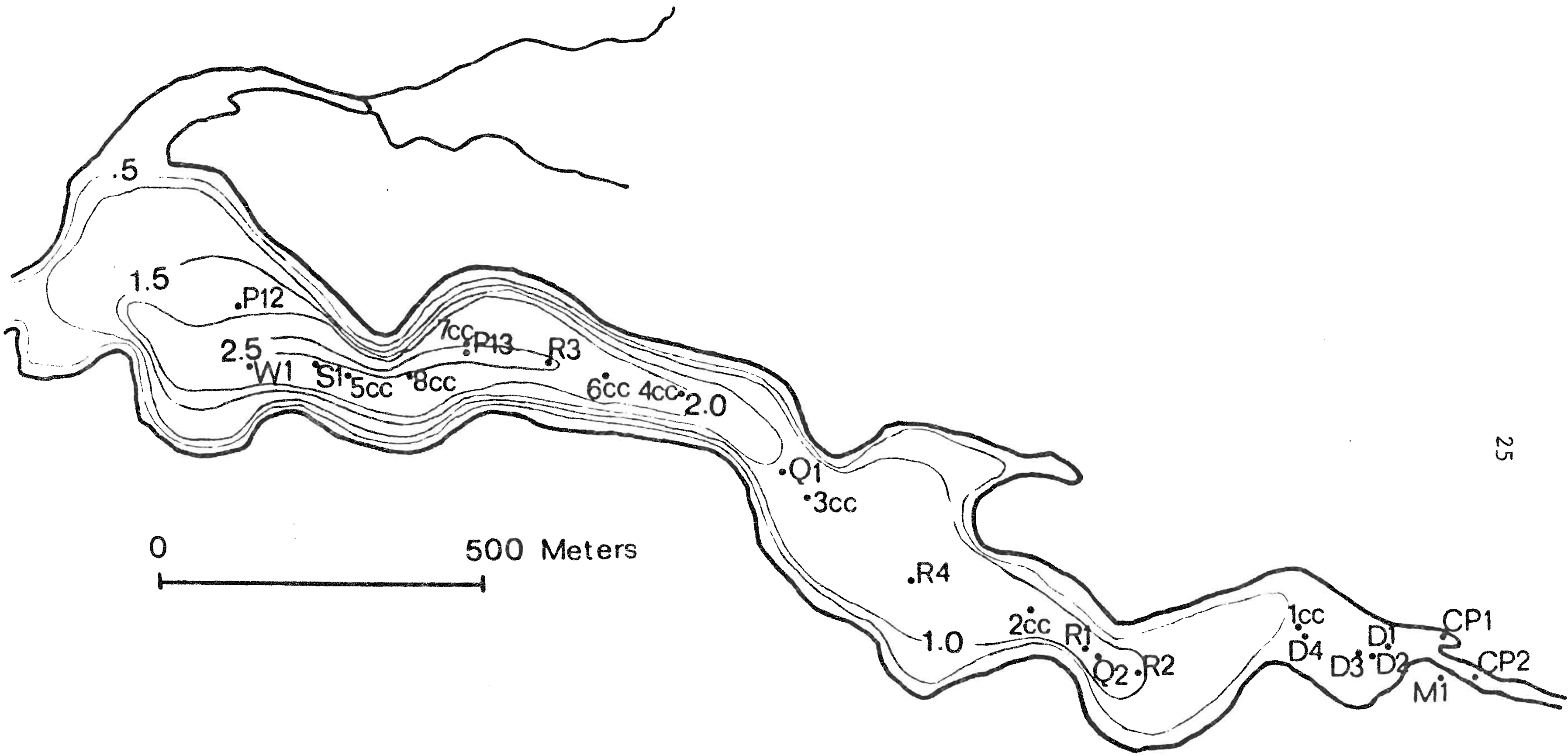


Figure 8. Bathymetric map of the lagoon at Sixteen Mile Creek. Depths are shown in 0.5 m contour intervals. Core locations are also identified.

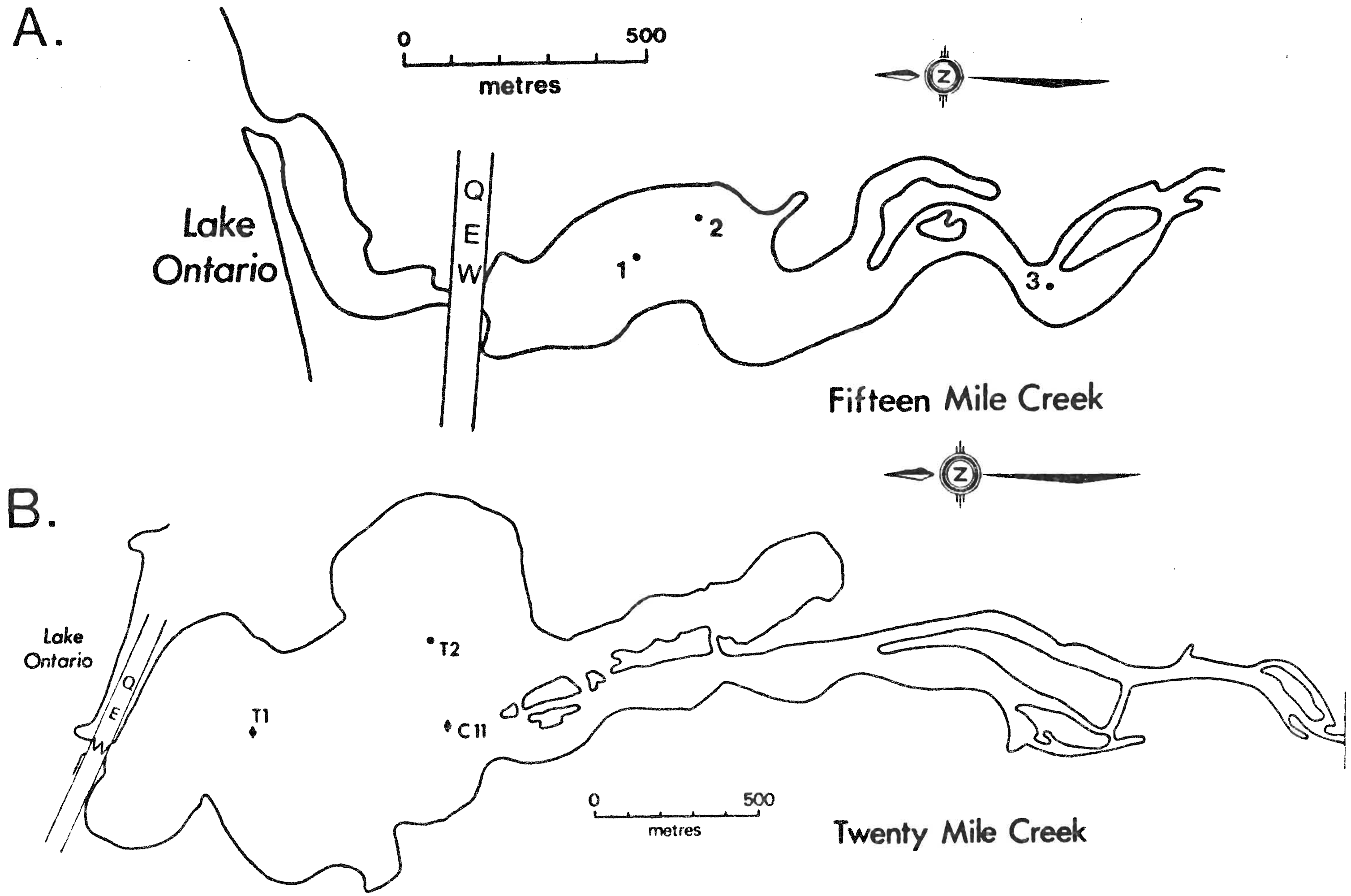


Figure 9A. Core locations of samples from the lagoon on Fifteen Mile Creek.
Figure 9B. Core locations of samples from the lagoon on Twenty Mile Creek.
(from Otto and Dalrymple, 1983)

otherwise in extruded cores. This was performed by placing 1 m segments of whole cores directly on the film and X-raying them for the proper exposure times. The upper, less consolidated sediment was exposed for 2 minutes at 90 KV. The denser sediment and those cores wrapped in aluminum foil were exposed for 2.5 minutes at 110 KV.

Grain Size Analysis

The grain size analyses were performed to determine the temporal and spatial changes of sediment types and paleoenvironments in the three lagoons. Prior to the size determination, organic matter was removed by adding hydrogen peroxide according to procedures described by Carver (1971). Samples were then wet sieved with a 230 mesh screen (4 phi, 0.0625 mm), retaining the sand fraction for dry sieving. The standard pipette technique (Carver, 1971; Folk, 1974) was used for the fraction less than 4 phi (0.0625 mm). The silt and clay fractions were placed in 1000 ml sedimentation cylinders with calgon solution to prevent flocculation. The withdrawal times and depths used were arranged to obtain 1/2 phi intervals and are summarized in Carver (1971). The sand fractions were sieved with Fisher-Wheeler seive shakers at 1/2 phi unit intervals using a shaking time of 30 minutes. A statistical analysis was conducted on the samples from Sixteen Mile Creek to determine mean size and to measure sorting and kurtosis. The method used is discussed in Folk (1974). Results are listed in Appendix I. Six samples from 3 cores from the lagoon on Fifteen Mile Creek, 13 samples (core C11) from Jordan Harbour and 104 samples (12 cores- M1, M2, M4, M6, R2, D3, Q1, P12, D1, R4, R1, and R3) from the lagoon and marsh on Sixteen Mile Creek were analyzed.

Organic Content Analysis

The organic content was used as one criterion in differentiating stratigraphic units. Thirteen samples from 3 short cores were obtained from the lagoon on Fifteen Mile Creek, 81 samples from 2 cores from Jordan Harbour, and 226 samples from 12 cores from the lagoon and marsh on Sixteen Mile Creek. The samples were first oven dried for 24 hours at 100 ^{0}C to remove the water, then cooled and weighed. Because organic material is combustible at 550 ^{o}C, the samples were heated to that temperature for 1 hour then cooled and reweighed to determine the percent of organic material in the total sediment sample relative to the weight before combustion. Details of this method are discussed in Carver (1971). Carbonates were not removed prior to measuring organic content

Moisture Content Analysis

The moisture content was obtained for 2 cores (41 samples) from the Sixteen Mile Creek Lagoon and 1 core (47 samples) from Jordan Harbour. The procedure consisted of taking equal volumes of sediment with a 2.5 cm diameter by 7.6 cm length plastic cylinder inserted through the center of the core. The samples were then dried at 100 ^{o}C for 24 hours. The water content (weight loss) was then calculated as a percent of the dry weight. One of the purposes of this analysis was to determine the amount of compaction in each unit in order to calculate accurate sedimentation rates. A complete list of the results from the moisture content and organic content analyses are summarized in Appendix I.

Geochemical Analysis

A chemical analysis of the sediment using x-ray fluoresence was conducted to determine the temporal and spatial changes in the lagoon of Sixteen Mile Creek.

An analysis of the major elements (SiO_2, Al_2O_3, MgO, Fe_2O_3, CaO, Na_2O, K_2O, TiO_2, MnO, P_2O_5) was conducted to determine the composition of the sediment and to aid in the selection of standards for the trace element analyses. Six samples, three from the mouth and three from the head were used for the major element analysis. Concentrations were calculated using an existing computer program (H2/MA).

Twelve cores (136 samples) were analyzed for five trace elements (Cu, Ni, Zn, P, and Ca) from Sixteen Mile Creek. One core (25 samples) from Twenty Mile Creek was also analyzed for the same trace elements for comparison with the results from Sixteen Mile Creek. The standards were chosen to represent the composition of the till and local bedrock of the area. These include shale, dolostone, limestone, granite, rhyolite and syenite. Calibration curves for the 5 trace elements were constructed by plotting the number of counts against concentration (Figures 10-13). Actual concentrations of Cu, Zn, and Ni were calculated using an existing computer program (H2/TR). Concentrations of P and Ca were determined using the calibration curves. The results are presented in Appendices V and VI.

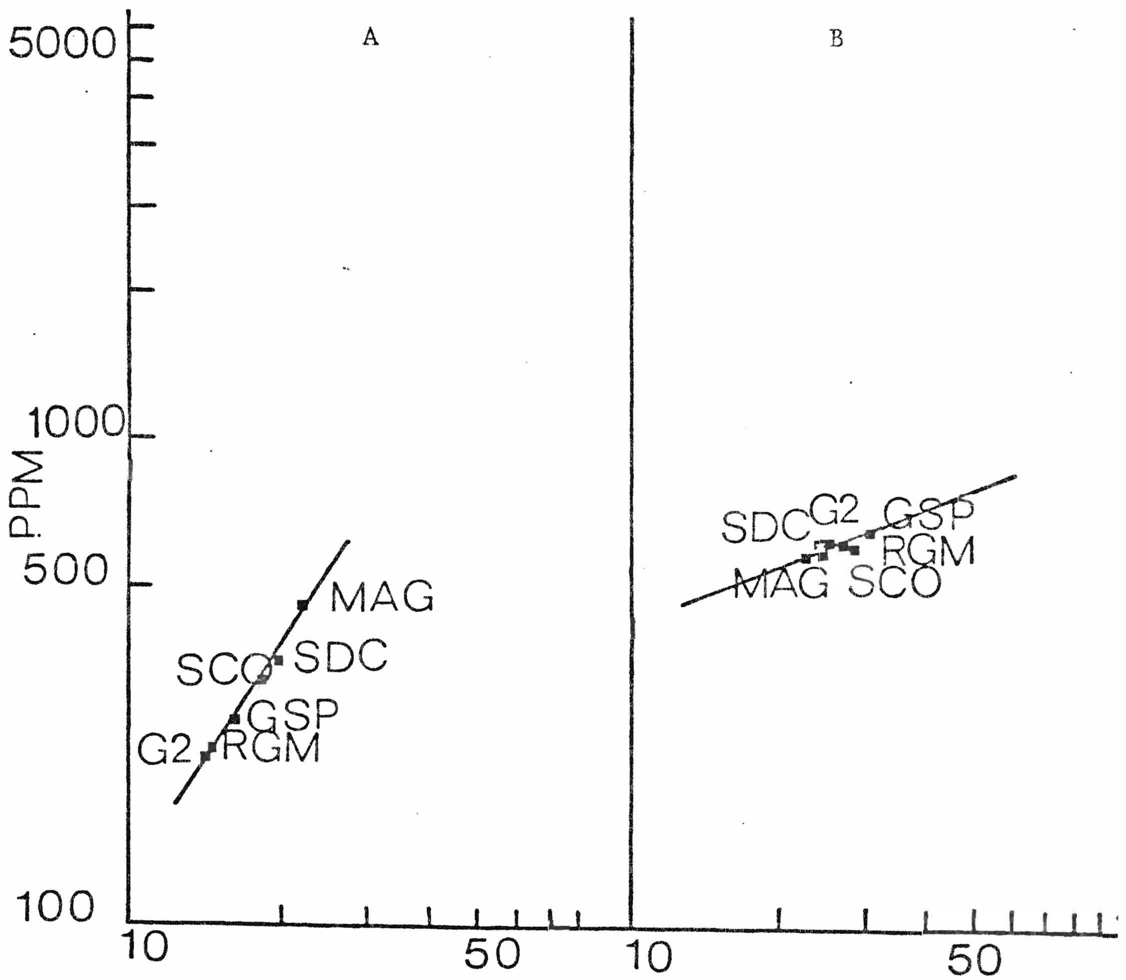


Figure 10. A. Calibration curve for Nickel.
B. Calibration curve for copper. Abbreviations represent the names of the standards.

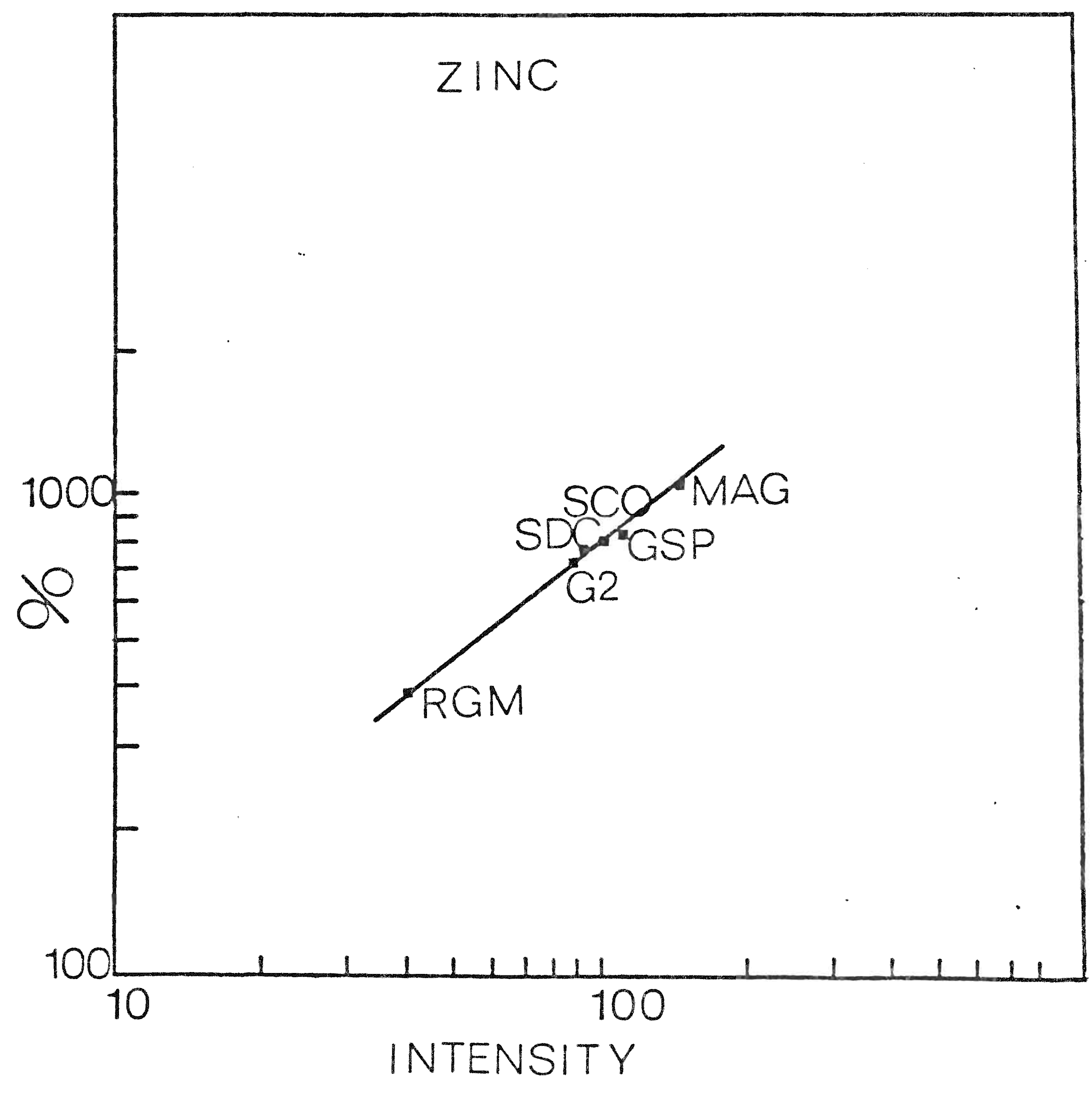


Figure 11. Calibration curve for zinc. For explanation of abbreviations see Figure 10.

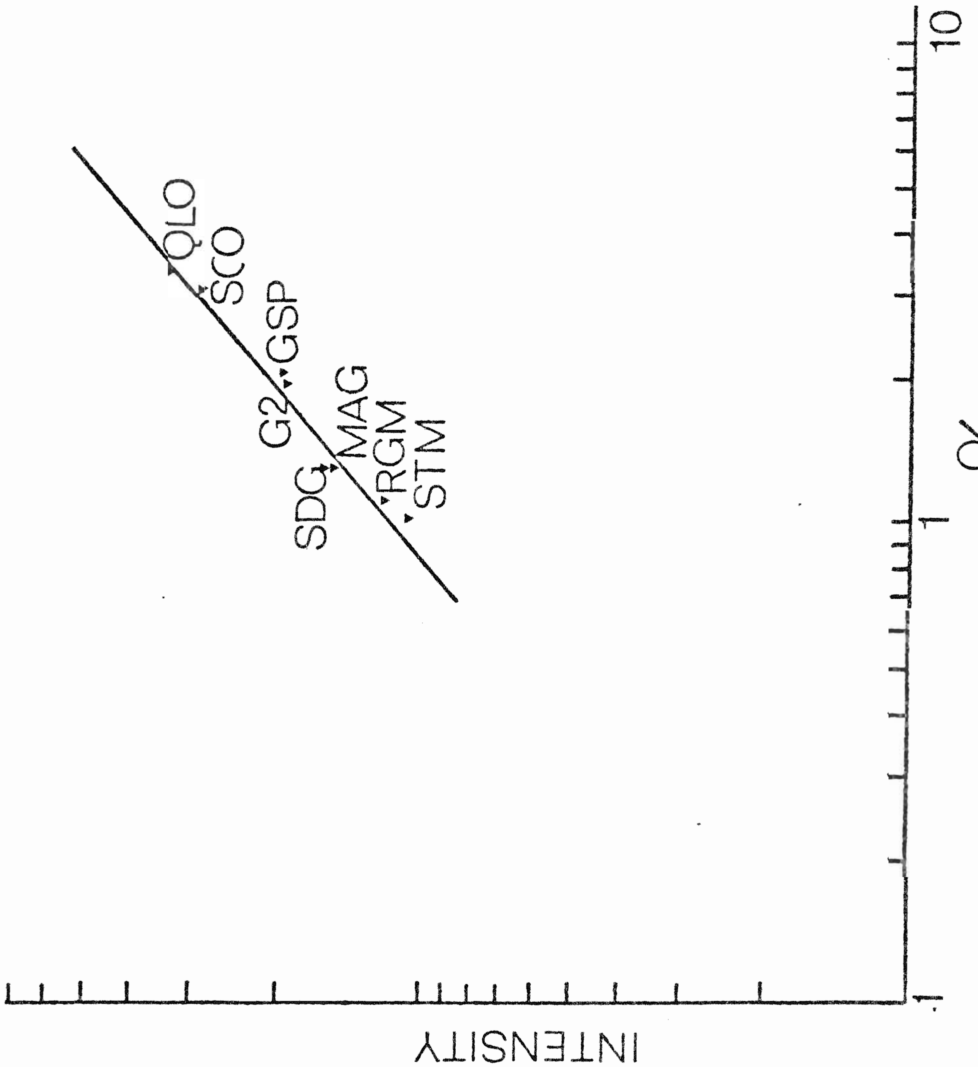


Figure 12. Calibration curve for calcium. For explanation of abbreviations see Figure 10.

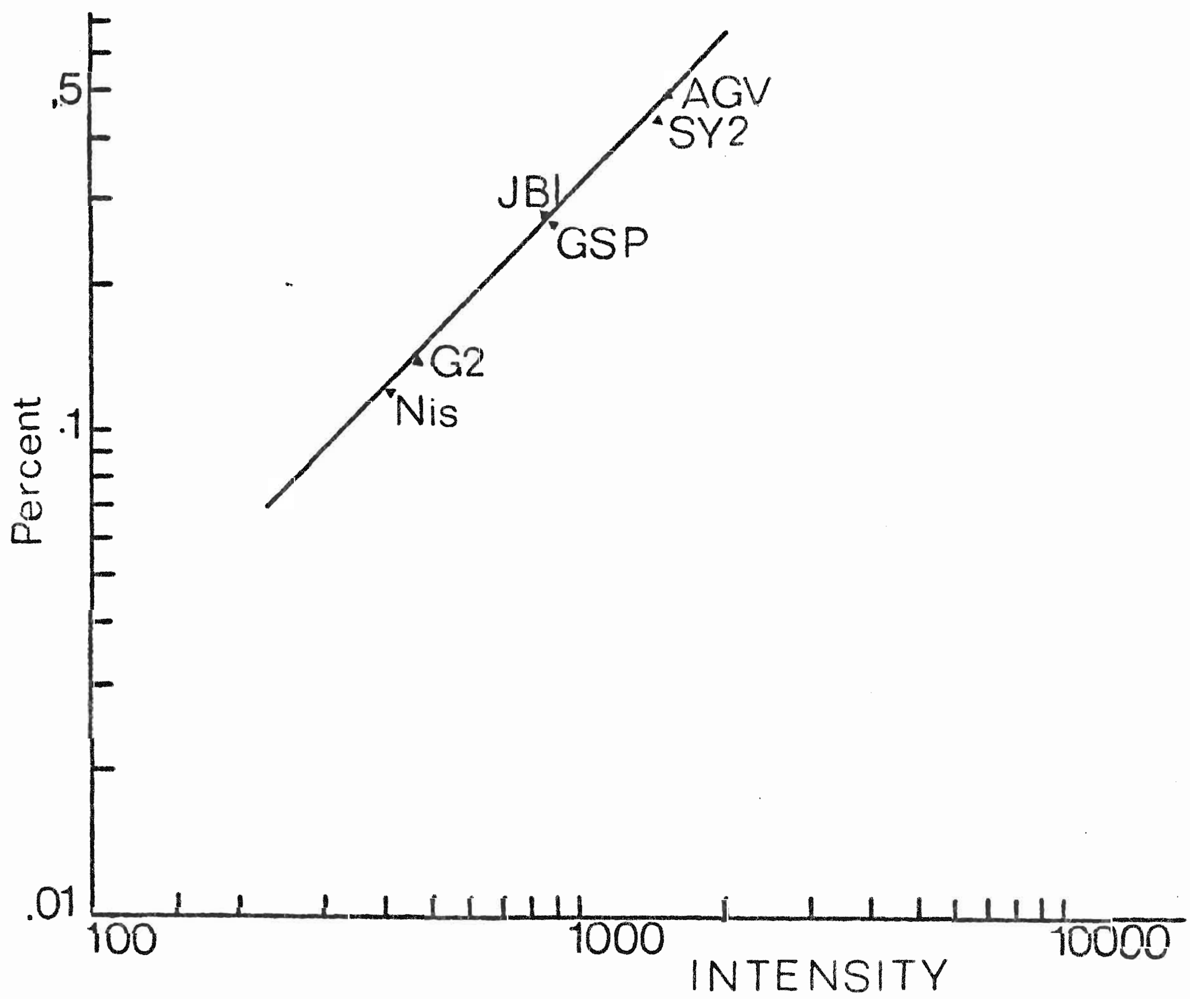


Figure 13. Calibration Curve for Phosphorous. For explanation of abbreviations see Figure 10.

Palynological Analysis

Two cores (S1 and P1) from the lagoon on Sixteen Mile Creek were used for the pollen analysis in this study. Core S1 was a deep core sampled at 10 cm intervals. P1 was a short core collected to provide a more detailed analysis of the sediment. Sampling of this core was at 1 cm intervals.

The techniques that were used for the slide preparation are summarized in Bassett et al. (1978). Pollen grains were identified by comparison of the samples to actual pollen photographs (McAndrews et al., 1973; Adams and Morton, 1972, 1974, 1976, 1979). Percentages of each pollen type were calculated relative to the total of arboreal pollen count. Line traverses were made across the entire slide to conduct the pollen counts.

RESULTS

The lagoon at Sixteen Mile Creek and its adjacent environments were investigated in detail while only reconnaissance analyses of the lagoons on the Fifteen and Twenty Mile Creeks were conducted for comparison.

Sixteen Mile Creek

Physiography and Bathymetry

The open water extent of the lagoon has a maximum north-south length of 2.6 km as measured from the mouth to the channel entrance along the meandering axis. It has an east-west width of about 200 m giving a surface area of over 40 km^2. Depths range from zero to 2.5 m as indicated on the bathymetric map (Figure 8). The valley walls adjacent to the lagoon reach a maximum height of 15.2 m. Most of these relatively steep sloped walls are vegetated with coniferous and deciduous trees; however, some of the near vertical walls throughout the lagoon are bare of vegetation, providing a source of sediment to the lagoon. A barrier bar produced by wave action in Lake Ontario separates the lagoon from the lake. During high flows the outlet is breached; however, during low flows littoral drift produces a continuous bar across the mouth.

The construction of the Q.E.W in 1938 caused a deepening in the lagoon. A weir beneath the Q.E.W. raised the water by approximately 0.5 m, flooding overbank environments that were previously used as farmland. When the bridge abutments were built, a narrower channel was produced, restricting the flow out of the lagoon. The portion of the lagoon north of the Q.E.W. was not examined for this study.

The delta occupies the area immediately downstream from the marsh and extends for approximately 200 m into the open water of the lagoon. The delta is a shallow subaqueous environment, (average water depth 0.5 m) providing a favorable habitat for abundant aquatic growth. It is separated from the subaerial marsh by a break in slope.

The channel meanders through the marsh and empties into the lagoon at the delta (Figure 14). Only the reach 500 m upstream from the delta to the gauging station was investigated for this study. The channel is about 4 m wide at the gauging station, increasing to 25 m in width 150 m further downstream. From there it remains constant in width as the channel extends through the marsh. During bankfull conditions the water depth is approximately 0.5-0.6 m. This single channel is bordered by a floodplain approximately 125 m in total width. The valley walls adjacent to the floodplain reach a height of 21.3 m.

The marsh is a densely-vegetated lowland adjacent to the channel and is subject to frequent flooding. The floor of the marsh is covered with matted Typha (cattail) leaves and roots. Typha and Carex (sedge) occur mainly in the lower wetter

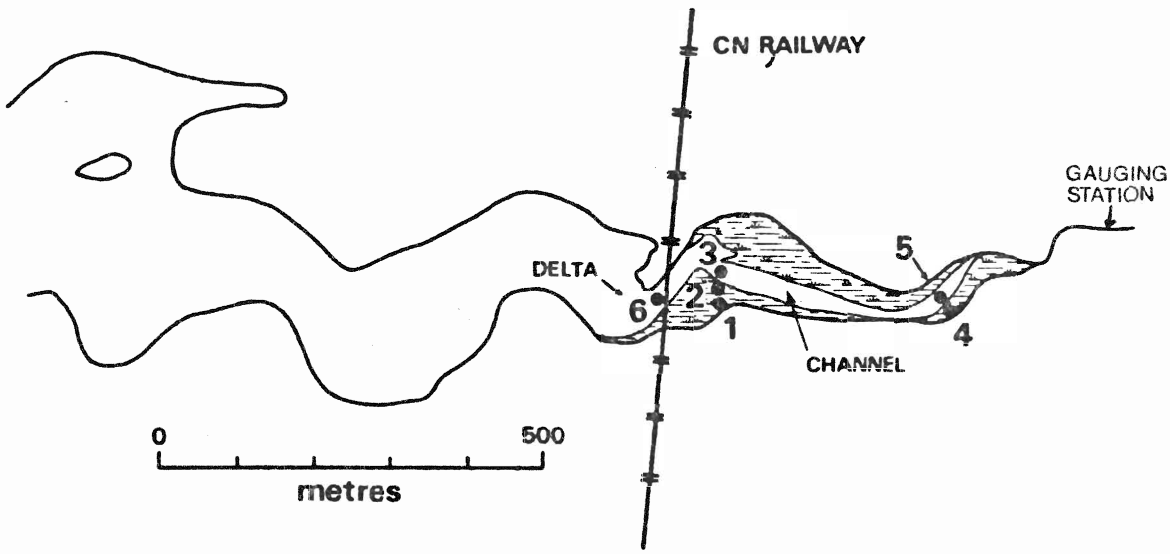


Figure 14. Physiographic map of the delta, channel, and marsh at Sixteen Mile Creek. Numbers show locations of cores.

portions while a variety of grasses are more abundant further headward. Trees eventually dominate higher, drier areas colonizing any natural levees first. The marsh extends 600 m south of the railroad bridge and has a total width of approximately 125 m (Figure 14). The elevation of the marsh exceeds the lagoon by 0.3 m in the higher areas.

Stratigraphy and Sedimentology

The stratigraphy of the lagoon, delta, channel and marsh has been established, based on the examination of the deep cores obtained from these environments. In the lagoon and delta, five stratigraphic units have been identified based on organic content and colour (Figure 15). Four stratigraphic units have been identified in the channel and marshland based on the same criteria

The five informal units which occur in the lagoon and delta are, from the base up: (1) Pink Clay; (2) Bottom Sand; (3) Gyttja; (4) Brown Clay; and (5) Gray Clay. In the marsh the four are: (1) Till; (2) Sand; (3) Orange Sandy Silt (Gyttja equivalent) and (4) Gray Clay. Their physical characteristics and environmental interpretation are discussed below in stratigraphic/chronologic order. Detailed core description are in Appendix III.

Till. The lowest unit obtained in the marsh is dense till. Pink pebbles from the Queenston Formation are present in a

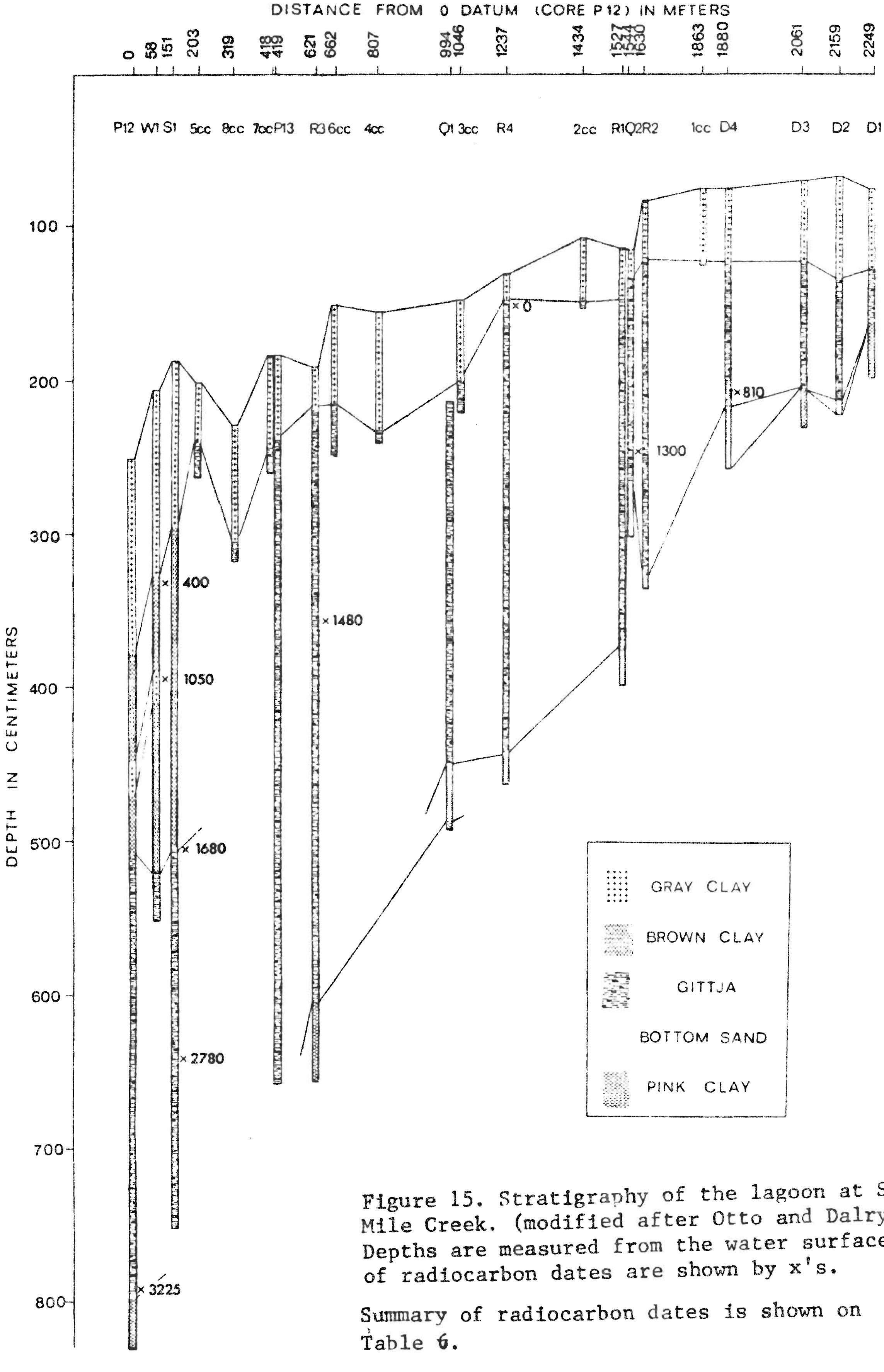


Figure 15. Stratigraphy of the lagoon at Sixteen Mile Creek. (modified after Otto and Dalrymple,1981). Depths are measured from the water surface. Locations of radiocarbon dates are shown by x's.

Summary of radiocarbon dates is shown on Table 6.

Table 6. SUMMARY OF RADIOCARBON DATES FROM FIFTEEN, SIXTEEN, AND TWENTY MILE CREEK LAGOONS.

Sample Number	Radiocarbon Lab Number	Unit	Date	Depth From Water (cm)	Elev Ref to LWD
Sixteen Mile Creek					
W1/2s7	BGS721	Brown Clay	400±100	369	69.15
W1/3s1	BGS746	Brown Clay	1050±120	380	?
W1/3s6	BGS747	Brown Clay	1700±120	420	68.76
W1/4s2	BGS723	Gyttja	1110±120	469	68.25
P12/10s5	BGS680	Pink Clay	3225±110	828	64.63
S1/5s1	BGS693	Brown Clay	1680±100	510	67.58
S1/9s1	BGS694	Gyttja	2780±100	645	66.23
R3/1s6 & 2s1	BGS703	Gyttja	420±100	275	?
R3/2s6 & 3s1	BGS692	Gyttja	1440±100	360	?
R4/1s3 & 1s4	BGS722	Gyttja	recent	150	71.86
Q2/4s1	BGS679	Gyttja	1130±175	305	70.33
D4/5s5 & 6s2	BGS704	Gyttja	810±140	202	72.22
Fifteen Mile Creek					
15-1	BGS745	Brown Clay	440±100	92.5	72.33
Twenty Mile Creek					
C11/4s4	BGS683	Gyttja	1750±120		
C117s4	BGS682	Gyttja	1940±120		

Definitions: LWD= Low Water Datum. Note: Radiocarbon dates have not been corrected.

compact brown matrix that exhibits concoidal fracture. Analysis of a sample from core M1 indicates that the mean grain size from this unit is 5.8 phi and that it is composed of 24% sand, 58% silt and 18% clay. It has an average organic content of 2% and a moisture content of 17%.

This unit is present in core M1 (the marsh) and core M5 (the channel), and it is presumed to extend throughout the entire area. Based upon similarities in colour and stratigraphic position this unit appears to correspond to the Halton Till described by Feenstra (1972). The contact between the till and overlying sandy gravel is abrupt and marked by a colour and texture change.

Pink Clay. The Pink Clay is the lowest unit obtained in the lagoon. It is a massive, poorly sorted clayey silt (as defined by Sheppard and Moore, 1954) with sorting values (Folk, 1974) that range between 2.0 phi units and 3.85 phi units. Based upon 12 samples, results show an average size distribution containing 15% sand, 54% silt and 31% clay (Figure 16). Individual mean grain sizes range from 5.4 phi to 7.8 phi and do not show any trend down the axis of the lagoon (Figure 17). The organic content varies from 2-9 % and the water content averages 26%. Pollen was not observed in this unit however sponge spicules and diatoms were present. These organisms were not identified in this analysis. This unit is very compact and difficult to penetrate, and was not reached in every core. In the X-ray photograph, the Pink Clay appears massive and homogenous. It appears to be present throughout the length of the lagoon however because it was encountered at

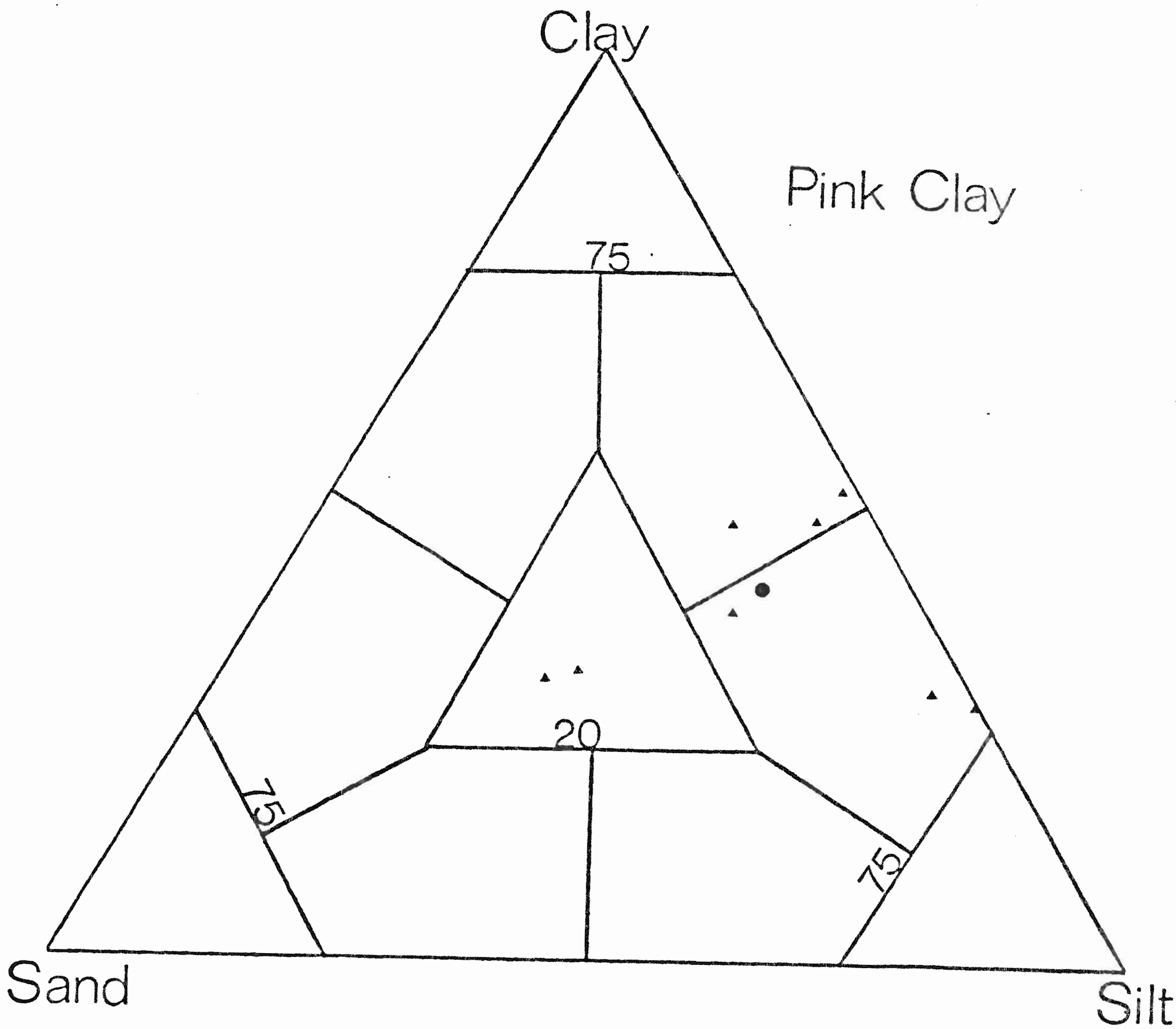


Figure 16. Textural triangle diagram of the Pink Clay (divisions after Sheppard and Moore, 1954). The symbol which is different from the others represents the average value.

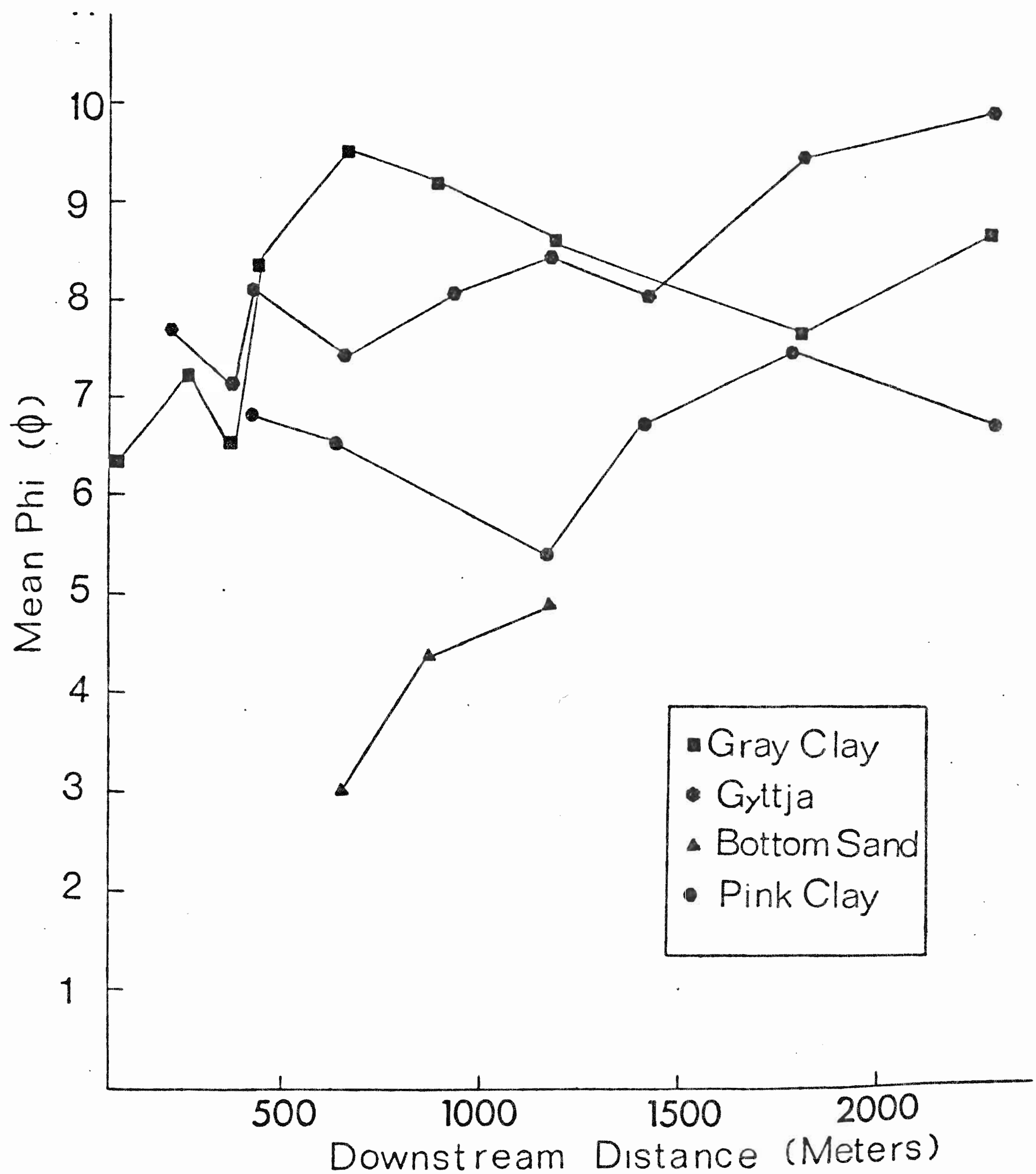


Figure 17. Downstream variation in mean grain size. The four lines represent each stratigraphic unit.

158 cm from the water surface in the delta region (core D1) and at 800 cm near the weir (core P12). Its upper surface slopes markedly (0.3 cm/m) downstream. The upper contact is abrupt and characterized by an increase in organic content and a change in colour.

Three possible depositional environments exist for the Pink Clay: (1) a till, (2) fluvial and (3) lacustrine. The most probable origin however, is either a glacial or post-glacial lacustrian deposit because it contains diatoms and sponge spicules while pollen was not observed. This unit is unlikely to be a till because of its high organic content and its lack of larger clasts and concoidal fracture. A fluvial origin can be eliminated because the unsorted nature of the sediment and its lack of downstream fining.

Although the exact age of this unit is unknown, at least two possibilities exist with respect to its relative age. If the Pink Clay occurs beneath the till recovered in the marsh, it is probably a glacial lake deposit. On the other hand, if this unit is restricted to within the valley walls, it was deposited after the valley was eroded at a time when Lake Ontario was at an elevation higher than today. The actual Pink Clay- Till contact was not encountered in any of the cores therefore it was not determined whether this unit is a glacial or post-glacial lacustrine deposit.

Bottom Sand. The "Bottom Sand" from the lagoon and the "Sand" from the marsh are discussed together as one unit because they appear to be stratigraphically equivalent. A mixture of sand, silt and clay averaging 38% sand, 30% silt and 32% clay (Figure 18) overlies the Pink Clay in the lagoon. The upstream equivalent, composed of sandy gravel, overlies the till in the marsh and channel (cores M1, 2, 4, and 5). Fine sand occurs at the base of core M3. The maximum thickness of "Bottom Sand (40 cm) is present in the delta in comparison to the "sand" of the marsh which ranges from 82-101 cm. Samples from the lagoon indicate that individual mean grain sizes exhibit a downstream fining ranging between 2.6 phi and 4,9 phi (Figure 17). Sorting values range between 2.2 to 3.9 phi units (Figure 19). Samples from cores M1 and M5 (Table 7) indicate that the mean sediment size is 3.7 phi with 11% gravel, 48% sand, 29% silt and 11% clay. Ten samples from cores M2 and M4 indicate an average organic content of 3%, while 7 samples from core M2 give an average moisture content of 19%.

This unit appears to be present only throughout the headward portion of the lagoon and marsh as it was not recovered lakeward of core Q1. It is possible that it has a rather limited width and was missed in the distal cores

The contact between the Pink Clay and Bottom Sand occurs at a depth of 200 cm in the delta and descends to 450 cm in core Q1 (Figure 15). Sedimentary structures have not been observed but laminations produced by whole leaves occur in many of the cores. The contact between the sand and the overlying

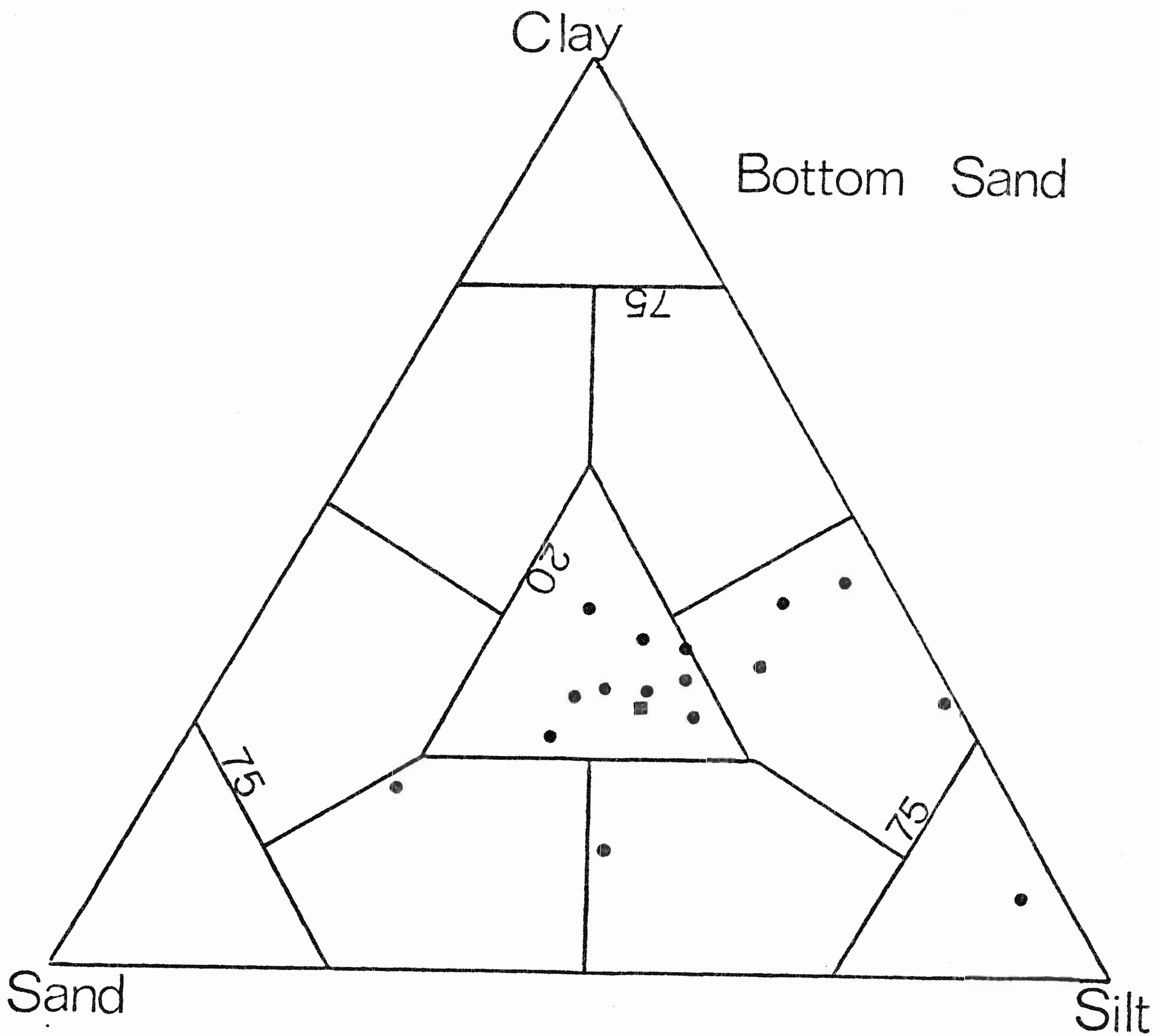


Figure 18. Textural triangle diagram of the Bottom Sand. The symbol which is different fr om the others represents the average value.

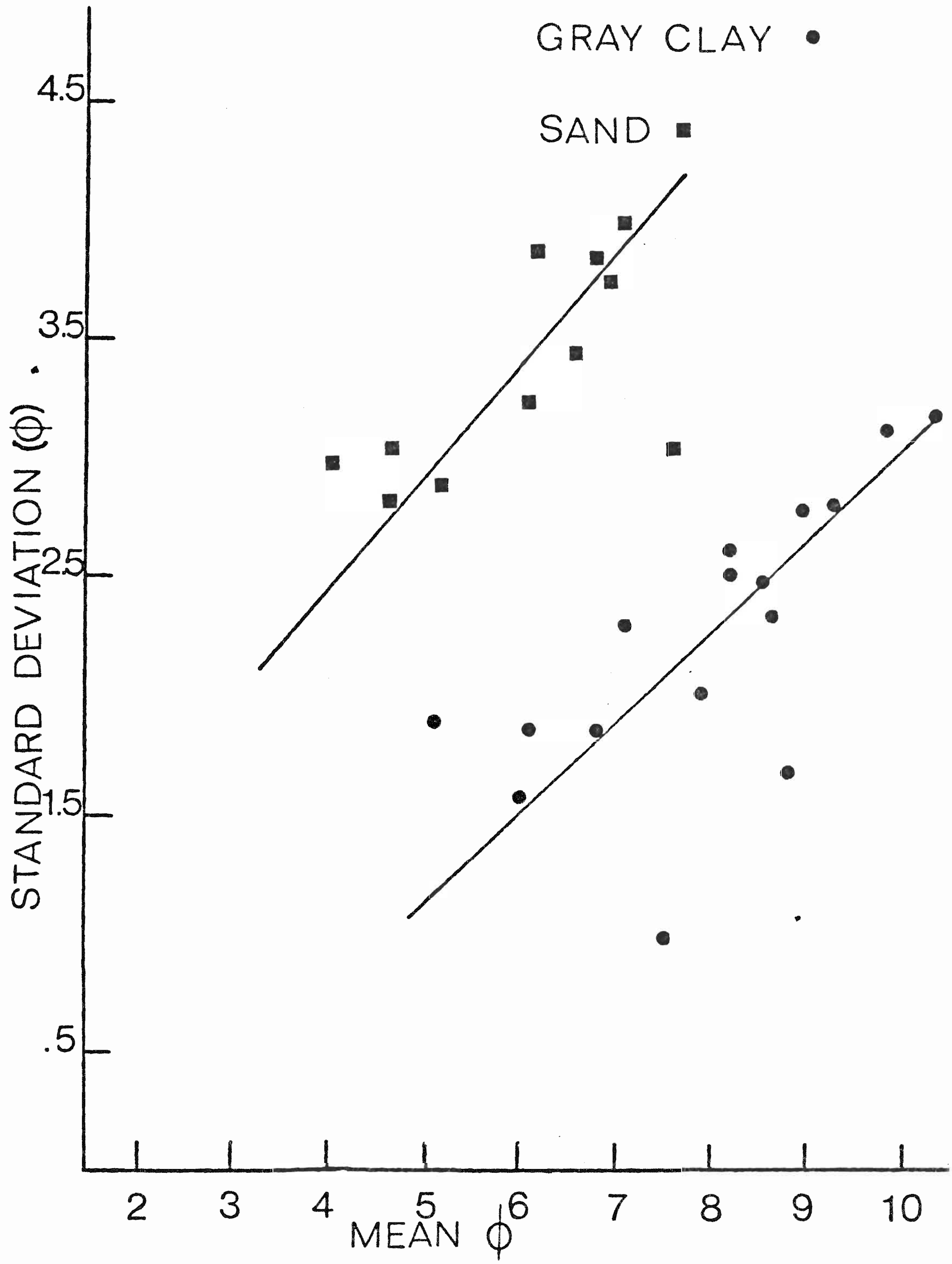


Figure 19. Relationship between mean size and sorting values for the Gray Clay and Bottom Sand. The lines are approximations.

Table 7. AVERAGE CHARACTERISTICS OF THE STRATIGRAPHIC UNITS RECOVERED IN VIBRACORES FROM THE CHANNEL, MARSH AND DELTA OF THE SIXTEEN MILE CREEK (from Otto and Dalrymple, 1982).

Unit	Thickness (cm)	Mean Grain Size (phi)	% Gr	% Sa	% Si	% Cl	% Mois	% Org
Gray Clay	52-145	6.2-8.2		9	60	31	33	5
Orange Sandy Silt	37-57	4.8	-	29	46	25	21	3.5
Sandy Gravel	82-101	0.7-5.0	12	48	29	11	19	3
Till	?	5.7	-	24	58	18	17	2

Defininitions of abbreviations are:Gr= gravel; Sa= sand; Si= silt; Cl= clay; Mois= moisture; org= organic.

Gyttja is gradational.

In the marsh, the "Sand" is characterized by an upward fining from gravel to sand that in turn grades upward into 52 cm of alternating 1-5 cm thick layers of sand and clay. The alternating layers possibly represent deposition during periods of high and low flow. Similar sand and clay laminations are present in the modern channel.

Based on the texture and downstream fining, this unit is interpreted as having a fluvial or deltaic origin. It is presumed to occur further lakeward of core Q1, however; was missed due to its limited lateral extent. The fining upward trend as a whole may be a result of rising lake level which caused transgression of the delta. The laminations of sand and leaves suggest alternating periods of high and low flows. The coarser texture of the "Sand" and "Bottom Sand" relative to the modern delta/channel environment suggests this unit was a result of a higher energy environment.

Gyttja. The Gyttja is an organic-rich, brown silty clay averaging 2% sand, 45% silt and 53% clay (Figure 20) with mean grain sizes ranging from 5.6 phi to 10.0 phi. The sorting values range from 1.0-4.0 phi units. The relatively high water content, as much as 35%, shows a positive correlation to the organic content (Figure 21). Variations in organic content are apparent on the the X-ray photographs and appear as laminations resulting from the variations in the relative abundance of organic material. The general vertical trend in organic content shows an upward increase throughout the Gyttja in most cores

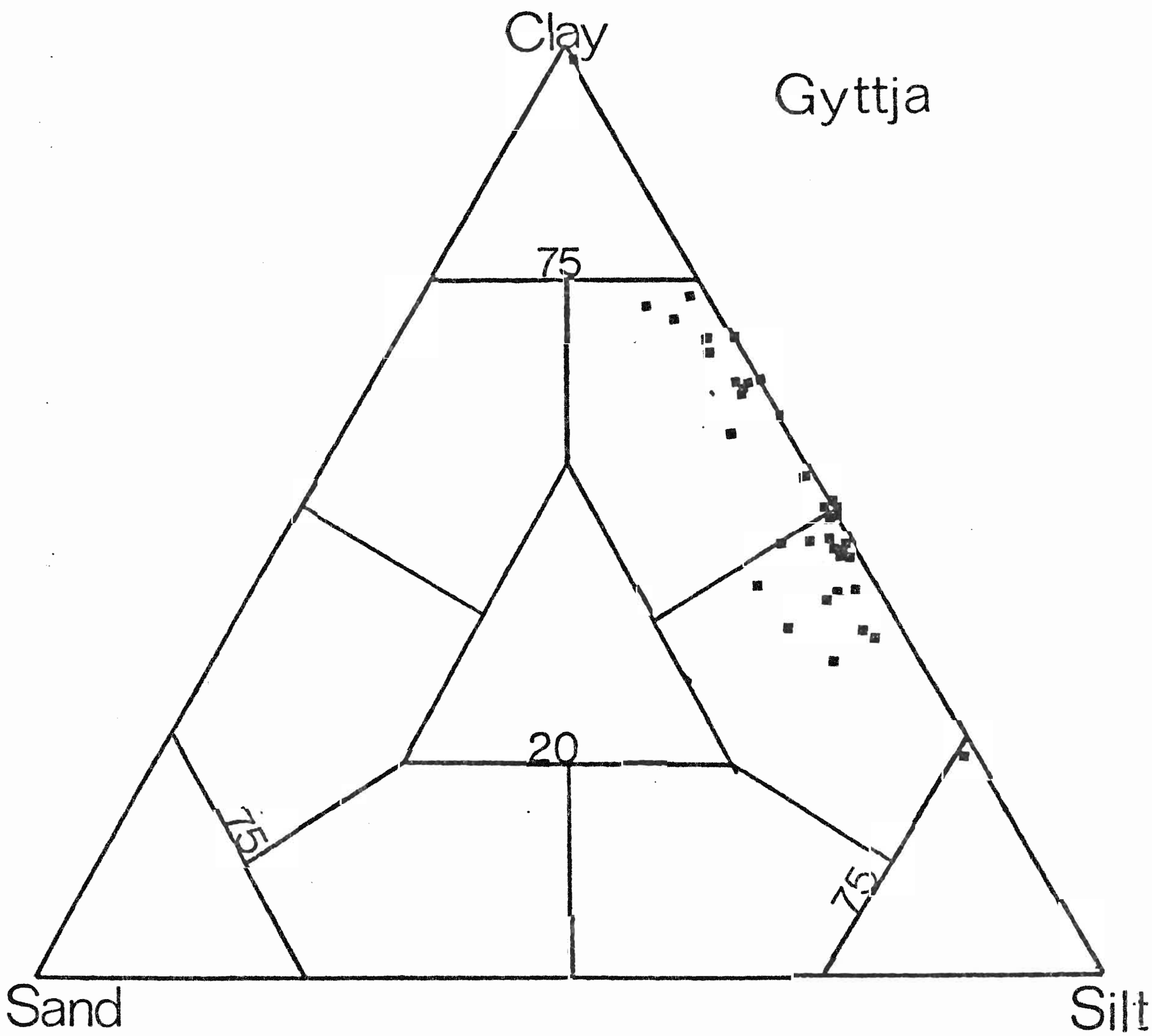


Figure 20. Textural diagram of the Gyttja. The symbol which is different from the others represents the average value.

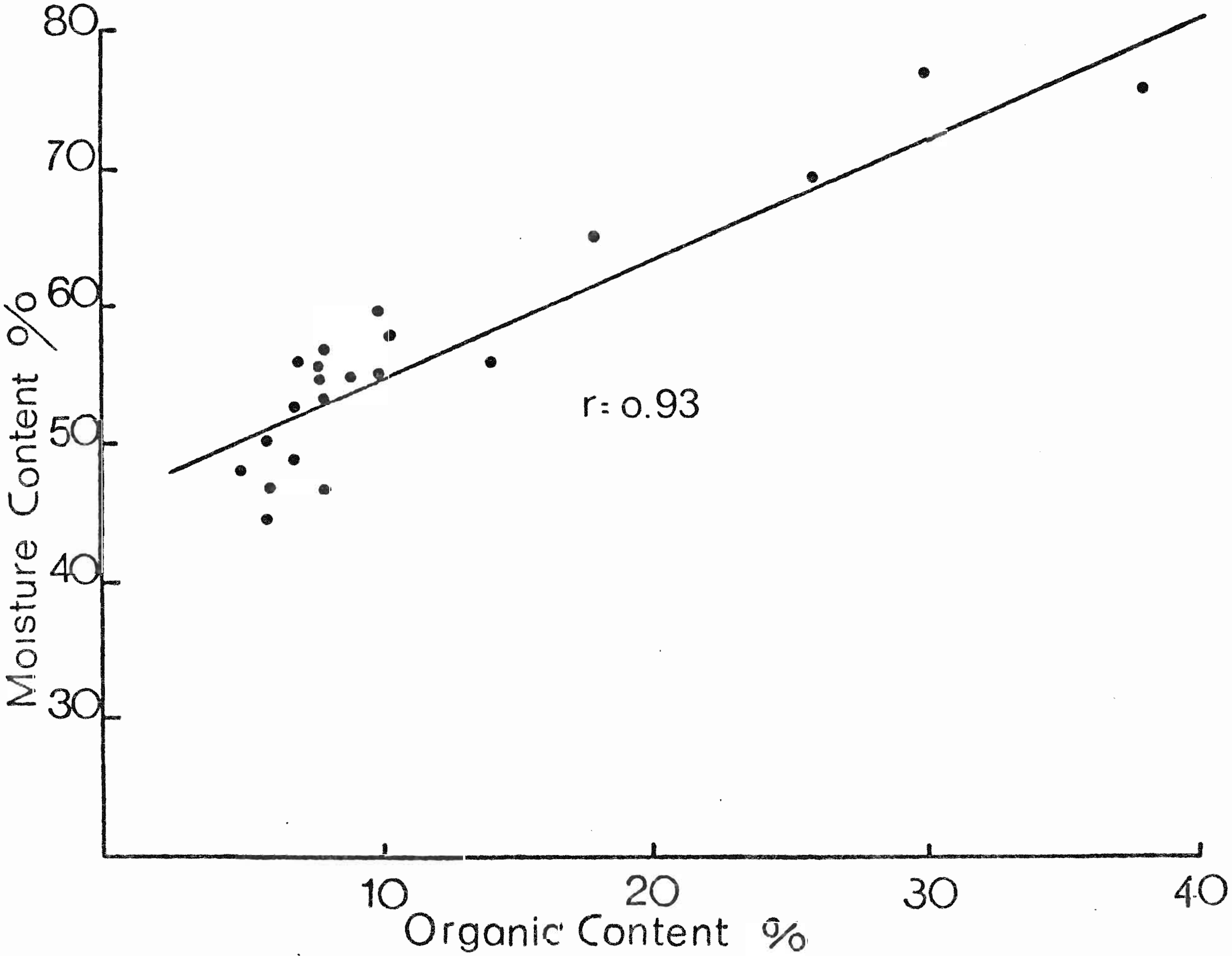


Figure 21. The relation between organic content and moisture content.

(Figure 22). In core P12 however, the maximum occurs 50 cm below the contact with the Brown Clay. These data will be discussed below in more detail.

The Gyttja is the thickest unit in the lagoon, ranging from 45 cm at the head to 400 cm in core P13. The contact between the Gyttja and the overlying Gray Clay is abrupt and is marked by a colour change and a sudden decrease in organic content (Figure 22). The contact between the Brown Clay and Gyttja in the lower part of the lagoon is more gradual as there is no colour change. However, the organic content of the Brown Clay is lower and no laminations are present. The upper surface of the Gyttja slopes 0.08 cm/m north from a depth of 125 cm in the delta to 240 cm in core P13. From there it descends 260 cm over a distance of approximately 500 m to 500 cm (.048 cm/m) in cores P12 and S1.

Radiocarbon dating was conducted on 8 samples from the Gyttja. The results and their corresponding elevations are shown in Table 6. One sample from the base of the Gyttja in core P12 (P12/10s2), a sample from near the center (S1/9s1) and one at the top (S1/5s1), were used to determine sedimentation rates using radiocarbon years. The rate of deposition in the lower half of the Gyttja was 0.36 cm/year while the top half of this unit was 0.19 cm/year. The reduction in sedimentation rates may be a result of the capture of Sixteen Mile Creek by Twenty Mile Creek (J.J.Flint, personal communication, 1981) or it may be a result of a reduction in runoff. Radiocarbon dates obtained from the base of the Gyttja along the length of the lagoon show that deposition of this unit began approximately 3250 ± 110 years ago near the mouth and

810 ± 140 years ago in the delta. This indicates that the unit is time transgressive.

The depositional environment of this unit is interpreted as a marsh or shallow lagoon (water depths less that 0.25 m). Substantiating evidence for this came from the pollen analysis. High concentrations of _Gramineae_ (grass) pollen occur throughout the Gyttja with a decrease shown near the top. This type of vegetation is generally prolific in a marsh environment and is present in the marsh of the Sixteen Mile Creek. It was also noted that the pollen appeared whole and undamaged, suggesting limited transport. Additional evidence supporting the interpretation of a shallow water origin for the Gyttja is shown by the diatom analysis. A more complete discussion of the pollen analysis may be found below in the Palynology Results.

The time-transgressive, shallow water characteristic of this unit suggest a gradual rise in the level of Lake Ontario, drowning the floodplain adjacent to the ancient channel beginning at the mouth. This may be a result of differential isostatic rebound which raised the water level along the entire southern Ontario shoreline.

The decrease in organic content occurred when high waters drowned the marsh. The Gyttja was not encountered in surface samples from any modern setting in any of the three lagoons. The apparent environmental conditions necessary for the

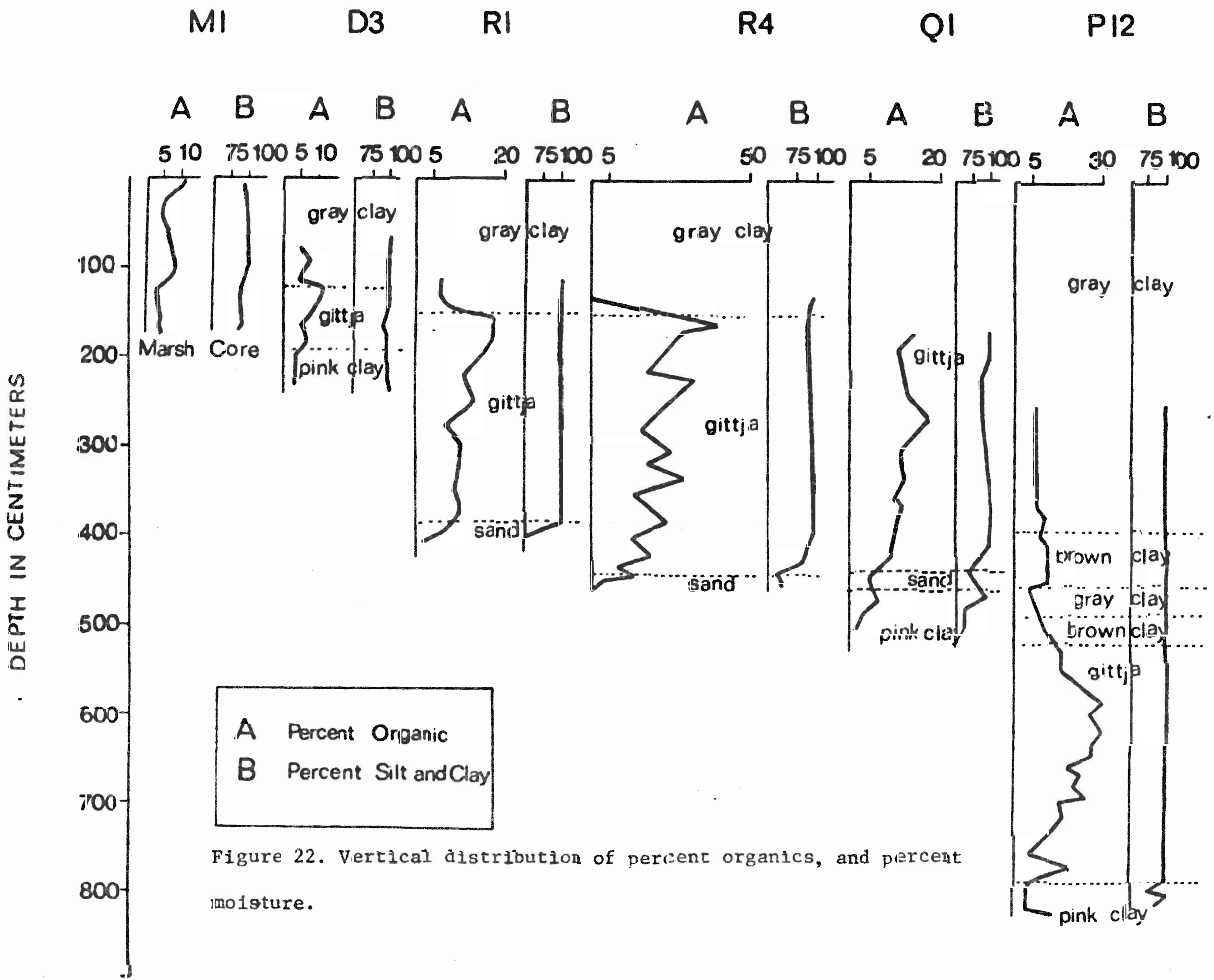


Figure 22. Vertical distribution of percent organics, and percent moisture.

production of Gyttja are very shallow water, abundant organic material and low clastic input. Due to the high water levels of the lagoons and deforestation, these conditions are no longer satisfied.

Orange Sandy Silt. The Orange Sandy Silt is present in cores M2, M3, and M4 from the marsh and channel. Analysis of a sample from core M2 gave a mean size of 4.8 phi. It is composed of 42% sand, 48% silt and 18% clay. the organic content for 9 samples from cores M2 and M4 average 3.5%, while an average moisture content of 21% was obtained from core M2 (4 samples).

The brownish colour and streaks of orange surrounding the remains of roots that occur in this unit indicate that it was deposited subaerially in an oxidizing environment. It is probably an ancient soil horizon and is possibly the upstream equivalent to the Gyttja.

Brown Clay. This unit is a brown silty clay averaging 40%, silt and 60% clay (Figure 23). It occurs above the Gyttja only at the distal end of the lagoon; core 8cc marks the approximate location where this unit pinches out (Figures 8 and 15). The mean grain sizes of 5 samples range between 8.3 phi and 9.6 phi, and moisture content ranges from 90% to 140%. The organic content of the Brown Clay decreases from 30% near the base to 9% near the top (Figure 22). It is present at a depth of 300 cm in core S1 and descends to 375 cm in core P12 with a maximum thickness of 215 cm. Cores P12 and W1 have a 20 cm layer of Gray Clay in the middle of the Brown Clay. The contact between the top of the Brown Clay and the overlying grayish

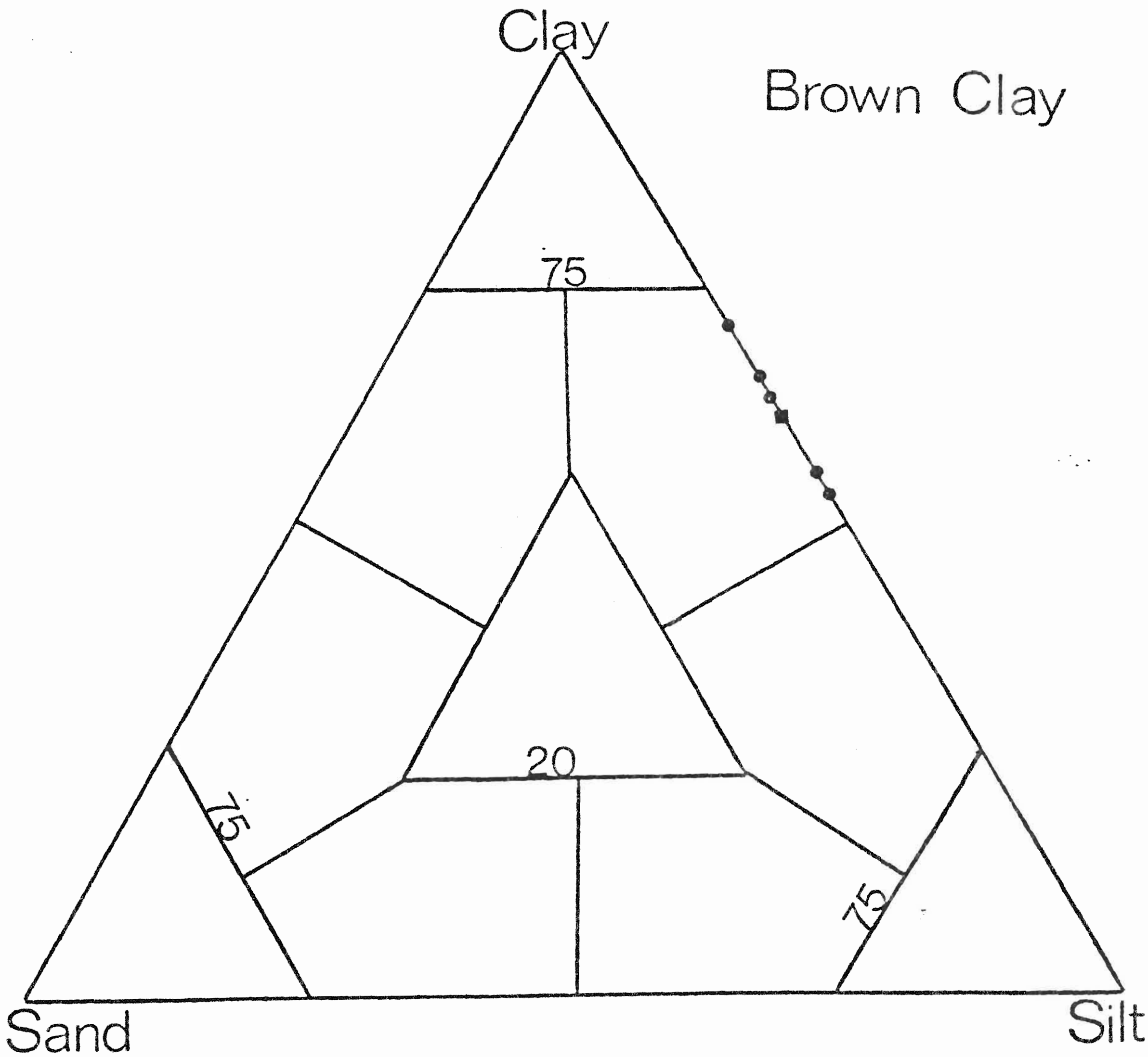


Figure 23. Textural triangle diagram of the Brown Clay. The symbol which is different from the others represents the average value.

clay is abrupt and marked by a colour change and a decrease in organic content.

Radiocarbon dating of samples from near the base of this unit indicate deposition began 1690 $\pm$ 100 B.P. and continued between 1104 $\pm$ 100 to 1050 $\pm$ 100. A sample obtained 35 cm beneath the Brown Clay-Gray Clay contact indicates an age of 400 $\pm$ 100 years B.P. Based upon these data, it was determined that the average deposition rate for the Brown Clay was 0.19 cm/year. Assumming the overlying 35 cm of sediment was deposited at 0.19 cm/year, the end of the Brown Clay occurred between 1734 and 1834 considering the 100 year limit of error.

Several factors indicate that the Brown Clay is a result of a deepening near the mouth of the lagoon. Compared to the lower portions of the Gyttja, the Brown Clay contains a higher percentage of algal spores and a smaller percentage of *Gramineae* (grass) pollen (see below) . Further supporting evidence of a deepening is shown by the diatom analysis discussed in more detail in the Palynology Results.
As the marsh became flooded, open water conditions provided more favorable conditions for algal blooms. The decrease in organic content further substantiates an environmental change. The start of deposition of Brown Clay closely corresponds to the end of the Sub Atlantic climatic episode (Table 5). Each climatic episode is characterized by a change in climatic conditions. (Bryson et al., 1970). The actual affect of such a climatic episode for southern Ontario has not been documented and additional investigations are required. Alternatively, the gradual decrease of organic content at the top of the Gyttja

near the mouth, may reflect a continuous deepening as a result of differential isostatic rebound.

Gray Clay. The uppermost unit present in all the cores in the lagoon is a highly bioturbated gray silty clay. A similar Gray Clay lies abruptly above the Orange Sandy Silt in the marsh and at the surface interlaminated with sand in the channel. Based upon 29 samples from the lagoon, the Gray Clay was found to have an average grain size which ranges between 5.3 phi and 10.2 phi consisting of 3% sand, 43% silt and 54% clay (Figure 24). This unit has sorting values ranging from 0.89 to 3.1 phi units (Figure 19). The average mean grain size shows an inverted "V" shaped trend with distance downstream (Figure 17). It increases rapidly from 6.3 phi in the stream channel to 9.5 phi in core R2, but further downstream it slowly decreases to 7 phi in core R3, only to become finer again by core P12 (8.6 phi). The coarser sizes near core R3 could be produced by wind-generated currents in the shallow water depths which cause resuspension of the sediment or possibly by the small tributary that enters the lagoon near core R4. Three cores from the marsh indicate that average mean sizes in the Gray Clay range from 6.15 phi to 8.2 phi with 9% sand, 60% silt and 31% clay. The 30 samples that were used from the lagoon to determine organic content show an average of 6%. The 18 samples from the marsh give an average organic content of 5%; however, the upper 30 cm of sediment from all the marsh cores contain abundant coarse organic debris. The Gray Clay has a relatively uniform thickness of 50 cm from the delta to core 7cc. From there, it thickens to 80 cm in core 5cc and reaches a maximum

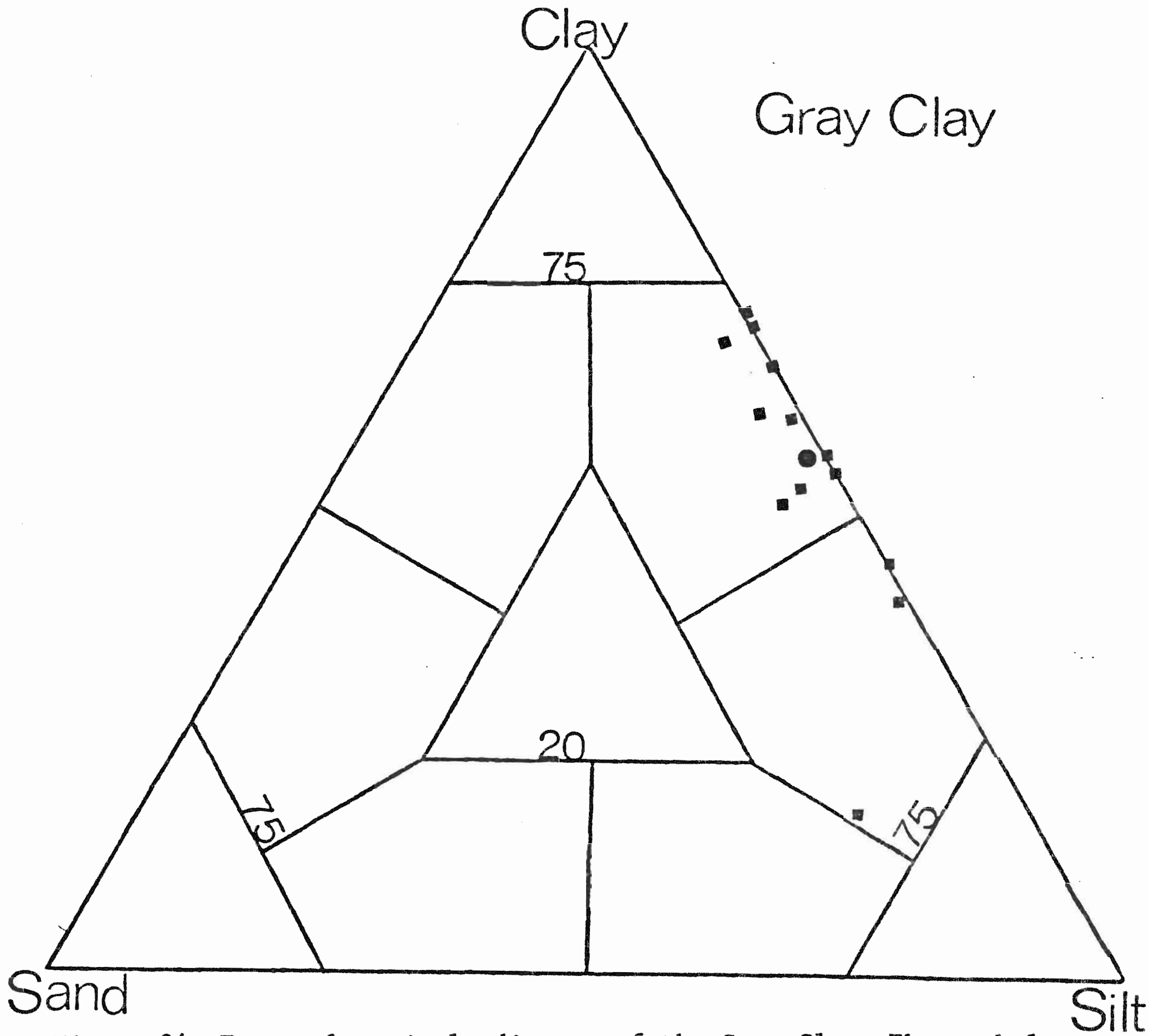


Figure 24. Textural traingle diagram of the Gray Clay. The symbol which is different from the others is the average value.

of 126 cm in core W1.

Within the Gray Clay there is a black lamina composed of charcoal which may be traced throughout the entire lagoon (Figure 25). In the delta, it has a thickness of 10 cm whereas downstream near the mouth, the lamina thins and is not easily recognized. Characteristically throughout the lagoon, the sediment above the black lamina is soft, highly bioturbated and contains a moisture content of over 100%. Below this marker, the sediment is denser, bioturbation is negligible, and the moisture content varies from 40% in the delta to 90% near the mouth. It is suggested that this layer may represent a forest fire somewhere within the drainage basin or it may possibly due to field clearing by settlers. Radiocarbon dating of this layer indicates that it is too recent to date by this method. This lamina also appears to separate the Gray Clay into two portions, an upper portion which is bioturbated and a nonbioturbated lower portion. One explanation for this change is the introduction of a bioturbating organism by the European settlers. Scott and Crossman (1973) describe the introduction of the carp into Lake Ontario late in the 19th century. Carp feed on the surficial soft sediment, disturbing the sediment and producing turbid water. Carp are present in the Sixteen Mile Creek Lagoon therefore the highly bioturbated nature of the upper Gray Clay may be due to the introduction of this organism by the European settlers.

Using the base of the Gray Clay and the black lamina as time lines, the relative amount of accumulation along the lagoon was investigated. Above the marker lamina the actual

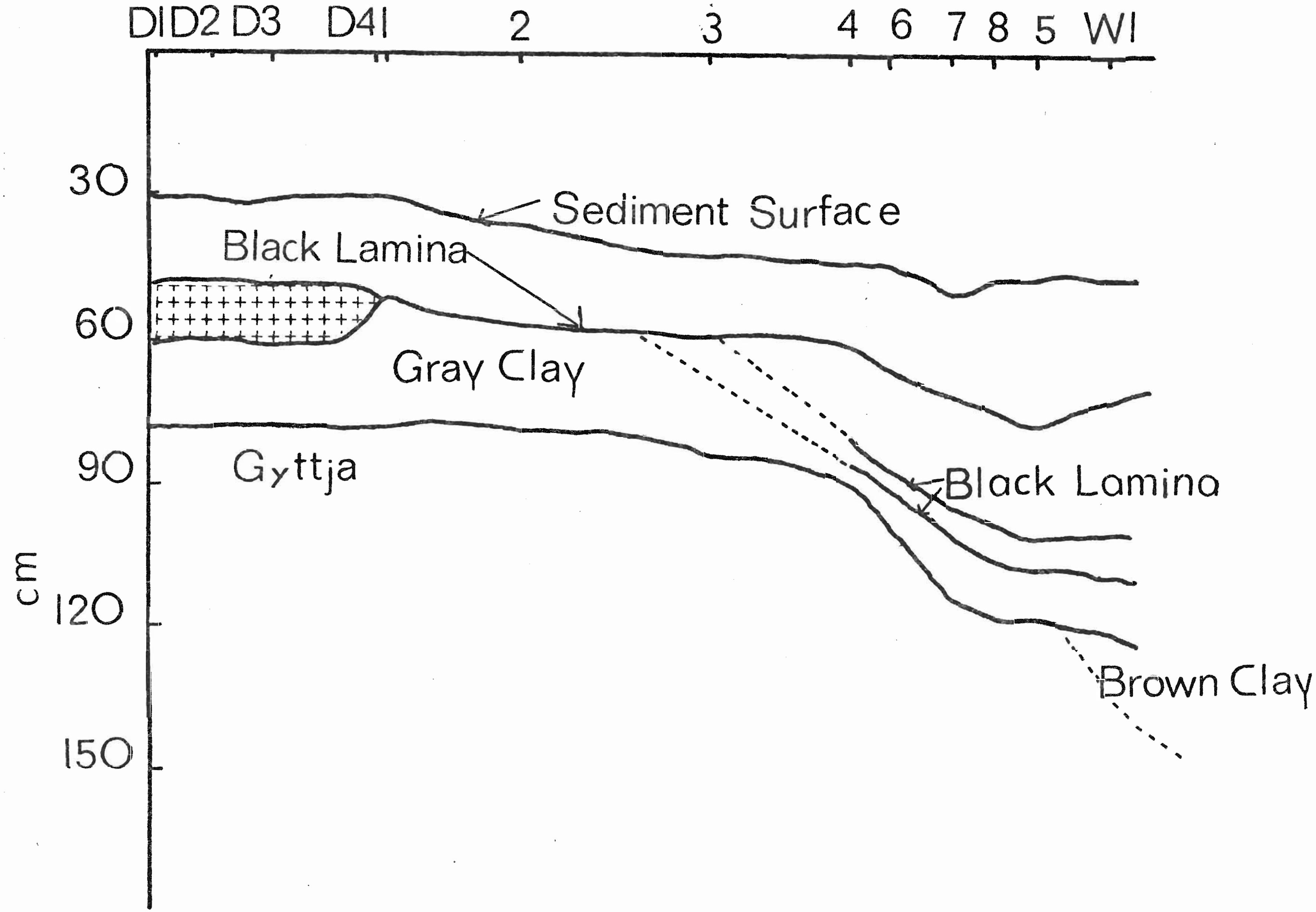


Figure 25. Straigraphy of the Gray Clay.

thickness from core D1 to core 4cc, remains uniform at 10 cm (Figure 25). From core 4cc to the mouth the sediment thickness above the marker increases to 21 cm. Below the marker, in the same upstream section, a relatively uniform 18 cm thickness of sediment occurs; however, from core 4cc to the mouth the thickness increases significantly to 80 cm. This increased thickness near the mouth may be due to an additional source of sediment such as the near vertical eroding bluffs which occur at the downstream end of the lagoon. Another potential source of sediment to that area is a tributary that enters the lagoon on its eastern side. On the other hand, it may be the result of greater deposition near the mouth caused by the deepening.

To calculate absolute rates of deposition in the Gray Clay relative compaction had to be considered. A plot of the moisture content against sample depth for cores W1 and D2 shows that the percent of water decreases rapidly about 20 cm below the sediment surface for both cores. This is above the black lamina in both cores. (Figure 26). The zone between the top of the unit and the depth at which the moisture content stabilized is the region in which compaction is not complete. The difference between the maximum percentage of water and the stabilized water content occurring at a 20 cm depth is a measure of the maximum compaction expected to occur. It was determined that the upper 20 cm of sediment in the Gray Clay would compact 39%, reducing the total average thickness from 130 cm to 122 cm.

Radiocarbon dates from within this unit indicate that it is a recent deposit (Table 6). As previously discussed, a date

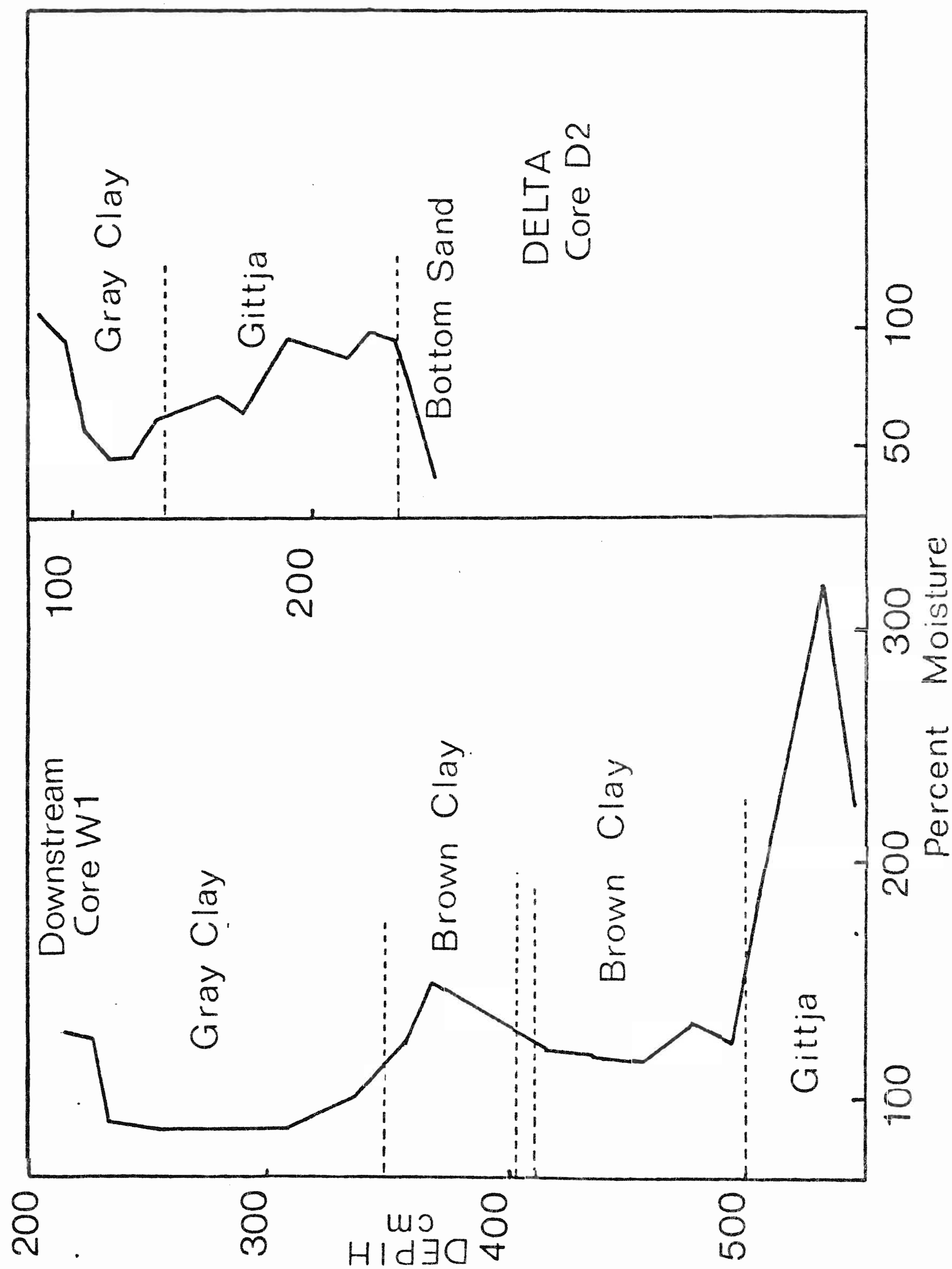


Figure 26. Vertical distribution of moisture content. Core W1 represents the downstream end and core D1 represents the delta. For core locations refer to Figure 8.

of 400+100 B.P was obtained 35 cm beneath the Gray Clay-Brown Clay contact. Calculations indicate that the deposition of Brown Clay ended approximately between 1734 and 1834. The date correponds to deforestation which occurred in 1850 in southern Ontario (McAndrews and Boyko, 1972). The change in colour between the Brown Clay and Gray Clay may be the result of a change in soil horizon. Studies have shown that the upper soil strata of the Sixteen Mile Creek drainage basin are brown with gray soils below (Wickland and Mathews, 1964). It has been suggested that the Brown Clay originated from erosion of the upper soil horizon while the Gray Clay was eroded from the lower strata after the overlying material was removed (Otto and Dalrymple, 1983). The decrease in organic content may be the result of deforestation which caused an increase in clastic material relative to the organic material. Additional evidence from the pollen analyses which is discussed below in more detail, shows that a rise of Ambrosia (ragweed) occurs between 5 and 30 cm above the base of the Gray Clay with a mean corrected depth of 102 cm from the sediment surface. In addition, the results of the chemical analysis also discussed below, show an increase in concentration of Ca and Zn with the Ambrosia rise.

Assumming that the Ambrosia rise at a corrected depth of 102 cm occurred in 1850, (McAndrews and Boyko, 1972), sedimentation rates in the Gray Clay reached 1.02 cm/year near the mouth. The minimum sedimentation rates from the beginning of the Gray Clay in 1734 to 1850 were calculated to be 0.14 cm/year and maximum rates from 1834 to 1850 were 1.6 cm/year.

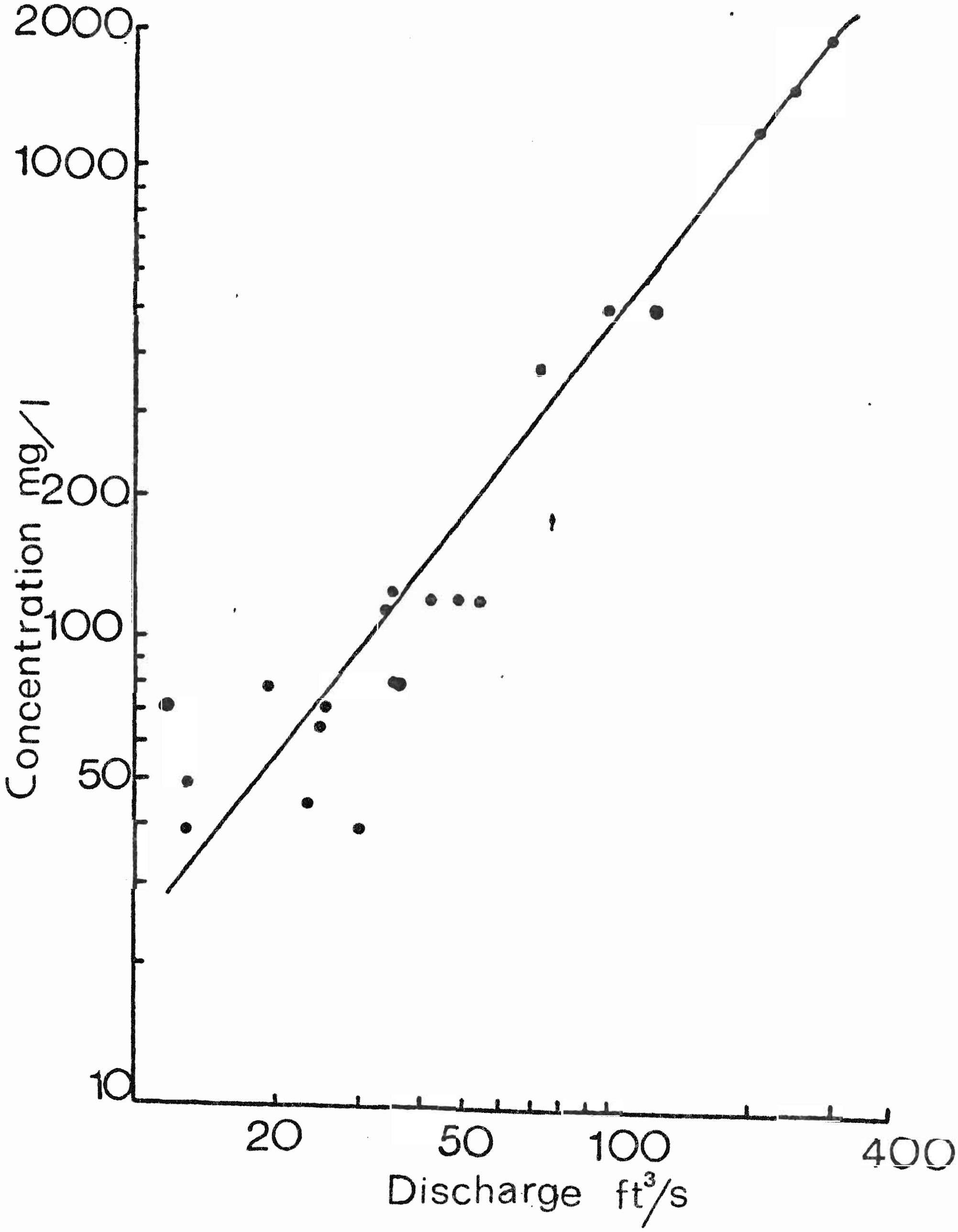
Hydraulics

Stratigraphic information and 14C dates indicate that sedimentation rates in the lagoons have increased significantly since deforestation occurred. In order to obtain an estimate of the present rate of infilling, samples of suspended sediment and their corresponding discharges were collected on the Sixteen Mile Creek during March and April, 1980. the hydraulic data and sediment concentrations data are summarized in Table 8. Also the power relation between discharge and suspended sediment concentration is shown in Figure 27. These data were used in conjunction with discharge data collected for high flows during the fall of 1978 and the spring of 1979 by Flint (personal communication, 1980). the data collected for that period show that discharge at bankfull conditions is approximately 2.05 m^3/s with a concentration of suspended sediment of 385 mg/l. In contrast, the discharge at approximately halffull conditions is 0.30 m^3/s with a concentration of suspended sediment of 71 mg/l. The discharge which occurred most frequently was 1.04 m^3/s and peak flows for that period reached 22.7 m^3/s. For comparison, average long term maximum and mean discharges of Twenty Mile Creek were also examined. Results show the average discharge is 3.5 m^3/s and the peak for that period of record is 130 m^3/s (Figure 30). From the continuous discharge data of Flint, (personal communication, 1980) a discharge frequency histogram was determined (Figure 28). Only discharges above 7.9 ft^3/s (0.22 m^3/s) were considered because sediment is only

Table 8. SUMMARY OF HYDRAULIC DATA

Sample Date	Qs T	Q m^3/s	Con mg/l	A m^2	W m	V m/s	d m	WP m	HR	S
3/17/80	472.8	3.5	502	4.8	5.5	0.7	0.9	7.2	0.7	.00115
3/20/80	23.8	1.5	120	3.0	4.3	0.5	0.7	5.7	0.5	.00037
3/21/80A		2.8		2.6	4.2	1.1	0.6	5.4	0.5	.00056
3/21/80B	429.3	1.7	507	2.0	4.2	0.8	0.5	5.2	0.4	.00082
3/22/80	219.5	2.0	385	2.5	4.4	0.8	0.6	5.5	0.4	.00082
3/24/80	19.6	1.0	81	2.3	4.0	0.4	0.6	5.1	0.5	.00059
3/26/80	27.6	1.0	82	2.4	4.2	0.4	0.6	5.3	0.4	.00074
3/27/80	9.7	0.8	40	2.1	4.2	0.4	0.5	5.2	0.4	.00074
3/29/80	8.7	0.7	44	1.8	4.2	0.1	0.4	5.0	0.4	.00077
3/31/80	35.1	1.0	127	2.1	4.1	0.5	0.5	5.4	0.4	.00074
4/2/80	16.2	0.7	72	2.0	4.4	0.4	0.5	5.0	0.4	.00033
4/6/80	11.5	0.5	78	1.8	4.0	0.3	0.4	4.9	0.4	.00056
4/7/80	6.1	1.0	71	1.3	3.5	0.2	0.4	4.2	0.3	.00067
4/14/80	34.1	0.4	116	2.3	4.9	0.4	0.5	5.8	0.4	.00056
4/9/80	5.6	2.1	50	1.4	3.8	0.3	0.4	4.6	0.3	.00082
4/10/80	13.5	0.7	60	4.8	4.4	0.4	1.1	6.6	0.7	.00037
4/13/80	4.0	0.4	39	1.5	4.0	0.2	0.4	4.8	0.3	.00032
4/17/80	46.4	1.2	122	2.8	5.2	0.4	0.5	6.3	0.4	.00052

Definitions of abbreviations are: Qs= suspended sediment discharge; Q= discharge; Con=concentration; A=area; W=width; V=velocity; D=depth; W.P.= wetted perimeter; H.R.=hydraulic radius; S=slope; T=metric tonnes.



Igure 27. Sediment Rating Curve for the Sixteen Mile Creek.

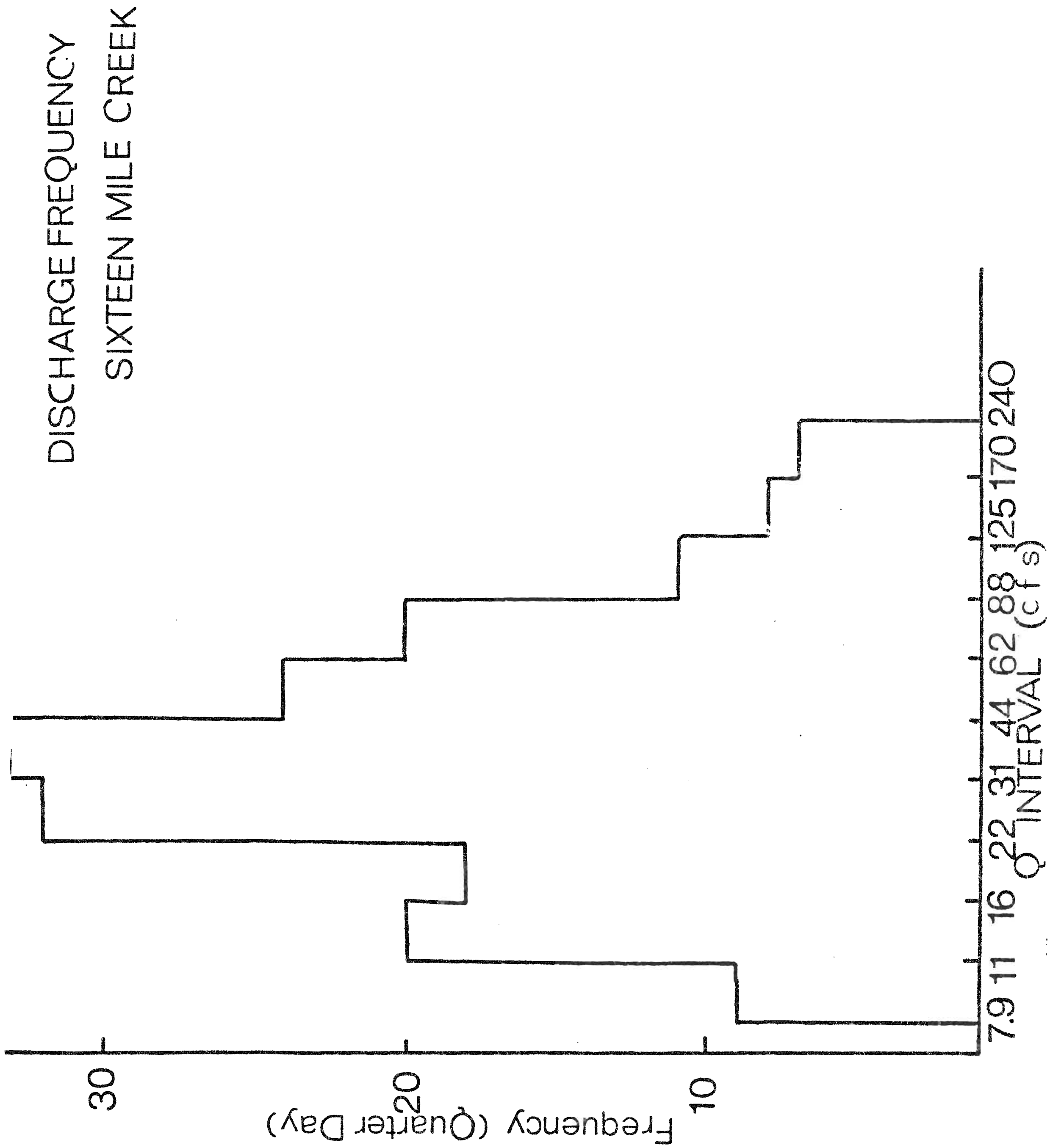


Figure 28. Discharge frequency histogram fro the Sixteen Mile Creek.

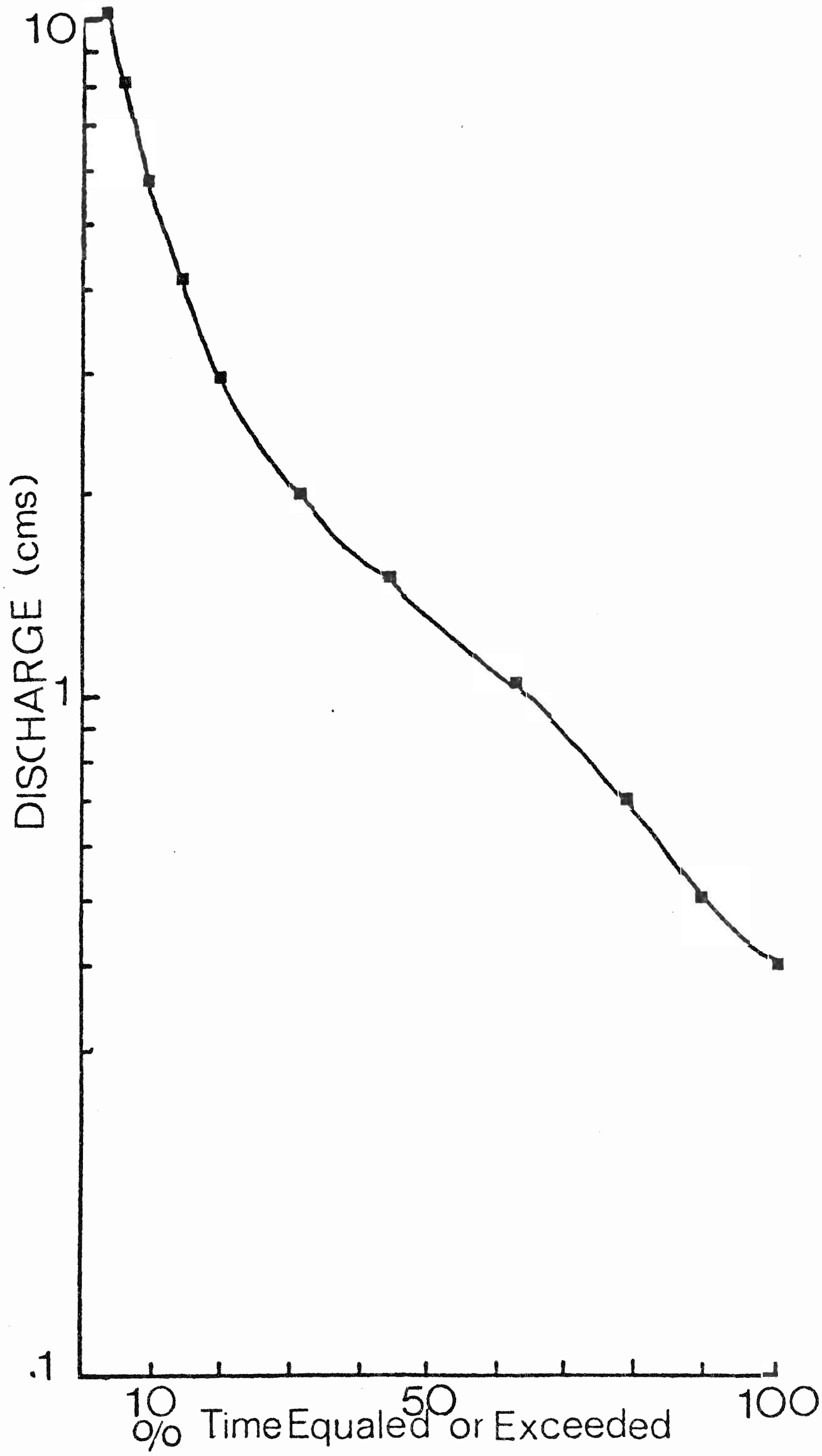


Figure 29. Flow duration curve for the Sixteen Mile Creek. (Data from Flint, 1982, personal communication)

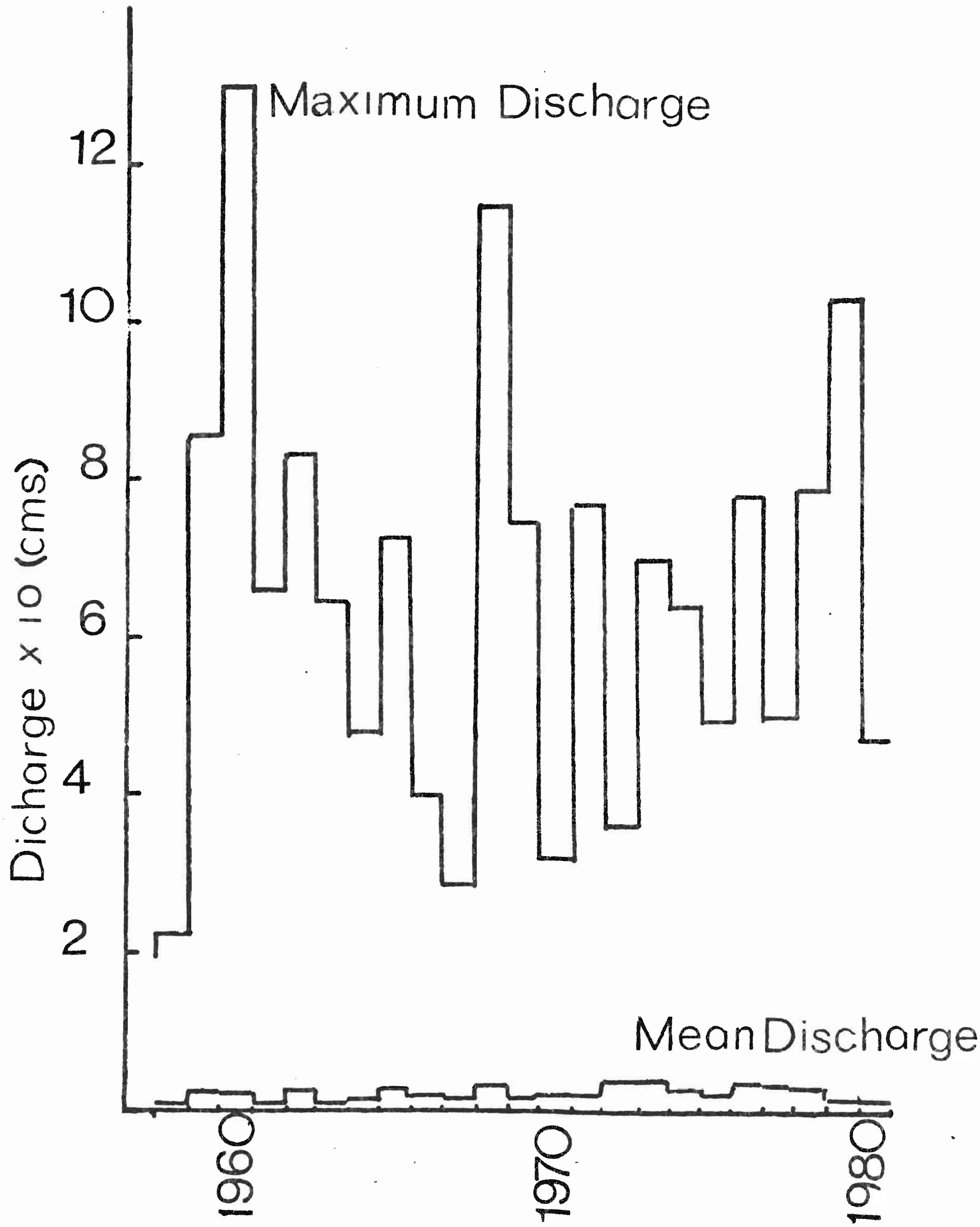


Figure 30. History of maximum and mean discharges on Twenty Mile Creek. (Ontario Inland Waters Directorite, 1980).

transported during flows that exceed these values. From the discharge frequency histogram, a cummulative flow duration curve was constructed using quarter day intervals (Figure 29).

Results from the sediment concentration-discharge relation (Figure 27) were compared to the data for two stations on Sixteen Mile Creek measured by Novakowski (1979). His upper station is located above the escarpment and the lower station is located below. Figure 31 shows that the lower station requires higher discharges to transport suspended sediment of similar concentrations. Between the middle and lower stations, sediment is being deposited due to changes in the channel morphology such as slope, width and depth which results in a loss of competancy.

The total amount of sediment entering the lagoon was determined by summing the amount of sediment for each discharge class from the discharge frequency histogram (Figure 28) (Table 9) using the relation between discharge and sediment concentration (Figure 27). The present rate of infilling of dry sediment in the lagoon on the Sixteen Mile Creek is calculated to be 14,486 metric tonnes.

Further analyses were conducted to determine the actual thickness of sediment currently being deposited in the lagoon. The total volume of sediment entering the lagoon was calculated using:

$$V = \frac{W}{D}$$

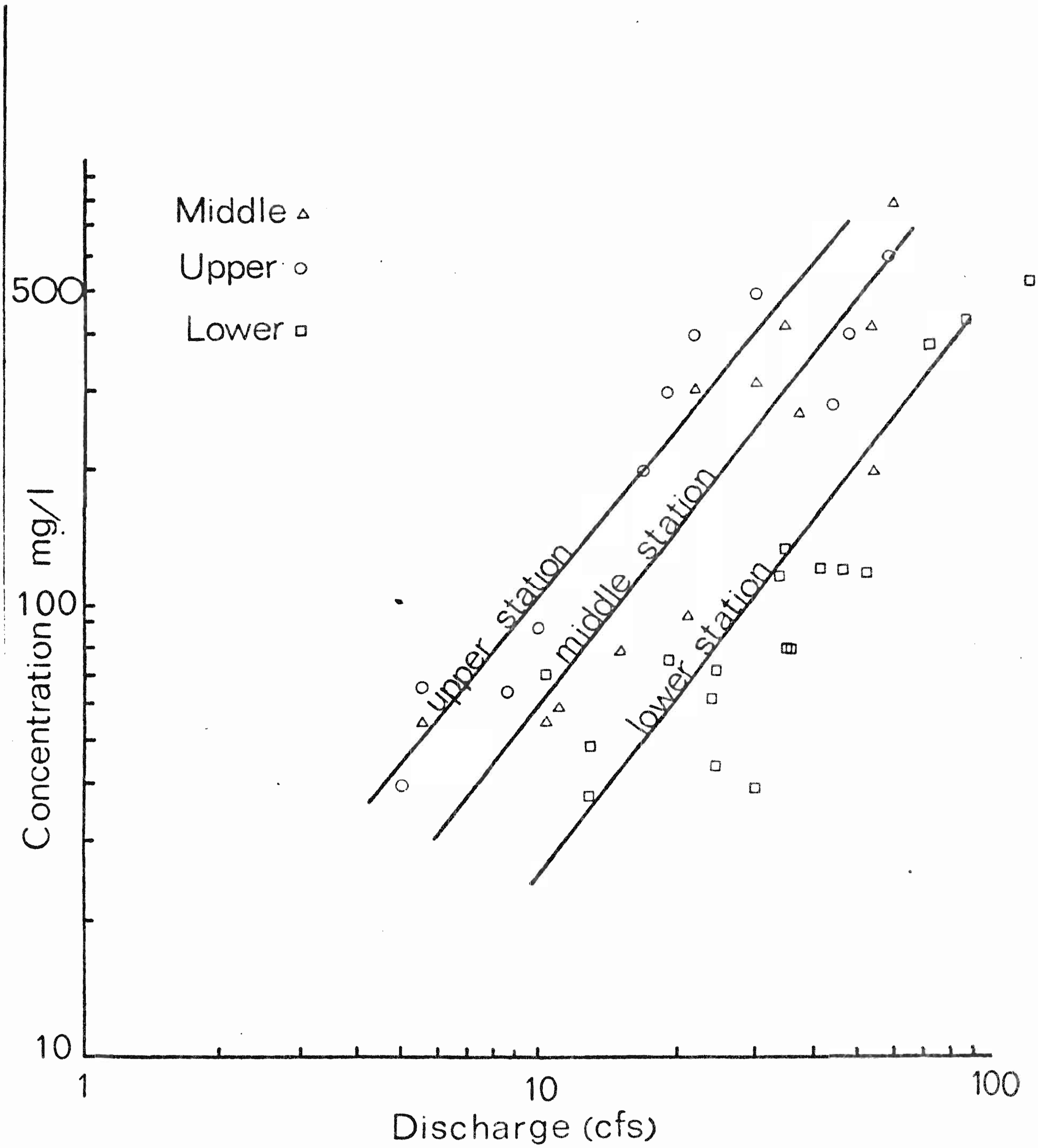


Figure 31. Sediment rating curve for three stations on Sixteen Mile Creek.

Table 9. SEDIMENT YIELD CALCULATIONS

Q	Freq.	Time	cu%	Con.	Wt.	Wt.
cms	1/4 day	sec.	Freq.	mg/l	kg	metric T
22.7	2	43,200	1	7200	7,048,166	7048
16.2	1	21,600	2	4600	1,604,664	1604
11.6	2	43,200	3	3000	1,504,656	1504
8.21	5	108,000	5	1900	1,684,692	1684
5.8	7	151,200	9	1250	1,098,090	1098
4.2	8	172,800	14	790	570,620	570
3.0	11	237,600	20	520	373,127	373
2.0	20	432,000	31	325	293,069	293
1.5	24	518,400	44	205	155,520	155
1.1	33	712,800	62	130	98,224	98
0.7	32	619,200	79	82	42,509	42
0.5	18	388,800	89	53	11,127	11
0.4	20	432,000	100	34	5,581	6
						14,486

Note: Definitions of abbreviations are: Q=discharge; cu%= cummulative percent; Con.= concentration of suspended sediment; T=tonnes.

Where

$V =$ Volume (cm^3)

$W =$ Weight (gm)

$D =$ density (gm/cm^3)

The average wet density of the Gray Clay was determined measuring the weight of thirteen samples of known volume. Results indicate that the average wet weight per unit volume is 0.92 gm/cm^3. The total dry weight of sediment previously calculated entering the lagoon (14,486 metric tonnes) was recalculated to include the moisture content of the uppermost layer of Gray Clay (130%). The total wet weight of sediment is 21,729 metric tonnes. From these data the volume of sediment entering the lagoon is 3.62×10^{10} cm^3.

By knowing the area of the lagoon (4.0×10^{10} cm^2) and the total volume of sediment being deposited, it is possible to calculate the thickness using:

$$T = \frac{V}{A}$$

where,

$T =$ Thickness (cm)

$V =$ Volume (cm^3)

$A =$ Area (cm^2)

Results indicate a wet thickness of 0.905 cm of sediment is being deposited each year at the current rate of input. This is similar to the post-settlement rate determined using stratigraphic information from the cores (1.02 cm/year).

Several assumptions were made in determining the rate of infilling using the suspended sediment and discharge data. It was assummed that all of the sediment brought to the lagoon was through the channel. The two small tributaries which enter the lagoon bring additonal sediment which was not included in the calculation. No data were available at the mouth of the lagoon; therefore, any sediment that entered Lake Ontario was not deducted from the estimate of 0.905 cm/year.

Geochemistry

Six samples from the lagoon on Sixteen Mile Creek were analyzed for 10 major elements; two samples were from the Gray Clay, one from the Brown Clay, two from the Gyttja and one from the Pink Clay. Three samples were from cores near the head of the lagoon and in the delta, and three were from near the mouth. The purpose of selecting samples from each end of the lagoon was to compare the distribution of elements along the lagoon.

The results (Table 10) show few differences between stratigraphic units and core locations. High values for SiO_2, Al_2O_3, Na_3O, and K_2O reflect the abundance of quartz and clay minerals in the sediment, the primary material composing

Table 10. SUMMARY OF MAJOR ELEMENT ANALYSIS FOR SIX SAMPLES FROM THE SIXTEEN MILE CREEK LAGOON (from Otto and Dalrymple,1981)

	D3/1	D3/10	D3/15	W1/9	W1/9	P12/7s3
SiO_2	69.20	71.20	71.50	62.58	66.72	69.28
Al_2O_3	13.59	13.89	13.18	17.13	15.08	13.47
MgO	1.53	0.98	0.95	1.92	1.04	1.23
Fe_2O_3	5.52	4.74	4.96	7.32	6.03	5.15
CaO	1.65	0.96	0.93	2.23	1.01	1.27
Na_2O	3.09	3.34	3.28	1.46	2.83	3.33
K_2O	2.78	2.73	2.69	3.55	3.26	2.83
TiO_2	0.93	0.91	0.89	1.02	1.01	0.87
MnO	0.07	0,07	0.00	0.04	0.07	0.07
P_2O_5	0.36	0.33	0.30	0.36	0.38	0.32
	98.72	99.15	98.68	97.61	97.43	97.81

Note: total iron expressed as Fe_2O_3

The first part of all sample numbers gives the core number: D3 comes from the head of the lagoon, and W1 and P12 from the downstream end. The stratigraphic units from which each sample was taken are as follows: D3/1- Gray Clay; D3/10-Gittja; D3/15-Pink Clay; W1/9-Gray Clay; W1/25-Brown Clay; P12/7s3-Gyttja.

the tills of the watershed (Feenstra, 1972). The low values for Ca and Mg possibly result from leaching of calcite and dolomite from surficial soils in the source area, and/or in situ dissolution.

Eight cores from the lagoon, 2 from the channel and 1 from the marsh of the Sixteen Mile Creek were analyzed for 5 trace elements. Appendix V summarizes the average results for each of the five units. Appendix VI summarizes all the geochemistry data. A total of 25 samples from 1 core obtained from the delta region of Twenty Mile Creek were also analyzed for these elements.

In the analysis of trace elements, an attempt was made to relate concentration to grain size to determine what fraction of the total sediment the elements are bound to. Figure 32 shows that in the Gray Clay, there is a positive relation between the concentration of both Ni and Zi and the mean grain size as expressed in phi units. The correlation coefficients for the two elements are 0.96 and 0.54 respectively. The Gyttja (Figure 33) shows similar, but weaker trends with the correlation coefficient being 0.52 and 0.22. The results suggest that the Ni and Zi are bonded to the clay size fractions of the sediment. An inverse relation exists between the concentration of calcium and mean grain size in phi units within the Gray Clay and the Gyttja (Figure 34). This suggests that the limestone and/or dolomite fragments are more abundant in the coarser fraction of the sediment. A plot of Cu and P against grain size show a wide scattering of the data indicating that no relation exists between these parameters.

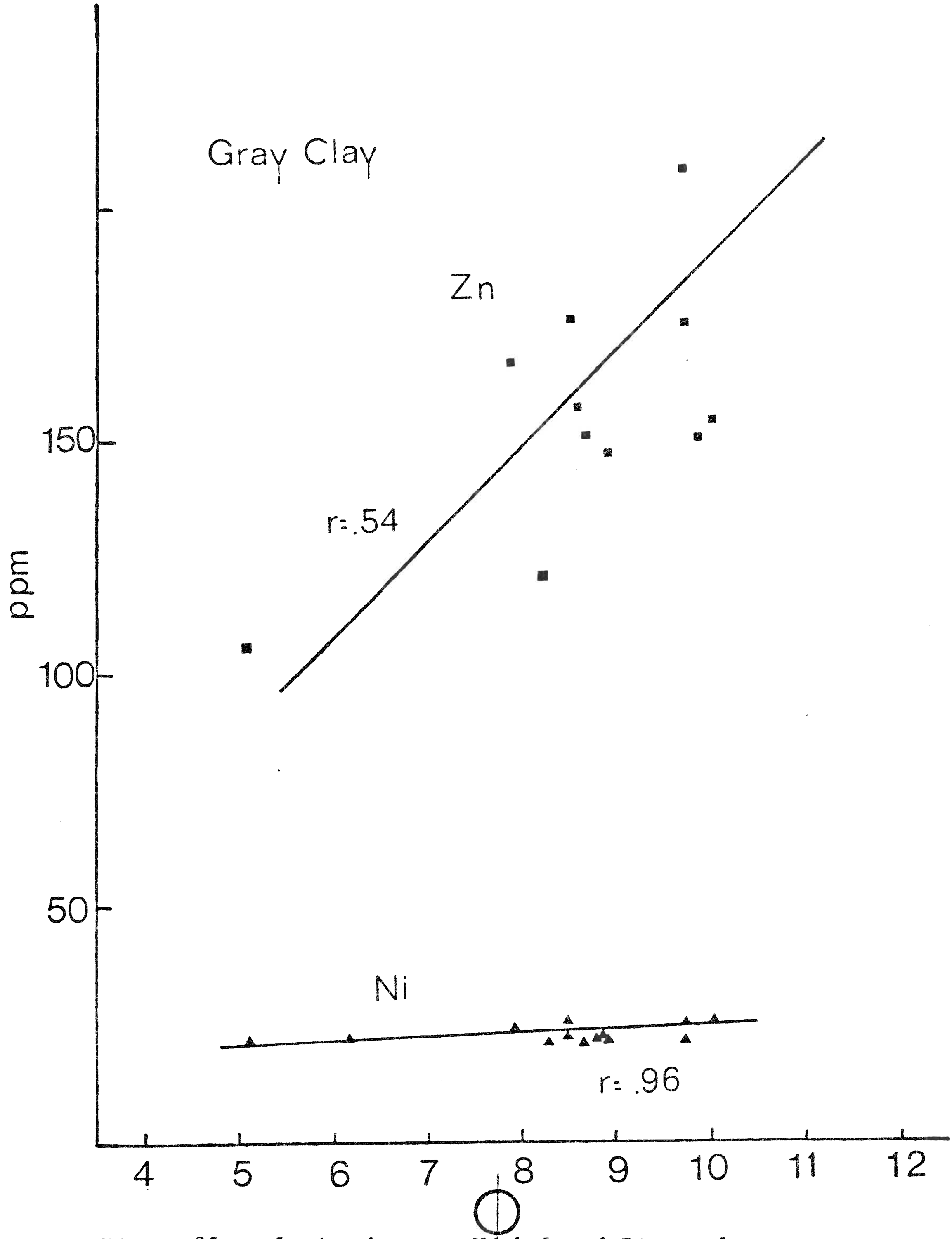


Figure 32. Relation between Nickel and Zinc and mean grain size in the Gray Clay.

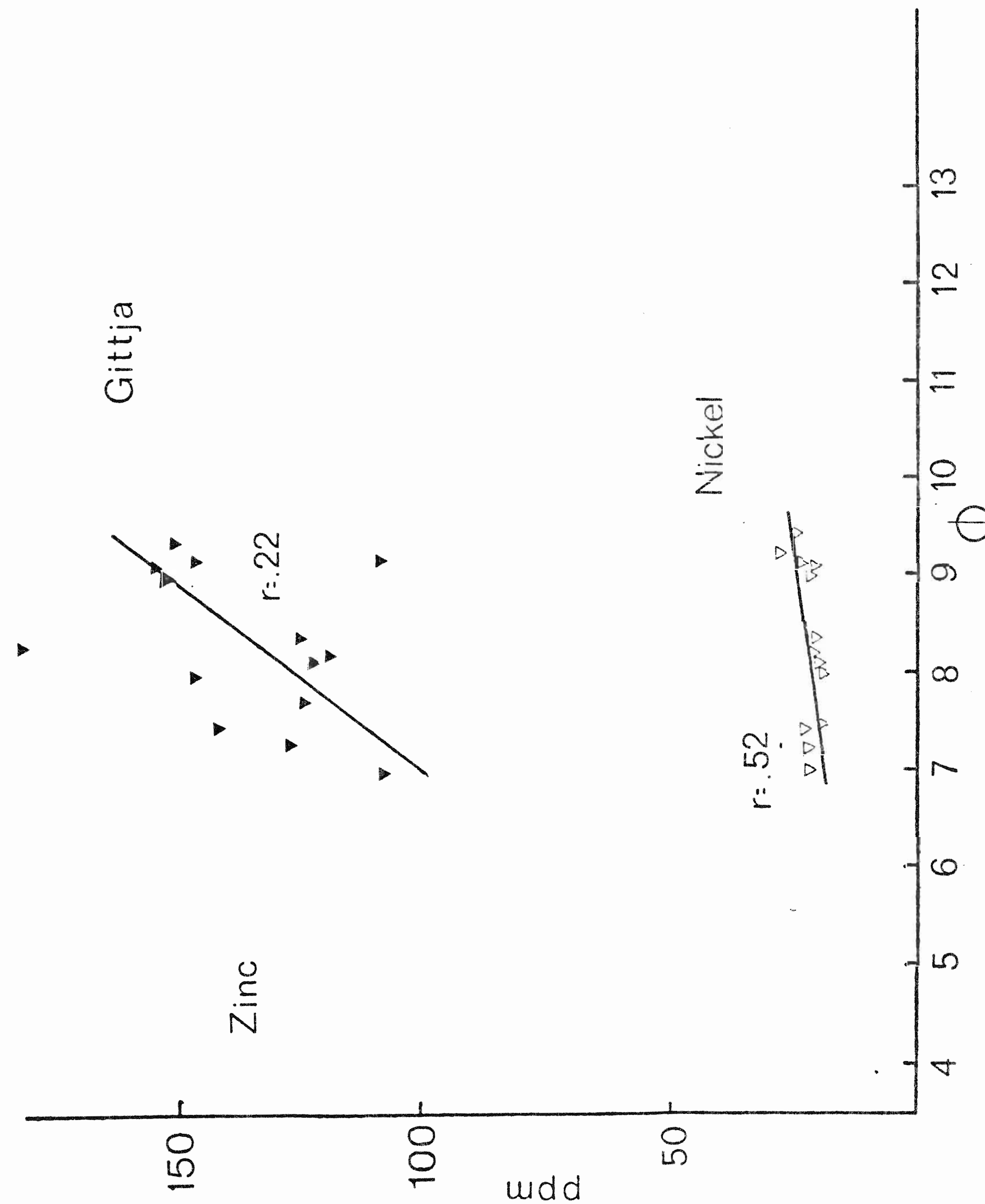


Figure 33. Relation between nickel and zinc and mean grain size in the Gittja.

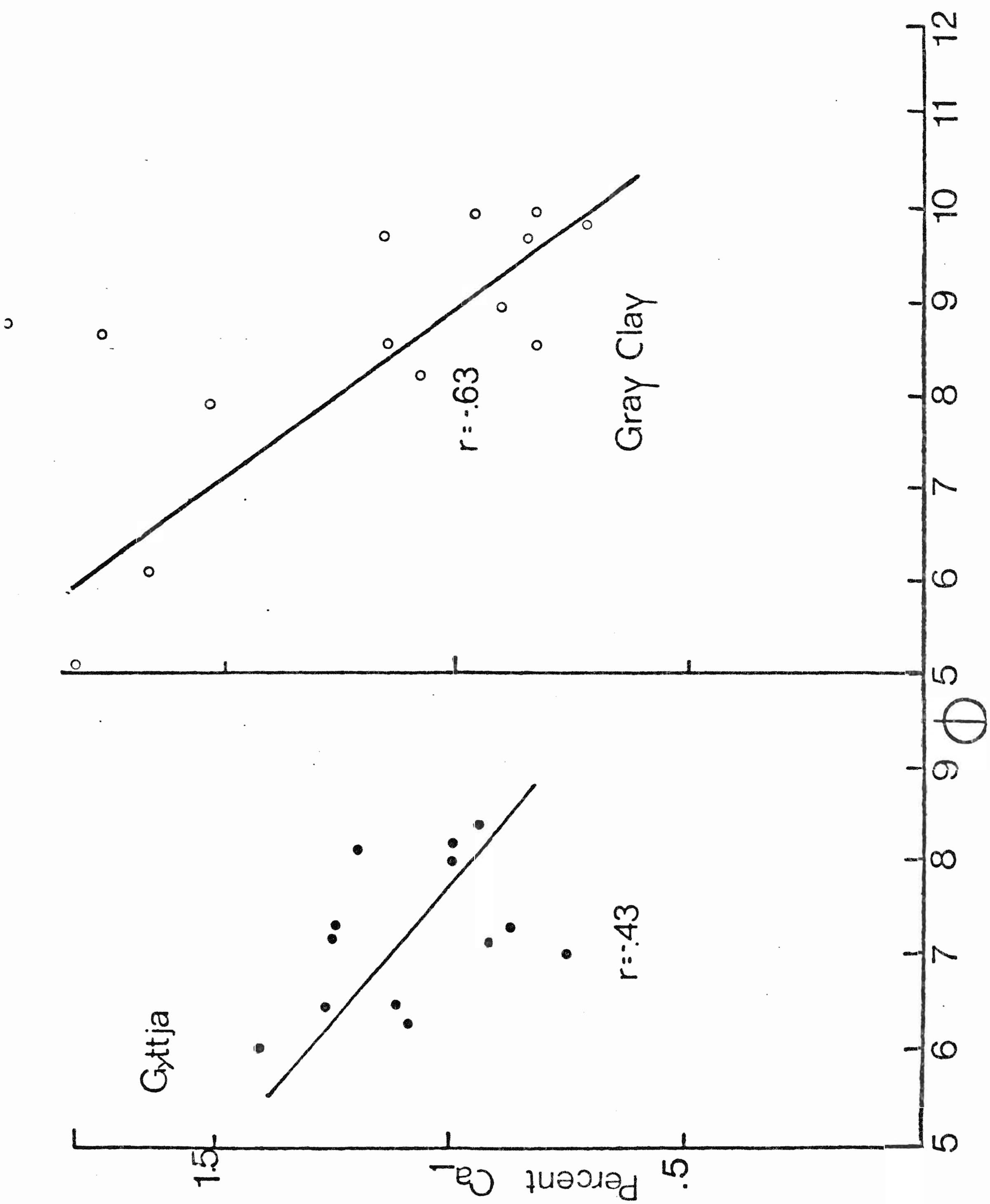


Figure 34. Relation between Calcium and mean grain size in the Gray Clay and Gyttja.

Each of the five trace elements was related to organic content. An analysis was conducted of all of the samples with respect to each element for three of the units, Pink Clay, Gyttja and Gray Clay. Generally results show a wide scattering of data. A weak positive relation between P and Ca and organic content were determined within the Pink Clay with correlation coefficients of 0.45 and 0.58 respectively (Figure 35). In the Gyttja a similar relation was determined, however significant variability occurs between the delta and lagoon. Further analysis of the data was conducted by examining only samples from local environments for each of the trace elements and again relating them to organic content. In the delta (cores D1, D2, D3,and D4), where the Gyttja is more recent in age, a wide range of concentrations occur between 0.8% and 1.8% for Ca and from 0.16% to 0.27% for P. Results from the delta also show that the correlation coefficient for Ca and percent organic is 0.84 whereas no relation exists between percent P and percent organic. In the lagoon, (core Q1) concentrations of Ca vary only between 0.9% and 1.4% while concentrations of P range between 0.20% and 0.27%. In this core, a strong positive relation is shown between both P and Ca and organic content with correlation coefficients of 0.92 and 0.97 respectively. Core R1 shows a positive relation between P and CA and organic content with correlation coefficients of 0.85 and 0.24 respectively. The results suggest that the Ca and P are bonded to the organic material but with significant local variations. No relation occurs between Ca, P and organic content in the Gray Clay however, nor was a relationship observed between Cu,

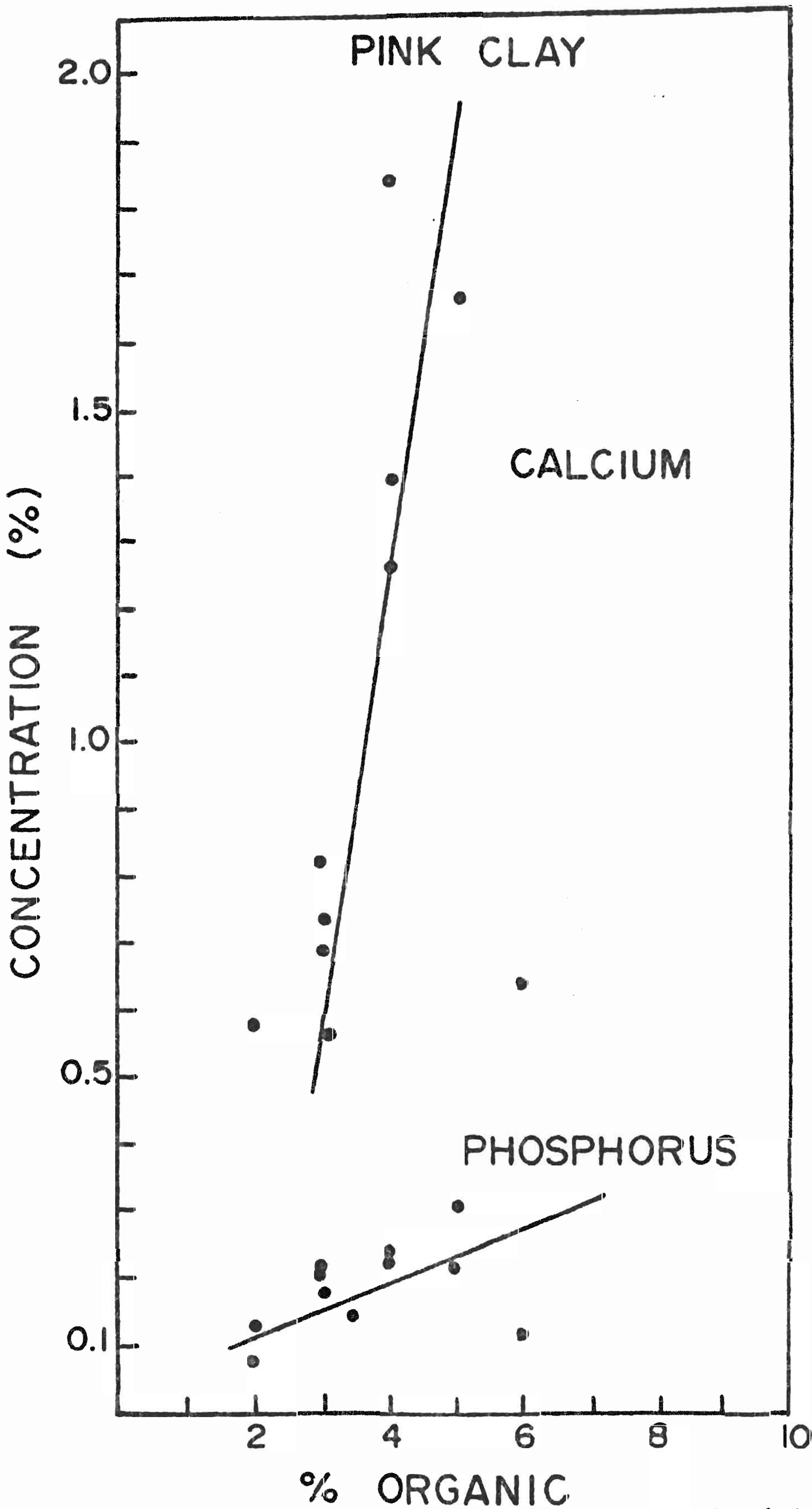


Figure 35. Relation between phosphorous and calcium and organic content in the Pink Clay.

Ni, and Zn and organic content in any of the units.

The average concentration of trace elements from the top 20 cm of surface sediment samples for the channel, marsh, delta and mouth regions on the Sixteen Mile Creek were compared (Table 11). This stratigraphic interval was chosen to represent the most recent accumulation of trace elements in these selected environments. Average concentrations were calculated for two channel cores, 1 marsh core, cores D1, D2, D3, and D4 from the delta, and cores P12 and W1 from the mouth (Figure 8). The single surficial sample from Twenty Mile Creek core was also used for comparative purposes. Table 11 also summarizes the concentration of trace elements for each of the same environments from Sixteen Mile Creek from the lower portion of the Gray Clay. These samples represent the "background" concentrations which occurred before man introduced chemical fertilizers and pesticides for farming activities and other chemicals used in industry. Results show (Table 11) that P does not vary greatly between any of the environments or between the upper surface and "background" averages.

Concentrations of Ca appear highest in the channel in both the upper sediment as well as "background" values (Table 11). The most likely explanation for these high percentages is that the coarse material found in the channel is rich in Ca. High concentrations of Ca also occur in the upper 20 cm sediment at the mouth. This indicates that the recent accumulation at the downstream end of the lagoon is possibly the result of an additonal source of Ca near the mouth. A large farm with a variety of livestock is located in this area possibly contributing additional Ca to the lagoon. Another possible source responsible for the increased Ca concentration is the salt from the Q.E.W.

The concentration of Zn with respect to downstream distance show trends which are similar in the upper 20 cm to the lower sediment profile, although generally, concentrations are slightly higher in the upper sediment. The longitudinal distribution of Zn may be due to the previously discussed relation between Zn and grain size,however; it is also possible that the high concentration of Zn which occurs at the mouth is result of automobile exhaust from the QEW. The concentrations which appear slightly higher in the upper 20 cm of sediment may have resulted from agricultural practices or from industrialization.

The distribution of Cu in the lower sediment profile appears to be fairly uniform throughout the lagoon. In the upper 20 cm of sediment, the concentrations appear generally higher and the distribution shows an increase with distance downstream. Since Cu does not appear to be related to grain size or organic content, the increase in the upper 20 cm near the mouth, may be the result of an additional source of input. One possible explanation for this is the affects of exhaust from traffic using the Q.E.W.

The distribution of Ni shows increases in concentration with distance downstream throughout the entire sediment profile. This is possibly due to the relation between Ni and grain size, however; it may also be due to another source which occurs at the mouth. The increase in the concentration of Ni may be caused from the automobile exhaust from the QEW.

Table 11. AEREAL VARIATIONS IN THE AVERAGE CONCENTRATIONS OF TRACE ELEMENTS WITHIN THE UPPERMOST 20 CM OF THE GRAY CLAY COMPARED TO THE LOWER SEDIMENT PROFILE ("BACKGROUND").

Environment		Phosphorous (%)	Calcium (%)	Zinc (ppm)	Copper (ppm)	Nickel (ppm)
Sixteen Mile Creek						
Channel	U	0.25	3.95	56.4	27.6	19.1
	L	0.24	2.06	92.8	35.2	20.6
Marsh	U	0.22	1.09	119.5	28.8	19.1
	L	0.21	1.97	94.4	47.2	20.2
Delta	U	0.24	1.22	147.4	58.7	21.7
	L	0.23	1.06	132.7	49.7	21.4
Mouth	U	0.23	2.19	181.2	63.0	25.4
	L	0.23	1.81	156.8	48.7	26.0
Twenty Mile Creek						
Delta		0.24	2.02	221.4	110.7	23.3

Definitions:U= upper 20 sediment of sediment; L=lower sediment profile values (background).

The variability of the longitudinal and vertical distribution of trace element concentrations in the Gray Clay may be partly the result of mans introduction of the carp to Lake Ontario in the 19th century (Scott and Crossman, 1973). These fish may have significantly influenced the distribution of elements in the upper sediment due to burrowing activities. The true changes in distribution and concentraton of these elements may not have been detected as a result.

The concentrations of Ca, Zn and Cu in the delta region of the Twenty Mile Creek are approximately twice as high as the concentration of those same elements in the Sixteen Mile Creek. This probably occurs because the drainage basin of Twenty is larger with a greater amount of industrial development and urbanization. In comparison, the concentrations of Zn and Cu are higher in Lake Ontario than in the Sixteen Mile Creek Lagoon (Kemp and Thomas, 1976). This illustrates the unpolluted nature of the Sixteen Mile Creek watershed. Twenty Mile Creek has higher concentrations of Cu than Lake Ontario indicating it has the capability of being an affective sediment trap.

In-core averages of the trace element concentrations were determined for the Gyttja, Bottom Sand and the Pink Clay and plotted against distance downstream. In the Gyttja, the downstream changes in concentration of P, Ca, and Cu are erratic showing no apparant trend. One possible explanation for the general downstream increases in the abundance of Zn and Ni is probably the relation between grain size and each of these two elements. In the Bottom Sand, the aerial variation of the

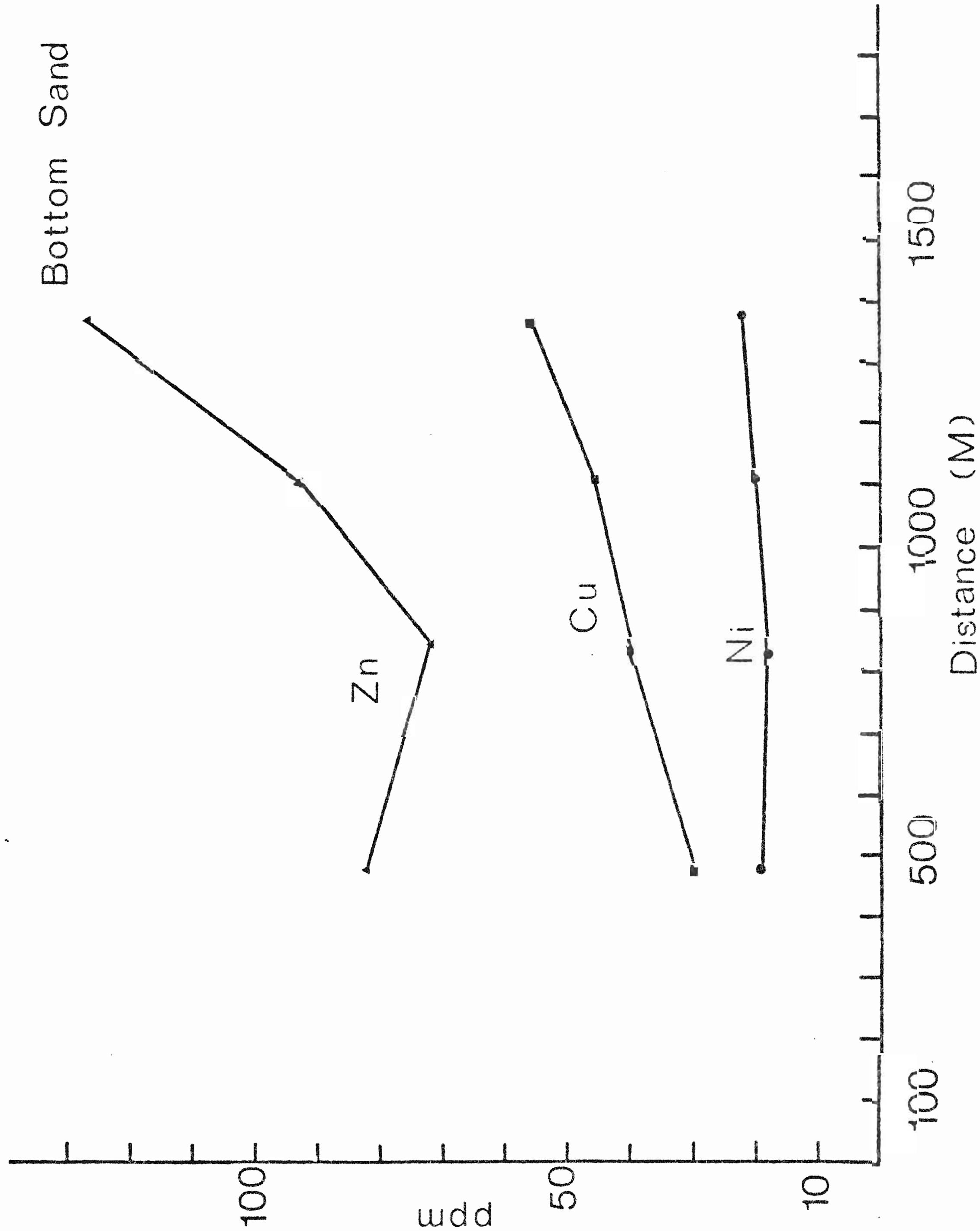


Figure 36. Downstream variation of Zn, Cu, and Ni in the Bottom Sand.

average concentrations of Zn, Cu and Ni show similar trends, all increasing in concentration near the mouth (Figure 36). The explanation for these increases of Zn and Ni have been previously discussed with the Gray Clay and Gyttja. These two elements appear to be bonded to the clay fraction of the sediment. In contrast to Ni, Cu and Zn, the concentration of Ca in the Bottom Sand generally decreases toward the mouth (Figure 37). This is explained by the grain size dependance of Ca and the downstream fining of this unit. The P appears to be evenly distributed throughout the Bottom Sand as it was in the Gray Clay and shows no apparent relation to grain size. The downstream changes in concentration of trace elements in the Pink Clay are erratic and show no apparent trends.

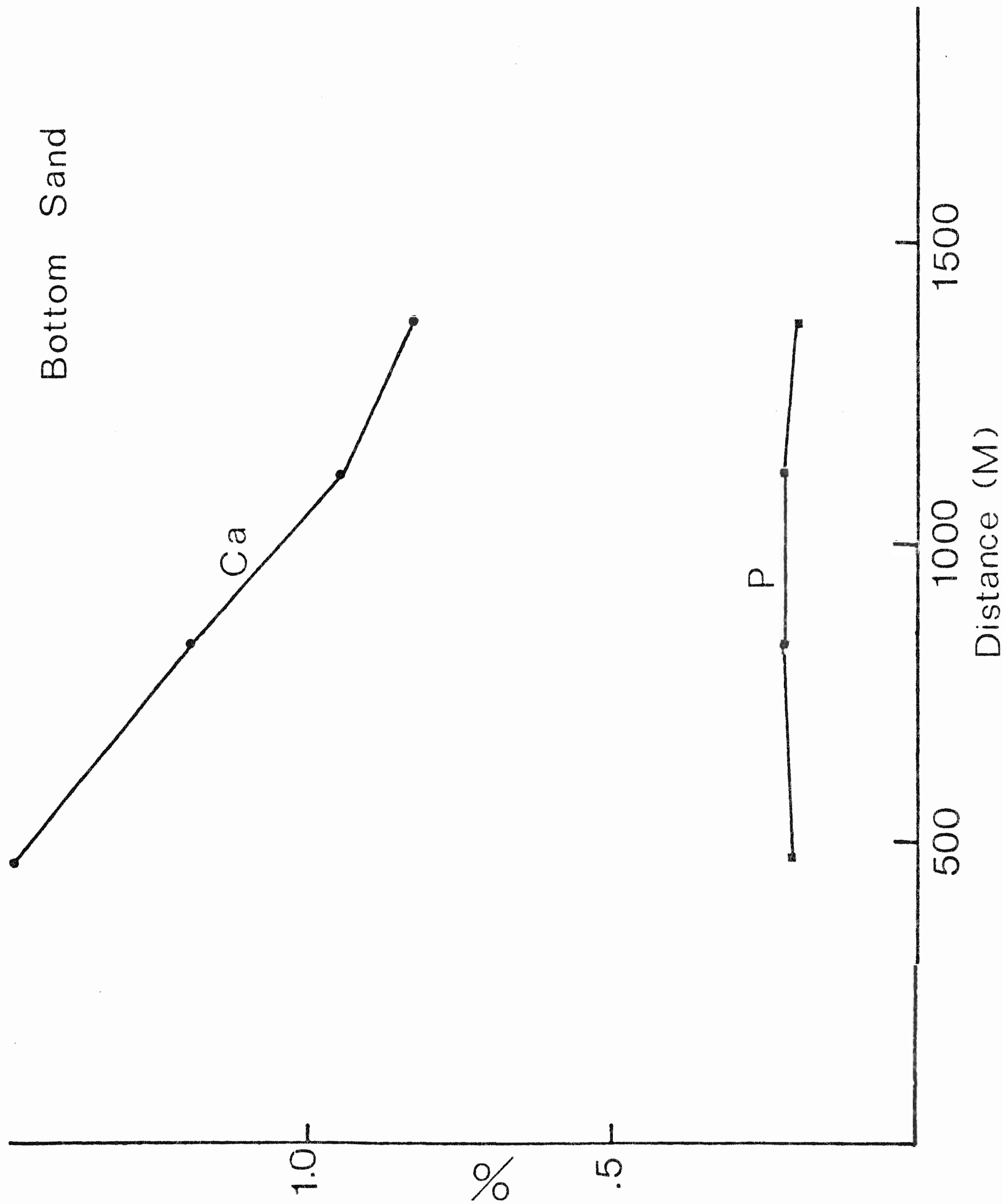


Figure 37. Downstream variation of phosphorous and calcium in the Bottom Sand.

Palynology

The pollen analyses had three primary objectives: (1) to locate the position of deforestation in the sediment for the calculation of recent sedimentation rates; 2) to aid in the interpretation of the depositional environment for each unit; and 3) to determine whether the clay layers in the Gyttja were the result of periodic flooding due to lake level fluctuations or seasonally produced high flows. The most abundant arboreal pollen are _Pinus_ (pine), _Fagus_ (beech), _Quercus_ (oak), _Acer_ (maple), and _Ulmus_ (elm). The percentages, although erratic, indicate a general upward decrease of hardwoods and a slight increase in _Pinus_ to a peak just below the Brown Clay-Gray Clay contact (Figure 39). This trend is similar to those found in other studies of fossil pollen in Southern Ontario (McAndrews 1976, 1972). The increase in _Pinus_ is dated as occurring in the 17th century and is believed to have resulted from one of two alternatives. McAndrews (1976) has discussed the affect of the activities of local Indians on the pollen record; results show that pine succeeded beech and maple on the abandoned corn fields. Thus the increase in pine reflects an increase in Indian agricultural forest clearing. Other studies suggest the _Pinus_ increase is a result of a climatic deteriortation (the Little Ice Age). All of the pollen show a decrease at the beginning of depostition of the Gray Clay as a result of poor pollen preservation either from bioturbation or oxidation.

Inconclusive results suggest that no relation exists

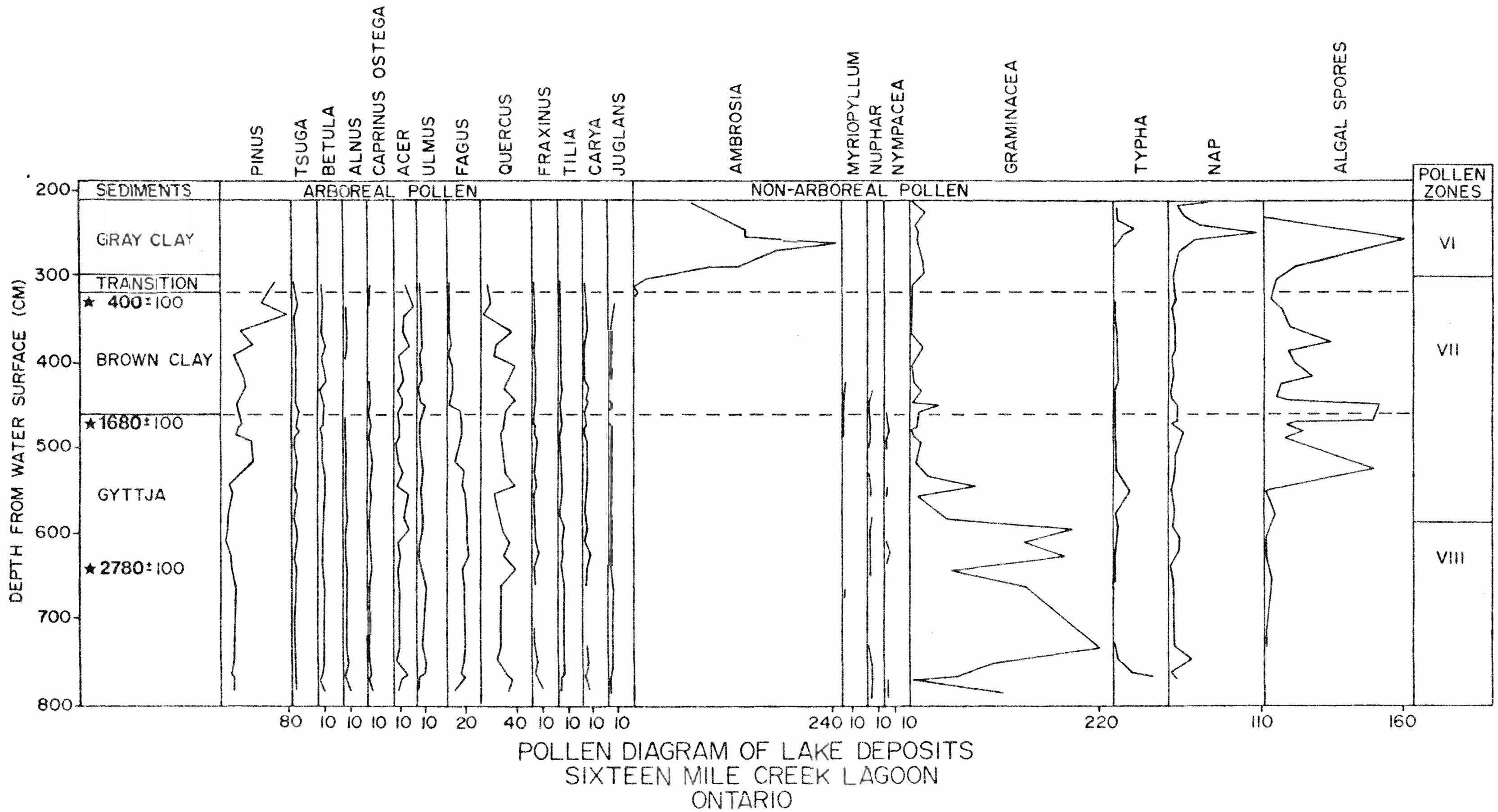


Figure 38. Pollen diagram for the Sixteen Mile Creek.

between clay layers in the Gyttja and abundance of aquatic pollen. This may be due to the typically low production of pollen from the aquatics or the results of poor pollen preservation. however, the non-arboreal pollen shows high concentrations of *Graminaea* (grass) pollen decreasing upward in the Gyttja as the number of algal spores increase suddenly (zone 2; Figure 39). Selected samples from core S1 were sent to J. Smol (Dept. of Biological Sciences, Queen's University) for a diatom analysis. Smol (personal communication, 1983) qualitatively assessed the relative quantity of benthic and pelagic diatoms. He found a higher percentage of benthic diatoms in the Gyttja; however near the contact between Brown Clay and Gyttja, he found a transition with an increase in pelagic diatoms such that in the Brown Clay the majority were pelagic. This supports the deepening explanation for the origin of the Brown Clay. The high percentage of *Graminaea* pollen in the Gyttja clearly indicates a marshland environment. A local restricted wetland characterized by a high production of grass may have been completely surrounded by a forest canopy.

Figure 39 shows that the *Ambrosia* (ragweed) rise occurs between 5-30 cm above the Brown Clay-Gray Clay contact. This is below the charcoal horizon previously shown on Figure 25. Because the Gray Clay is a highly bioturbated unit, the affects of bioturbation on the *Ambrosia* rise were investigated. Generally bioturbation broadens the peakwithou actually shifting the center. (Dickman, 1982, personal communication)

Studies by McAndrews (1972) and McAndrews and Power (1973)

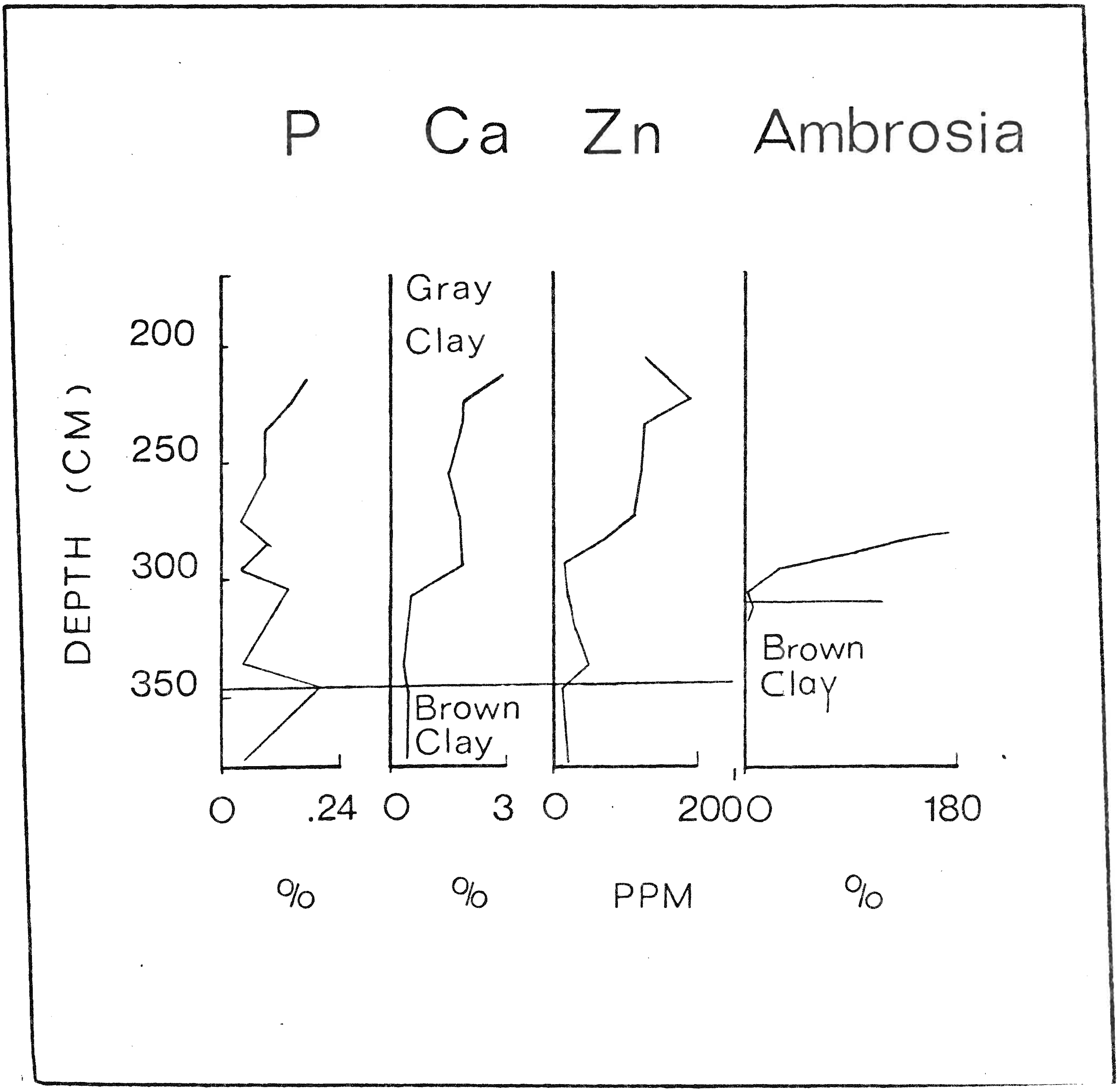


Figure 39. Vertical distribution of Phosphorous, Calcium, Zinc and Ambrosia. Data were obtained from core P-12 for the chemical analysis and pollen data were obtained from core S-1.

have shown that a time lag occurs between deforestation and the *Ambrosia* rise. Settlement in southern Ontario started in the 1790's. The *Ambrosia* rise has been dated at 1850 A.D. in southern Ontario (McAndrews and Boyko, 1972). This is a 60 year time lag from the start of European settlement.

Diagenetic changes were observed within the pollen from samples in the Gyttja and Brown Clay. These changes occur as pyrite crystals in the pollen and other organic debris. The abundance of pollen and the presence of pyrite in the Gyttja and Brown Clay implies that the environment was stagnant and reducing (Garrels and Christ, 1965). In the Gray Clay, pyrite was not present in the pollen. This coupled with the poor preservation of the pollen, indicates a change in conditions to a more oxidizing environment.

Stratigraphy of the Twenty Mile Creek Lagoon

Two deep cores and one shallow core were collected from the lagoon on Twenty Mile Creek (Figure 9B). The stratigraphic units identified are similar to the units present in Sixteen Mile Creek Lagoon. From the base up, these units have been called (1) Clay, (2) Sand, (3) Gyttja, (4) Brown Clay, and (5) Gray Clay. The "Bottom" Clay, which was reached in only one deep core (C11), is a dense, light grayish pink clayey silt. The average mean grain size is 6.0 phi with 19% sand, 61% silt and 20% clay. The average organic content is 5%. Based on similarities in stratigraphic position, colour, grain size and organic content, it is correlated with the Pink Clay on Sixteen Mile Creek. This unit has been interpreted as a glacial or post-glacial lacustrine deposit of regional extent. The contact between the clay and sand above is abrupt and marked by a change in color and texture.

The sand is a fine to medium-grained, silty, clayey sand which was only encountered in core C11. It has an average mean grain size of 4.2 phi and consists of 55% sand, 25% silt and 20% clay with an average mean organic content of 8%. Based on the stratigraphic position and similarity to the "Bottom Sand" of Sixteen Mile Creek, this unit has been interpreted as fluvial or fluvial-deltaic in origin. The upper contact of the sand is gradational with a trace of organic material occurring in the sand while sand layers are present near the base of the overlying Gyttja.

The Gyttja from the lagoon on Twenty Mile Creek has similar characteristics to the Gyttja on Sixteen Mile Creek. It is a Brown Clayey silt which contains alternating clay- and organic-rich lamina ranging from 13-20% in organic content. The average mean grain size of the clastic component is 8.3 phi with 4% sand, 51% silt and 45% clay. The coarse nature of this material may be due to the position of core C11 which was obtained near the head of the lagoon. Moisture content ranges between 12-90%. The average thickness of this unit is 319 cm. Based upon radiocarbon dating results from Flint (personal communication, 1982), rates of deposition were calculated for the Gyttja. The average rate of deposition in the lower Gyttja is 0.26 cm/year, increasing to 0.65 cm/year near the top of the unit. The contact between the Gyttja and the Brown Clay above is marked by a decrease in organic content. Radiocarbon dating of a sample obtained near the base of the Gyttja in core C11 gives an age of 1940 years B.P.

The Brown Clay, contemporaneous with the upper part of the Gyttja, is a uniform silty clay obtained only in core T1 near the mouth of the lagoon (Figure 9B). A similar distribution was documented for the Brown Clay of the lagoon from Sixteen Mile Creek. Grain size analyses and organic content were not determined for this unit because it was not present in the core that was used for these analyses. The approximate thickness of this unit is 85 cm. Radiocarbon dating was conducted on a sample at the base of the Brown Clay in core T1. Results indicate that deposition began 1640 years ago; this is approximately equivalent to the age obtained from the bottom of the Brown Clay in the Sixteen Mile Creek Lagoon. The rate of sedimentation for the Brown Clay on the Twenty Mile Creek Lagoon is 0.08 cm/yr. This was determined by assuming that deposition of the 85 cm of Brown Clay occurred between 1640 years B.P. and 440 years B.P. This is slightly less than the 0.12 cm/yr value calculated for the Sixteen Mile Creek .

The Gray Clay is a bioturbated silty clay that covers the entire floor of the Twenty Mile Creek Lagoon, overlying both the Brown Clay and the Gyttja. It has a fairly uniform thickness of 58 cm. Moisture content varies between 32-53%. It was determined using the same method described for samples from Sixteen Mile Creek, that the upper 40 cm of sediment would compact 20%. The average mean grain size is 7.9 phi, and it has an average organic content of 5%. By comparison, the average compacted thickness near the mouth on Sixteen Mile Creek is 122 cm. The lower value on Twenty may be due to a greater proportion of sediment being carried through the lagoon and deposited in Lake Ontario. Another possible explanation for this unusually low thickness may be the dredging in the Jordan Harbour. Radiocarbon dating shows that the deposition of this unit began after 440 ± 100 years B.P. in core T1. This is consistant with dates obtained 35 cm below the base of the Gray Clay on Sixteen Mile Creek. Sedimentation rates corrected for compaction give values of 0.33 cm/year compared to 1.02 cm/year on the Sixteen Mile Creek.

Stratigraphy of Fifteen Mile Creek Lagoon

Only short cores were obtained from the lagoon of Fifteen Mile Creek (Figure 9A), one each from the delta, near the center, and at the mouth. Three stratigraphic units have been identified based on colour, organic content and grain size. From the base up, they are (1) Gyttja, (2) Brown Clay, and (3) Gray Clay.

Only the top of the Gyttja was reached in the shallow cores. It is similar in colour and texture to the Gyttja from the lagoons on Sixteen and Twenty Mile Creek: Analyses of 2 samples give a mean grain size of 8.6 phi with 1% sand, 37% silt, and 62% clay, and an average organic content of 13%. The upper contact of this unit is characterized by a decrease in organic content. The overlying unit in cores 2 and 3 is Gray Clay; however, in core 1 the overlying unit is Brown Clay.

The Brown Clay of Fifteen Mile Creek appears to have a similar areal extent to the Brown Clay of the Sixteen and Twenty Mile Creek Lagoons as it was encountered only near the mouth. Analysis of this unit indicates a mean size of 8.9 phi with 0.5% sand, 35.5% silt and 64% clay and an average organic content of 6%. It has a thickness of 19 cm. The contact between the Brown Clay and overlying Gray Clay is marked by a change in colour.

The Gray Clay occurs in all three cores. Grain size analyses give a mean size of 9.0 phi with 31% silt and 68% clay, and an average organic content of 7%. These values are similar to those for the Gray Clay in the Sixteen and Twenty Mile Creek Lagoons. As in the other lagoons, the Gray Clay also shows extensive bioturbation. Examination of organisms recovered from the sediment reveals that they are larvae of *Donatia* (M.Dickman, personal communication, 1982) which is a type of beetle that feeds on the submerged underground stems and roots of aquatic plants such as *Nymphaea* (lily), *Sagittaris* (arrow-head), and *Potamogeton* (pondweed) which are abundant throughout this lagoon, in contrast to the other two. The thickness of the Gray Clay is about 40 cm in cores 1 and 3, and 13 cm in core 2. Radiocarbon dating of a sample obtained from just below the base of the Gray Clay (within the Gyttja) indicated that deposition began shortly after 480 ± 100 ^{14}C years ago, giving an average deposition rate of 0.09 cm/year. It appears that this unit clay, began synchronously in all three lagoons.

DISCUSSION

The stratigraphic correlations between the three lagoons and the synchroneity of events indicate that their historical developments must have resulted from regional environmental factors. These factors include lake level changes, variations in runoff due to climatic changes, the affect of isostatic rebound and deforestation for agricultural or lumbering purposes. These changes are reflected in the physical, chemical and biological characteristics of the sediment.

The textural and compositional similarities of the Bottom Clay in the Sixteen and Twenty Mile Creek Lagoons and the presence of diatoms and sponge spicules suggest a regional, glacial or post-glacial lacustrine origin for this unit. Although the exact age is unknown, analysis of the overlying unit indicate that the Bottom Clay was deposited at least prior to 3250 years ago during a period of higher lake levels.

The Pink Clay-Bottom Sand contact probably represents an unconformity which was produced when Lake Ontario was at a lower level. As lake level began to rise, the deposition of sand occurred as the delta transgressed. The relatively coarse texture of this sediment relative to the modern channel sand, indicates that the Sixteen Mile Creek had a greater competancy than at present. The actual affect of the capture on the Sixteen and Twenty Mile Creek Lagoons is shown by the opposite trends of sedimentation rates of the Gyttja in the two lagoons. In the Sixteen Mile Creek Lagoon, the lower Gyttja had a rate of 0.36 cm/year which was then reduced to 0.19 cm/year. On Twenty Mile Creek Lagoon, the lower Gyttja had an accumulation rate of 0.26 cm/year with an increase to 0.65 cm/year near the top.

The overlying Gyttja is a time-transgressive unit which was deposited in a shallow, stagnant, organic-rich environment. The allochthonous leaf material in this unit combined with the abundant grass pollen suggests that a dense forest canopy surrounded a grassy wetland. The high concentration of benthic organisms in the Gyttja further supports a shallow water environment. This setting must have been reducing after deposition as indicated by the formation of pyrite crystals in the organic matter and the preservation of pollen. Deposition of Gyttja in the Sixteen Mile Creek began 3250 years ago at the mouth and prior to 3300 years ago at the mouth of the Twenty Mile Creek Lagoon. In the delta region of Sixteen Mile Creek, deposition of this unit began 810 years ago. The transgression resulted from rising lake levels which caused stream aggradation. Evidence for this is shown in the delta cores where the ancient alluvial sediments have a relatively thin overlying deposit of Gyttja while the thickness of this unit increases toward the mouth. Two possible reasons for this rise of Lake Ontario are discussed below. Rising lake levels may be primarily the result of differential isostatic rebound of the northeastern rim of Lake Ontario however, the rise which initiated deposition in the lagoons began approximately at the same time as erosion of the St. Clair Outlet caused a drop the level of Lake Huron (Lewis, 1969).

Thus, the resulting increased flow through the lower Great Lakes may have contributed to the rise at this time. The deposition of Gyttja ended approximately 1640 years ago at the downstream end of the lagoons while Gyttja continued to be produced throughout the remaining wetland and over the newly submerged areas upstream.

Evidence suggests that the Brown Clay is a result of additional deepening. The diatom analysis indicates that a high concentration of pelagic organisms occur in this unit which is separated from the underlying Gyttja by a transition zone that contains both benthic and pelagic diatoms. Additional evidence which suggests gradual deepening include a progressive upward decrease in organic content (Figure 22), and a decrease in the concentration of *Graminacea* pollen (Figure 38). Thus as the water levels continued to rise, the distal portion of the lagoon became flooded producing an open water environment in which the Brown Clay formed, while simultaneously upstream, dry low-lying areas became grassy wetlands where Gyttja was deposited. Sedimentation rates in the Brown Clay on the Sixteen Mile Creek average 0.19 cm/year, similar to the rate of the upper Gyttja (0.15 cm/year).

The inception of the Brown Clay corresponds closely to the end of the climatic episode known as the sub-Atlantic (Table 4), but the affect of this change in the climate has not been conclusively determined in southern Ontario. It is evident however from the analysis of the Brown Clay that this unit is the result of a rise lake level possibly produced by increased precipitation.

The most recent event in the lagoon's history resulted in the onset of deposition of the Gray Clay. Although the exact date of this is not known, it has been determined to have begun between 1734 and 1834 based upon average sedimentation rates of the Brown Clay. Additional supporting evidence include the *Pinus* peak indicating that it post-dates the 17th century (McAndrews and Boyko, 1972), and the Ambrosia rise which pre-dates 1850 (McAndrews and Boyko, 1972). The origin of the Gray Clay is believed to be related to the colonization and deforestation of this region which increased the quantity of sediment entering the lagoon by about five times over the previous rate. At this time, changes in the colour, organic content, and geochemistry of the sediment also occurred. The transition from brown to gray corresponds to greater amounts of soil sediment from the c horizon. Organic content was reduced as it was diluted by the increased input of clastic material as a result of deforestation. The changes in the concentration of trace elements occurred soon after the beginning of the Gray Clay deposition. Increases in Ca and Zn occurred simultaneously with the increase in *Ambrosia* (Figure 39), suggesting that the affect is possibly related to post-colonization activities and use of chemical fertilizers and the affect of the Q.E.W. Furthermore, another post-colonization change in the Gray Clay is the upward increase of bioturbation. Studies by Scott (1974) have shown that carp, disturb the bottom sediment during feeding and breeding activities. The presence of carp in the lagoon at Sixteen Mile Creek indicates that they could be the cause of bioturbatio.

The construction of the weir at the mouth of the Sixteen Mile Creek Lagoon at the time when the Q.E.W. was built had a significant affect on the water level and caused the transgression of the Gray Clay over the marsh. At the head of the lagoon, land which had been farmed previously became inundated.

SUMMARY AND CONCLUSIONS

The three small lagoonal complexes studied along the northern shore of the Niagara Peninsula, Lake Ontario, have similarities in morphology, sedimentation characteristics and historical development. Each complex is separated from the lake by a barrier bar produced by wave action. The open water environments of the three lagoons are characteristically deeper near their mouths. The recent bottom sediments (Gray Clay) are similar in color, texture and organic and moisture content. This gray silty clay has a relatively low organic content and high moisture content. Water depths decrease toward the headward sections of the lagoons where coarser deltaic deposits occur. Aquatic plants such as waterlilies, arrowheads and pondweed grow in this environment. The marsh rises up to 0.5 m higher than the delta and is thickly vegetated with cattails and sedges in the wetter parts, while grasses dominate the higher headward portion. Sediments of the marsh are primarly silts and clays. The channel which meanders through the marsh has bottom sediments composed of laminated gravels, sands and clays.

The general sequence of sediments recovered from cores in the lagoons, from base up are Till, Clay, Sand, Orange Sandy Silt, Gyttja, Brown Clay and Gray Clay. The till was deposited during the Port Huron advance approximately 13,200 years ago. It is presumed to occur beneath the entire area. Erosion of the till is presumed to occur before the onset of the overlying clay. The clay is possibly a Pleistocene or post-Pleistocene lacustrine deposit present at least on the Sixteen and Twenty Mile Creek Lagoons. The Holocene sediments have been deposited over the last 3,250 years and reach a maximum thickness of 5.5 m on the Sixteen Mile Creek. Of these, the sand is a fluvial/deltaic deposit which was laid down when Lake Ontario was at a lower level. It is present in the lagoons of both Sixteen and Twenty Mile Creek Lagoons and in the marsh of Sixteen Mile Creek. The Orange Sandy Silt was recovered only in the marsh of the Sixteen Mile Creek. It has been interpreted as being a buried soil horizon, possibly the upstream equivalant of the Gyttja. The thickest unit of the five Holocene sediments is the Gyttja, a time transgressive organic rich, silty clay which was deposited in a stagnant, shallow water environment. Deposition of this unit continued until the onset of the Brown Clay at the downstream end of the lagoon approximately 1680 years ago. More recently in the headward reaches, the Gyttja was submerged by the Gray Clay approximately between 1734 and 1834. Vertical changes in relative sedimentation rates in the Gyttja may be attributed to the capture of the Sixteen Mile Creek by Twenty Mile Creek between 1500-2000 years ago. On the lagoon of the Sixteen Mile Creek, the lower Gyttja has a deposition rate of 0.35 cm/year and 0.15 cm/year near the top. In comparison, the lagoon on Twenty Mile Creek has a deposition rate of 0.26 cm/year in the lower Gyttja, increasing to 0.65 cm/year near the top. An additional feature in the Gyttja that may have resulted from the stream capture is the upward increase of organic content on the Sixteen Mile Creek concurrently with the upward decrease of organic content on Twenty. This infers that less clastic sediment was deposited in the lagoon at Sixteen Mile Creek relative to the input of organic material as a result of the decrease in drainage basin area and stream capacity. Deposition rates for the Gray Clay are up to five times the rate for the Brown Clay.

The primary controlling factors in the characteristics of the lagoon sediment have been environmental changes caused particularly by rises in lake level at rates higher than the deposition. This rising lake level may be related to differential isostatic rebound of the Ontario Basin but additional factors, which may have affected the sedimentation in the lagoons, are also suggested to account for the synchroneity of the transition between units.

Changes in upper Great Lakes drainage may be one such factor. The beginning of Gyttja deposition closely corresponds in time to a drop in the level of Lake Huron produced by erosion of the St. Clair Outlet. This drop in Lake Huron caused a simultaneous rise in the level of the lower lakes as a result of the increased through-flow, possibly flooding the mouths of creeks entering Lakes Erie and Ontario.

Climatic changes may also have had an impact on lake levels. The transition of Gyttja to Brown Clay occurred about 1640 years ago on all the three lagoons, suggesting a common cause. This time corresponds closely to the end of the sub-Atlantic climatic episode (1675 years B.P., Bryson and Wendland, 1970). Further investigation of the affect of climatic changes on lake levels is warranted.

The recent, 18-19th century, activities of European settlers caused a 5 fold increase in the input of clastic material, and virtually stopped the input of organic matter (leaves and other forest debris) as a result of the clearing of land for lumber and agriculture purposes. A change in the colour of the sediment occurred possibly as a result of deforestation and corresponds to the gray parent material. The decrease in organic material produced more oxygenated conditions resulting in poor pollen preservation and the end of reducing conditions which characterized the Gyttja. The introduction of the carp to Lake Ontario (and thus to the Sixteen Mile Creek) in the late nineteenth century may have contributed to the highly bioturbated nature of the upper Gray Clay. The lower portion of this unit which is laminated and shows no signs of bioturbation, was probably deposited before the introduction of the carp.

Increases in trace element concentration were determined in recent deposits of the Gray Clay. Sediments from the lagoon on Sixteen Mile Creek are relatively unpolluted while sediments from the lagoon on Twenty Mile Creek have higher concentrations of the same trace elements. The distribution of trace elements shows that, except for calcium, the other elements are more commonly attached to the fine fraction of the sediment or to the organic material. The highest concentrations of trace elements generally occur in either the delta or in the lagoon near the mouth. Zn and Cu occur in the highest concentrations near the mouth with secondary high levels occurring in the delta. This implies that there are several sources, the Q.E.W., local affects due to farming and river transported material. The actual amount of stream-born pollutants that remain trapped in the lagoon is unknown. There is little difference between trace element concentration in the Sixteen and Twenty Lagoons and Lake Ontario. The relatively higher concentration of Cu in the Twenty Mile Creek Lagoon, however, implies the the lagoons may be traps for such pollutants.

Results from the sediment discharge analysis show that the rate of sedimentation approximately equals the long term rate even though the water discharge was relatively low. This strongly suggests that a sizeable fraction of sediment is trapped in the lagoon.

This study also showed that the lagoonal subenvironments are extremely sensitive to lake level change and to the impact of man's activities. Ancient sediments can, therefore, be used to make interpretations of past environments and to trace the historical development of such complexes.

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APPENDICES

Appendix I. Grain Size Analysis Summary of Samples

(StDe=standard deviation; Sk=skewness; Kurt=kurtosis; GC=Gray Clay; G=Gyttja; S=Sand; PC=Pink Clay)

	Unit	% Sand	%Silt	%Clay	Mean	StDe	Sk	Kurt
Core M1								
Sample 1s1		5	70	25	6.75	1.85	0.1351	0.6216
1s6		3	61	36	7.85	2.65	0.2453	0.8113
2s3		0	58	42	7.65	2.65	0.0943	0.4131
3s1		3	56	41	-	-	-	-
5s1		11	56	33	7.90	3.50	0.4286	-
7s1		9	55	36	7.65	3.15	0.2063	-
8s1		14	56	30	7.25	3.05	0.4096	-
Core R2								
Sample 1s1	GC	4	22	74	10.36	3.15	0.1111	-
1s3	GC	-	40	60	9.30	2.80	0.2143	-
1s4	G	-	40	60	7.50	2.60	0.2308	0.4065
2s1	G	3	53	44	8.07	3.33	0.2913	0.4865
2s2	G	1	50	49	9.60	-	-	-
3s1	G	1	51	48	8.55	3.75	0.1467	-
3s3	G	2	55	43	-	-	-	-

Sample	Unit	%Sand	%Silt	% Clay	Mean	StDe	Sk	Kurt
4s1	G	1	44	55	9.60	4.00	0.3000	-
4s3	S	10	55	35	7.56	3.04	0.8424	0.4531
5s1	S	26	47	27	6.54	3.40	0.5330	0.4846
5s3	S	67	19	14	3.04	4.62	0.2771	0.5617
5s4	S	36	40	24	6.15	3.85	0.3766	0.2338
6s1	S	28	47	25	2.01	-1.19	2.1765	-5.2697

Core D3

Sample								
1S1	GC	0	57	43	7.90	2.00	0.0500	0.4500
1S5	GC	0	47	53	9.12	2.78	0.3165	0.4083
2S1	G	1	23	76	8.90	2.90	0.2414	-
3S1	GC	2	53	45	-	-	-	-
3S2	GC	0	53	47	8.95	2.75	0.3458	0.5636
4S1	G	0	65	35	8.12	2.97	-0.1429	-
4S3	G	6	60	34	8.01	2.99	0.4783	0.6689
5S1	G	4	62	34	8.30	3.50	0.4286	-
5S2	G	4	58	38	8.10	3.40	0.6471	0.5000
5S3	G	0	69	31	6.60	1.00	1.200	2.60
6S2	G	8	65	27	7.15	2.85	0.4035	0.4211

	Unit	% Sand	%Silt	% Clay	Mean	StDev	Sk	Kurt
Core Q1								
Sample								
2s1	G	4	66	30	7.00	3.40	0.9941	0.3000
2S2	G	2	32	66	9.41	2.58	0.1681	-
2S3	G	10	53	37	7.00	3.15	0.1429	0.4762
3S2	G	10	61	29	7.00	2.80	0.3571	0.4464
4S3	G	5	34	61	9.20	2.90	0.0690	-
5S2	G	1	43	56	9.00	3.50	0.1429	-
6S1	G	6	47	47	9.15	3.85	0.3506	-
6S4	S	29	36	33	6.80	3.80	0.1053	0.3947
7S2	S	6	10	84	-	-	-	-
7S3	S	31	21	48	7.05	3.95	0.1646	0.2532
8S1	PC	37	30	33	6.75	3.85	0.1169	0.4416
Core P12								
Sample								
1S1	GC	0	28	72	8.8	1.68	-0.2560	0.4554
2S4	GC	0	29	71	9.7	2.60	0.1923	-
2S6	BC	0	34	66	-	-	-	-
2S8	BC	0	47	53	9.95	3.45	0.4493	-
3S1	BC	0	45	55	8.35	1.85	0.0811	1.0000
3S2	BC	0	37	63	9.70	3.10	0.2903	-
3S7	BC	0	38	71	10.05	2.95	0.4573	-
5S2	G	0	26	74	-	-	-	-
6S3	G	0	49	51	-	-	-	-
7S3	G	0	29	71	-	-	-	-

Sample	Unit	%Sand	% Silt	% Clay	Mean	StDev	Sk	Kurt
9S2	G	3	28	69	-	-	-	-
9S4	S	6	69	25	6.85	2.35	0.4468	0.6596
10S1	S	1	69	30	7.10	2.30	0.3913	1.087
10S2	S	41	37	22	6.30	3.07	0.5837	0.6817
10S3	S	0	72	28	-	-	-	-
10S4	S	10	54	32	-	-	-	-
Core D1								
Sample								
1S1	GC	6	55	39	6.15	1.75	0.2000	0.3429
1S2	GC	7	39	54	8.20	2.60	0.1538	0.9423
1S4	GC	25	70	5	5.10	1.90	-0.3684	0.7632
4S7	G	0	1	99	7.25	2.50	0.1896	0.3932
Core R4								
Sample								
1S1	GC	0	45	55	8.52	2.48	0.0363	0.5323
1S2	GC	5	27	68	8.55	3.05	0.1148	0.4590
2S1	G	7	16	77	-	-	-	-
3S1	G	3	26	71	9.00	2.60	-0.2308	-
3S6	G	2	62	34	8.70	3.00	0.6133	-
4S3	G	4	46	50	8.85	3.35	0.0985	-
5S1	S	15	44	45	7.90	3.50	0.0857	0.4286
5S2	S	45	33	22	6.10	3.20	0.6563	0.5156
5S4	S	42	42	16	5.15	2.85	0.2632	-

	Unit	% Sand	% Silt	% Clay	Mean	StDev	Sk	Kurt
Core R1								
Sample								
1S1	GC	1	41	58	8.65	2.35	0.0638	0.4255
1S3	GC	0	34	66	9.85	3.15	0.2065	-
1S4	G	0	31	69	-	-	-	-
2S4	G	0	40	60	-	-	-	-
3S2	G	2	55	43	8.30	2.70	0.2593	0.5370
4S3	G	1	55	44	-	-	-	-
5S3	G	0	60	40	-	-	-	-
6S1	S	1	68	31	7.45	2.75	0.3091	0.6727
6S3	S	5	44	51	9.50	3.50	0.4286	-
6S4	S	48	40	12	4.60	2.80	0.1786	0.9464
Core R3								
Sample								
1S1	GC	1	59	40	7.52	.89	-0.2584	2.2809
1S3	G	3	33	64	9.80	3.50	0.2286	-
2S1	G	2	23	75	10.60	3.60	0.4444	-
2S2	G	0	50	50	-	-	-	-
2S5	G	1	49	50	9.15	2.85	0.4035	-
3S3	G	1	33	66	9.70	3.40	0.3235	-
3S5	G	4	33	63	9.45	3.05	0.3115	-0.4263
6S1	PC	4	51	45	8.50	3.50	0.6286	-
6S3	PC	17	46	37	7.60	3.70	0.2973	-
7S3	PC	14	58	28	7.50	3.60	0.4722	0.4028

Sample	Unit	%Sand	%Silt	%Clay	Mean	StDev	Sk	Kurt
Core M2								
2S1	GC	12	42	46	8.6	-	-	-
2S2	GC	14	54	32	7.5	-	-	-
2S3	GC	8	50	42	8.4			
2S8	SG	57	29	14	5.0	-	-	-
Core M4								
4S1	GC	10	66	24	7.1	-	-	-
4S2	BC	42	43	15	4.8	-	-	-
Core M6								
6S1	GC	1	80	19	6.15	-	-	-
6S2	GC	11	65	24	7.15	-	-	-
6S3	BC	15	50	35	6.90	-	-	-
6S4	SG	58	30	12	4.65	-	-	-

Appendix II: Organic and Moisture Content Results For Sixteen Mile Creek Lagoon.
The tabulated values are the results for each sample. (depth is from water surface, %org= % organic, % mois= %moisture, GC= Gray Clay, G= Gyttja, BC= Brown Clay, BS= Bottom Sand, PC= Pink Clay).

Sample	Depth	%Org	%Mois	Unit	Sample	Depth	%Org	%Mois	Unit
Core M1					Core D1				
1	5	11	-	-	1	83	5	-	GC
2	20	7	-	-	2	95	8	-	GC
3	30	5	-	-	3	105	6	-	GC
4	40	4	-	-	4	113	5	-	GC
5	50	4	-	-	5	125	17	-	G
6	88	7	-	-	6	135	10	-	G
7	98	8	-	-	7	145	10	-	G
9	115	5	-	-	8	165	3	-	PC
10	125	3	-	-	9	168	2	-	PC
11	140	3	-	-	10	178	3	-	PC
12	155	4	-	-					
13	165	3	-	-					
14	174	4	-	-					

Sample	Depth	%Org	%Mois	Unit	Sample	Depth	%Org	%Mois	Unit
Core D3					Core D4				
1	81	5	-	GC	9	100	-	-	GC
2	91	7	-	GC	3	111	8	-	GC
3	101	6	-	GC	13	122	5	-	GC
4	111	4	-	GC	15	131	8	-	G
5	121	11	-	G	16	144	13	-	G
6	95	11	-	G	17	130	13	-	G

Sample	Depth	%Org	%Mois	Unit	Sample	Depth	%Org	%Mois	Unit
D3 (cont)					D4 (cont)				
7	107	5	-	GC	18	141	14	-	G
8	116	8	-	GC	19	155	15	-	G
9	146	8	-	G	20	170	9	-	G
10	163	5	-	G	21	185	9	-	BS
11	168	6	-	G	22	195	13	-	BS
12	185	6	-	G					
13	199	3	-	PC					
14	208	3	-	PC					
15	222	3	-	PC					
16	231	3	-	PC					
Core D2					Core W1				
1	85	6	105	GC	1S1	215	8	131	GC
2	95	6	95	GC	1S2	225	7	129	GC
3	105	6	57	GC	1S3	235	5	93	GC
4	115	6	45	GC	1S5	255	6	90	GC
5	125	6	45	GC	1S7	275	6	102	GC
6	135	7	61	GC	1S9	295	5	90	GC
9	87	6	54	GC	2S1	308	7	89	GC
10	110	15	103	G	2S4	338	7	112	GC
11	120	14	94	G	2S6	358	8	129	BC
12	160	10	70	G	2S7	368	10	150	BC
13	170	8	64	G	3S1	377	10	150	BC
15	190	13	95	G	3S2	378	9	124	BC

Sample	Depth	%Org	%Mois	Unit	Sample	Depth	%Org	%Mois	Unit
16	215	9	78	G	:3S4	397	6	83	GC
17	225	13	98	G	:3S5	407	7	95	GC
18	235	10	95	G	:3S6	417	8	122	BC
19	250	9	75	S	:4S1	448	8	118	BC
20	261	3	38	PC	:4S2	458	8	117	BC
					:4S3	468	10	123	BC
					:4S4	478	11	141	BC
					:5S1	494	14	124	BC
					:5S2	504	18	183	BC
					:6S1	532	30	320	G
					:6S2	542	26	225	G
					:6s3	552	38	282	G
Core R4					:Core R1				
1S1	132	6	-	GC	:1S1	115	7	-	GC
1S2	144	9	-	GC	:1S2	135	7	-	GC
1S3	144	23	-	G	:1S3	146	22	-	G
1S4	167	47	-	G	:1S4	155	22	-	G
1S5	177	28	-	G	:2S1	168	23	-	G
1S6	187	34	-	G	:2S2	188	21	-	G
2S1	200	24	-	G	:2S3	196	19	-	G
2S2	215	21	-	G	:2S4	205	17	-	G
2S3	225	35	-	G	:2S5	215	14	-	G
2S4	235	33	-	G	:3S1	230	14	-	G
2S5	245	28	-	G	:3S2	243	16	-	G
3S1	284	19	-	G	:4S1	277	9	-	G

Sample	Depth	%Org	% Mois	Unit	Sample	Depth	% Org	%Mois	Unit
3S2	304	27	-	G	:4S2	297	13	-	G
3S3	314	22	-	G	:4S3	314	13	-	G
3S4	324	20	-	G	:5S2	339	12	-	G
3S5	334	31	-	G	:5S3	356	11	-	G
3S6	344	18	-	G	:6S1	371	12	-	G
4S1	384	27	-	G	:6S3	393	8	-	G
4S2	394	19	-	G	:6S4	401	2	-	BS
4S3	404	16	-	G					
4S4	414	19	-	G					
4S5	424	18	-	G					
5S1	431	13	-	G					
5S2	443	13	-	BS					
5S3	466	7	-	BS					
5S4	481	4	-	BS					

Appendix III: Summary of textural data (organic content moisture content; grain size) for Fifteen and Twenty Mile Creek Lagoons. The tabulated values are the average of all the analyses for each stratigraphic unit in each core. (n= number of samples analysed; Gr= gravel; Sa= sand; Si= silt; Cl= clay).

Core	Unit	Organic Content %	N	Moisture Content %	N	Mean Phi	Grain Size %Gr	%Sa	%Si	%Cl	N
Fifteen Mile Creek											
1	Gray Clay	8	2	-	-	-	-	-	-	-	
	Brown Clay	5.6	2	-	-	8.9	0	tr	35	65	1
	Gyttja	12	1	-	-	8.8	-	-	-	-	1
2	Gray Clay	5	1	-	-	-	-	-	-	-	
	Gyttja	12	1	-	-	8.4	-	-	-	-	1
3	Gray Clay	7	3	-	-	9.0	0	tr	32	68	1
	Gyttja	14	1	-	-	-	-	-	-	-	-
Twenty Mile Creek											
C11											
	Gray Clay	8.0	3	-	-	7.9	0	1	49	50	2
	Gyttja	13.8	22	-	-	8.3	0	4	51	45	4
	Bottom Sand	7.7	4	-	-	4.2	0	55	25	50	4
	Pink Clay	5.2	4	-	-	6.0	0	20	60	20	3
T1											
	Gray Clay	5.2	6	51	6	-	-	-	-	-	-
	Brown Clay	8.0	10	49	10	-	-	-	-	-	-
	Gyttja	12.5	30	54	30	-	-	-	-	-	-

Appendix IV: Core Descriptions and Sample Locations for selected cores from the Sixteen and Fifteen the Fifteen Mile Creeks. See Figures 8 and 9A for core locations. Cores are described from the base up with the thicknesses shown on the right and the samples retained for laboratory analysis shown on the left.

Core W1

Sample Number	Description	Thickness (cm)
6S3	Brown, laminated, Gyttja.	18.0
	Black, organic rich, Gyttja.	0.5
6S2	Brown, laminated, Gyttja.	16.0

Gyttja

Brown Clay

Sample Number	Description	Thickness (cm)
5S3-6S1	Brown, low organic content, clay.	15.0
	Brown, laminated (leaves), clay.	2.5
5S2	Brown, low organic content, clay.	8.0
	Brown, organic rich, laminated clay.	3.0
5S1	Brown, low organic content, clay.	8.0
4S4	Brown, organic rich, clay.	0.5
4S3	Brown, low organic content, clay.	15.0
4S2	Brown, organic rich, clay.	3.5
	Light grayish-brown, clay.	1.5
4S1	Brown, low organic content, clay.	13.0
3S7	Brown, organic rich, clay.	5.5
3S6	Brown, low organic content, clay.	13.0
	Brown, organic rich, clay.	5.0
	Brownish gray, clay.	4.0

Brown Clay

Gray Clay

Sample Number	Description	Thickness (cm)
3S3-3S4	Gray, laminated, clay.	17.0
	Gray, organic rich, clay.	1.0

Gray Clay

Brown Clay

Sample Number	Description	Thickness (cm)
	Brown, clay.	6.0
	Gray organic rich clay.	1.0
2S7-3S2	Brown, organic rich clay.	24.5
2S5-2S6	Brown, low organic content clay.	9.0

Brown Clay

Gray Clay		
2S4	Brown to gray, bioturbated, clay.	13.5
	Gray, organic rich, clay.	0.5
2S1-2S3	Gray, laminated, mottled clay.	39.5
1S9	Brown, gray, clay.	8.0
1S7-1S8	Black, laminated, clay.	18.0
1S4-1S6	Gray, mottled, clay.	33.0
1S1-1S4	Black, soft bioturbated, clay.	28.0

Top of core W1

Core R3

Sample Number	Description	Thickness (cm)
	Pink, organic poor,sandy, clay.	36.0
Pink Clay		
------------	------------	------------
Gyttja		
	Brown, low organic content, fine	
	Brown, organic rich, gyttja.	4.0
	Brown, low organic content, gyttja.	6.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	7
	Brown, organic rich, gyttja.	4.5
	Brown, low organic content, gyttja.	4.5
	Brown, organic rich, gyttja.	4.5
	Brown, uniform, medium textured, gyttja.	97.0
	Brown, low organic content, fine grained, gyttja.	11.0
	Brown, uniform, medium textured, gyttja.	3.0
	Dark brown,organic rich, coarse textured gyttja.	23.0
	Brown, low organic content, fine grained gyttja.	6.0
	Brown, organic rich, medium grained gyttja.	8.0
	Brown, laminated, low-organic, fine grained, gyttja.	17.0
	Brown, organic rich coarse grained gyttja.	8.5
	Brown, uniform, medium grained gyttja.	16.5
	Brown, organic rich, coarsening with depth gyttja.	23.0
	Brown, low organic content, gyttja.	14.0
	Brown, organic rich, gyttja.	2.0
	Brown, low organic content, gyttja.	2.0
	Brown, organic rich gyttja.	4.0
	Brown, low organic content, gyttja.	5.0
	Brown, organic rich, gyttja.	10.0
	Light brown, low organic content, gyttja.	23.0
	Brown, organic rich, coarse textured gyttja.	

Core R4

Sample Number	Description	Thickness (cm)
5S4	Brown, sand.	4.0
5S3	Brown, clay and sand.	6.0
	Brown, sand with pebbles.	3.0
Bottom Sand		

Gyttja		
5S2	Brown, sandy, gyttja.	14.0
4S4-5S1	Brown, organic rich, gyttja.	61.0
	Brown, medium textured, gyttja.	28.0
	Brown, organic rich, gyttja.	1.0
4S3	Brown, medium textured, gyttja.	6.0
	Brown, coarse, gyttja.	4.0
4S2	Brown, organic rich, gyttja.	15.0
	Brown, medium textured, gyttja.	15.0
4S1	Brown, medium organic rich, gyttja.	11.0
3S3-4S1	Brown, coarse textured, organic, rich gyttja.	34.0
3S2	Brown, medium textured, organic rich, gyttja.	15.0
	Brown, low organic content, fine gyttja.	3.0
3S1	Brown, medium textured, organic rich, gyttja.	14.0
2S4-2S5	Light brown, fine textured, low	
2S3	Brown, coarse grained, gyttja.	21.0
2S2	Brown, low organic content, gyttja.	6.0
1S3-2S1	Brown, coarse textured, gyttja.	43.0
	Brown, low organic content, gyttja.	2.0
	Brown, organic rich, gyttja.	3.0
1S2	Brown, low organic content, gyttja.	7.0
Gyttja		

Gray Clay		
1S1	Gray, clay.	16.0

Top of Core R4

Core D1

Sample Number	Description	Thickness (cm)
5S2-6S3	Pink, compact, uniform, low organic content, sandy, clay.	36.5
Pink Clay		
Gyttja		
	Brown, organic rich, gyttja.	2.0
	Brown, organic rich, fine grained, gyttja.	8.0
	Brown, organic rich, coarse, gyttja.	2.0
	Brown, gyttja.	15.5
	Brown, wood.	0.5
	Brown, gyttja.	0.5
	Brown, organic rich, gyttja.	1.0
4S1	Brown, gyttja.	8.0
Gyttja		
Gray Clay		
1S5-1S6	Gray, compact, organic rich, clay.	23.0
1S4	Gray, organic rich, bioturbated, clay.	10.0
1S1-1S3	Gray, mottled, bioturbated, clay.	20.0

Top of Core D1

Core Q1

Sample Number	Description	Thickness (cm)
8S1	Pink, uniform clay, some fine sand.	45.0
Pink Clay		
Gyttja		
	Brown, low organic content, gyttja.	11.0
	Brown, low organic content, gyttja with few organics.	13.0
7S1	Brown, organic rich, gyttja.	6.0
	Brown, low organic content, gyttja.	4.0
	Brown, low organic content, sandy, gyttja.	7.0
6S4	Brown, low orgnaic content, gyttja.	7.0
	Brown, organic rich. gyttja.	0.5
	Browm, low organic content, gyttja.	7.0
6S2	Brown, organic rich, gyttja.	1.0
	Brown, low organic content, gyttja.	2.0
	Brown, low organic content, gyttja.	3.5
	Brown, organic rich, gyttja.	0.5
6S1	Brown, low organic content, gyttja.	13.0
	Brown, organic rich, gyttja.	1.0
5S1	Brown, low organic content, gyttja.	26.0
	Brown, uniform, gyttja.	6.0
5S2	Brown, coarse organic rich, gyttja.	6.0
	Brown, low organic content, gyttja.	5.0
4S4	Brown, organic rich, gyttja.	13.0
4S3	Brown, low organic content, gyttja.	9.0
	Brown, organic rich, gyttja.	11.0
	Brown, organic rich, gyttja with wood	
4S2	Brown, organic rich, gyttja.	8.0
	Black, organic rich, gyttja.	1.0
4S1	Brown, organic rich, gyttja with wood.	7.0
	Brown, organic rich, gyttja.	53.0
	Brown, organic rich, (leaf lamina) gyttja.	0.5
	Brown, organic rich, gyttja.	0.5
	Brown, organic rich (lamina lamina) gyttja.	0.5
3S2	Brown, organic rich, gyttja.	2.5
	Brown, uniform, gyttja.	19.0
3S1	Brown, organic rich, (leaves) gyttja.	1.0
	Brown, low organic content, gyttja.	1.0
2S3	Brown, organic rich, gyttja.	1.0
	Brown, wood in gyttja.	0.5
	Brown, organic rich gyttja.	31.0
	Brown, low organic content, gyttja.	4.0

2S2	Brown, laminated gyttja.	8.5
2S1	Brown, organic rich, gyttja.	25.5

Gyttja

Gray Clay (sample not described)

Core R2

Sample Number	Description	Thickness (cm)
6S4	Brown,organic rich sandy clay.	6.5
6S33	Brown, sandy clay with pebbles.	4.0
Bottom Sand		
Gyttja		
6S2	Brown, low organic content, gyttja.	0.5
6S2	Brown, organic rich, gyttja.	0.5
6S2	Brown, low organic content, gyttja.	0.5
6S2	Brown, organic rich, gyttja.	0.5
6S2	Brown, low organic content, gyttja.	0.5
6S2	Brown, organic rich, gyttja.	0.5
6S2	Brown, low organic content, gyttja	0.5
6S2	Brown, organic rich, gyttja.	0.5
6S2	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	5.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	0.5
6S1	Brown, organic rich, gyttja.	0.5
6S1	Brown, low organic content, gyttja.	1.5
6S1	Brown, organic rich, gyttja.	0.5
6S1	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	2.0
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	4.0
	Brown, organic rich, gyttja.	7.5
	Brown, organic rich, sandy gyttja.	1.0
	Brown, low organic content, sandy gyttja.	0.5
	Brown, organic rich sandy, gyttja.	0.5
	Brown, low organic content, sandy gyttja.	0.5
	Brown, orgnaic rich, sandy gyttja.	0.5
	Brown, low organic content, sandy gyttja.	0.5
	Brown, organic rich sandy, gyttja.	0.5
	Brown, low organic content, sandy gyttja.	0.5
	Brown, organic rich sandy, gyttja.	0.5
	Brown, low organic content sandy gyttja.	0.5
	Brown, organic rich sandy, gyttja.	0.5
	Brown, Sand.	6.0
5S4	Brown, organic rich, sandy gyttja.	
	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	0.5

		Brown, low organic content, gyttja.	0.5
		Brown, organic rich gyttja.	0.5
		Brown, low organic content, gyttja.	0.5
		Brown, organic rich gyttja.	0.5
		Brown, low organic content, gyttja.	0.5
		Brown, organic rich, gyttja.	0.5
		Brown, low organic content, gyttja.	4.0
		Brown, organic rich, gyttja.	7.5
5S3		Brown, laminated gyttja.	7.0
		Brown, low organic content, gyttja.	5.0
		Brown, laminated gyttja.	7.0
		Brown, low organic content, gyttja.	2.0
5S2		Brown, laminated gyttja.	4.0
		Brown, low organic content, gyttja.	1.0
		Brown, organic content, gyttja.	1.0
		Brown, low organic content, gyttja.	1.0
		Brown, organic rich, gyttja.	1.0
5S1		Brown, uniform, gyttja.	4.0
		Brown, organic rich, gyttja.	1.0
		Brown, uniform, sandy, gyttja.	10.0
		Brown, organic rich, gyttja.	0.5
		Brown, low organic content, gyttja.	0.5
		Brown, organic rich, gyttja.	0.5
		Brown, low organic content, gyttja.	0.5
		Brown, organic rich, gyttja.	0.5
		Brown, low organic content,gyttja.	0.5
4S3		Brown, organic rich, gyttja.	0.5
4S2		Brown, low organic content, gyttja.	1.5
4S1		Brown, organic rich, gyttja.	2.5
		Brown, low organic content, sandy gyttja.	3.5
		Brown, low organic content, gyttja.	3.0
		Brown, organic rich, gyttja.	1.0
		Brown, low organic content, gyttja.	7.5
		Brown, organic rich, gyttja.	2.5
3S2		Brown, low organic content, gyttja.	7.0
		Brown, organic rich, gyttja.	0.5
3S1		Brown, uniform, gyttja.	12.5
		Brown, organic rich, gyttja.	0.5
		Brown, uniform, gyttja.	8.5
2S2		Bronw, organic rich gyttja.	1.0
		Brown, uniform, gyttja.	8.0
		Brown, low organic content, gyttja	1.0
2S1		Brown, uniform, gyttja.	16.0
		Brown, coarse textured, gyttja.	5.0
1S4	Gyttja	Brown, low organic content, gyttja.	4.0

	Gray Clay		
1S3		Gray, organic rich clay.	11.0
1S2		Gray low organic content, clay.	4.5
		Gray, organic rich, clay.	10.5
1S1		Gray, black, soft, clay.	8.0

Top of Core R2

Sample Number	Description	Thickness (cm)
Core Q2		
	Brown, leaf layer, gyttja.	2.0
	Brown, laminations of clay and sand.	4.0
	Brown, wood in gyttja.	6.0
5S1	Brown, laminations of clay and sand.	4.5
	Brown, organic rich, gyttja.	0.5
	Brown, laminations of clay and sand.	3.5
	Brown, organic rich, gyttja.	1.0
	Brown, laminations of clay and sand.	6.0
	Brown, laminated leaf layers with sand, pebbles of Grimsby Sandstone at the base.	6.0
	Brown, sand.	0.5
4S2	Brown, medium textured, gyttja.	7.5
	Brown, sand.	1.0
	Brown, medium textured Gyttja.	13.0
	Brown, organic rich Gyttja.	3.0
4S1	Brown, organic rich Gyttja.	6.0
	Brown, laminated with leaves and clay, Gyttja.	13.0
2S1+2S2+3S1	Brown, uniform fine textured Gyttja with Leaves.	21.0
	Brown, uniform, organic rich, coarse textured, Gyttja.	39.0
	Brown, organic rich, Gyttja.	4.0

Gyttja

Gray Clay

1S1	Gray, soft,organic rich, clay.	14.0

Top of Core Q2

Core D4

Sample Number	Description	Thickness (cm)
	Brown, sand.	1.0
	Brown, organic rich, sand.	1.0
6S2	Brown, organic rich (wood), sand.	2.0
	Brown, organic rich, sand.	1.0
	Brown, coarse, organic pieces, sand.	3.0
6S33	Brown, laminated, organic rich clayey, sand.	5.0
6S1	Brown, organic rich with wood, sand.	4.0
	Brown, organic rich, leaf layers, sand	4.0
	Brown, laminated, organic rich, clayey, sand.	4.0
5S3	Brown, organic rich (wood), sand.	3.5
	Brown,organic rich, gyttja.	2.0
	Brown sand.	1.0
	Brown, organic rich, gyttja.	1.5
	Brown sand.	1.0

Bottom Sand

Gyttja

	Brown, organic rich (leaf lamina), gyttja.	0.5
	Brown, gyttja.	2.0
	Brown, organic rich (leaf lamina), gyttja.	1.0
	Brown, laminated, clayey gyttja.	2.0
	Brown laminated, low organic content, gyttja.	2.0
	Brown, organic rich, gyttja.	7.0
	Brown, organic rich, (pieces of organic) clayey, gyttja.	7.0
5S1	Brown, coarse textured, gyttja.	29.0
4S2	Brown, low organic content, gyttja.	3.5

Gyttja

GrayClay

1S4	Gray, uniform , mottled, clay.	19.5
1S3	Black, organic rich, clay.	0.5
	Gray, bioturbated, clay.	7.5
	Black, organic rich, clay.	0.5
1S2	Gray bioturbated, clay.	3.5
	Black, organic rich, clay.	0.5

	Gray, organic rich, bioturbated, clay.	2.0
1S1	Gray, bioturbated, mottled, clay.	14.0

Top of Core D4

Core D3

Sample Number	Description	Thickness (cm)
5S2;5S3;6S1-6S3	Pink, uniform clay	25.0
Pink Clay		

Gyttja		
	Brown, low organic content with sand gyttja.	5.0
	Brown, organic rich gyttja.	2.0
4S3;5S1	Brown, low organic content gyttja.	14.0
	Black, organic rich, gyttja.	1.0
4S2	Brown, fine textured, gyttja.	8.0
	Black, organic rich, gyttja.	1.0
4S1	Brown, fine textured, sandy, gyttja.	10.0
3S1;3S2	Brown, laminated, organic and clay gyttja.	12.0
Gyttja		

Gray Clay		
2S2	Gray, sandy, uniform, clay.	10.0
2S1	Brown, laminated with leaf layers, coarse gyttja.	16.5
1S4;1S5	Gray, dense, organic rich,clay.	20.0
1S3	Gray, organic rich, bioturbated clay with shells.	10.0
1S1;1S2	Gray, soft, mottled, bioturbated, clay.	20.0

Top of Core D3

Core D2

Sample Number	Description	Thickness (cm)
6S3	Brown, finely laminated clay with sand.	5.0
	Brown, organic rich, leaf layers	1.0
6S3	Brown, organic rich, coarse sand	10.0
Bottom Sand		
Gyttja		
	Brown, laminated with leaves gyttja.	7.0
	Brown, low organic content, gyttja.	1.0
	Brown, laminated sand with clay and leaves, gyttja.	17.0
	Brown gyttja.	12.0
5S3	Brown, organic rich (leaf layers) gyttja.	8.0
	Brown, low organic content gyttja.	4.0
5S2	Brown, sandy gyttja.	6.0
	Brown, organic rich (with leaf layers) gyttja.	1.0
4S2;5S1	Brown, laminated gyttja.	17.0
3S1;4S1	Brown, low organic, coarse textured and compact gyttja.	12.0
Gyttja		
Gray Clay		
1S5;2S1	Gray, laminated, organic rich clay.	20.5
1S5	Gray, laminated, organic rich clay.	5.5
1S4	Gray, bioturbated, compact clay.	12.0
1S2;1S3	Gray, highly bioturbated clay.	11.5
1S1;1S2	Blackish gray clay.	18.5

Top of Core D2

Core P12

Sample Number	Description	Thickness (cm)
10/S4	Brown wood, organic rich, sandy clay.	4.0
	Brown, organic rich sandy clay.	10.0
10/S2-10/S3	Pink, sandy, clay	27.5
9/S4-10/S1	Pink, low organic content, sandy clay.	20.5
Pink Clay		
Gyttja		
8/S3-9/S3	Brown, uniform, gyttja.	2.5
	Brown, organic rich, gyttja.	0.5
8/S2	Brown, uniform, gyttja.	4.5
	Brown, organic rich, gyttja.	0.5
8/S1	Brown, uniform, gyttja.	4.5
	Brown, organic rich gyttja.	0.5
7/S3	Brown, uniform gyttja.	4.5
	Brown, organic rich, gyttja.	0.5
7/S2	Brown, uniform with coarse organic gyttja.	32.5
	Brown, organic rich, gyttja.	0.5
	Brown, uniform, gyttja.	19.9
7/S1	Brown, low organic content, gyttja.	0.5
	Brown, uniform, gyttja.	2.0
	Brown, low organic content,gyttja.	0.5
	Brown, uniform, low organic content, gyttja.	31.0
	Brown, organic rich, gyttja.	2.5
6/S4	Brown, low organic content, gyttja.	5.5
	Brown, organic rich, gyttja.	0.5
	Brown, low organic content, gyttja.	2.0
6/S3	Brown, organic rich, gyttja.	3.5
6/S2	Brown, low organic content, gyttja.	3.5
	Brown, low organic content, gyttja.	6.5
6/S1	Brown, organic rich, gyttja.	2.0
	Brown, low organic content, gyttja.	3.0
	Brown, organic rich, gyttja.	0.5
5/S4	Brown, low organic content, gyttja.	5.0
	Brown, organic rich, gyttja.	2.5
	Brown, medium textured gyttja.	2.5
	Brown, organic rich, gyttja.	8.0
5/S3	Brown, low organic content, gyttja.	5.5
	Brown, organic rich, gyttja.	6.0
	Brown, low organic content, gyttja.	12.0
5/S1	Brown, organci rich, gyttja.	17.0
	Black, organic rich, gyttja.	0.5
	Brown, organic rich, gyttja.	11.0

	Brown, low organic content, gyttja.	7.5
4/S5	Brown, organic rich, gyttja.	4.0
4/S4	Brown, low organic content, gyttja.	8.0
	Brown, organic rich, gyttja.	2.0
4/S3	Brown, low organic content, gyttja.	3.0
	Brown, organic rlch, gyttja.	0.5
	Brown, low organic content, gyttja.	2.5
	Brown, organic rich, gyttja.	3.0
4/S2	Brown, medium textured, gyttja.	11.0
	Brown, organic rich, gyttja.	15.0
4/S1	Brown, uniform, gyttja.	2.0
	Brown, organic rich, gyttja.	5.0
Gyttja		

Brown,Clay		
	Dark brown, low organic content gyttja	5.0
3/S8	Light brown, clay.	4.5
	Dark brown, organic rich, clay.	3.5
	Light brown, low organic content, clay	3.5
3/S7	Dark brown, clay.	6.5
	Light brown, low organic content, clay	6.0
3/S6	Brown, organic rich, clay.	4.5
Brown Clay		

Gray Clay		
3/S4-3/S5	Gray uniform, clay.	18.5
2/S8-3/S3	Brown, uniform, compact, clay	51.5
2/S6-2/S7	Light brown, uniform, low organic content clay.	22.0
2/S3-2S5	Brown to gray, clay.	15.0
2/S1-2/S2	Gray, bioturbate, mottled clay.	30.0
1/S1-1/S8	Gray, bioturbated, soft, mottled clay	84.0

Top of Core P12

Core P13

Sample Number	Description	Thickness (cm)
10S2	Brown, low organic content gyttja.	14.0
10S1	Brown, organic rich, gyttja.	4.0
9S2	Brown, low organic content, gyttja.	3.0
9S1	Brown, laminated, organic rich, gyttja	9.0
8S1;8S2	Brown, low organic content gyttja	7.0
8S1	Brown, sand.	4.0
7S3	Brown, low organic content, gyttja.	10.0
	Brown, medium textured gyttja.	11.0
7S1	Brown, organic rich, gyttja.	9.0
6S3	Brown, organic increasing with depth, gyttja.	15.0
6S22	Brown, organic rich, gyttja.	15.0
6S1	Brown, low organic content, gyttja.	11.0
	Brown, organic rich, gyttja.	4.5
5S2	Brown, low organic content, gyttja.	16.0
5S2	Brown, uniform textures, gyttja.	13.0
5S1	Brown, low organic content, gyttja.	4.0
	Brown, uniform, medium textured gyttja	4.5
	Brown, low organic content, gyttja.	2.5
4S2;4S3	Brown, uniform, medium textured, gyttja.	32.7
	Brown, organic rich, gyttja.	0.5
	Brown, uniform, medium textured gyttja.	2.5
	Brown, organic rich, gyttja.	0.5
4S1	Brown, uniform, medium textured gyttja.	18.0
	Brown, organic rich gyttja.	4.0
3S4	Brown, coarse textured gyttja.	23.0
	Brown, low organic content, some coarse organic debris, gyttja.	4.0
3S2;3S3	Brown, uniform, gyttja.	22.0
3S2	Brown, low organic content, some coarse organic debris, gyttja.	5.0
3S1	Brown, uniform, gyttja.	22.0
	Brown, organic rich, gyttja.	8.0
	Brown, low organic content, gyttja.	5.0
2S6	Brown, organic rich gyttja.	8.0
	Brown, low organic content, gyttja.	4.5
	Brown, organic rich gyttja.	4.0
2S5	Brown, low organic content, gyttja.	13.5
2S4	Brown, organic rich, coarse textured gyttja.	5.0
2S3	Brown, low organic content, gyttja.	21.0
2S2	Brown, organic rich, gyttja.	15.0
2S2	Brown, low organic content, gyttja.	10.0
2S1	Brown, organic rich, gyttja.	9.0
	Brown, low organic content, gyttja.	5.0

	Dark organic rich ,gyttja.	8.0
1S5	Brown, uniform, medium textured	4.0
1S5	Brown, low organic content, gyttja.	4.0
	gyttja.	
	Brown, uniform, medium textured	7.0
	Brown, organic rich, gyttja.	1.5
1S4	Brown, medium textured gyttja.	15.5
	gyttja	

Gyttja

Gray Clay

1S2;1S3	Gray, uniform, clay.	19.0
1S1	Gray, soft, mottled, clay	20.0

Top of Core P13

Core R1

Sample Number	Description	Thickness(cm)
6/S4	Pink and brown clayey sand.	10.0
	Brown, sand, mixed with clay.	10.5
Bottom Sand		
Gyttja		
6/S3	Brown, clay	3.5
6/S2	Brown, some organic, clay.	7.5
	Brown, low organic content, gyttja.	0.5
	Brown, organic rich, gyttja.	1.0
	Brown,low organic content, gyttja.	1.0
	Brown, sandy, gyttja.	1.0
	Brown, low organic content, gyttja.	1.0
	Brown, sandy, gyttja.	8.0
	Brown, low organic content, gyttja.	1.0
6/S1	Brown, sandy gyttja.	5.0
	Brown, organic rich, gyttja.	2.0
5/S3	Brown, uniform, gyttja. lamina)	8.5
	Brown, low organic content, gyttja.	0.5
	Brown, organic rich ,(leaf lamina).	0.5
	Brown, low organic content, gyttja.	1.0
	Brown, organic rich, (leaf lamina) gyttja.	
	Brown, low organic content, gyttja.	1.0
	Brown, organic, content, (leaf lamina) Gyttja.	1.0
	Brown, low organic content, gyttja.	3.0
	Brown, organic rich, gyttja.	1.0
5/S2	Brown, low organic content, gyttja.	3.0
	Brown, organic rich, gyttja.	
	Brown, low organic content, gyttja.	3.0
	Brown, organic rich, gyttja.	1.0
	Brown, low organic content,	

	gyttja.	2.0
	Brown, organic rich, gyttja.	1.0
	Brown, low organic content, gyttja.	6.0
	Brown, organic rich, gyttja.	
5/S1	Brown, organic rich, gyttja.	1.0
4/S3	Brown, uniform, organic rich, gyttja.	52.5
	Brown, organic rich, (leaf lamina) gyttja.	1.0
	Brown, uniform textured gyttja.	32.0
	Brown, organic rich, gyttja.	1.0
	Brown, low organic content, gyttja.	8.0
	Brown, organic rich, gyttja.	4.0
	Brown, low organic content, gyttja.	1.0
	Brown, organic rich gyttja.	9.0
4/S2	Brown, low organic content gyttja.	1.0
	Brown, organic rich, gyttja.	4.0
4/s1	Brown, low organic content, gyttja.	1.0
	Brown, organic rich, gyttja.	4.0
	Brown, low organic content, gyttja.	1.0
	Brown, organic rich, gyttja.	4.0
	Brown, low organic content, gyttja.	1.0
3/S2	Brown, organic rich, gyttja.	4.0
	Brown, low organic content, gyttja.	1.0
	Brown, organic rich, gyttja.	4.0
3/S1	Brown, low organic content, gyttja.	1.0
	Brown, organic rich, gyttja.	6.0
2/S4	Brown, low organic content, gyttja.	3.0
2/S3	Brown, piece of wood.	1.0
2/S1-2/S2	Brown, coarse grained, gyttja.	9.0
1/S3	Brown, organic rich, gyttja.	1.0
	Brown, gyttja.	3.0
	Brown, organic rich gyttja.	1.0

Gyttja

Gray Clay

1/S2	Gray, uniform, clay.	13.0
	Gray, organic rich, clay.	1.0
	Gray, clay.	3.0
	Gray, organic rich, clay.	1.0
	Gray, clay.	3.0

	Gray, organic rich, clay.	1.0
1/S1	Gray, clay.	12.0

Top of Gray Clay

Core M1

Sample Number	Description	Thickness(cm)
S5	Brown, very hard, compact with few large pebbles, till.	47.0
Till		
Sand		
S4	Brown, coarse, sandy, gravel.	32.0
S3	Brown, oxidized with pink coloured sand.	50.0
Gray Clay		
S1-S2	Gray, organic rich, clay.	77.0

Top of Core M1

Core M2

Sample Number	Description	thickness(cm)
	Brown, coarse, sandy, clayey, gravel.	8.0
	Pinkish, clayey, sand.	48.0
	Pinkish, sand.	4.5
Sand	Gray to pinkish sandy clay.	27.0

Orange Sandy Silt

	Brown, uniform, some organic, clay.	37.5
	Black, organic rich, clay.	8.5
	Gray clay.	14.0
	Black, organic rich, sandy clay.	0.5
	Gray, speckled, organic rich, clay.	55.0

Top of Core M2

Core M3

Sample Number	Description	Thickness(cm)
S10-S11	Brown to Gray, clayey, sand.	48.0
Sand		
Orange Sandy Silt		
S9-S7	Brownish, orange, clay and silt.	38.0
Gray Clay		
	Gray to black, massive clay.	14.0
S6-S5	Gray, laminated, organic rich, clay.	50.0
SI-S2	Gray, some organic, sandy clay.	45.0
S1	Black to gray, organic rich, clay.	22.0
	Brownish, gray orange rich,clay.	13.0

Top of Core M3

Core M4

Sample Number	Description	Thickness (cm)
S3	Pinkish, clayey, sandy, gravel.	36.0
	Pink to brown, sand and clay.	20.0
Sand		
Orange Sandy Silt		
S2	Brown, oxidized clay with sand.	50.0
Gray Clay	Black, organic rich, clay.	10.0
	Gray, with wood, clay	77.0
S1	Brownish, gray, organic rich, clay.	13.0

Top of Core M4

Core M5

Sample Number		Description	Thickness(cm)
		Pink, dense, hard, till.	60.0
		Darker pink layer, till.	8.0
S4	Till	Grayish blue to pink, hard, dense till.	14.0
	Sand		
S3		Brown, coarse, sandy gravel.	20.0
		Brown, sand.	28.0
		Brown, clayey sand.	15.0
S2		Brown to gray sand.	38.0
		Brown to gray clay.	4.0
		Brown, to gray clay.	0.5
		Brown to gray clay.	2.0
		Brown to gray sand.	0.5
		Brown to gray clay.	3.0
		Brown to gray sand.	0.5
		Brown to gray clay.	5.0
		Brown to gray sand.	0.5
		Brown to gray clay.	5.0
		Brown to gray sand.	0.5
		Brown to gray clay.	5.0
		Brown to gray sand.	0.5
		Brown to gray clay.	14.0
		Brown to gray sand.	1.0
		Brown to gray clay.	5.0
		Brown to gray sand.	8.0

Top of Core M5

Core M6

Sample Number		Description	Thickness(cm)
S4	Sand	Pinkish, sand.	14.0
	Orange Sandy Silt		
		Brown, oxidized, sandy clay.	9.0
		Brown, Sand.	0.5
		Brown, oxidized, sandy clay.	13.0
		Brown, sand.	0.5
S3		Brown, oxidized sandy clay.	35.0
	Gray Clay		
S2		Dark, gray, low organic content, clay.	25.0
		Gray Clay.	17.0
		Gray, organic rich, clay.	2.0
S1		Gray, organic rich with roots, clay.	101.0

Top Of Core M6

Core 15-1

Sample Number	Description	Thickness (cm)
S5	Brown, low organic content, gyttja	9.0
	Brown, coarse organic rich, gyttja.	0.5
Gyttja		
Brown Clay		
S4	Brown, low organic content, clay.	9.5
S3	Brown, organic rich, clay.	6.0
	Gray Clay	
S2	Dark gray, organic rich, clay.	19.5
	Black to gray, organic rich, with bioturbating organisms, and leaf layers,clay.	19.5

Top of Core 15-1

Core 15-2

Sample Number	Description	Thickness(cm)
S9	Brown, fine, low organic content gyttja.	10.0
Gyttja		
Brown Clay		
S8	Brown, low organic content, clay.	3.0
S7	Brown, some organic clay.	14.5
Gray Clay		
S6	Brown, to black, bioturbated, clay.	14.5

Top of Core 15-2

Core 15-3

Sample Number	Description	Thickness(cm)
S13	Brown, gyttja.	4.0
	Brown, laminated, gyttja.	15.0
Gyttja		
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Gray Clay		
	Gray to brown clay.	11.5
	Gray to black, organic rich, clay.	3.0
	Gray Clay.	15.5
	Gray to black, organic rich, clay.	13.0
	Black to gray, bioturbated, clay.	24.0

Top of Core 15-3

Appendix V. Summary of Geochemistry Averages

Core	Unit	P M	P St	Ca M	Ca St	Zn M	Zn St	Cu M	Cu St	Ni M	Ni St	No of Samples
D1												
	GC	0.23	0.01	1.30	0.46	162	68	68	26	22	1	4
	G	0.19	0.01	1.30	0.68	111	24	110	8	22	2	2
	PC	0.09	0.03	0.60	0.04	100	27	32	10	20	2	3
D3												
	GC	0.24	0.05	1.20	0.25	135	31	56	37	22	1	5
	G	0.20	0.05	0.80	0.07	137	17	69	31	21	0.5	4
	PC	0.20	0.02	0.70	0.06	129	21	48	40	22	2	3
D4												
	GC	0.23	0.01	1.40	0.27	148	35	51	22	21	0.6	3
	G	0.23	0.04	1.20	0.15	152	31	38	6	21	0.4	6
	S	0.20	0.01	1.60	0.14	83	14	30	4	19	0.7	2
R1												
	GC	0.22	0.61	1.50	0.34	141	16	45	6	21	0.6	3
	G	0.23	0.01	1.20	0.08	152	31	75	31	22	1.3	11
	S	0.22	-	1.20	-	72	-	40	-	19	-	2
R4												
	GC	0.22	-	0.97	-	167	-	68	-	24	-	2
	G	0.23	-	1.10	-	128	-	41	-	22	-	1
	S	0.22	-	1.95	-	93	-	46	-	21	-	2

Core	Unit	P M	P St	Ca M	Ca St	Zn M	Zn St	Cu M	Cu St	Ni M	Ni St	NO of Samples
W1												
	GC	0.23	8.30	1.86	0.58	160	19	55	11	27	1.60	9
	BC	0.22	0.10	1.02.38		127	8	71	18	29	2.2	10
P-12												
	GC	0.24	5.80	1.75	0.82	176	11	42	9	23	-	3
	BC	0.22	8.90	1.59	1.41	154	34	74	35	24	-	5
	G	0.23	0.02	1.05	0.09	161	-	71	49	27	-	4
	PC	0.24	-	1.65	-	57	-	37	-	19	-	5
Q1												
	G	0.23	0.02	1.04	0.15	162	31	172	160	25	1.9	10
	S	0.17	6.90	0.76	0.13	115	42	68	27	22	2.6	3
	PC	0.13	-	0.58	-	80	-	105	-	19	-	1

Twenty Mile Creek

Core	Unit	P M	P St	Ca M	Ca St	Zn M	Zn St	Cu M	Cu St	Ni M	Ni St	NO of Samples
C11												
	GC	0.24	-	2.02	-	221	-	110	-	23	-	2
	G	0.25	-	2.16	-	250	-	85	-	23	-	15
	S	0.24	-	2.77	-	144	-	49	-	21	-	4
	C	0.24	-	3.47	-	96	-	43	-	19	-	4

Definitition of terms: P=Phosphorous; Ca=Calcium; Zn=Zinc; Ni=Nickel; Cu= Copper;Mean= mean concentrtion; St=Standard Deviation; GC=gray Clay; G=gyttja; BC=Brown Clay; S=Sand; PC= Pink Clay; concentration of P and Ca are expressed in %. Concentration of Zn, Cu and Ni are expressed in ppm.

Appendix VI. Geochemistry Results

Core/Sample	Unit	P %	Ca %	Zn ppm	Cu ppm	Ni ppm
D4						
9	GC	0.23	1.20	137	76	21
2	GC	0.24	0.82	188	40	21
13	GC	0.22	1.35	121	36	22
15	G	0.16	0.96	116	43	21
16	G	0.27	1.23	124	43	21
17	G	0.26	1.37	201	41	21
19	G	0.23	1.35	148	30	21
20	G	0.23	1.28	166	37	21
21	S	0.19	1.50	73	28	19
22	S	0.21	1.70	93	33	20
D3						
1S1	GC	0.23	1.50	167	121	24
1S3	GC	-	-	98	35	21
1S4	GC	0.22	1.10	105	37	22
1S5	GC	0.31	1.20	156	33	22
3S1	GC	0.20	0.90	148	52	22
4S1	G	0.20	0.90	119	88	21
4S2	G	0.19	0.78	149	41	21
4S3	G	0.20	0.75	154	45	21
5S1	G	0.20	0.87	126	102	22
5S3	PC	0.20	0.69	127	24	21

		P	Ca	Zn	Cu	Ni
		%	%	ppm	ppm	ppm
6S1	PC	0.22	0.74	131	25	21
6S2	PC	0.18	0.82	130	94	24
D1						
1S1	GC	0.24	1.65	258	87	23
1S2	GC	0.25	1.08	121	54	20
1S3	GC	0.23	0.82	163	92	21
1S4	GC	0.22	1.80	107	38	22
D5	G	0.20	1.80	128	116	24
D17	G	0.18	0.84	94	105	21
D18	PC	0.08	0.57	130	21	21
D19	PC	0.07	0.58	92	39	20
D10	PC	0.12	0.64	78	36	20
D2						
1	GC	-	-	132	82	22
2	GC	-	1.60	138	41	21
4	GC	-	0.76	108	67	21
9	GC	-	0.77	98	52	21
17	G	-	1.60	122	86	21
18	G	-	1.40	133	71	20
19	G	-	1.59	40	26	19
20	PC	-	-	88	25	20

		P	Ca	Zn	Cu	Ni
		%	%	ppm	ppm	ppm
P-12						
1S1	GC	0.24	1.95	187	50	22
1S5	GC	0.24	12.45	165	33	22
2S4	GC	0.25	0.84	175	44	22
2S6	BC	0.23	0.94	126	33	22
2S9	BC	0.23	0.96	154	111	26
3S3	BC	0.23	1.15	208	100	27
3S4	BC	0.21	4.10	125	40	21
3S7	BC	0.22	0.82	155	87	26
4S1	G	0.23	0.93	205	29	22
6S3	G	0.25	1.15	143	120	29
7S3	G	0.21	1.06	92	29	22
9S2	G	0.22	1.05	203	107	28
9S4	PC	0.22	1.27	64	32	20
10S1	PC	0.23	1.40	70	37	20
10S2	S	0.23	1.85	44	40	17
10S3	S	0.22	1.67	56	42	19
10S4	S	0.31	2.05	55	36	19
Q1						
2S2	G	0.22	0.94	153	85	25
2S3	G	0.23	1.15	143	302	25
3S1	G	0.24	1.01	153	587	23
3S2	G	0.27	1.41	109	96	24
4S1	G	0.24	0.96	219	171	28

		P	Ca	Zn	Cu	Ni
		%	%	ppm	ppm	ppm
4S3	G	0.23	1.00	195	110	28
5S1	G	0.21	0.99	155	87	23
5S2	G	0.24	1.10	185	112	27
6S1	G	0.24	0.94	148	86	24
6S2	G	0.20	0.93	158	88	24
6S4	S	0.19.	0.82	128	70	23
7S2	S	0.27	0.88	169	55	24
7S3	S	0.12	0.78	83	43	19
8S1	PC	0.13	0.58	81	106	19
R-4						
1S1	GC	0.22	0.80	176	84	26
1S2	GC	0.22	1.14	158	54	22
5S1	G	0.23	1.13	128	41	21
5S2	S	0.21	0.77	75	37	19
5S4	S	0.24	1.13	111	55	22
W-1						
1S1	GC	0.24	2.75	180	60	25
1S2	GC	0.23	2.05	188	75	28
1S3	GC	0.22	2.02	170	67	26
1S5	GC	0.23	1.87	168	57	30

		P %	Ca %	Zn ppm	Cu ppm	Ni ppm
1S7	Gc	0.22	2.05	165	55	27
1S8	GC	0.23	2.03	153	54	27
1S9	GC	0.22	2.10	135	43	26
2S4	GC	0.22	0.85	145	42	28
2S5	BC	0.25	0.96	136	66	31
3S2	BC	0.23	0.96	136	55	27
3S5	BC	0.22	1.05	114	54	28
3S6	BC	0.23	0.87	130	53	26
4S1	BC	0.22	0.85	124	59	28
4S2	BC	0.21	0.87	118	97	31
4S3	BC	0.22	0.88	120	35	28
4S4	BC	0.22	0.88	129	78	28
5S1	BC	0.22	0.85	135	88	30
5S2	BC	-	2.10	133	93	33
R-1						
1S1	GC	0.22	1.75	151	51	21
1S2	GC	0.23	1.15	122	40	21
1S3	GC	0.20	0.72	150	43	22
2S3	G	0.25	1.20	193	68	22
2S4	G	0.23	1.15	148	54	21
2S5	G	0.23	1.20	187	133	25
3S1	G	0.22	1.20	120	111	21

		P	Ca	Zn	Cu	Ni
		%	%	ppm	ppm	ppm
3S2	G	0.25	1.25	187	67	22
4S1	G	0.21	1.25	120	111	21
4S2	G	0.23	1.20	126	55	21
4S3	G	0.22	1.18	130	56	22
5S3	G	0.21	1.00	152	92	24
6S1	G	0.26	1.26	126	35	21
6S3	S	0.21	1.09	185	47	22
6S4	S	0.22	1.20	72	40	19
CP-2						
27		0.29	4.10	69	30	19
28		0.25	2.25	91	40	20
29		0.24	1.24	112	42	21
210		0.24	1.27	115	44	21
211		0.22	4.40	68	29	20
CP-5						
51		0.22	3.80	44	25	19
52		0.24	2.50	87	27	21
53		0.24	2.25	82	32	21
54		0.21	3.55	61	34	20
55		0.21	1.15	85	28	20

		P	Ca	Zn	Cu	Ni
		%	%	ppm	ppm	ppm
C-11						
2	GC	0.22	2.20	181	51	23
3	GC	0.26	1.85	262	170	24
4	G	0.31	2.30	286	243	23
6	G	0.23	2.55	189	51	23
9	G	0.22	2.00	287	81	27
14	G	0.24	2.85	184	79	21
15	G	0.25	1.99	231	116	26
16	G	0.25	1.70	301	75	25
17	G	0.23	1.30	306	95	23
18	G	0.25	1.43	243	87	24
19	G	0.23	1.55	249	51	22
20	G	0.24	2.00	342	84	25
21	G	0.23	2.49	294	72	26
22	G	0.26	2.10	298	80	23
23	G	0.24	2.49	186	37	20
24	G	0.25	2.49	207	58	23
26	G	0.25	3.20	153	67	21
27	S	0.28	2.55	102	25	20
28	S	0.25	2.99	169	42	20
29	S	0.24	2.49	128	72	21
30	S	0.23	3.05	176	57	21
31	BC	0.27	3.30	110	41	20
32	BC	0.23	3.70	76	25	19
33	BC	0.24	3.30	112	83	19
34	BC	0.23	3.60	86	23	20