



Quaternary Geology

Long Point–Port Burwell Area

**Ontario Geological Survey
Report 298**

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P.J. Barnett

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This report is dedicated to the memory of

Dr. Jaan Terasmae, Professor of Geology, Brock University

teacher, colleague, friend.

*for his contributions to our understanding of the Quaternary history
of Ontario.*

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Quaternary Geology

Long Point–Port Burwell Area

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Abstract

The Quaternary deposits and features observed within the Long Point–Port Burwell area are of Late Wisconsinan age. The deposits range between 75 and 100 m thick and completely cover the Devonian rock strata beneath.

The oldest sediment present is the Catfish Creek Till, a very gritty, sandy, clayey silt diamicton, which discontinuously overlies the deeply buried bedrock surface in the western half of the area. Deposits of Port Stanley and Wentworth tills (both stone poor, clayey silt to silty clay diamictons) crop out at the surface and form laterally extensive sheets in the subsurface.

Most of the map area is covered by glaciolacustrine sediments. Glaciolacustrine sediments also interfinger with the till layers at depth. Large ice-contact glacier-fed lakes fronted the ice margin during deglaciation of the map area.

The deposits observed at surface and in sections along river valleys and lake bluffs, record a fluctuating eastward recession of the ice margin (Erie lobe) during the Port Bruce Stade (Port Stanley Till) and Mackinaw Interstade (Wentworth Till). Six end moraines mark former positions of the Erie lobe ice margin during the deglaciation of the map area.

With eastward retreat of the ice margin, water levels in the Lake Erie basin fell. The sediment sequence of the Jacksonburg delta records the lowering of water level to approximately 183 m asl and defines a glacial lake at this level that probably drained westward. The part of the map area deglaciated during the existence of this lake supported a diverse assemblage of plants now found in arctic, boreal and prairie environments. Spruce trees were probably present as early as 13 400 years BP.

A previously unknown postglacial lake level, that may have existed only 2000 to 3000 years ago, was identified approximately 5 m above the present level of Lake Erie. A moraine dam across the Niagara River is suggested as the controlling sill of this lake.

The stratigraphy of the Lake Erie shore bluffs is summarized in cross sections and should be useful as a basis for future shore management studies. Few coarse mineral aggregate resources occur in the Long Point–Port Burwell area. A thick cover of glaciolacustrine fine-grained sediments hinders further mineral aggregate extraction.

Barnett, P.J. 1998. Quaternary geology, Long Poing–Port Burwell area; Ontario Geological Survey, Report 298, 143p.

Introduction

PURPOSE

This report presents information on the distribution and characteristics of the geological materials forming the Long Point–Port Burwell area landscape. The Quaternary geology maps (Maps 2600 and 2601) in the back pocket display the areal distribution of the geological materials at a detail consistent with the scale of these maps (1:50 000). The properties and relationships of the materials identified on these maps are discussed in the report. An attempt is made, by way of cross sections and discussions in the text, to present as much information as possible on the conditions occurring below the first metre of sediment in the report area.

This information should be used as a basis for outlining the natural geological resources of this area (availability, quantity and quality) and for recognizing potential hazardous areas related to geological conditions. Future land-use planning, environmental, engineering, hydrological and soil studies may refer to this report for basic geological information. However, this report does not replace the need for site specific geological investigations.

LOCATION AND ACCESS

The Long Point–Port Burwell area is located along the north-central shoreline of Lake Erie (Figure 1). It includes the land area displayed on the National Topographic Series maps of Long Point (40 I/10) and Port Burwell (40 I/11). This area is bounded by latitudes 42°30'N and 42°45'N, and longitudes 80°00'W and 81°00'W.

The study area is situated within Elgin County and the Regional Municipality of Haldimand–Norfolk. More specifically, the area lies within Malahide and Bayham townships and Delhi and Norfolk township municipalities. Major communities within the area include Turkey Point, St. Williams, Port Rowan, Long Point, Langton, Straffordville, Vienna and Port Burwell.

Access to the area is via the King's highways 19, 24 and 59 and a network of regional, county and township roads. A seldom used spur of the Canadian Pacific Railway serves Straffordville and Port Burwell. Lake Erie provides a major means of water access to the study area.

The report area is primarily rural, with agriculture being the main source of income to the inhabitants. Tourism and commercial fishing, centred around Lake Erie,

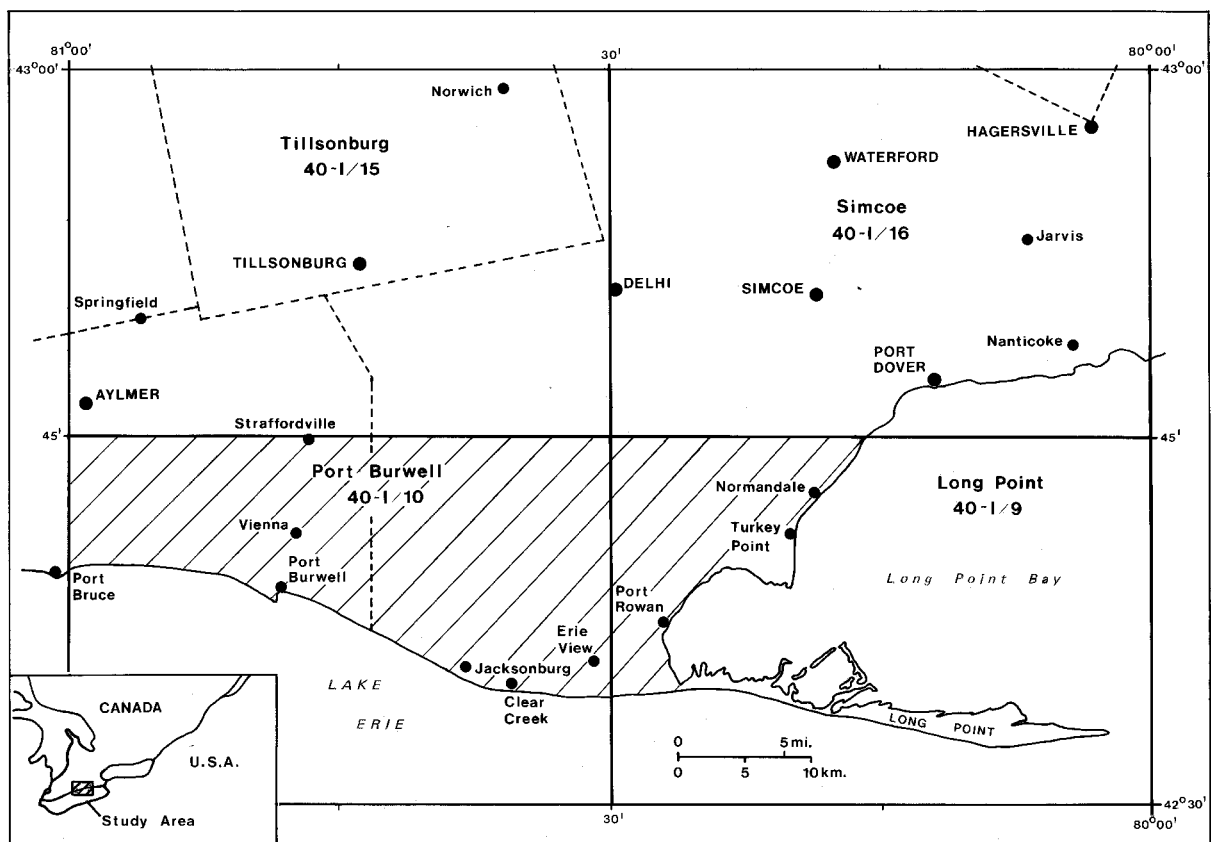


Figure 1. Location map of study area.

and light service industries situated in the larger communities are additional sources of income.

PRESENT GEOLOGICAL SURVEY

Geological mapping and stratigraphic studies within the Long Point–Port Burwell area were undertaken during the summers of 1982 and 1983. Techniques used to observe the geological materials within the report area included the examination of the natural and man-made exposures and the use of soil probes, hand augers and shovels in areas where natural exposures were lacking. Airphotos, at the scale of 1:15 840, were used to delineate the surface distribution of the geological materials encountered.

Gross physical properties and the identification of materials were determined in the field. Material deemed “representative” of certain map units was sampled, to be analyzed for more detailed information on physical and chemical properties.

Particular attention was paid to the stratigraphy of the sediments exposed by erosion along the Lake Erie shoreline. Here, exposures up to 30 m or more provided the opportunity to observe some of the sediments that occur at depth within the area (Appendix 1). In addition, several reverse circulation holes were drilled to observe the entire sequence of Quaternary sediments overlying the bedrock (Appendix 2). Both of these investigations enabled detailed study of the relationships and characteristics of the sediment deposited. The geological processes involved in the deposition of the different types of sediments are discussed (see “Stratigraphy”).

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The author was ably assisted in the field by A. Zilans, S.L. Waters, and J.M. Sando during the summer of 1982, A.F. Bajc in the fall of 1982, J.M. Sando during the summers of 1983 and 1984, and D.S. Turnbull during the summer of 1985. The work and efforts of all these student assistants are gratefully appreciated.

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Laboratory analyses were performed by the Geoscience Laboratories, Ontario GEOservices Centre. B.G. Warner identified the plant macrofossils, A. Morgan and A.V. Morgan identified the insects, and C.E. Winn examined the pollen assemblages of several organic sites described herein. Radiocarbon dates were done at the Brock University, Geological Sciences Radiocarbon Dating Laboratory.

Additional subsurface information was gained through the use of water-well data supplied by the Ontario

Ministry of Environment and Energy, and engineering reports made available by the Ontario Ministry of Transportation.

The author appreciated the kindness of the residents of the area who permitted access to their lands.

PREVIOUS WORK

One of the earliest descriptions of Quaternary sediments in the Long Point–Port Burwell area was by Wilkins in 1878. He gave a brief account of several interesting features in the area and noted the occurrence of a few “leaf-impressions, apparently of the birch, the maple, the elm and the poplar” below a sequence of stratified clays and a thick sequence of stratified, lacustrine sands (Wilkins 1878, p.82; the writer was unable to relocate this site).

Very few Quaternary geology studies have been carried out in the report area since then. Most studies involving Quaternary geology have been undertaken for other purposes, such as the evaluation of mineral and water resources and environmental assessment. The resulting reports usually contain only a very general and brief account of the Quaternary geology.

Keele (1924), in his preliminary report on the clay and shale deposits of Ontario, presented a generalized description of the shore bluffs between Port Rowan and St. Williams. He also described a section at Port Rowan where material was extracted for the production of drain tile and hollow bricks.

The Ontario Department of Planning and Development produced 3 conservation reports that give descriptions of the Quaternary deposits within the study area. Their reports on Big Otter Creek (1957) and Big Creek Region (1958) give only brief accounts; however, the Catfish Creek report (1951) goes into considerable detail on the Quaternary geology and drift thickness of this drainage basin. These reports also provide information on the history, forestry and water resources of their respective areas.

The Ontario Water Resources Commission has published reports on the water resources of Big Creek (Yakutchik and Lammers 1970) and Big Otter Creek (Sibul 1969) drainage basins. Information on the Quaternary geology and history, as well as information on the availability of groundwater, is presented. Additional groundwater studies in the area include those of Novakovic and Farvolden (1974), Sklash (1975) and Sklash et al. (1976).

An environmental appraisal of the Regional Municipality of Haldimand–Norfolk has been published in 2 volumes by the Ontario Ministry of Treasury, Economics, and Intergovernmental Affairs (Chanasyk 1970a, 1970b). In this report, maps and general information on the geology, drift thickness, bedrock topography and natural resources are presented.

Sanford (1953, 1954) produced drift thickness and bedrock topography maps based only on oil and gas borings covering the study area. Maps of the area’s drift thickness and bedrock topography have also been produced based on the record of water well and oil and gas

borings (Barnett and Bajc 1983; Barnett and Sando 1983; Barnett and Waters 1983; Barnett et al. 1983).

Maps of the Quaternary geology made during the present study are the first to cover the entire land portion of the Long Point and Port Burwell National Topographic Series maps (Barnett 1983; Barnett and Zilans 1983; Maps 2600 and 2601, back pocket).

Reports published previously on the Quaternary geology of the Simcoe (Barnett 1978) and Tillsonburg (Barnett 1982) areas present information on the properties and distribution of the Quaternary sediments observed in the adjacent map areas to the north. Preliminary maps and marginal notes on the Quaternary geology of the east half of the St. Thomas map area (Dreimanis 1970) and the Port Stanley map area (Dreimanis and Barnett 1985) also give information that pertains to the study area.

The Lake Erie shore bluffs in the study area have been included in several studies in the past. The most comprehensive is an unpublished report by Zeeman (1980) entitled the *Stratigraphy and Textural Composition of Bluffs Soil Strata, North Shore of Lake Erie between Rondeau and Long Point*. Dreimanis and Reavely (1953), Dreimanis (1971) and Rukavina and Zeeman (1987) also present some information on the bluff stratigraphy in this area.

The engineering properties of Quaternary sediments at several bluff sites within the area are included in a thesis by Gelinis (1974). Additional information on geotechnical properties of sediments exposed within the area and immediately west of the study area include those of Gelinis and Quigley (1973), Quigley and Gelinis (1975), Quigley and Tutt (1968), Quigley et al. (1977), Quigley and DiNardo (1980), Quigley and Zeeman (1980), and Zeeman (1978).

Boyd (1981) has reviewed the literature dealing with the erosion and accretion of Canadian Great Lakes' shorelines. He established 162 erosion measurement stations, 10 of which were located within the study area. At each of these sites, profiles of the bluff and nearshore areas were measured, materials exposed along the bluff described, and samples of each unit were taken between 1973 and 1980. His report summarizes this information and discusses the effects of geomorphological elements on shoreline erosion and processes. The *Coastal Zone Atlas* demonstrates on airphotos the erosion and accretion that has occurred within the Great Lakes area (Environment Canada–Ontario Ministry of Natural Resources 1975).

The National Water Research Institute of the Canada Centre for Inland Waters (Environment Canada) has prepared several other published and internal reports on Lake

Erie, including information on lake processes, sediment transport and nearshore bottom sediments. These reports, too many to reference here, are listed in this Institute's annual reports. However, information on the report area is contained in the unpublished report by Zeeman (1980) mentioned previously; a report by Coakley (1983), which presents results on the borehole stratigraphy and history of Long Point sediments; and reports by St. Jacques and Rukavina (1973) and Rukavina and St. Jacques (1978) describing the nearshore lake-bottom sediments of Lake Erie. Philpott (1986) also lists a series of published and unpublished studies done for the federal government that deal with shoreline erosion in the Port Burwell area.

A special issue of the Journal of the Fisheries Research Board of Canada (March 1976) contains several interesting papers dealing with Lake Erie as it was in the early 1970s. Sly (1976) discussed the influence of the bedrock geology and the effects of Pleistocene events on Lake Erie and its basin. Thomas et al. (1976) describe the surficial sediments of Lake Erie, and several other papers describe the circulation patterns, geochemistry, temperature variations and bacterial distribution, to mention only a few topics, covered in the 21 papers included in this volume.

Some theses pertaining to the map area include those of Wood (1951) on shore erosion, Woods (1955) and Bourne (1961) on port geography, Hill (1964) on physical features and recreation, Lewis (1966) on Lake Erie sediments, Kmiecik (1976) on effects of shore protection structures, Coakley (1985) on evolution of Lake Erie and Barnett (1987) on the sedimentology and stratigraphy of Quaternary sediments exposed along the Lake Erie shore bluffs. Theses by Dalrymple (1971), Bou (1975) and Stewart (1982) describe sediments exposed immediately to the west of the study area.

The Ontario Agricultural College has produced soil maps of the County of Norfolk (*circa* 1928) and of Elgin County (1929). The Ontario Soil Survey has re-mapped the area covered by the Long Point and Port Burwell National Topographic Series map sheets at a scale of 1:25 000. Preliminary maps for the Regional Municipality of Haldimand–Norfolk (Langway 1980a, 1980b; Montgomery 1980; Patterson 1980; Presant 1980) and for Bayham Township (Aspinal and Schut 1984) have been released. Presant and Acton (1984) have prepared a report on the soils of the Regional Municipality of Haldimand–Norfolk.

Keele (1924) and Guillet (1977) evaluated the clay and till deposits of the area for their potential as raw materials for brick and tile. An assessment of the mineral aggregate potential for the Township of Delhi has been prepared by the Ontario Geological Survey (1984).

Geological Setting

BEDROCK GEOLOGY

Bedrock is not exposed in the study area as it is covered by Quaternary sediments of variable thickness. Bedrock geological mapping has therefore, out of necessity, relied principally on information gathered from oil and gas well logs, cuttings and cores, and on geological mapping of adjacent areas where bedrock outcrops occur. Several bedrock geology maps include the area that this report covers. These are maps by Stauffer (1915), Caley (1941), Sanford (1969, 1979), Sanford et al. (1979) and Sanford and Baer (1981). The latter 2 maps include the distribution of the bedrock formations beneath Lake Erie.

Sanford and Baer (1981) suggest that 3 formations and 1 group, all of Devonian age, subcrop within the map area. These are, from oldest to youngest, the Amherstburg, the Dundee and the Marcellus formations, and the Hamilton Group (Figure 2).

The Amherstburg Formation, part of the Detroit River Group, "consists of grey brown or dark brown, fine to coarse grained, coral-stromatoporoid bioclastic limestone" (Uyeno et al. 1982, p.11). In a borehole drilled approximately 3 km northeast of Normandale, Uyeno et al. (1982, p.43) report a thickness of 25 m for this formation. The Amherstburg Formation subcrops only beneath Lake Erie in the Long Point–Port Burwell map area (see Figure 2).

A large portion of the area is underlain by the Dundee Formation. This formation "consists of medium to thick bedded, dark brown, fossiliferous, micritic limestone. Bituminous limestones and shale partings are common" (Uyeno et al. 1982, p.15). The Dundee Formation generally thickens southwestward and reaches a maximum thickness of about 40 m beneath Lake Erie. Its contact with the underlying Amherstburg Formation is a sharp discontinuity (Uyeno et al. 1982).

The Marcellus Formation overlies the Dundee Formation in the southwestern part of the Long Point–Port Burwell area. This formation is a bituminous, black shale. It has a sharp contact with the underlying Dundee Formation; however, its contact with the overlying grey shales of the Hamilton Group is gradational and often obscure (Musial 1982). It is usually recognized by its gamma log signature in subsurface geophysical logs. Musial (1982) suggested that this formation forms a lens-shaped mass below central Lake Erie, where it reaches thicknesses of up to 25 m.

The Marcellus Formation thins towards the north. North of the Lake Erie shoreline, it ranges in thickness between 3 and 15 m (Johnson 1985). The Marcellus Formation subcrops beneath the cover of Quaternary sediments in a narrow belt, up to 20 km wide (Sanford and Baer 1981). However, because it is thin and relatively soft, its distribution is probably not continuous over this zone due to preglacial and glacial erosion. Marcellus shale fragments are common in the Port Stanley Till layers exposed along the Lake Erie shore bluffs west of Port Burwell. They account for up to 29% of the pebble size fraction in samples of this till.

Rocks of the Hamilton Group overlie the Marcellus Formation beneath Lake Erie along the southern boundary of the map area. The Bell Formation, the lowest formation of the Hamilton Group, consists of blue and grey calcareous shale with thin limestone lenses in the lower part (Uyeno et al. 1982). The remaining formations of the Hamilton Group, with the exception of the Ipperwash Formation, are composed predominantly of shale with varying amounts of limestone interbeds. The Ipperwash Formation is a coarse-grained bioclastic limestone (Uyeno et al. 1982).

The organic carbon content of the Marcellus Formation averages 13.4% by weight (Musial 1982). This high

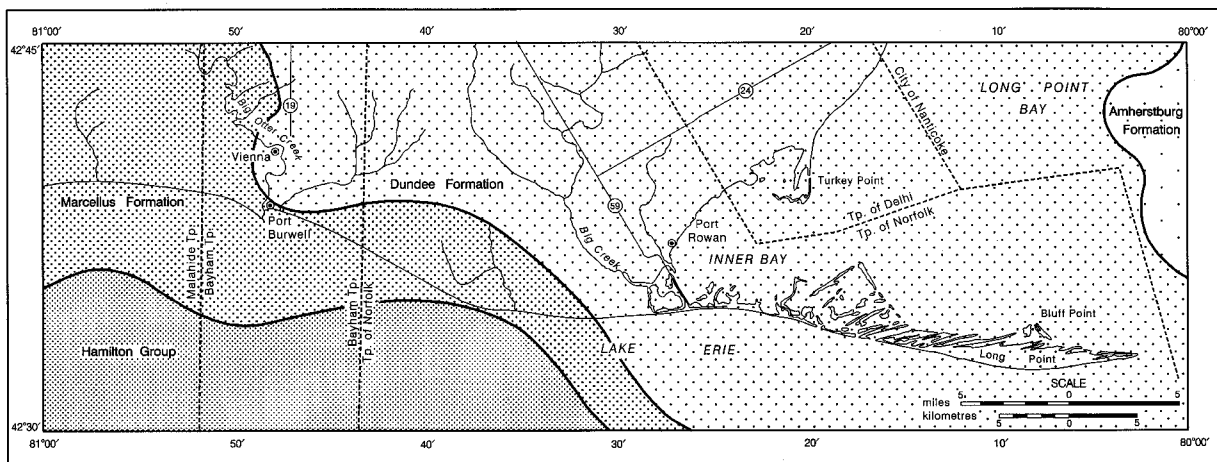


Figure 2. Bedrock geology of the study area (after Sanford and Baer 1981).

value has created interest in the Marcellus Formation as a source rock for oil and gas. Inventory and evaluation of the Marcellus Formation has been done as part of the Hydrocarbon Energy Resources Program of the Ministry of Natural Resources (Telford 1984; Johnson 1984, 1985; Johnson et al. 1985; Harris 1985). Conventional oil and gas resources have also been evaluated as part of the Hydrocarbon Energy Resources Program (Trevail 1984).

The bedrock formations beneath the Long Point–Port Burwell area have been a source of natural gas since 1910, when gas was first discovered in this area (Beards et al. 1969). Natural gas is extracted primarily from Silurian rocks at depth. Natural gas is trapped in the Irondequoit, Thorold, Grimsby and Whirlpool formations primarily in porosity and permeability pinch-outs in the dolostones and sandstones. It is also trapped in the Guelph Formation in dolomitized bioherm patch reefs (Beards et al. 1969). Depths to gas-bearing strata vary depending on the field. They range between 850 feet (259 m) and 1925 feet (587 m) below the surface in the Long Point–Port Burwell map area (Beards et al. 1969). A summary of oil and gas exploration, drilling and production is published yearly by the Ministry of Natural Resources (e.g., Habib and Trevail 1984).

BEDROCK TOPOGRAPHY

In the study area the surface of the bedrock is generally smooth to gently undulating and slopes gently toward the south (Figure 3). Along the northern edge of the Long Point–Port Burwell area, the bedrock surface is often above 500 feet (152 m) asl and beneath Lake Erie, at one locality, the bedrock surface falls below 300 feet (92 m) asl. Figure 3 is based on Bedrock Topography Series Preliminary Maps P.2583 and P.2584 of the Ontario Geological Survey (Barnett and Sando 1983; Barnett and Waters 1983). Other compilations of the bedrock topography of selected parts of the Long Point–Port Burwell area include those of Dreimanis (1951), Sanford (1953, 1954), Sibul (1969), Chanasyk (1970b) and Yakutchik and Lammers (1970).

Evidence of a preglacial drainage network is minimal. A possible preglacial channel cut into rock and trending southeastward toward the centre of the Lake Erie basin is located east and northeast of Turkey Point (see Figure 3). Other preglacial channels may have existed in the vicinity of Port Rowan–Clear Creek and Port Burwell. The broad valleys in these areas were probably widened during glaciation by glacial erosion of the relatively soft underlying Marcellus shale. The trend of these valleys is toward the south-southeast. Their alignment is nearly parallel to the prominent ice flow direction and were probably scoured by ice spreading out radially from the Lake Erie basin. The abundance of Marcellus Formation shale fragments in Port Stanley Till down the glacier ice-flow direction from these valleys is possibly further evidence for this glacial scour.

The limited evidence cited above, however, does support the existence of an eastwardly flowing master chan-

nel, the Erigan River, flowing through the Lake Erie basin as suggested by Spencer (1890). It also suggests that both preglacial fluvial erosion and glacial erosion were important in shaping the bedrock surface in the Great Lakes region.

PHYSIOGRAPHY

The study area can be generally described as an elevated, gently dipping plain. This plain, a former lake bottom, dips gently toward Lake Erie at about 2.5 m/km. It ends abruptly at the shore cliffs of Lake Erie some 30 m above lake level. The maximum elevation in the study area of 251.5 m asl occurs in the northwest corner along the crest of a morainic ridge about 2 km northeast of Luton. The Lake Erie beach, at 173.3 m asl (International Great Lakes Datum), marks the lowest level of land in the area. The lake plain is deeply dissected by several creeks that flow into Lake Erie. Local relief along these creeks, such as Big Creek and Big Otter Creek, can exceed 30 m.

Chapman and Putnam (1984) included this area in their Norfolk sand plain physiographic region, which they suggested was part of a gently sloping fan-shaped body of sand, whose apex occurs in the vicinity of Brantford, Ontario. Deposited as deltaic and nearshore sands and silts into large proglacial lakes in the Lake Erie drainage basin, these sediments were subjected to reworking by the waves of subsequent lower lake levels and by the wind.

On close examination, the plain is gently stepped where the notches or abandoned shore cliffs of these ancestral lakes left their marks. Sand dunes, formed as a result of wind activity, add locally to the relief of the sand plain (1 to 10 m). One large cliff-top dune west of Jacksonburg, The Sand Hills, rises 30 m above the surrounding plain. The morainic ridge, mentioned previously, also rises some 23 m above the general level of the plain.

Of necessity of scale, Chapman and Putnam's physiographic regions are generalized. Small areas of fine-textured sediments (till, glaciolacustrine silts and clays) form inliers within the cover of sand in several places in the study area. These finer-textured inliers generally coincide with the positions of end moraines, of which 6 cross the study area. Inliers also occur along creeks and immediately inland of the Lake Erie shoreline.

Chapman and Putnam (1984) also defined an Erie spits physiographic region in which they included the major sand spits of Lake Erie: Long Point, Turkey Point and Rondeau. The first 2 of these occur within the study area.

Long Point consists of a series of beach ridges, marshes and sand dunes rising up to 10 m above the level of Lake Erie (Coakley 1985). Long Point extends some 40 km into Lake Erie. Its physiography has recently been described in greater detail by Coakley (1985). Turkey Point spit is 4.5 km long and divides the bay protected by Long Point into two parts, Inner Bay and Long Point Bay. Turkey Point spit has been heavily developed for tourism while a great part of Long Point spit is still relatively undis-

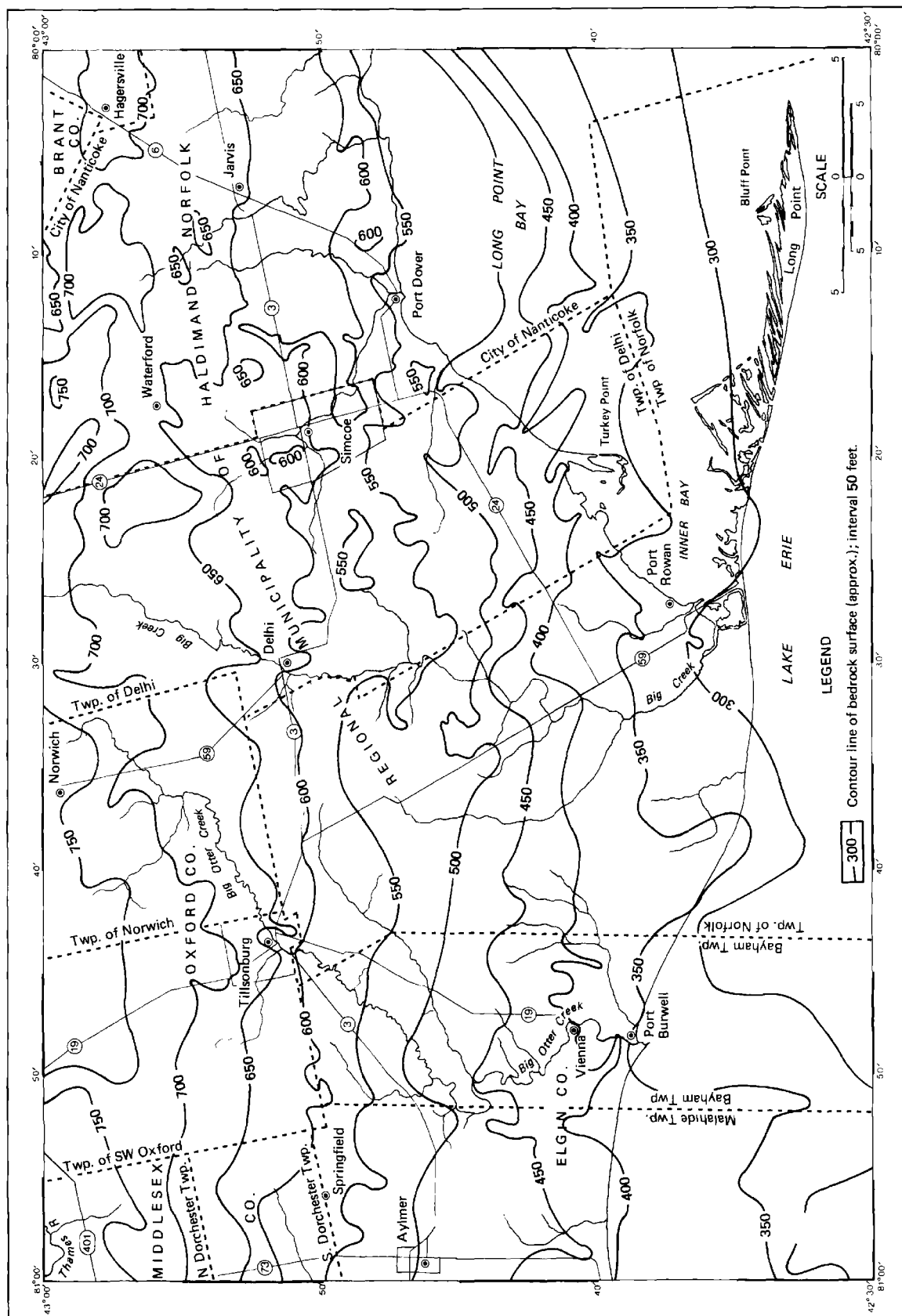


Figure 3. Bedrock topography of the study area and adjacent Tillsonburg and Simcoe map areas (*after* Barnett and Ferguson 1975; Barnett and Starkoski 1978a, Barnett and Sando 1983; Barnett and Waters 1983).

turbed. Archaeological records on Long Point extend back to approximately 2250 years BP (Fox 1986).

DRAINAGE

The study area is drained by Catfish Creek, Silver Creek, Big Otter Creek, Little Otter Creek, Clear Creek, Big Creek, Dedrick's Creek, Normandale Creek, Fishers Creek, their tributaries and numerous unnamed creeks which flow directly into Lake Erie.

Big Creek and Big Otter Creek are the largest streams in the area and drain approximately 180 km² and 90 km², respectively. Hydrological characteristics of these creeks are discussed by Yakutchik and Lammers (1970) and Sibul (1969). Catfish Creek drains approximately 16 km²; Silver Creek, about 40 km². Little Otter Creek drains 100 km² of the area; and 65 km² is drained by Clear Creek. Dedrick's Creek drains 79 km² of land. The remaining land area, approximately 190 km², drains via small creeks directly into Lake Erie.

A weakly developed trellis pattern of drainage has formed in the report area. Trellis patterns usually develop in areas where a strong lithostructural fabric is imprinted on the landscape, for example, in areas of folded rock strata (Garner 1974). In the Port Burwell area this pattern is best developed where surface and near-surface end moraines cross the map area. The arrangement of these end moraines, combined with the relatively impermeable nature of the southeast-dipping till layers associated with them, helped in the development of the stream pattern. The unusual, near right angle bends of Clear and Dedrick's creeks along the Galt moraine are fine examples of a trellis pattern of drainage. Fishers and Normandale creeks, located northeast of Turkey Point, are more typical of dendritic stream patterns formed on granular surfaces in humid regions (Garner 1974).

Chapman and Putnam (1951, 1966, 1984) recognized that creeks flowing into Lake Erie west of the report area once extended much farther south, beyond the present shoreline. Several creeks in the Port Burwell area did as well. Big Otter Creek and its former tributary, Little Otter Creek, are excellent examples. With continued shoreline recession, Chapman and Putnam (1984, p.94) suggested that these creeks are "constantly growing headward under the influence of new gradients".

DRIFT THICKNESS

The bedrock surface in the Long Point–Port Burwell area is deeply buried by sediments deposited during the Quaternary Period. This cover of sediments can be thought of as a blanket which thickens generally toward the south as a result of the slope of the bedrock surface (*see* Figure 3). Along the northern edge of the report area, drift thickness is commonly about 250 feet (75 m) (Figure 4). Along the southern part of the land area, it thickens to over 300 feet (90 m) and even over 325 feet (100 m) in places. The blanket thickens locally along the Tillsonburg moraine, in the northwest corner of the Port Burwell map area, where it exceeds 325 feet (100 m).

Postglacial stream erosion has reduced the thickness of the drift in areas surrounding the creeks. In some instances, over 30 m has been removed. Lake Erie shore erosion has also affected the thickness of Quaternary sediments in the offshore. Sediments removed by lake erosion and a great portion of the sediments removed by stream erosion have been redistributed in the present lake basin.

Figure 4 summarizes Ontario Geological Survey Preliminary Maps P.2589 and P.2590, Drift Thickness Series (Barnett et al. 1983; Barnett and Bajc 1983). Other maps of drift thickness which cover parts of the study area include those of Dreimanis (1951), Sanford (1953, 1954), Sibul (1969), Yakutchik and Lammers (1970) and Chanasyk (1970b).

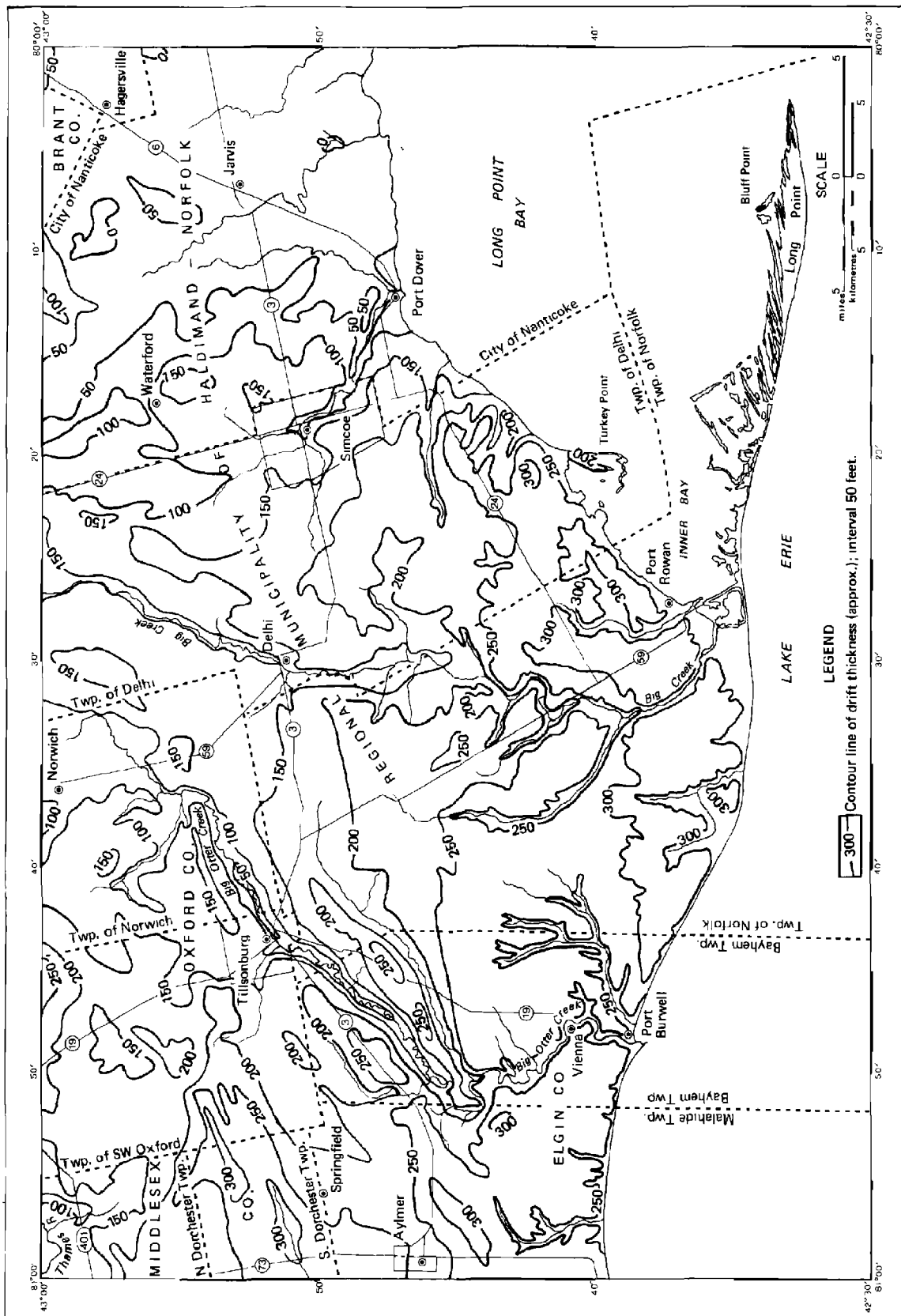


Figure 4. Drift thickness of the study area and adjacent Tillsonburg and Simcoe map areas (after Barnett and Ferguson 1978; Barnett and Starkoski 1978b; Barnett and Bajc 1983; and Barnett et al. 1983).

Quaternary Geology

GENERAL BACKGROUND

The Lake Erie basin played a major role in determining the types and characteristics of the sediments that were deposited within the basin during the Quaternary Period, and in particular the Late Wisconsinan Substage.

T.C. Chamberlin (1883, 1888) was the first to recognize the lobate nature of the continental ice margin and how landscape topography beneath the glacier affected the shape of the ice margin and direction of ice flow.

The southwest orientation of the shallow, broad Lake Erie basin, combined with the north-facing cuesta edge of the Appalachian Plateau south of the Lake Erie basin, deflected the flow of the continental glacier westward along the trend of the Lake Erie basin (Chamberlin 1883, 1888; Carmen 1946). Initially, the continental glacier entered the northeastern end of the Lake Erie basin and spread southward down the basin (Erie lobe) until it coalesced with another lobe of the continental glacier flowing southward in the Lake Huron basin (Huron lobe). During deglaciation, the reverse occurred. The northeastern end of the Lake Erie basin was the last part to become deglaciated.

As the continental glacier entered the Lake Erie basin, the existing drainage system in the basin became blocked and water levels began to rise. In general, the farther westward the glacier extended into the basin, the higher the water level in the basin became. However, because several of these high-level lakes occupied portions of both the Lake Huron and Lake Erie basins, the water level also depended on the position of the ice margin in the Lake Huron basin (Huron lobe).

The major outlets used by glacial lakes in the Lake Erie basin include: the Wabash River, Indiana; the Imlay Channel, Michigan; the Ubyly Channel, Michigan; the Grand River, Michigan; the Indian River Lowlands, Michigan; the Straits of Mackinac, Michigan; the Syracuse Channels, New York; and the Niagara River (Leverett and Taylor 1915; Hough 1958; Prest 1970; Fullerton 1980; Calkin and Feenstra 1985; Eschman and Karrow 1985).

Leverett and Taylor (1915, p.321) suggested that “the succession of lakes in this (Erie) basin is more complex than in any other part of the lake region”. Attempts to unravel the complex sequence of proglacial lakes that occurred in the Lake Erie basin have been many, the most recent being those of Barnett (1985), Calkin and Feenstra (1985), Coakley and Lewis (1985), Eschman and Karrow (1985) and Totten (1985).

Denton and Hughes (1981) have discussed the influence that basins, such as the Great Lakes basins, have on the profile and basal conditions of a continental ice sheet. In general, they suggested that the basins of the Great Lakes channelled ice streams underneath terrestrial portions of the ice sheet, resulting in the formation of ice lobes extending from the ice-sheet margin. As the ice

streams became channelized, ice velocities increased due to the convergence of flow lines. Increased velocities would, initially, tend to increase frictional drag and thus produce heat at the base of the glacier, resulting in increased melting.

Hughes (Denton and Hughes 1981) predicted that a basal thermal zone of melting would occur in the region of flow-line convergence. They defined a “melting zone” as a zone beneath the glacier that is completely frozen at its inner or up-ice boundary and completely thawed at its outer or down-ice boundary. The remainder of the zone consists of a mix of thawed and frozen patches that change progressively across the zone to the boundary conditions. Flow-line trajectories generally move toward the bed, and transport of debris toward the ice margin occurs primarily in the basal water created in the melting zone (Denton and Hughes 1981). Freeze-thaw quarrying and erosion can be deep in melting zones.

In the central part of the basin, a “melted zone” was predicted, in which flow-line trajectories are parallel to the base of the glacier and erosion uniform, but not necessarily deep (Denton and Hughes 1981).

Around the down-ice or distal end of the basin, a basal thermal “freezing zone” may have existed (Denton and Hughes 1981). A freezing zone has a similar mix of thawed and frozen areas as a melting zone, but its outer boundary is completely frozen and its inner boundary thawed. In a freezing zone, flow-line trajectories are upward and the transport of the debris toward the ice margin occurs predominantly within the glacier.

The study area, located near the central part of the Lake Erie basin, would generally be within the melted and melting zones predicted by Hughes (Denton and Hughes 1981). A peripheral freezing zone may have existed along the northern edge of the basin (i.e., in the Tillsonburg area) prior to the ice-marginal events that affected the study area.

Meltwater generated within the melting zone would become confined within the basin and combined with surface drainage to form the large proglacial lakes of the Lake Erie basin. With water being generated at the base of the glacier and water ponded in front of it, sediments beneath the glacier must have had a high moisture content. Depending on the ability of the subglacial environment to drain, either through a network of subglacial channels or through the sediments, there was a potential for pore-water pressure to build up beneath the glacier and for ice-bed uncoupling to occur.

The presence of “large amounts of water at the base causes the ice to be separated from the bed. Consequently the effective bed that the glacier ‘sees’ is smoother than the actual bed. It is reasonable to expect that the smoother the bed the faster a glacier will slide over it” (Weertman and Birchfield 1983, p.22). Denton and Hughes (1981) suggested that ice lobes could form solely as a result of large amounts of subglacial water, but ice lobes formed by this

mechanism alone are transient features which rapidly form and ablate (a behavior known as surging).

Kamb et al. (1985) have documented that surging of the Variegated Glacier in Alaska corresponded with peaks of high subglacial water pressure. Surging has also been previously suggested as a mechanism active along the Laurentide Ice Sheet in the Great Lakes region (Wright 1973; Clayton et al. 1985). However, as indicated by Chamberlin (1888) topographic control was also important in the Lake Erie basin. The lobate form of the ice sheet within the Lake Erie basin was probably the result of both the topography and the glacier's response to the concentration of meltwater at its base.

The rate of draining of the subglacial water could also have affected some of the properties of the sediments overridden or deposited beneath the glacier. White (1961, p.83), studying the consolidation of overridden silts and clays and tills collected in the Lake Ontario basin, concluded that the "resulting irregular and low results of P_c (preconsolidation pressure) are considered as due to incomplete drainage and consolidation of sampled materials when loaded by the ice". Based on consolidation tests on subglacial till samples deposited in the Lake Michigan basin, Mickelson et al. (1979, p.185) indicated that there was either no overconsolidation or "the excess above the overburden stress is less than the total stress the glacier ice would be expected to exert".

Both of these studies suggest that overridden sediments in basin settings may not have been drained during loading and that high hydrostatic pressures could have existed beneath the glacier.

The types and characteristics of sediments deposited in a glaciated basin environment and the transitions (i.e., contacts) from one sediment type to another may be unique to this environment. It may not be possible, for example, to apply the criteria considered diagnostic of subglacial till in a terrestrial environment to the glaciated basin environment.

STRATIGRAPHIC FRAMEWORK

The nomenclature and stratigraphic framework of Quaternary sediments in southern Ontario have been summarized by Dreimanis and Karrow (1972), Karrow (1974, 1984) and Cowan et al. (1975, 1978). In the United States adjacent to Lake Erie the stratigraphic classification of Pleistocene deposits presented by Willman and Frye (1970) is commonly followed. This study will follow the stratigraphic classification of Dreimanis and Karrow (1972).

The Quaternary materials in the study area were deposited primarily during the Late Wisconsinan Substage. Older deposits, representing the Middle Wisconsinan, are exposed in the Lake Erie bluff approximately 35 km west of the study area, near Port Talbot (Dreimanis 1958); along the Catfish Creek valley north of Sparta (Dreimanis and Barnett 1985); and at Innerkip, about 25 km north of the study area (Cowan 1975). Sediments that may be equivalent to the Middle Wisconsinan deposits mentioned above

were encountered during drilling of a well located 1.65 km west-northwest of Little Aylmer along the Michigan Central Railway just north of the study area (Dreimanis 1951). The log of the well, as reported by E. Hoover from memory to A. Dreimanis, is presented in Table II of Barnett (1982, p.9). Middle Wisconsinan deposits may be present at depth elsewhere in the report area, buried beneath the Late Wisconsinan sediments.

During Late Wisconsinan time, 3 significant periods of ice advance, or stades, termed the Nissouri, Port Bruce and Port Huron (Dreimanis and Karrow 1972) directly affected the Lake Erie basin. These stades were separated by 2 periods of general ice-margin recession, or warmer periods, called the Erie and Mackinaw interstades.

The Nissouri Stade is represented by the Catfish Creek Till in southwestern Ontario. This till outcrops along Catfish Creek and in the Lake Erie bluffs west of the study area. During the Nissouri Stade, the margin of the continental glacier, the Laurentide Ice Sheet, advanced into Ohio and Indiana. The outer limit of the advance is thought to be marked by the Cuba and Hartwell moraines in those states (Goldthwait et al. 1965; Dreimanis and Goldthwait 1973).

Mapping in the Woodstock area (Cowan 1975) indicates that the initial movement of the ice sheet was controlled by the orientation of the Great Lakes basins, but it changed to a more regional flow, from the north-northeast, during the maximum advance of this stade. During recession, as the ice thinned, flow once again was controlled by the Great Lakes basins (Dreimanis 1961, 1964; Cowan 1975).

During the Nissouri Stade, the Laurentide Ice Sheet entered Ohio and reached its southernmost position between 17 000 and 23 000 years ago (Dreimanis and Goldthwait 1973). Along the margin in Ohio, the Navarre and Kent tills and Lavery and Hagersville tills are probably equivalent to the Catfish Creek Till (Dreimanis and Goldthwait 1973; White 1982).

During the subsequent Erie Interstade, about 15 500 years BP, as the ice front receded into the Lake Erie basin, several high-level lakes occupied the uncovered part of the basin (Dreimanis 1969; Mörner and Dreimanis 1973). At maximum Erie Interstade retreat, Lake Leverett is believed to have existed in the Lake Erie basin (Mörner and Dreimanis 1973). The period of glacial advance that followed the Erie Interstade is termed the Port Bruce Stade (Dreimanis and Karrow 1972). During this stade, the flow direction of the advancing glacier was controlled by the Lake Erie basin and flow was outward from the basin. Overriding of the Erie Interstadial glaciolacustrine sediments occurred. The incorporation of these fine-grained sediments into the base of the glacier as it overrode them resulted in the deposition of the fine-grained Port Stanley Till in Ontario. Equivalents of the Port Stanley Till in Ohio include the Hayesville, Hiram and Ashtabula tills (Dreimanis and Goldthwait 1973; White 1982). The youngest member of the Ashtabula Till related to the Girard moraine, however, may correlate with the Wentworth Till in Ontario (Leverett 1902; Mickelson et al. 1983).

A series of high-level proglacial lakes (glacial lakes Maumee I to IV) occupied the western end of the Lake Erie basin during the initial stages of eastward withdrawal of the ice margin. With further eastward recession of the ice margin a series of progressively lower level lakes (Arkona to Ypsilanti) existed in the Lake Erie basin (Hough 1958; Kunkle 1963; Wall 1968; Fullerton 1980). Dreimanis and Karrow (1972) referred to this period of general ice recession as the Mackinaw Interstade.

“After a pronounced retreat of the Erie Lobe, a glacial readvance built the Paris and Galt moraines (Karrow 1963). They contain the sandy Wentworth Till, except where finer-grained lacustrine sediments have been incorporated” (Goldthwait et al. 1965, p.93).

The younger, silty clay Halton Till occurs to the east of the Wentworth Till and is found in several moraines along the crest of the Niagara Escarpment. “These escarpment moraines may have been built during the time of Lake

Whittlesey, 13 000 years ago, since Whittlesey beaches are found along drumlins that are in the front of them” (Goldthwait et al. 1965, p.95).

The position of the ice margin that supported Lake Whittlesey 13 000 years ago, during the Port Huron stadial advance in the Lake Erie basin, has been the subject of debate in the past. Earlier workers placed it at the Fort Erie moraine, the approximate margin of the Halton Till (Leverett 1902; Leverett and Taylor 1915); later Chapman and Putnam (1951, 1966) and Dreimanis and Goldthwait (1973) placed it at the Paris and Galt moraines, both composed of Wentworth Till. More recently evidence has been presented that supports the earlier workers’ views, with minor variations (Barnett 1978, 1979; Cowan et al. 1978).

Following the Port Huron Stade the margin of Laurentide Ice Sheet receded into the Lake Ontario basin never to enter the Lake Erie basin again.

Geomorphology

GENERAL

A large part of the Long Point and Port Burwell map areas is occupied by Lake Erie. Ancestral Lake Erie levels submerged the entire study area during the Late Wisconsin, resulting in the ground surface having the characteristics of a broad, flat plain. The distribution of sediments in this landscape is shown on 2 Quaternary geology maps (Maps 2600 and 2601, back pocket; *see also* Barnett 1983; Barnett and Zilans 1983).

MORAINES

Six moraines cross the study area, although only 1 retains any positive topographic expression. Four of these moraines are aligned slightly oblique to the present-day Lake Erie shore and are composed of Port Stanley Drift. They are the last 4 of a series of 8 end moraines composed of Port Stanley Drift that mark positions of ice-margin stands or minor readvances of the glacier during its general recession. The Ingersoll moraine marks approximately the farthest northward extent of the Erie lobe during the Port Bruce Stade. The Westminster, St. Thomas, Norwich,

Tillsonburg, Courtland, Mabee and Lakeview moraines complete this series (Figure 5).

The remaining 2 moraines, oriented nearly perpendicular to the local trend of the Lake Erie shoreline, are composed of Wentworth Till and associated sediments. These are the continuation of the Paris and Galt moraines, 2 strongly developed moraines north of the report area. The younger Moffat moraines (Karrow 1963) may be exposed near Port Rysse in the Lake Erie shore bluffs, where there is an irregular, hummocky, upper surface of the Wentworth Till (Barnett 1978).

Tillsonburg Moraine

The Tillsonburg moraine (Taylor 1913) is the oldest moraine that crosses the study area. This moraine's southernmost ridge rises above the lake plain 2 km west of Luton and continues northeastward toward Summers Corners in the Tillsonburg map area (*see* Map 2601, back pocket). It rises over 10 m above the surrounding lake plain and is the only moraine within the study area with positive relief.

Several limbs of the Tillsonburg moraine have been identified in the Tillsonburg map area to the north (Barnett 1982). The southernmost limb of the Tillsonburg moraine loses its positive relief about 3 km east of Summers

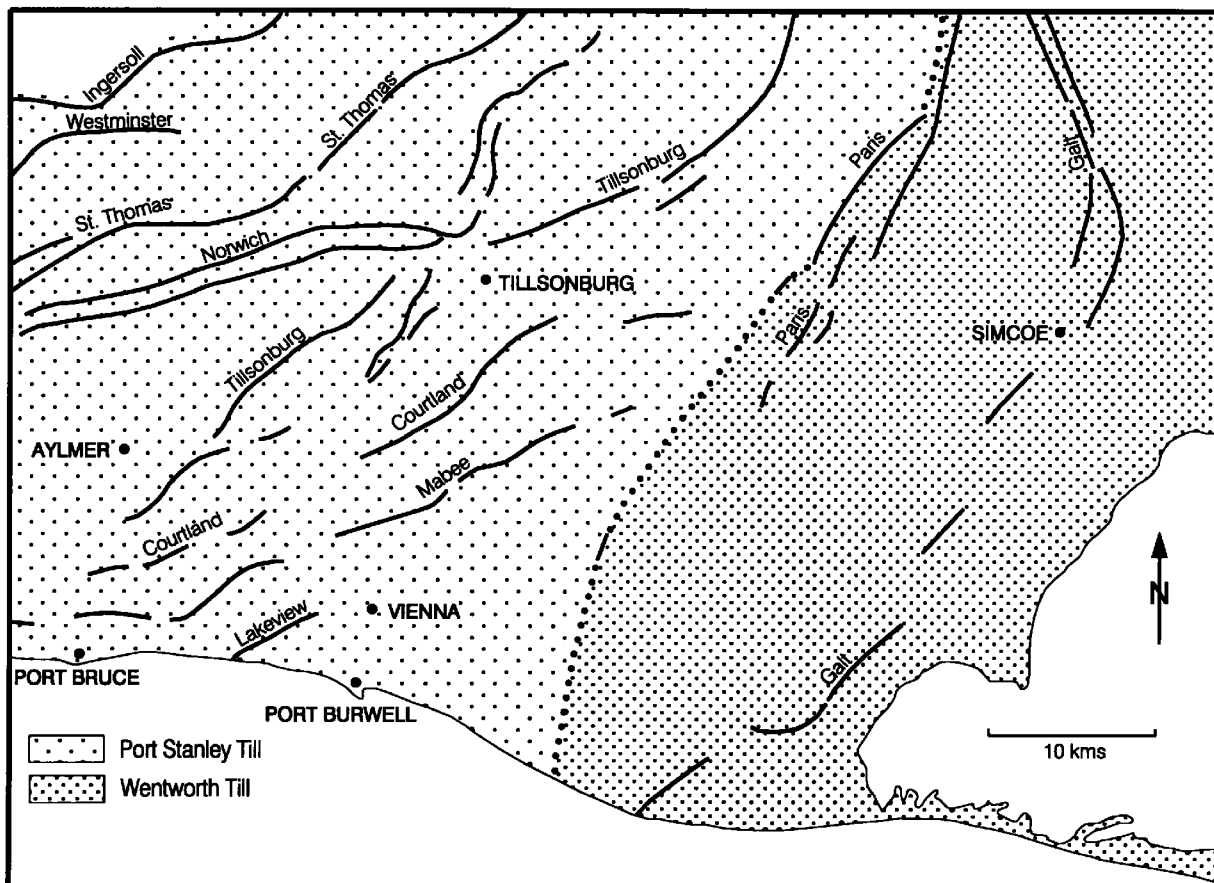


Figure 5. Moraines of the study area and adjacent Tillsonburg and Simcoe map areas (*after* Barnett 1984, 1985).

Corners in the Long Point–Port Burwell area and becomes buried to the east beneath the Norfolk sand plain. The drainage divide between Big Otter and Little Otter creeks, north of Highway 3, may be the topographic expression of the southern limb of the Tillsonburg moraine. It rises above the sand plain again at Arthur's Corners and joins with the other limbs in the northeast corner of the Tillsonburg area, where it rises 21 m above the surrounding Norfolk sand plain. West of the study area the southern limb of the Tillsonburg moraine has been traced through Sparta and Union (Dreimanis and Barnett 1985).

Cowan (1972) and Barnett (1978) have suggested that the Tillsonburg moraine may be capped by Port Stanley Till and cored by older drift in the Brantford and Simcoe areas. However, within the Tillsonburg area (Barnett 1982), the moraine appears to be cored only with Port Stanley Drift. In this area it is composed of massive to faintly stratified clayey silt containing some very coarse sand, pebbles, cobbles and few boulders (interpreted as Port Stanley Till). Each limb of the Tillsonburg moraine appears to have been formed by a minor readvance of the glacier margin during general recession back into the Lake Erie basin (Barnett 1982).

Courtland Moraine

The Courtland moraine (Barnett et al. 1976) has no positive relief in the study area but is a distinct ridge between Courtland and Eden in the Tillsonburg area (Barnett 1982). It is traced westward in the study area as a belt of massive and thinly bedded, clayey silt diamicton (interpreted as Port Stanley Till) approximately 3 to 4 km south of the Tillsonburg moraine (Barnett 1983). It forms the drainage divide between Big Otter and Little Otter creeks west of Straffordville and is likely the cause of the large U-shaped bend in Big Otter Creek at the north end of the study area. The moraine then passes through Fairview and Mount Salem and is crossed by Highway 73 about 0.5 km south of Dunboyne (*see* Map 2601, back pocket). Dreimanis and Barnett (1985) have traced the moraine westward to Port Stanley, where it has been truncated by Lake Erie shore erosion.

The Courtland moraine was formed during a minor readvance of the glacier during the late stages of the Port Bruce Stade (Barnett 1982).

Mabee Moraine

The Mabee moraine was first recognized in the Tillsonburg area (Barnett et al. 1976). It has very little topographic expression in that area or in the present study area. Composed of massive to faintly stratified, clayey silt diamicton, interpreted as Port Stanley Till, it can be traced from Mabee southwestward through Straffordville, Calton and Grovesend, where it bends westward and parallels the Lake Erie shoreline (*see* Map 2601, back pocket). It continues westward parallel to the lakeshore until it swings south and meets the Lake Erie shoreline just east of Dexter (Dreimanis and Barnett 1985).

The Mabee moraine was formed by a minor readvance of the glacier front during general recession into the Lake Erie basin (Barnett 1982).

Lakeview Moraine

The Lakeview moraine was initially identified during the field work for this study (Barnett 1983). It was defined as a moraine that lacks topographic expression. A series of outcroppings of Port Stanley Till, which forms the moraine, delineates its location (*see* maps in back pocket). The moraine has been recognized from the Lake Erie shore near Lakeview, inland to Vienna (Barnett 1985). It marks the termination of a small readvance.

Unnamed Moraine

A short ridge identified on the Lake Erie bottom about 1.5 km east of Port Burwell (C.F.M. Lewis, Geological Survey of Canada, personal communications, 1983) may be an additional moraine composed of Port Stanley Drift. The exposure of Port Stanley Till just east of Port Burwell may be the expression of this ridge in the shore cliffs.

Paris Moraine

The Paris moraine was named by Taylor (1913). It occurs as 1 prominent ridge north of Scotland (Cowan 1972) and divides into 3 ridges between Vanessa and Delhi (Barnett 1978). South of Delhi, Taylor (1913) suggested it was “scarcely perceptible as a ridge, but exerting some control over minor drainage”. It was “only vaguely delineated by the presence of the slightly coarser Wentworth Till” in the Tillsonburg area (Barnett 1982). This is also true in the present report area. Wentworth Till was found just west of Venison Creek about 3 km east of Glen Meyer and is probably associated with the oldest limb of the Paris moraine (*see* Map 2601, back pocket). The undulating surface of the lower till at The Sand Hills Park area may be the hummocky surface of the Paris moraine. As suggested by Taylor (1913), the moraine extends to the Lake Erie shore just west of Port Rowan.

Galt Moraine

The Galt moraine (Taylor 1913) is a prominent ridge north of Simcoe. Taylor (1913) states that the Galt moraine “is still a distinct ridge at Port Ryerse, where it is cut off by the lakeshore”. A distinct ridge was not observed by the author at Port Ryerse; however, the buried surface of the Wentworth Till is hummocky east of there (Barnett 1978). Barnett (1978) suggested that this moraine may be an extension of the Moffat moraines (Karrow 1963) rather than the Galt moraine.

South of the Simcoe area, there is no positive relief associated with the Galt moraine. It is buried for the most part below the lake plain. A series of outcroppings of Wentworth Till southwest from the Town of Simcoe, through St. Williams and Clear Creek, ending at the Lake Erie bluffs in The Sand Hills area, probably delineate this moraine (*see* Maps 2600 and 2601, back pocket). Thick sections of till

exhibiting an irregular till surface (hummocky), commonly associated with moraines, occur along Clear Creek and at several other localities. These occurrences, along with the outcrop pattern of Wentworth Till, support the proposed location of the Galt moraine.

LAKE PLAIN

The entire study area is a lake plain with the exception of the low morainic ridge (Tillsonburg moraine) located in the northwest corner. This gently south-sloping plain, the surface of which is primarily sand, was submerged by several glacial lakes during and following deglaciation of the area. It was most likely formed as the result of sedimentation in glacial lakes Whittlesey and Warren with minor contributions by the sequence of lower-level lakes that followed.

A prominent step in the lake plain at Straffordville separates the higher glacial lake Whittlesey plain from the lower plain of glacial Lake Warren. However, this distinction is not well developed elsewhere in the report area.

Fine-grained silt and clay occasionally form the surface sediments of the lake plain. They occur inland from Lake Erie between Silver Creek and Port Burwell, and between Clear Creek and St. Williams. Fine-grained lake sediments also occur inland along Big Otter Creek southwest of Straffordville, and along Big Creek east of Langton. Till forms the surface sediments of the lake plain along the moraines previously mentioned.

ABANDONED SHORELINES

Although the study area was submerged by several high-level lakes in the Lake Erie basin following deglaciation, evidence of shorelines is poor. The area's gently sloping nature, the lack of sources of coarse material at the surface to form distinct shoreline features and the subsequent modification of the landscape by wind are the principal reasons for this poor record. To the north of the report area, however, where the land surface is higher and morainic ridges protrude above the levels of these pre-existing lakes, the shoreline record is better developed (Figure 6).

The most distinct and highest shoreline features in the study area occur along the southern flank of the Tillsonburg moraine. A shore cliff and a series of gravelly sand beaches rise toward the northeast from approximately 238 m to 241 m asl. These deposits continue into the Tillsonburg area, where they have been identified as shoreline deposits of glacial Lake Whittlesey (Barnett 1979, 1982). The Whittlesey shoreline formed approximately 13 000 years ago during the Port Huron Stade and is the best-developed abandoned shoreline along the north shore of Lake Erie. During Lake Whittlesey, the glacier margin stood at the Port Huron and Wyoming moraines in the Lake Huron basin (Taylor 1897) and at the margin of the Halton Till, as defined by Feenstra (1974, 1975), in the Lake Erie basin (Barnett 1979).

A paleogeographic map and water-plane curve for this lake have been constructed previously (Barnett 1979, Figures 3 and 4). The isobase lines were constructed as straight lines even though slightly curved lines, paral-

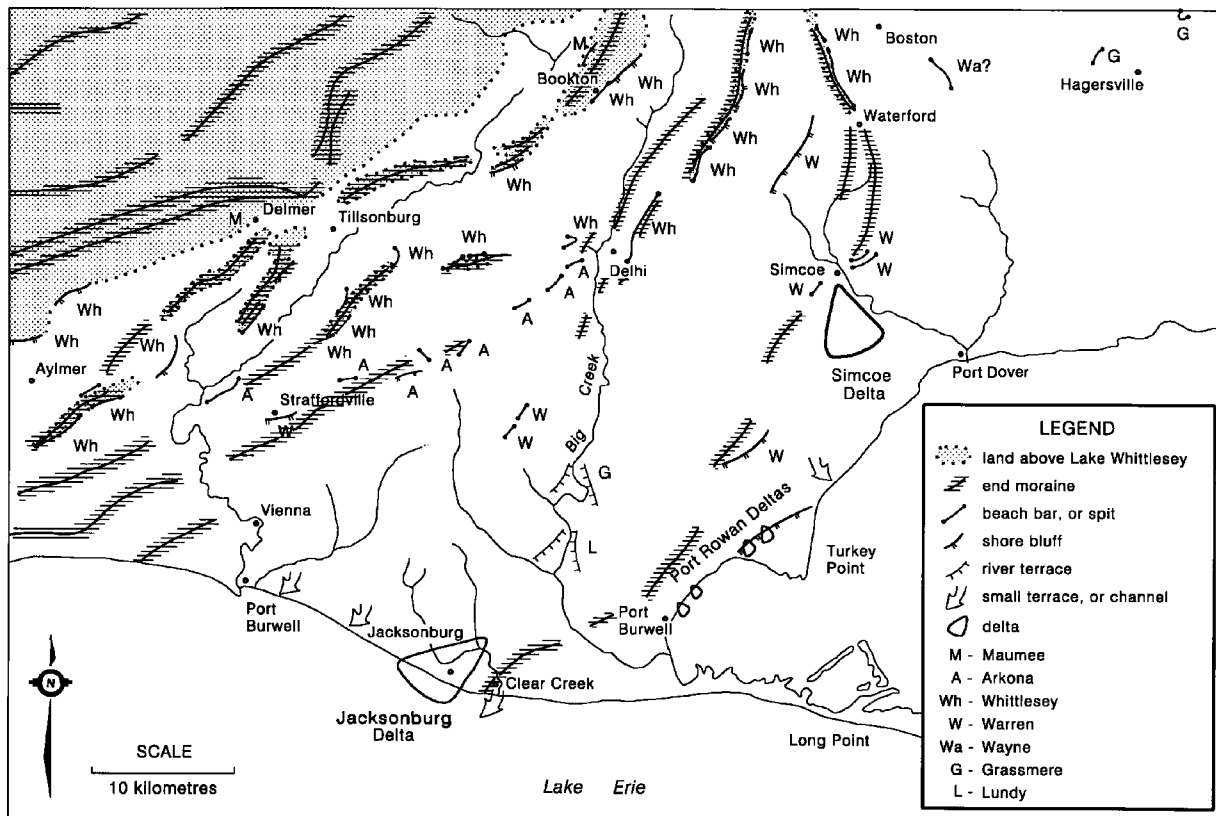


Figure 6. Shoreline features in the study area and adjacent Tillsonburg and Simcoe map areas (after Barnett 1985).

lel to the orientation of former ice margins, are thought to be more representative. However, major curving of isobase lines is not supported by the distribution and elevation of Lake Whittlesey shoreline features (Barnett 1979, Figure 4, Appendix 1; Barnett 1982, Figure 8). Phanerozoic and Recent tectonic movements, as suggested by Sanford et al. (1985), may have subsequently adjusted these shoreline features as well, hindering any detailed reconstruction of isostatic rebound.

The next highest shoreline feature is located on the western edge of the study area approximately 3 km west-northwest of Luton. It is built at an elevation between 228 and 232 m and is buried beneath a cover of sand which is in part eolian. It has been traced westward into the adjacent Port Stanley map area, where it has been assigned to a level of glacial Lake Arkona (Dreimanis and Barnett 1985).

Three levels of glacial Lake Arkona have been previously recognized elsewhere in the lakes Huron and Erie basins (Hough 1958). However, only 1 level has been identified along the north shore of Lake Erie (Barnett 1985). In the Tillsonburg area, glacial Lake Arkona features rise toward the northeast from 230 m near Straffordville to 235 m north of Lynedoch. These features have been generally modified by glacial Lake Whittlesey, a younger and higher level lake, and are often buried beneath its sediments. Glacial Lake Arkona features are built on the proximal (ice-contact) sides of the Courtland and Mabee moraines in the Tillsonburg area; however, the relationship of this lake's shoreline to the Paris moraine is obscured by Lake Whittlesey and eolian sediments (Barnett 1982, 1985).

Distinct but discontinuous shore cliffs occur between Mount Salem and Straffordville and in the Glen Meyer–Langton area. They separate 2 levels of lake plains, where present, creating a step-like feature in the Norfolk sand plain (see Map 2601, back pocket). The base of the shore cliff occurs at an elevation of about 227 m at Mount Salem and 228 m at Straffordville; at Straffordville the shore cliff is well developed and is up to 4 m high. Between Glen Meyer and Langton the abandoned shore cliffs are at elevations between 228 and 232 m.

Glacial Lake Warren formed beaches about 13 m below those of Lake Whittlesey in the area north of the study area (Barnett 1978, 1982). The shore cliffs discussed above may have formed in this lake. A pair of beach ridges at Simcoe occurring at elevations of 238 m and 235 m have been attributed to glacial Lake Warren levels (Barnett 1978, 1985).

Very low, discontinuous, and indistinct benches that are cut into the Norfolk sand plain near Frogmore, may also be abandoned shore cliffs of an ancestral lake in the Lake Erie basin. These features are commonly associated with, or buried by, large, linear sand dunes. As a result, their origin is difficult to determine. The indistinct benches occur at an elevation of 210 m, 9 km east-northeast of Port Burwell; between 213 and 216 m, 12 km northeast of this community; and at an elevation of 219 m, 15 km north of Port Burwell. If they are abandoned shoreline features,

they may be associated with glacial Lake Grassmere or one of several other short-lived postglacial lake stages in the Lake Erie basin.

ALLUVIAL TERRACES

Four sets of alluvial terraces have been previously recognized along the valleys of Big and Big Otter creeks (Barnett 1978, 1982). Several abandoned river terraces occur along these creek valleys in the report area, as well. Up to 4 terrace levels can be identified along any one reach of these creeks.

Fanning out of river terraces along Big Creek occurs at an elevation of approximately 206 m and at 198 m. This may mark the ancestral shorelines of glacial Lake Grassmere and glacial Lake Lundy, respectively. No such fanning of terraces is recognized along Big Otter Creek, however.

Alluvial terraces occur along several other creeks in the report area, but are usually fewer in number. Two hanging fluvial terraces are exposed in the Lake Erie shore cliffs between Port Burwell and Jacksonburg. About 3 km east of Port Burwell, the base of the alluvium in one of these terraces occurs approximately 19 m above the present level of Lake Erie. The base of alluvium at the other site, 8 km southeast of Port Burwell, occurs at about 15 m above the present Lake Erie level. Neither of these terraces can be directly related to the specific water levels that existed in the Lake Erie basin. However, the lake levels indicated by these hanging terraces were lower than the elevations of these terraces (193 and 189 m) and their shorelines were located farther out in the Lake Erie basin than the present shoreline.

An abandoned channel of Clear Creek is cut 5 m below the level of Lake Erie. This channel must have been cut at a time when the water level in the Lake Erie basin was lower than at present (Barnett et al. 1985).

Along several small gullies that drain into Inner Bay behind Long Point, several fan-shaped features occur approximately 5 m above the present level of Lake Erie. Abandoned alluvial terraces grade to each of these fan-shaped features. These features are interpreted as deltas. Their identification as deltas, as opposed to alluvial fans, is difficult due to the lack of information on their internal structure; however, the coincidence of the elevations to which they are built combined with the associated older alluvial terraces graded to them strongly suggest they are deltas (Barnett 1985).

WETLANDS

Two large marshes occur behind Long Point spit and Turkey Point spit. These are the major areas of organic sediment accumulation in the study area. Numerous small seasonal ponds occur in depressions in areas of the fine-textured surface soils, in particular along the several end moraines within the area. Bog iron has formed where heavy mineral-rich surface sands occur within broad shallow depressions on the surface of underlying finer-textured

sediments. It has been extracted in the past from deposits in Houghton Township.

SAND DUNES

A large part of the area mapped as glaciolacustrine sand has been modified by wind to various degrees. Sand dunes reaching heights of over 9 m have formed on the sand plain surface. The shapes of the dunes are highly irregular and similar to those described in the Simcoe area to the north (*see* Barnett 1978, Figure 7). Well-formed transverse, and, to a lesser degree parabolic, dunes are present. But hybrid forms of these 2 types of dunes are the most common. Dune shapes are similar to those described in North Karelia, Finland, by Lindroos (1972).

Initially, these dunes were thought to have formed immediately after the sand plain became exposed as water levels lowered in the Lake Erie basin following deglaciation (Barnett 1978). However, it now appears that there was some delay before the dunes began to form. At the

Bouchaert and Mabee buried peat sites, located immediately north of the study area, organic accumulation ceased approximately 11 000 years BP when the marsh area became buried beneath wind-blown sand (Barnett 1982). However, some of the dunes appear to have also formed in response to the clearing of the land by early settlers (Barnett 1982).

Cliff-top dunes are presently forming along the crest of the Lake Erie shore cliffs between Houghton and Clear Creek. The Sand Hills, located 1 km southwest of Jacksonburg, are cliff-top dunes. Built 30 m above the surrounding lake plain, they are exceptional examples.

Ancestral shoredunes may be present 1 km north of Fishers Glen. These highly irregular mounds of sand occur at elevations of 207 to 210 m and may have formed along the shoreline of glacial Lake Grassmere. Farther inland, several of the larger transverse dunes are located adjacent to identified ancestral shoreline features. Several others may mark additional shorelines which remain unrecognized.

Stratigraphy

INTRODUCTION

The stratigraphic framework and nomenclature of Quaternary sediments most used in southern Ontario is that presented by Dreimanis and Karrow (1972) and Karrow (1984).

A brief summary of Late Wisconsinan history was previously presented in the section entitled “Stratigraphic Framework”. There is no indication of pre-Late Wisconsinan sediments in the study area; however, they may be present at depth. Except for some of the oldest deposits in the area, the stratigraphy is well exposed in the Lake Erie shore bluffs (Figure 7a–g, back pocket).

The oldest material exposed in the lake bluffs occurs in the segment of bluffs between Port Bruce and Port Burwell (Figure 8). Here, 3 layers of massive, clayey silt diamicton (Port Stanley Till) are arranged in an overlapping pattern separated by thinly bedded diamicton, rhythmically bedded sands and silts, and silt and clay rhythmites. Only 2 of the massive diamicton layers can be observed in the bluffs at any one locality. The massive diamicton layers slope gradually toward the east and eventually decline below lake level. Most of the sediments exposed in the bluff segment between Port Bruce and Port Burwell are considered to be Port Stanley Drift.

Between Port Burwell and Jacksonburg, the lake bluffs are composed almost entirely of stratified sediments

(Figure 9). A small outcrop of massive, clayey silt diamicton, interpreted as Port Stanley Till, occurs at the base of the bluffs about 1 km east of Port Burwell. The stratified sediments overlying the massive diamicton include a conformable sequence of highly contorted, rhythmically bedded silts and clays at the base; relatively undisturbed silt and clay rhythmites; silt rhythmites; and sand rhythmites. This sequence of rhythmites is in turn overlain unconformably by flat-bedded and trough cross-bedded sands.

The highly contorted, rhythmically bedded silts and clays, although conformable with the overlying rhythmites, are considered part of the Port Stanley Drift. They contain abundant ice-rafted debris and thin, discontinuous beds of clayey silt diamicton, interpreted as Port Stanley flowtills, hence their inclusion in Port Stanley Drift. The remaining sediments of this bluff segment between Port Burwell and Jacksonburg (*see* Figure 9) are described in greater detail under the heading “Sediments of the Jacksonburg Delta”.

A major rounded promontory in the Lake Erie coastal outline occurs immediately east of Jacksonburg. In this area the bluffs are composed of over 20 m of massive, clayey silt to silty clay diamicton, interpreted as Wentworth Till (Figure 10). This material is relatively more resistant to shore erosion processes than the surrounding noncohesive sediments, hence the natural development of

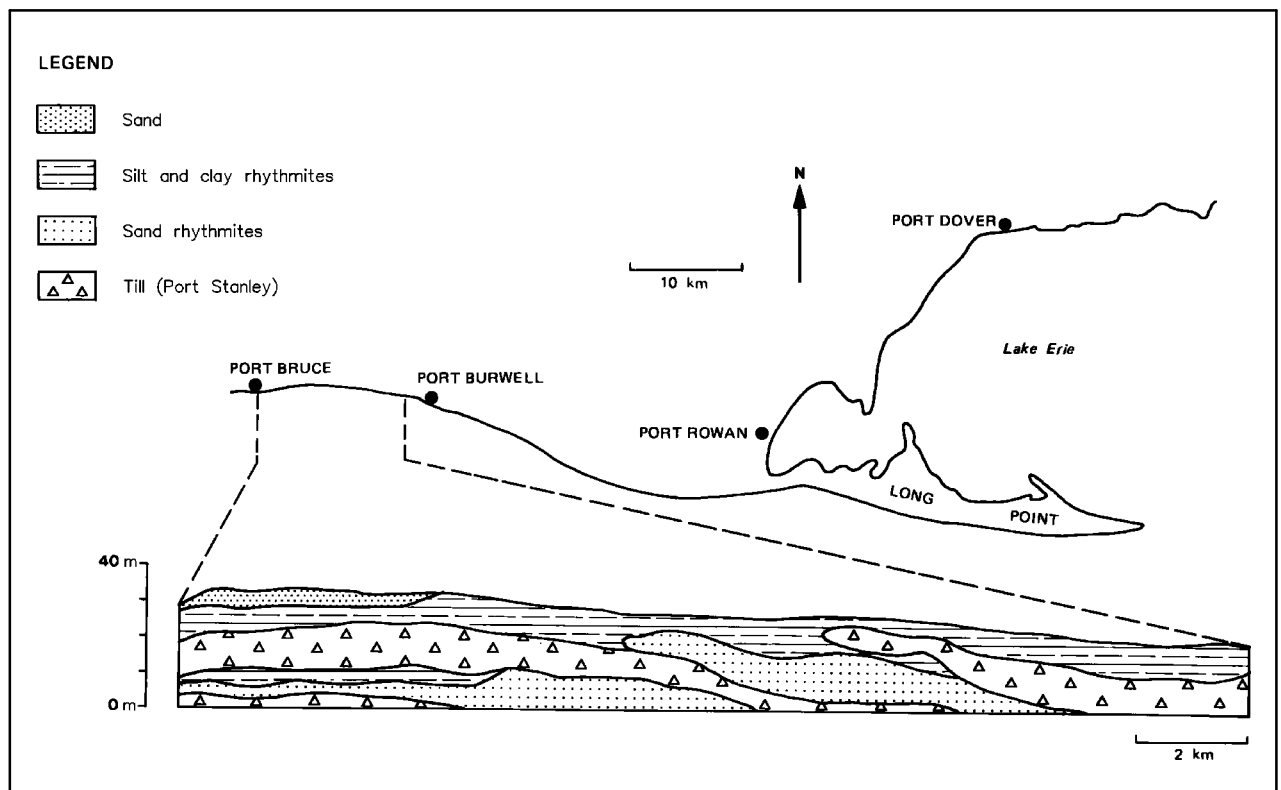


Figure 8. General stratigraphy of the Lake Erie shore bluffs between Port Bruce and Port Burwell (*after* Barnett 1983).

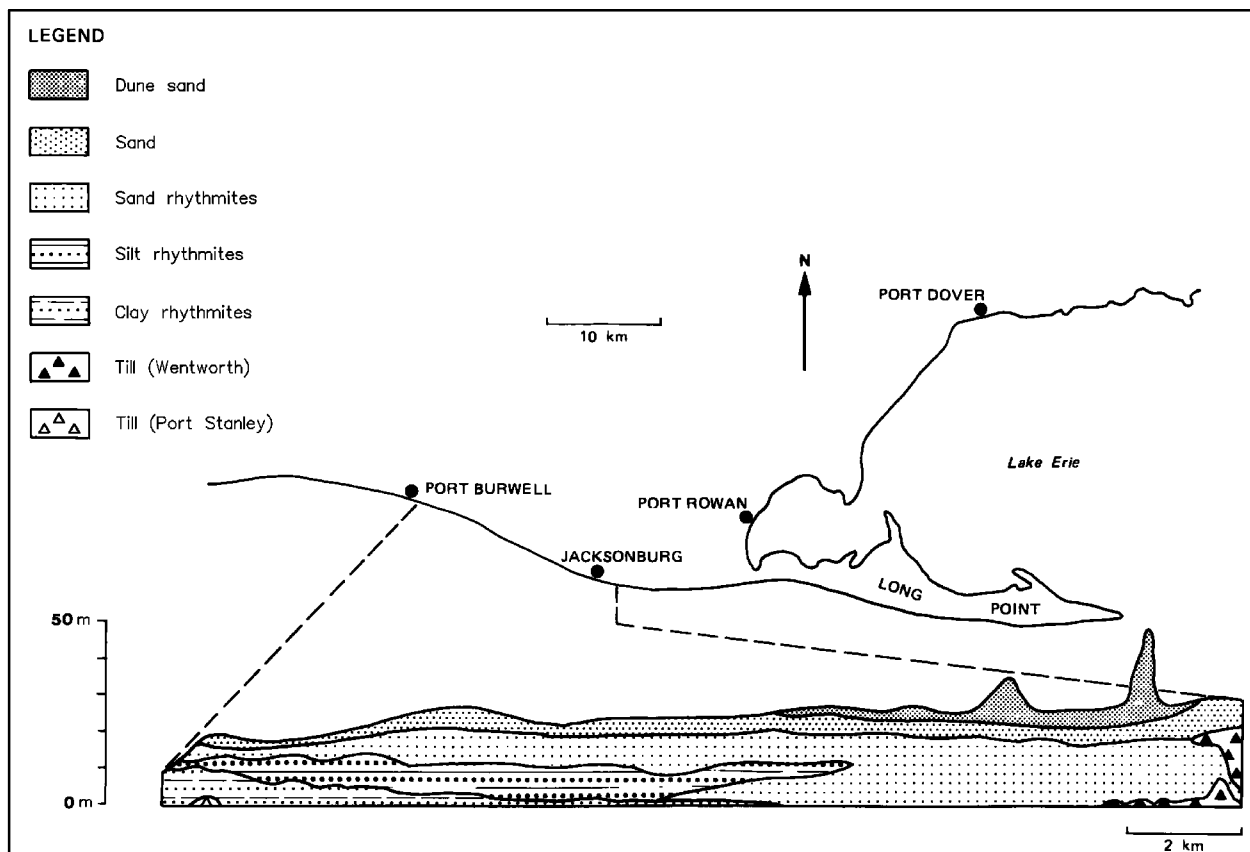


Figure 9. General stratigraphy of the Lake Erie shore bluffs between Port Burwell and Jacksonburg (after Barnett 1983).

the promontory in the coastal outline. The bluff exposures present a cross section through the Paris and Galt moraines, which mark the farthest westward extent of the glacial advance that deposited the Wentworth Till (see Figure 5). These moraines continue beneath Lake Erie, where they are referred to as the Norfolk moraine (Sly and Lewis 1972).

At the eastern end of the bluff segment, the hummocky nature of the Galt moraine is preserved in the shore bluffs, with stratified silts infilling the depressions and the entire sequence capped by stratified clays. Toward the west, the surface of the moraine is higher and has been planed off. The original hummocky surface of the Paris moraine is preserved beneath sand rhythmites of the Jacksonburg delta.

The portion of the Lake Erie bluffs located between Erie View and Turkey Point is protected from erosion by Long Point and Turkey Point spits and, as a result, is vegetated and relatively stable. Exposures of the sediments composing the bluffs are relatively few; however, the general stratigraphy appears to be: Wentworth Till (clayey silt diamicton) at the base, overlain by rhythmically bedded sands immediately west of Turkey Point, which in turn are overlain by silt and clay rhythmites capped by stratified sands. The sand rhythmites appear to pinch out toward the west.

The sediments making up the Lake Erie shore bluff east of Turkey Point are well exposed. Figure 11 summarizes the general stratigraphic relationships present.

The Wentworth Till rises above water level at only a few localities along the lower part of the bluff. It is coarser textured here than where it is exposed farther to the west. The irregular upper surface of the Wentworth Till in the vicinity of Port Ryerse may be the expression of the Moffat moraines as they enter the Lake Erie basin (Barnett 1978). Rhythmically bedded sands and silts are present in the lower part of the bluffs. They thicken and become coarser textured to the southwest, where they become the dominant component of the shore bluff just east of Turkey Point. Several discontinuous, thinly bedded, sandy-textured diamicton layers and lenses, interpreted as Wentworth Till, occur within the sand and silt rhythmites (see Figure 11).

At the southwestern end of the bluff segment, faintly stratified silts and clays overlie the sands and silts. These are in turn overlain by a coarsening-upward sequence of silts and sands. At the northeastern end, a thick sequence of silt and clay rhythmites overlies the sand and silt rhythmites.

Table 1 summarizes the Quaternary deposits that occur within the Long Point and Port Burwell areas and the events which they may represent. Descriptions of the different deposits follow. Results of laboratory analyses of individual samples are presented in Appendixes 3, 4, 5 and 6; those on diamicton units interpreted as tills, including flowtills, are summarized in Tables 2 and 3.

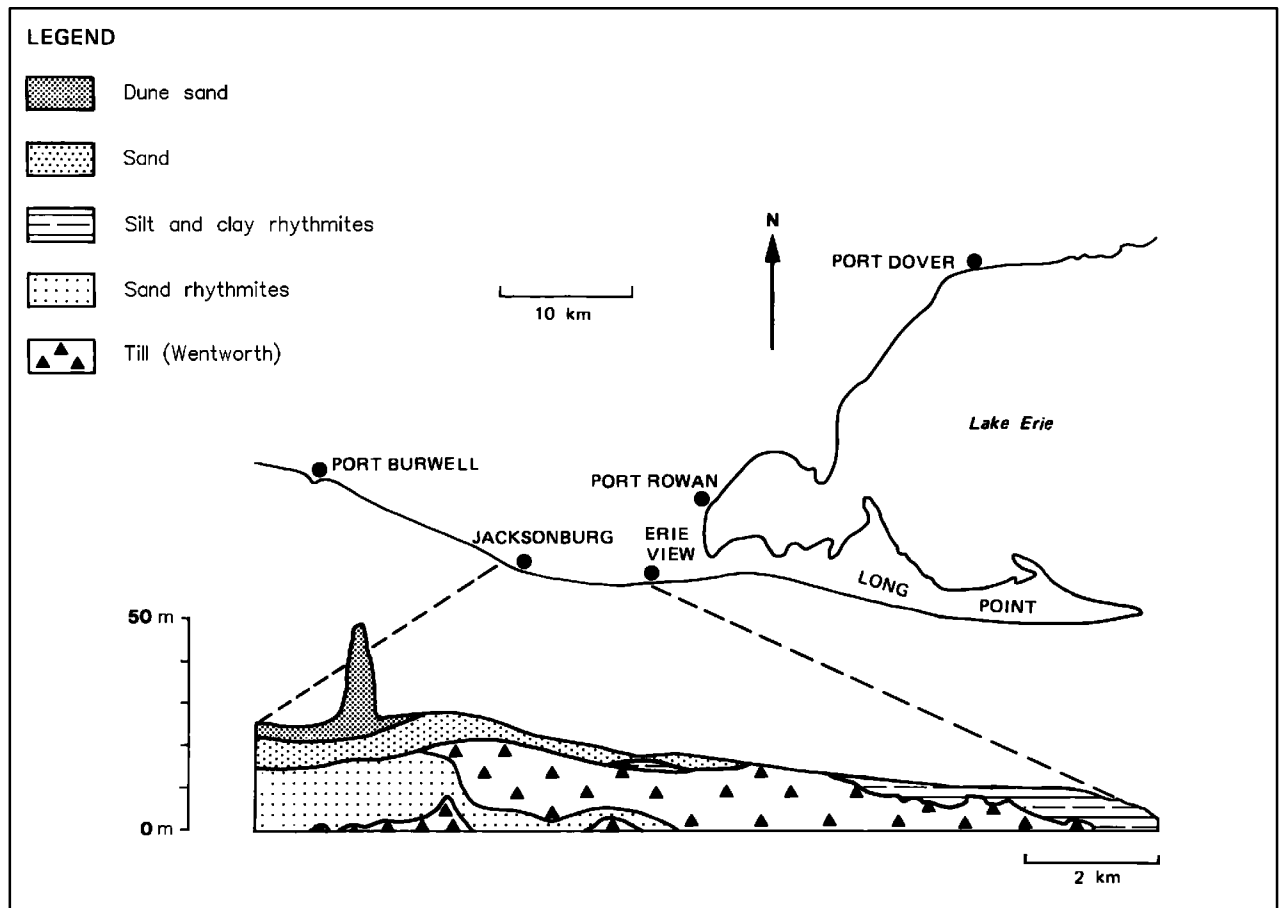


Figure 10. General stratigraphy of the Lake Erie shore bluffs between Jacksonburg and Erie View (after Barnett 1983).

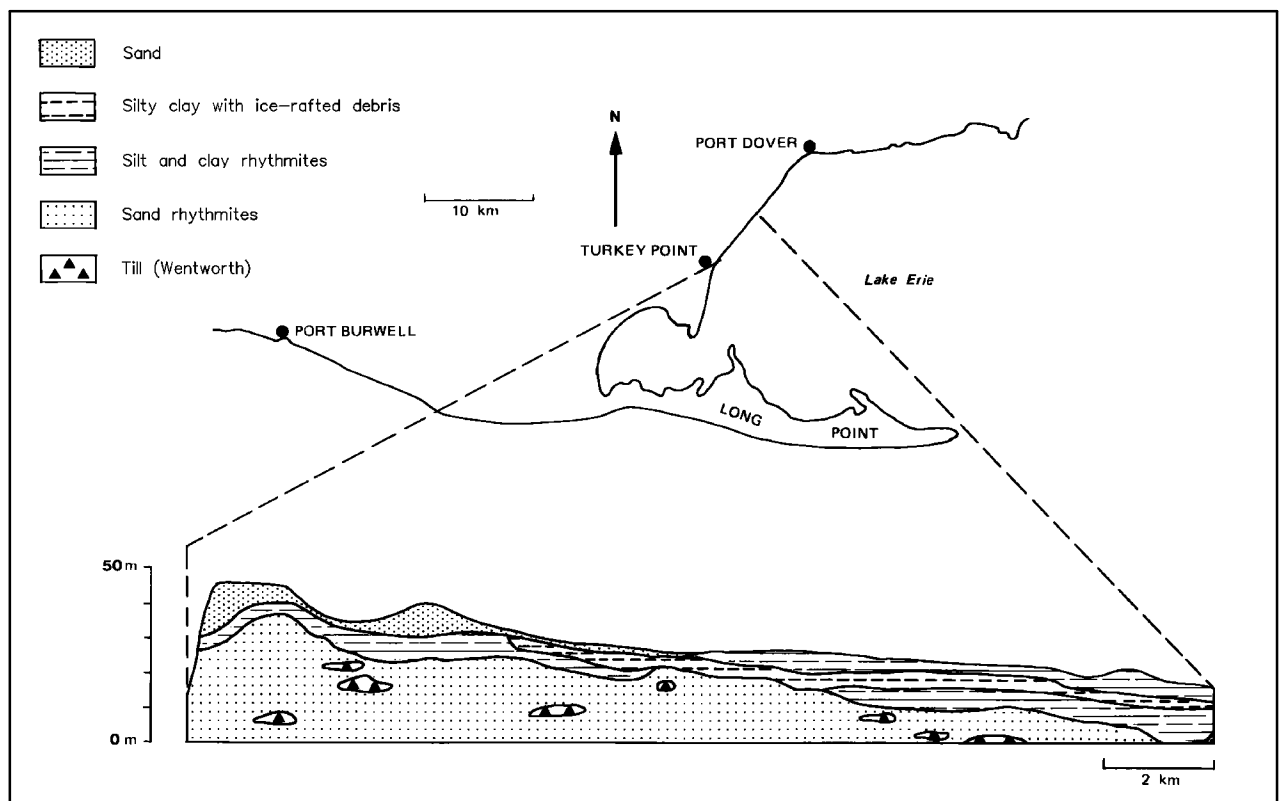


Figure 11. General stratigraphy of the Lake Erie shore bluffs between Turkey Point and Port Ryerse.

Table 1. Summary of Quaternary deposits and events in the study area.

Age	Time Stratigraphic Unit	Rock Stratigraphic Unit	Deposit or Event	Materials
RECENT	Port Huron Stade		Post-Whittlesey Lakes Lake Whittlesey	sand, silt, clay and clay with IRD*
	Mackinaw Interstade	Wentworth Drift	glaciolacustrine sediments of the Simcoe delta Wentworth Till glaciolacustrine sediments of the Jacksonburg delta Wentworth Till glaciolacustrine sediments of the Jacksonburg delta	clay and silt rhythmite sand and silt rhythmites silty clay to sand till sand with organic material silty clay till sand and silt rhythmites silt and clay rhythmites
Late Wisconsinan	Port Bruce Stade	Port Stanley Drift	glaciolacustrine sediment Port Stanley Till, layer D glaciolacustrine sediment Port Stanley Till, layer C glaciolacustrine sediments Port Stanley Till, layer B glaciolacustrine sediments Port Stanley Till, layer A	silt and clay (IRD)* clayey silt till silt and clay rhythmites sand and silt rhythmite clayey silt till silt and clay rhythmites sand and silt rhythmites clayey silt till sand, silt and clay clayey silt till
	Erie Interstade		no sediments observed	
	Nissouri Stade	Catfish Creek Drift	Catfish Creek Till	sandy, clayey silt till

*Ice Rafted Debris

Table 2. Summary of till analyses.

	Matrix Grain Size					Carbonate Content			Heavy Minerals			Atterberg Limits			
	n	Clay %	Silt %	Sand %	md(μ)	n	Total%	Ratio C:D	n	Total %	% Mag.	n	ll	pl	PI
Wentworth Till	17	34(13)*	57(11)	9(18)	10(19)	16	36(3)	1.4(0.3)	7	5.4(2)	7.5(2)	16	28(5)	16(2)	12(3)
Port Stanley Till	58	38(6)	56(10)	5(4)	4(2)	58	37(5)	1.8(0.4)	36	4.1(1)	8.6(2)	58	27(6)	16(1)	12(2)
Layer D (flowtill)	5	27(6)	69(7)	4(1)	8(4)	5	36(1)	1.4(0.3)	3	3.4(1)	7.3(1)	5	23(2)	14(1)	9(2)
Layer D (till)	7	33(6)	64(5)	3(2)	6(3)	7	37(1)	1.5(0.2)	2	4.9(0.3)	8.9(0.4)	7	25(2)	15(1)	10(3)
Layer C	10	41(4)	56(4)	3(1)	3(1)	10	36(2)	1.9(0.3)	9	3.7(1)	9.9(4)	10	29(2)	17(1)	13(2)
Layer B	7	41(2)	54(3)	5(2)	3(1)	7	36(1)	1.7(0.2)	1	3.4(-)	6.5(-)	7	29(1)	16(1)	13(1)
Layer A	3	39(3)	52(6)	9(5)	3(1)	3	37(2)	1.9(0.1)	2	3.3(0.2)	7.2(2)	3	29(1)	16(1)	13(1)
Mabee moraine	7	34(5)	61(4)	5(3)	5(2)	7	38(2)	1.9(0.4)	7	4.9(2)	7.9(2)	7	27(4)	16(2)	12(2)
Courtland moraine	5	34(6)	61(5)	5(1)	5(2)	5	39(2)	1.5(0.2)	4	5.3(1)	8.6(1)	5	26(3)	15(1)	11(2)
Tillsonburg moraine	4	29(2)	62(6)	9(6)	7(2)	4	38(2)	1.4(0.3)	3	3.6(2)	8.2(2)	4	24(2)	14(1)	10(2)
Catfish Creek Till	4	30(5)	47(13)	23(15)	9(7)	4	40.5(1)	2.2(1)	3	3.8(1)	10(2)	4	26(3)	14(2)	12(1)

Legend: md = median diameter (in microns); C:D = calcite:dolomite ratio; Mag. = magnetics; ll = liquid limit; pl = plastic limit; PI = plasticity index

* mean (standard deviation)

Table 3. Summary of till trace-element content.

	n	Trace Element Content (ppm)						
		Co	Cr	Ni	Zn	Pb	Ba	Li
Wentworth Till	15	11(2) *	55(7)	24(4)	83(17)	11(2)	380(33)	29(4)
Port Stanley Till	58	11(1)	55(5)	24(3)	83(14)	14(6)	379(31)	27(3)
Layer D (flowtill)	2	11(1)	50(4)	19(3)	78(8)	15(2)	415(21)	24(2)
Layer D (till)	7	11(1)	52(5)	21(2)	71(6)	10(1)	409(27)	26(4)
Layer C	10	11(1)	54(6)	24(2)	76(9)	11(4)	374(21)	26(2)
Layer B	7	11(1)	58(2)	25(2)	88(14)	15(7)	374(36)	28(3)
Layer A	3	12(1)	62(3)	28(3)	94(3)	18(2)	403(15)	31(2)
Mabee moraine	7	10(1)	52(1)	21(2)	72(7)	10(-)	374(23)	24(2)
Courtland moraine	5	10(1)	53(2)	22(2)	80(14)	10(1)	346(42)	25(1)
Tillsonburg moraine	4	10(1)	53(6)	22(2)	80(11)	10(-)	360(41)	24(1)
Catfish Creek Till	4	11(-)	70(14)	30(3)	79(12)	17(4)	343(30)	33(5)

*mean (standard deviation)

CATFISH CREEK DRIFT

Catfish Creek Drift of the Nissouri Stade was not observed during mapping of the Long Point and Port Burwell map areas. Catfish Creek Drift, however, can be seen in creek bank exposures along Catfish Creek north of Sparta, approximately 5 km west of the study area, where several layers of subglacial Catfish Creek Till outcrop (Dreimanis and Barnett 1985). Approximately 30 km west of the study area, Catfish Creek Drift is exposed along the Lake Erie shore cliffs between Plum Point and Port Talbot, where it has been extensively studied (Evenson et al. 1977; Gibbard 1980; Dreimanis 1982; Gibbard and Dreimanis 1984).

Catfish Creek Drift was probably encountered in borehole OGS-82-M-8 (Appendix 2) which is located 8.2 km west of Port Burwell. In this boring, approximately 10 m of light brownish-grey to grey, very gritty, sandy, clayey silt diamicton rests directly on the bedrock surface (Marcellus Formation). Several boulders and smaller clasts (greater than 2 mm) were encountered during the drilling of this unit. A thin gravel layer about 0.3 m thick separated the unit into two layers of roughly equal thickness. The lower 2 m of the lower layer is composed almost entirely of local bedrock fragments (Marcellus Formation shale). There was also a strong petroliferous odour in this zone.

Properties of samples taken from these 2 layers are summarized in Tables 2 and 3 and results on the individual samples are listed in Appendixes 3, 4, 5 and 6. Although sufficient information is lacking, these apparently structureless layers are considered to be deposited from glacial ice, and are therefore referred to as till.

Averaging about 20% sand and 30% clay, this unit is generally coarser than the younger, Port Stanley Till layers. The single low slope of the cumulative weight percentage probability plots (Figure 12), indicates the maturity of this material as a product of crushing and abrasion (Karrow 1976), hence supporting the interpretation that this material is till. It is extremely poorly sorted, generally platykurtic and is nearly symmetrical to slightly fine skewed

(Folk 1968; some phi values extrapolated). The lowest till sample (M-8-42, Figure 12) when plotted on cumulative weight percentage probability paper contains 3 straight line segments resulting from the addition of a large amount of silt-sized fragments of locally derived shale bedrock. The Catfish Creek Till samples also indicate a general trend of coarsening upward through the unit, possibly reflecting progressively more distant bedrock sources.

Total carbonate and carbonate ratios are marginally higher in these Catfish Creek Till samples than in Port Stanley Till samples, averaging over 40% total carbonate

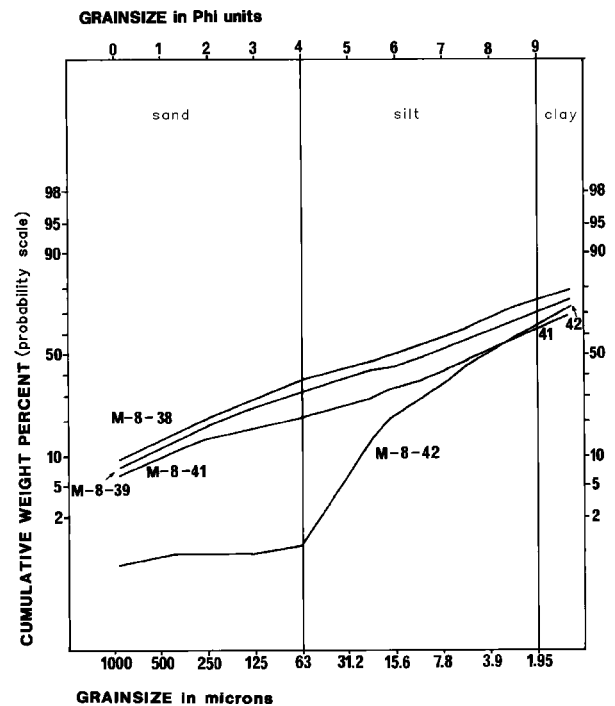


Figure 12. Cumulative weight percent probability plots of Catfish Creek Till samples. Sample numbers decrease from base of unit upwards. See Appendix 2, borehole M-8, for sample locations.

and a carbonate ratio of 2.2 (*see* Table 2). Carbonate ratios are usually less than 1 for samples of Catfish Creek Till in Ontario; however, the higher ratios found here probably reflect the incorporation of the local bedrock of the study area, which is dominated by limestone units (*see* Figure 2). The low garnet ratio (purple/red) determined on one sample of Catfish Creek Till (Appendix 3C) is consistent with garnet ratios determined on Catfish Creek Till samples from elsewhere in Ontario. Garnet ratios in southwestern Ontario till samples reflect distant source areas in the Precambrian Shield (Gwyn and Dreimanis 1979).

The trace element contents of Catfish Creek Till samples are similar to the trace element contents of Port Stanley and Wentworth till samples from the report area (*see* Table 3) and to trace element contents of till samples from the Tillsonburg area (Barnett 1982). The slightly higher mean chromium content in the Catfish Creek samples is the result of including the chromium content of sample M-8-42, an anomalously high value (90 ppm), into the data set. The higher chromium content of sample M-8-42 may be the result of the higher content of local shale fragments in this sample of Catfish Creek Till.

In the records of water wells that extend to the bedrock surface, there is often a layer or zone of coarser-textured material immediately above the bedrock. In the western part of the Port Burwell map area, this coarser material can reach a thickness of 21 m, but it is more commonly 1 to 3 m thick. It would appear that Catfish Creek Drift has a discontinuous areal distribution in the study area and is more likely encountered at depth directly overlying the bedrock surface in the western half of the Port Burwell map area.

PORT STANLEY DRIFT

Port Stanley Drift, deposited during the Port Bruce Stade, is the dominant sediment package in the western half of the Port Burwell map area and is well exposed in Lake Erie bluff exposures west of Port Burwell (*see* Figure 8). Its lowermost contact is placed at the first appearance of Port Stanley Till, and its uppermost boundary has been placed, somewhat arbitrarily, at the top of the highly contorted glaciolacustrine silt and clay unit that contains abundant ice-rafted debris and rare, thin, discontinuous beds of clayey silt diamicton (*see* Figure 8). With a total thickness of about 76 m in the study area, the Port Stanley Drift, as so defined, contains no fewer than 4 layers of massive, poorly sorted, clayey silt containing minor amounts of very coarse sand, pebbles, cobbles and boulders. These massive layers are separated by stratified sediments and can be traced along the Lake Erie shore bluffs or inland, in creek bank exposures, to where they terminate at an end moraine, such as the Tillsonburg, Courtland, Mabee or Lakeview moraines.

Sediment types and relationships within the Port Stanley Drift associated with the Lakeview moraine are discussed in detail in the section entitled "Sediments of the Lakeview Moraine". The sediment sequence present in the Lakeview moraine is similar to those associated with the other end moraines listed above. This sediment sequence

appears to be representative of the style of deposition associated with the recession of the glacier margin during the Port Bruce Stade.

Port Stanley Till

The massive layers within the Port Stanley Drift are interpreted as subglacially deposited tills. The reasons for this interpretation include their relationships with end moraines and the nature of their lower contacts.

Several properties of these till layers are summarized in Tables 2 and 3 and analytical results on individual samples are presented in Appendixes 3, 4, 5 and 6. In the remaining 3 boreholes drilled in the Long Point–Port Burwell area (Appendix 2), a thin zone of stony, slightly sandy, clayey silt occurred at the base of the boreholes. This basal material is thought to represent not the Catfish Creek Till but a local coarsening of the younger Port Stanley Till as a result of the incorporation of local bedrock fragments. Cumulative weight probability plots (Figure 13), indicate a general fining upward within this zone. Eventually, a grain-size distribution typical of Port Stanley Till is obtained at about 1 to 2 m above the bedrock surface.

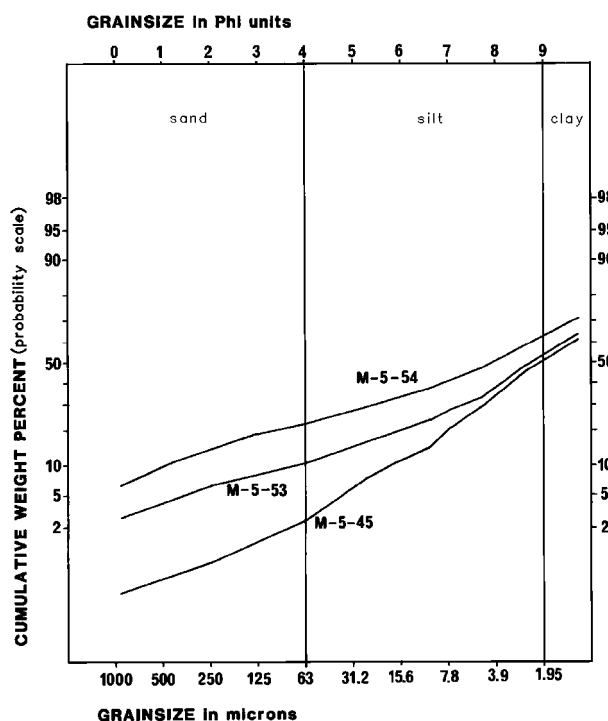


Figure 13. Cumulative weight percent probability plots of "local" Port Stanley Till samples. Sample numbers decrease from base of unit upward. *See* Appendix 2, borehole M-5, for sample locations.

On average, Port Stanley Till contains about 5% sand and 38% clay. Plots on cumulative weight percent probability paper usually consist of many short, straight lines, but can be generalized by 2 or 3 straight line segments (Figure 14). Two straight line segments on this type of grain-size plot suggest that the sediment is made up of more than 1 lognormally distributed component. If the sample of the

matrix plots as a straight line on this type of graph paper, the grain size of the sample would be lognormally distributed. This condition was approached by the 2 samples of Catfish Creek Till presented in Figure 12 (samples M-8-38, M-8-39). Port Stanley Till samples with the 2 or 3 straight line segments are similar to the immature Catfish

Creek Till sample (sample M-8-42) plotted in Figure 12, whose distribution was believed to be affected by extensive incorporation of the underlying shale. It is therefore suggested that the Port Stanley Till may not be a mature till, but one composed of some locally incorporated material.

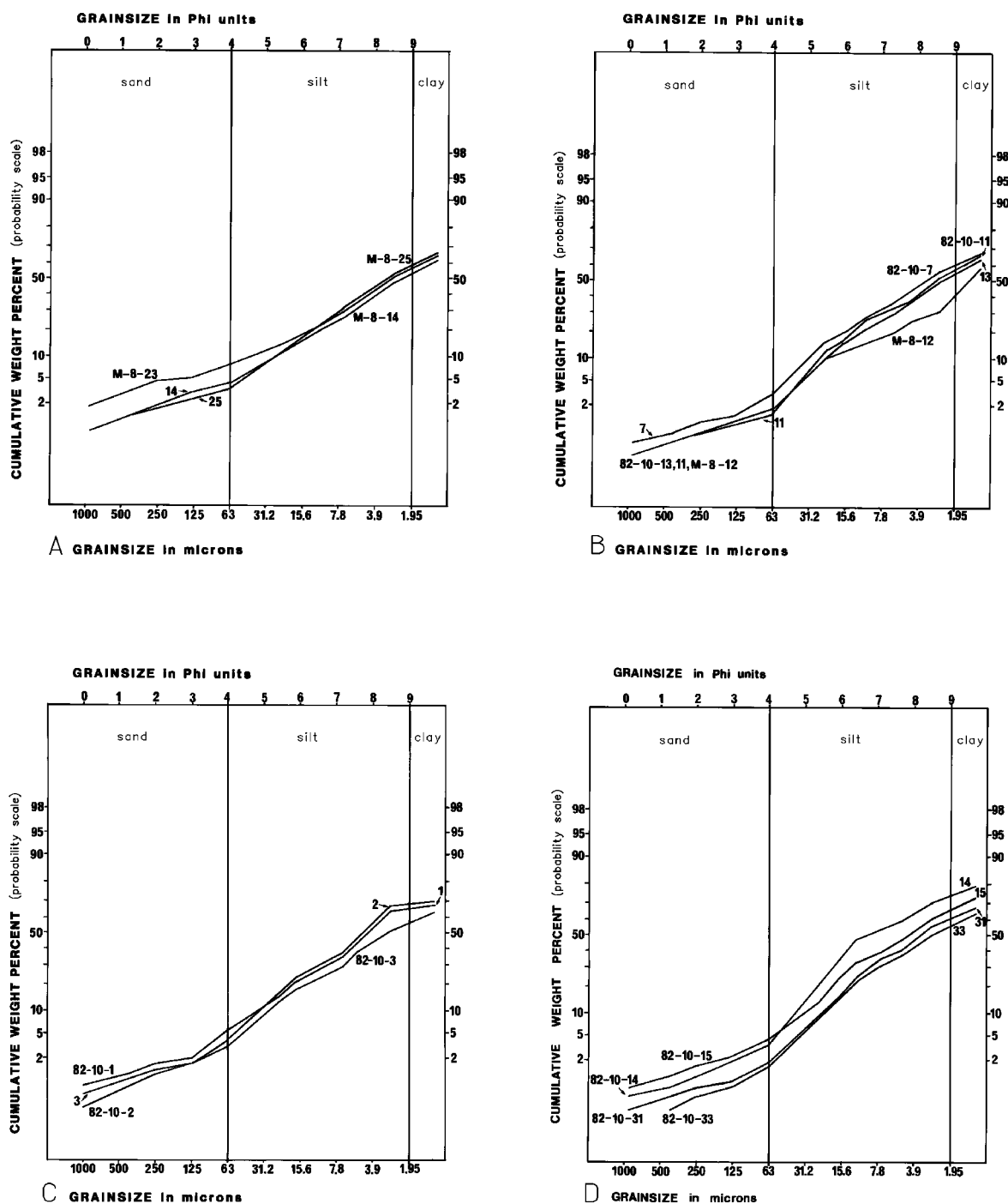


Figure 14. Cumulative weight percent probability plots of Port Stanley Till samples: samples in A are from layer A, B from layer B, C from layer C, and D from layer D. See Appendixes 2 and 3, 4, 5 or 6 for sample locations.

Port Stanley Till is very poorly to extremely poorly sorted, leptokurtic to platykurtic, and generally fine skewed to strongly fine skewed. However, some samples were near symmetrical and coarse skewed. Other properties of Port Stanley Till include: an average total carbonate content of approximately 37%, an average carbonate ratio of 1.7, and a total heavy mineral content of 4%, of which about 8% are magnetic (*see* Table 2). Some additional properties of Port Stanley Till and some of the properties of the individual layers of Port Stanley Till are also summarized in Tables 2 and 3. Properties of the Port Stanley Till in the study area are very similar to those reported in the Tillsonburg area (Barnett 1982, Table 4, p.19).

Sediments of the Lakeview Moraine

DESCRIPTIONS OF SEDIMENTS

The sediments related to the Lakeview moraine, exposed in the Lake Erie bluffs at McConnell's Nursery, approximately 8 km west of Port Burwell, are described below. The sediments are similar to sediment sequences associated with the Mabee, Courtland and Tillsonburg moraines (*see* Figure 5) and represent the suite of sediment types that make up Port Stanley Drift in the Long Point–Port Burwell area. The sediments composing the other moraines listed, are well exposed further along the Lake Erie bluffs to the west and inland in various creek exposures (Dalrymple 1971; Barnett 1982, 1984; Stewart 1982; Dreimanis and Barnett 1984, 1985).

The following description of sediments begins at the top of the lowermost package of diamictons exposed in the lake bluffs at McConnell's Nursery (Figure 15). This diamicton package is part of an earlier sequence of sediments, similar to that described below, but is associated with the formation of the older Mabee moraine.

Resting directly on the lowest diamicton unit is a rhythmically bedded, fine-grained sand and silt unit, designated informally as facies A (*see* Figure 15). This unit contains couplets composed generally of ripple cross-laminated or climbing ripple drift, fine-grained sand and very coarse silt, that grade upward through fine-grained silt into a clay layer at the top. Within the couplets, grain size generally decreases upward. However, in some couplets, grain size initially coarsens upward then fines within one couplet (Figure 16). Sedimentation appears to be dominantly from saltation with increasing input from suspension up through the couplet, according to criteria proposed by Visher (1969) and by Glaister and Nelson (1974).

Couplet thickness ranges from about 1 cm to 2.8 m, generally increasing in thickness upwards. The greatest variation in thickness occurs within the coarse-textured part of the couplet, which ranges from 0.5 cm to 2.6 m.

The fine sand to coarse silt component can contain Type A through to Type B climbing ripple drift laminations (Jopling and Walker 1968). In some cases, sinusoidal (Jopling and Walker 1968) or draped laminations (Gustavson et al. 1975) are present. Within the coarse component, irregu-

larly shaped clasts of clay up to 3 cm in diameter occur. Paleocurrent measurements indicate a fairly uniform direction of flow within couplets and between couplets, and generally indicate flow toward the south or southwest, approximately parallel to the paleo-margin of the glacier in this area.

Samples taken from within the sand-silt part have a range in Folk's (1968) Graphic Mean between 3.7 and 5.1, and are moderately to poorly sorted (Folk's Inclusive Graphic Standard Deviation of 0.71 to 1.26). They generally become more poorly sorted upward. The samples are leptokurtic and fine skewed to strongly fine skewed.

The fine part of the couplets is either silty clay or clay. It contains thin, silt or fine sand laminations which may be ripple cross-laminated. There is up to 80% clay-size material in some layers. Scour marks on the upper surface of the clay-silt part have been observed with clay balls present in the overlying sand-silt layer. Thin beds of brecciated clay also may be present.

The clay-silt component of the couplet is dominant in the lower 1 m of facies A, above which the sand-silt component is dominant. In places, thin beds of interlaminated silt and clay interfinger with the sediments of facies A. Thin, discontinuous diamicton lenses and layers may also be present.

At one locality (LP-85-18, Appendix 1), a large lens-shaped mound of highly deformed rhythmically bedded sediments was observed within 1 couplet. The dimensions of this mound were approximately 5 m high and 13 m across at the base. The layers of clay, silt and sand within the mound were brecciated and folded; in places, bedding was nearly vertical and dipping steeply to the north. The silty, very fine sands that occur beneath the mound of highly deformed sediments were deformed to a depth of 0.5 m into flame-like structures with heights of about 0.3 m. In an adjacent section (LP-85-17, Appendix 1; *see also* Figure 15) the sediments were not deformed and a bed of clay balls and small pebbles occurred at about the same stratigraphic position.

The overall shape and distribution of facies A is best described as ribbon shaped. It reaches a thickness of up to 15 m. Facies A pinches out laterally over distances of about 10 km and may extend for tens of kilometres up paleocurrent direction to the northeast, possibly to a sediment input source more than 50 km away.

Overlying facies A is a unit of rhythmically bedded silt and clay (facies B). This unit is composed of couplets that range in thickness between 1 and 10 cm. The coarse part of the couplets consists of planar laminated, ripple cross-laminated, or massive silt or very fine sand. The fine part is silty clay or clay.

The contact between facies A and B is gradational and is commonly irregular and wavy. At a few localities examined, a massive silt bed up to 0.3 m thick occurs at the base of facies B.

Within the couplets, coarse sand-sized and small pebble-sized drop clasts may be present. Occasionally, brecciated silt and clay layers occur. Brittle deformation, including low-angle reverse faults, may also be present in

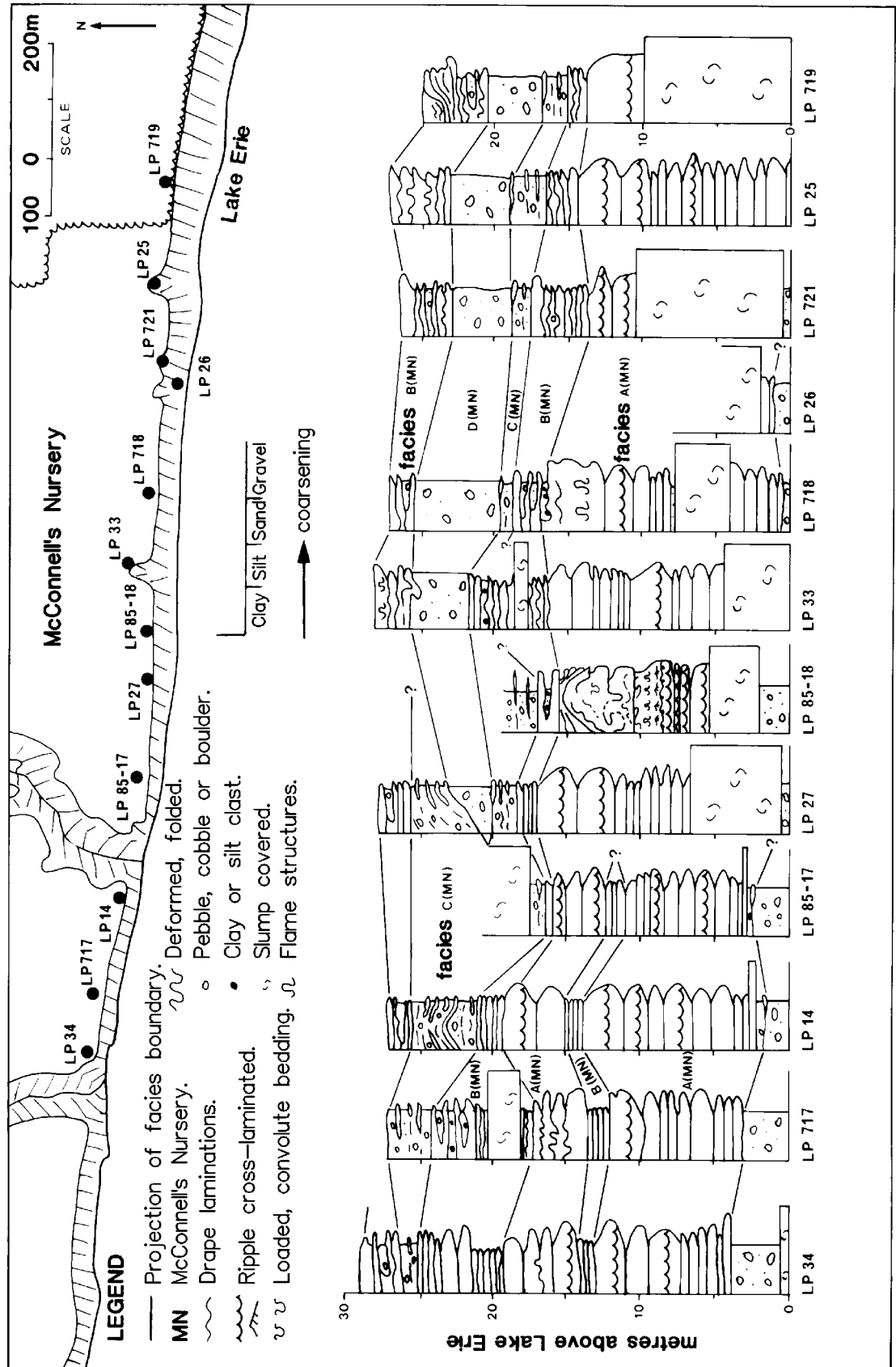


Figure 15. Sediments exposed along the Lake Erie bluffs near McConnell's Nursery (Lakeview moraine).

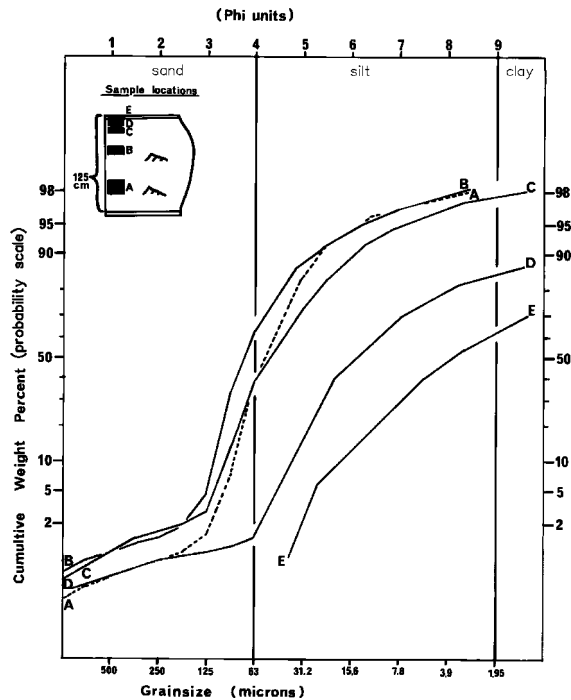


Figure 16. Cumulative weight percent probability plots of samples from one rhythmite of facies A, McConnell's Nursery. Inset is graphic representation of the rhythmite sampled and shows the location of samples plotted.

facies B. Displacements are usually on the order of millimetres to centimetres; however, displacements of 1 to 2 m have been observed. Nonbrittle deformation, such as folds, are also present.

In the upper part of facies B, there are thin, discontinuous, clayey silt diamicton layers up to 20 cm thick. Inter-

bedded and gradational contacts with overlying facies C are common.

Facies B varies in thickness from 0 to 10 m, generally thickens westward, and replaces facies A where facies A pinches out laterally away from the paleo-ice margin.

Facies C overlies facies B near McConnell's Nursery (see Figure 15). This facies is composed of discontinuous layers and lenses of massive, clayey silt to silt containing very coarse sand and small pebbles and clasts up to boulder size. These matrix-supported diamicton layers are separated by thin, discontinuous, fine sand or silt laminations (Photo 1). The layers of massive diamicton range between 20 and 60 cm thick. Their lower contacts can be conformable or erosional, the latter indicated by the truncation of the upper part of the underlying fine sand and silt laminations. Brecciation of these intervening silts and sands is common. Brittle deformation structures may also be found within facies C.

Texturally, the massive diamicton layers are similar to subglacially deposited Port Stanley Till in the report area. Cumulative weight percent probability plots of several samples from facies C are presented in Figure 17. The low slope of the cumulative percent probability plots demonstrates the poorly sorted nature of this material. The shapes of these curves are similar to the curve of debris flows presented by Glaister and Nelson (1974).

The thickness of facies C ranges between 0 and 8 m. Individual bed thicknesses tend to decrease westward and the unit does not appear to extend much farther than 1 km beyond the estimated paleo-ice margin position. In places, the diamicton beds form positive-relief mounds about 1 to 2 m high.

Facies D is texturally similar to facies C (see Figure 17) but appears structureless or massive (Photo 2). Predominantly a clayey silt to silty clay containing coarse-sand grains and a low content of clasts (i.e., less than 2%),



Photo 1. Thinly bedded diamicton, facies C, McConnell's Nursery.

it is a massive, matrix-supported diamicton (see Figure 15). It usually exhibits a conchoidal fracture pattern and near vertical joints. Subhorizontal parting and fissility may also be present. Its lower contact can be imperceptibly gradational, sharp, erosional, sheared or loaded (Photo 3).

This unit ranges in thickness from 0 to 5 m in the McConnell's Nursery area. It appears to thin northwestward to the position of the Lakeview moraine and eventually becomes interfingering with the stratified diamicton of facies C.

Facies C, the interbedded diamictons, also overlies the massive diamicton layer, facies D. Where facies C occurs above the massive diamicton, facies D, it is variable in thickness and can be up to 3 m thick.

Facies B, rhythmically bedded silt and clay, conformably overlies facies C. However, here, above the interbedded and massive diamicton units (facies C and D), it contains thin, discontinuous layers and lenses of massive diamicton and abundant ice-rafted debris in its lower parts. In this setting, facies B may also be highly deformed, but involves predominantly nonbrittle deformation.

INTERPRETATION

The regional geology and sediment characteristics indicate that deposition of all of the above-mentioned facies occurred in an ice-contact, glacier-fed lake, either beyond the ice in the lake basin or beneath the glacier.

The sedimentary structures and sediment characteristics of facies A indicate that its overall rhythmicity was probably produced annually (i.e., varves). Deposition of

facies A appears to have been dominated by quasi-continuous underflows (Gustavson 1975; Smith et al. 1982; Smith and Ashley 1985). The large size of the inflowing braided stream network likely moderated local variation in flow and probably provided a large amount of suspended sediment to the delta front.

The high amount of suspended sediment in the inflowing water ("sediment stratification", Smith and Ashley 1985) was most likely the main process responsible for the generation of underflows. Underflows, controlled by topographic lows within the basin, would tend to flow between previously deposited morainic ridges and/or along the ice margin where, as the ice margin receded into the basin, the deepest water occurred. Paleocurrent directions measured were parallel to the paleo-ice margin.

Subsequent underflows (quasi-continuous) may have kept the fine-textured sediments hovering in suspension above the lake bottom (the "nepheloid layer" of Reimer 1984, in Smith and Ashley 1985) to be deposited later once underflows ceased.

Slump-generated surge currents, probably triggered by mass movement further upslope on the delta front, or by mass flows of debris derived directly from the glacier terminus, may be responsible for the stratification within the fine-grained component of the rhythmite (winter layer) and for the occasional brecciated silt and clay layer. The positive-relief mound of deformed rhythmites found within the rhythmite sequence is probably slumped debris and is evidence of mass movement as an active process on the delta slope.

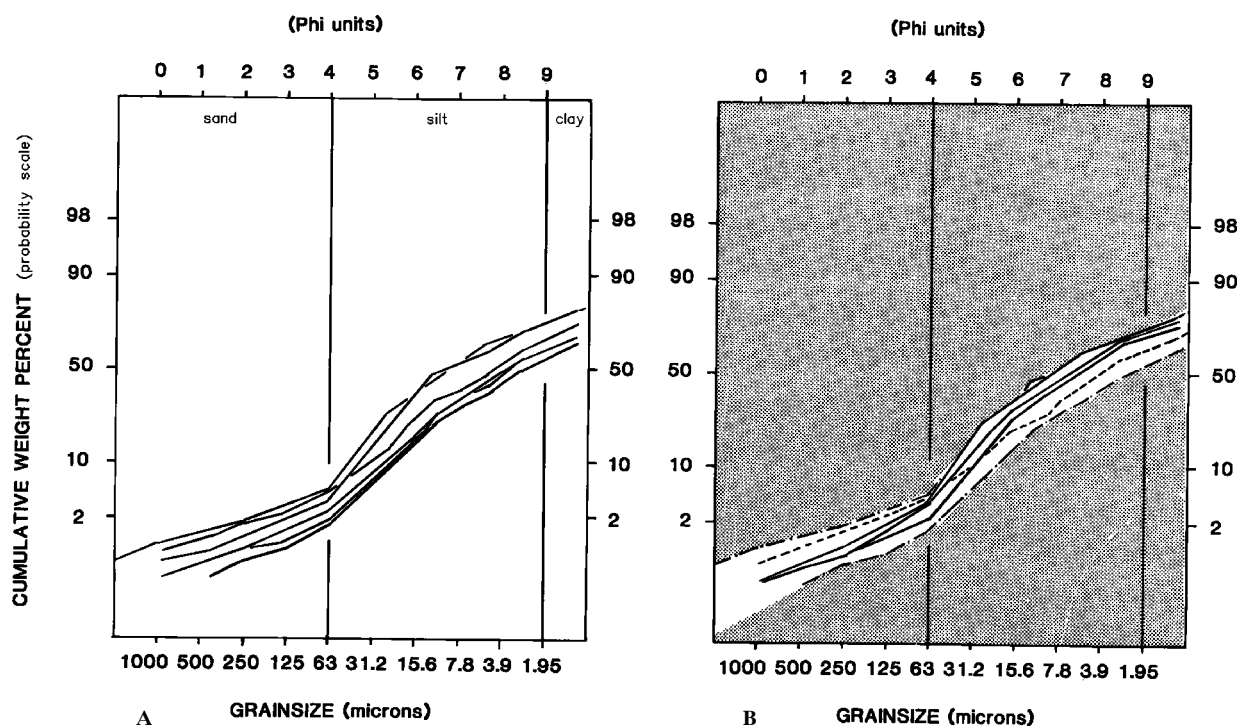


Figure 17. Cumulative weight percent probability plots of facies C and facies D, McConnell's Nursery. A) samples of massive diamicton, facies D (M.N.); B) samples of stratified diamicton, facies C (M.N.) (white area is envelope of massive diamicton samples displayed in A).

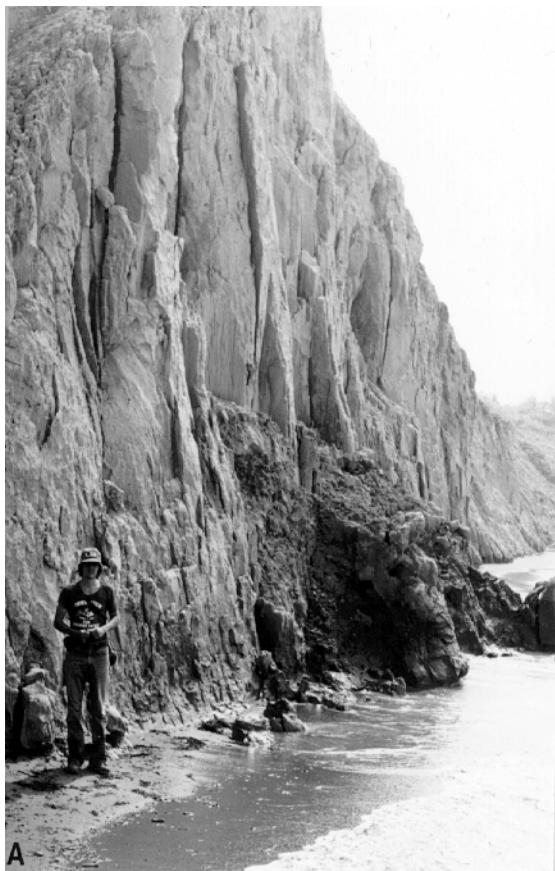


Photo 2. Massive diamicton, facies D, McConnell's Nursery.

Erosion on the tops of clay layers and the amount of clay clasts (rip-ups) within the summer layers also indicate that underflows were the dominant sedimentary process involved in the deposition of facies A.

Facies A is similar to sediments described by Ashley (1975) in glacial Lake Hitchcock; she suggested they were deposited in mid-delta foresets (Smith and Ashley 1985). However, the abundance of clay "balls" and the paleogeography of the study site suggest that facies A may have been deposited on the lower delta foresets. Facies B interfingers with facies A, and is most likely lake bottom sediments (i.e., bottomsets), generally deposited farther from the inflowing sediment source. The interfingering may be the result of lower inflows during several seasons or the periodic abandonment of distributary channels.

The presence of ripple cross-laminated, fine sand and silt in the summer layers of facies B couplets indicates that underflows were at least partly involved in the transportation and deposition of the sediments.

The interbedded nature of the contact between facies B and C and the stratified nature of facies C suggest deposition in water. The textural similarity with facies D and subglacially deposited Port Stanley Till throughout the region indicates a glacial source for facies C. Minor erosion along

the base of several massive diamicton layers within facies C, the silt or fine sand layers between the diamicton layers, the fan-shaped positive-relief features and the interbedded nature with the glaciolacustrine sediments indicate that facies C is composed of subaquatic, glacially derived debris flows or subaquatic flowtills.

The thickness of individual flowtills, between 20 and 60 cm, and their extent, approximately 1 km beyond the paleo-ice margin, are comparable to other debris flows or flowtills described elsewhere in the literature. Hester and DuMontelle (1971) discuss a fan-shaped debris flow cone extending approximately 3 km beyond the Shelbyville moraine in Illinois. The thickness of this till-like material is between 1.2 and 1.3 m. Hartshorn (1958) reported thicknesses of 1.2 to 1.8 m for Pleistocene flowtills and Boulton (1968) reported flowtills up to 0.75 m thick that extend up to 0.5 km beyond the ice margin of Stubendorfbreen, Vestspitsbergen.

Facies D, the massive diamicton, extends westward in the lake bluff only as far as the Lakeview moraine, where it becomes interfingering with facies C. Its lower contact, sometimes erosional and sheared, plus the brittle deforma-



Photo 3. Example of sheared contact at base of massive diamicton, facies D, McConnell's Nursery.

tion of the underlying sediments, support the conclusion that facies D is a subglacially deposited till.

Facies B above the diamicton units (facies C and D) is lake bottom sediment with depositional features indicating a decreasing-upwards influence of the glacier (i.e., fewer flowtills and less ice rafted debris). Deformation is the result of slumping, the melting of buried ice blocks, and/or the grounding of icebergs or lake ice.

SEDIMENTS OF THE JACKSONBURG DELTA

A large body of stratified sediments resting conformably on the Port Stanley Drift and exposed in the Lake Erie shore bluffs east of Port Burwell to about Jacksonburg is interpreted as a wave-influenced delta (*see* Figure 9). At Jacksonburg, the stratified sediments interfinger with Wentworth Till.

The body of stratified sediments form a general coarsening-upward sediment sequence that can be divided into 4 main facies associations: clay rhythmmites, silt rhythmmites, sand rhythmmites, and a facies association consisting of trough and low-angle cross-bedded and plane-bedded sands.

The stratified sediments tend to become younger toward the east, with the oldest sediments exposed immediately east of Port Burwell and the youngest sediments near Jacksonburg. The sediments generally become coarser in this direction, as well.

Facies Association 1

The lowermost facies association, Facies Association 1, consists of rhythmically bedded clay and silt, with clay being the dominant component. Sedimentation was dominantly from suspension, according to criteria established by Visser (1969) and Glaister and Nelson (1974). Couplet thicknesses range from 1 mm to 2 cm and layering for the most part is laterally continuous. Drop clasts are occasionally present (Photo 4). In places, this material is highly contorted, probably the result of penecontemporaneous slumping. The sequence of clay rhythmmites has an observed maximum thickness of 12 m and outcrops along the western end of the bluff segment between Port Burwell and Jacksonburg (*see* Figure 9).

Facies Association 2

Conformably overlying the clay rhythmmites are silt rhythmmites consisting of rhythmically bedded silt and clay. Silt dominates in individual rhythmmites and generally fines upwards to a clay layer at the top.

The silt portion of any one cycle is massive or contains penecontemporaneous deformation structures (i.e., load structures, ball and pillows, and convolute bedding) and commonly contains clay balls. Transportation was dominantly by saltation in the lowermost part of any one cycle but becomes dominated by deposition from suspension in the uppermost part, according to criteria suggested by Visser (1969) and Glaister and Nelson (1974). In the one cycle illustrated in Figure 18, sediment contribution from saltation decreases from over 90% near the base of the cycle to less than 30% near the top of the coarse component and contributes to less than 10% within the fine component of the cycle.

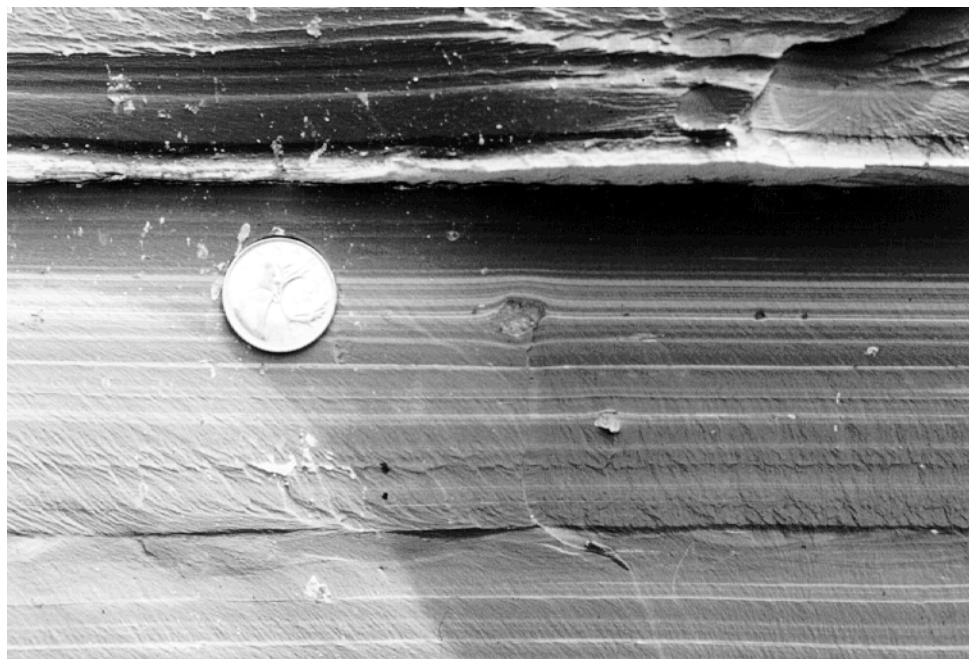


Photo 4. Silt and clay rhythmmites of Facies Association 1, Jacksonburg delta. Note drop clast to right of coin.

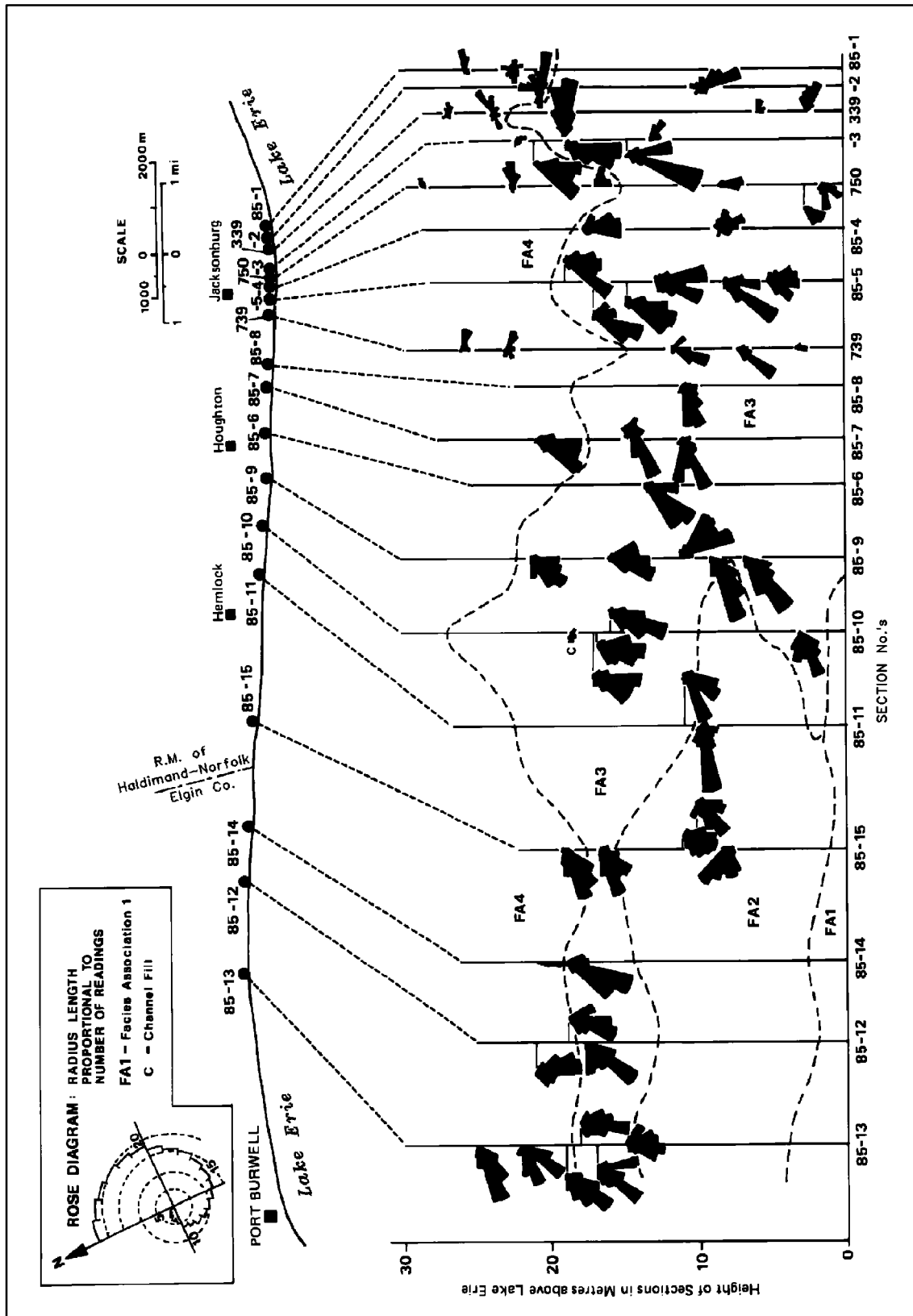


Figure 19. Summary of paleocurrent measurements (mostly from ripple cross-laminations) taken from Jacksonburg delta sediments.

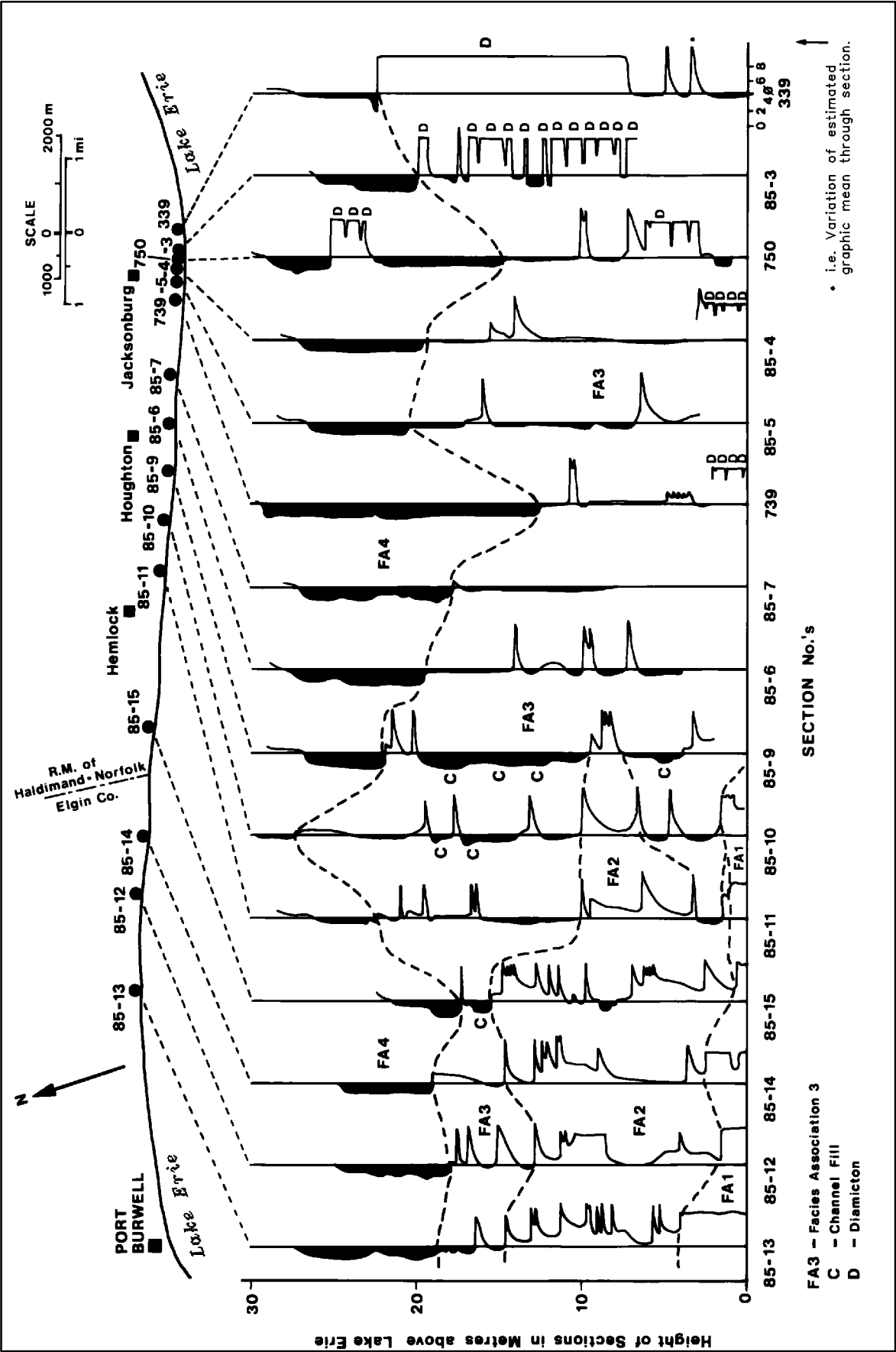


Figure 20. Summary of grain-size variations in sediments of the Jacksonburg delta.

Three different scour-and-fill sediment sequence types were observed. The first type consists of shallow and broad scours filled with undeformed, stratified sediments. They occur as solitary features or as composite features. The solitary scour-and-fill structures are, however, commonly associated with other solitary or composite scour-and-fill structures.

Solitary scours are small, on the order of 1.5 m deep and 12 m across. They are commonly filled with trough cross-bedded or ripple cross-laminated sand; rarely, flat-bedded sands fill the scour. The infilling sediment is usually coarser (about 1 ϕ difference) and better sorted (moderately well sorted to well sorted) than the host or incised material.

Composite scour-and-fill structures measuring up to 6 m deep and 100 m wide were observed. They are commonly filled with trough cross-bedded sands. Cross-bed sets range from 0.5 to 1.5 m thick and commonly have foreset laminae that are tangential to the set base. Occasionally, thin beds of ripple cross-laminated sands are preserved within the scour fill. As with solitary scour-and-fill structures, the composite scour-and-fill structures are filled with sands that are coarser and better sorted than the surrounding sediment. Rarely, a lag concentration of gravel or clay balls occurs along the base of the scour fill. The lag concentration can occur in both solitary or composite scour-and-fill structures.

The second type of scour-and-fill structure observed consists of channels about 1.5 m deep and 6 m wide filled with massive sand. The sand fill is not as well sorted and is slightly finer grained than the surrounding or incised sediment. This type of scour-and-fill structure occurs very rarely, and was observed only in 2 localities (LP-85-7, and near LP-85-15, *see* Appendix 1).

The third type of scour-and-fill structure observed (only 1 example, LP-85-6, Appendix 1) is relatively deep (2 m) and narrow (5 m) compared to the other types described previously. Sediment fills are deformed and brecciated and are similar to the surrounding sediments outside the scour. Normal and reverse faulting with small displacement occur within the sediments beneath the scour. Similar features were described by Postma et al. (1983), who attributed these to plug flow, a type of mass flow.

Facies Association 4

The uppermost facies association, number 4, rests unconformably above the sand rhythmite facies association. The contact is irregular, with scours penetrating over 3.5 m into the sand rhythmites. Occasionally, a thin lag concentration of stones, clay balls, or diamicton balls occurs along the lower contact.

An abrupt change in grain size also coincides with this contact. Sediments above the contact are coarser (on the order of 1 ϕ), better sorted (moderately well sorted to well sorted), leptokurtic and range from fine skewed (occasionally strongly fine skewed) through near symmetrical to coarse skewed.

The uppermost facies association is characterized by trough and low-angle cross-stratified sands and pebbly sands and by plane-bedded and ripple cross-laminated fine sands.

Plane-bedded and low-angle cross-bedded sands form a large part of this upper facies association. Bedding is commonly augmented by heavy mineral concentrations and is laterally consistent over tens of metres. The heavy mineral concentrations probably formed in the swash zone along a shoreline. Thin beds of ripple cross-laminated sand are commonly associated with these 2 facies. The ripple cross-laminae are usually of wave ripple (oscillatory) origin and indicate a dominant wave direction toward the southeast at the southern end of the bluff segment and towards the west in the western end, roughly parallel to the present-day shoreline (*see* Figure 19). Small scours, 0.3 to 0.6 m across, filled with trough cross-bedded fine sand, occur rarely within the plane-bedded and low-angle cross-bedded sands, as well.

Other areas of Facies Association 4 are dominated by trough cross-bedded sands. Set thicknesses range from 10 cm up to 2 m and foreset laminae are commonly tangential to the set base. Plane-bedded and ripple cross-laminated fine sand beds are commonly associated, but in this case the cross-laminae are usually current ripple in origin. Most of the trough cross-bedding occurs within solitary or composite channel scours and is commonly concentrated in certain areas along the shore bluffs. This concentration of scours probably represents the positions of distributary channels of the delta.

Discontinuous layers of clayey silt diamicton (Wentworth Till) occur within this facies association and in the sand rhythmites (Facies Association 3) beneath. They are discussed in the section entitled “Sediments of the Galt Moraine”.

Discussion

The entire stratified sediment body described above is interpreted as the product of a prograding delta that formed in response to a regional lowering of water level in the Lake Erie basin. Water level in the Lake Erie basin had probably fallen to an elevation between 181 and 185 m. The clay rhythmites were formed on the lake bottom, with deposition being predominantly from suspension. The thick sequence of silt and sand rhythmite facies was deposited on the delta slope by quasi-continuous density underflow currents. The uppermost facies association is interpreted as deltaic topset beds. Similar sediment sequences and distribution patterns have been described by Oomkens (1967) for the Rhône delta that were related to Type II, fluvial-wave interaction delta fronts, described by Elliott (1978). The laterally extensive plane-bedded and low-angle cross-bedded sands represent beach barrier or wave-dominated environments that are cut locally by distributary channel, trough cross-bedded sands (Elliott 1978).

The first type of scour-and-fill structures that are found within the silt and sand rhythmite facies associations are likely the result of the extension of these distributary channels down the delta slope. The second and third types

of scour-and-fill structures are probably associated with slumping on the delta slope; the third type is an example of a channelized plug flow and the second type, a channelized slump-generated grain flow. Other processes involved in the formation of this delta are discussed in greater detail in the section entitled "Sediments of the Galt Moraine".

Paleoecology

FOSSILS

Detrital organic material was observed within the upper three facies associations. It is most common in the uppermost units (facies associations 3 and 4), where it is concentrated on the lee sides of ripple forms and on the avalanche faces of cross-beds (Photo 5). Organic material was collected from 4 sites and has been identified by B.G. Warner of the University of Waterloo. Lists of plant taxa found at these 4 sites is presented in Tables 4, 5, 6 and 7.

Sites LP736 and LP319 (Vandervien Site; see Figure 7) are from sediment facies interpreted as deltaic topset beds, and collection sites LP339 and LP732 are from the rhythmically bedded fine sand facies association of the delta front. Of particular note is site LP339, where the organic material was sampled from silts and sands beneath a massive layer of Wentworth Till associated with the Galt moraine.

A wide range of plant taxa are represented at these 4 sites (see Tables 4, 5, 6 and 7). A variety of local habitats and a mix of plant taxa, with modern tundra, boreal and prairie affinities, are represented (Karrow and Warner 1988).

Tundra habitats are suggested by the presence of *Dryas integrifolia*, *Salix herbacea* and *Taraxacum* cf. *T. lacerum*, the arctic dandelion. Trees such as *Larix* and *Picea*, combined with *Menyanthes trifoliata* and *Cornus stolonifera*,

are best represented today in the boreal forest region and *Thalictrum venulosum*-type is confined to the central Great Plains of Canada today (Karrow and Warner 1988).

Contributions from several local habitats such as small lakes and ponds, open bog woodland and fens, wet and damp mud flats, lakeshores or depressions and drier dwarf shrub meadows, are found in the plant macrofossil assemblages (Warner and Barnett 1986).

Warner (Warner and Barnett 1986) has suggested that there is no modern analog for these assemblages and has proposed that reworking, transport and water-sorting played significant roles in the production of the observed plant macrofossil assemblages.

In addition to the plant taxa listed, there were numerous twigs and small pieces of wood collected from all 4 sampling sites, which have not been identified. These wood fragments, ranging in length from 0.2 to 7 cm, show signs of rounding and wear suggesting transport in streams or along a lakeshore (Warner and Barnett 1986).

Animal remains were not abundant; however, elytral fragments of at least 3 species of ground beetles (Carabidae, including the genera *Bembidion* and *Dyschirius*), 1 elytral fragment of a weevil (Curculionidae), 1 of a water beetle (Hydrophilidae, genus *Helophorus*), and the head of a fly were identified by A. Morgan and A.V. Morgan, of the University of Waterloo.

DATING

Two radiocarbon dates were obtained from the organic detritus sampled at the Vandervien Site (LP319). One date on several small pieces of wood yielded an age of $25\,800 \pm 600$ years BP (BGS-884). The second date of $13\,360 \pm 440$ years BP (BGS-929) was obtained on *Dryas integrifolia* leaves that were picked from the same bulk sample.



Photo 5. Detrital organic material in the Jacksonburg delta.

Table 4. List of plant taxa, LP319 Vanderven site.*

Dwarf shrub meadows and fellfield:	
<i>Carex bigelowii</i> -type	4
<i>Dryas integrifolia</i> leaves	1000+
<i>Dryas hypanthia</i>	21
<i>Dryas</i> sp.	4
<i>Salix herbacea</i> leaves	25
Salicaceae (Betulaceae) pistils	6
<i>Salix</i> twig fragments	3
<i>Salix</i> bud scales	10
<i>Taraxacum</i> cf. <i>T. lacerum</i>	1
Boreal and temperate, open bog woodland and fen:	
<i>Cornus stolonifera</i>	1
<i>Larix laricina</i> cone	1
<i>L. laricina</i> needles	9
cf. <i>Larix laricina</i>	1
<i>Menyanthes trifoliata</i>	2
<i>Picea</i> needles	3
<i>Rubus</i> sp.	1
<i>Selaginella selaginoides</i> megaspores	25
<i>Viola</i> sp.	5
Wet or damp mineral mud flats, lakeshores and depressions:	
<i>Ranunculus trichophyllus</i> -type	3
<i>Rorippa islandica</i>	1
<i>Sparganium minimum hyperboreum</i>	3
Submersed and floating-leaved aquatic macrophytes:	
<i>Brasenia schreberi</i>	13
<i>Ceratophyllum demersum</i>	2
<i>Chara</i> oospores	4
<i>Myriophyllum verticillatum</i> -type	2
<i>Najas flexilis</i>	9
<i>Nitella</i> oospores	3
<i>Potamogeton alpinus</i>	2
<i>P. filiformis</i>	24
<i>P. zosteriformis</i>	3
<i>Potamogeton</i> undiff.	14
Open, dry alvar, herbaceous meadows or open woodland:	
<i>Juniperus communis</i>	1
<i>Selaginella rupestris</i> megaspore	1
Indifferent, wide-ranging habitats:	
<i>Carex</i> (lenticular-type)	2
<i>Carex</i> (trigynous-type)	3
<i>Cerastium</i>	3
Cyperaceae undiff.	1
<i>Potentilla</i> sp.	2
<i>Ranunculus</i> sp.	2
<i>Silene</i>	2

* Seeds unless otherwise specified. Numbers per 0.04 m³ fresh sediment greater than 0.250 mm mesh sieve.

Identification and interpretations by B.G. Warner, University of Waterloo (from Warner and Barnett 1986).

Table 5. List of plant taxa, LP339.*

Dwarf shrub meadows and fellfield:	
<i>Dryas integrifolia</i> leaves	27
<i>Dryas hypanthia</i>	1
<i>Salix herbacea</i> leaves	5
<i>Salix</i> seed	1
Wet or damp mineral mud flats, lakeshores and depressions:	
<i>Ranunculus trichophyllus</i> -type	4
Submersed and floating-leaved aquatic macrophytes:	
<i>Najas flexilis</i>	4
<i>Potamogeton alpinus</i>	1
<i>P. filiformis</i>	1
<i>Potamogeton</i> sp.	1
Indifferent, wide-range habitats:	
<i>Cerastium</i>	2
Moss fragments	2

* Seeds unless otherwise specified. Numbers per 50 cm³ fresh sediment greater than 0.250 mm mesh sieve.

Identifications and interpretations by B.G. Warner, University of Waterloo.

DISCUSSION

If the paleogeography of these sites is considered in relation to the rest of southern Ontario, it is easier to understand the mixture of plant taxa represented by the plant macrofossils, and the radiocarbon dates obtained. The sites, as indicated previously, are within a large body of sand referred to as the Jacksonburg delta. The ice margin was fluctuating along the eastern edge of the delta at a position marked by the Paris, then Galt moraines. These moraines can be traced northward to Orangeville and beyond, and by so doing the position of the ice margin during the formation of the Jacksonburg delta can be established (Figure 21).

The Jacksonburg delta was probably fed by a large braided stream that flowed southward along the ice margin and which probably served as the trunk stream for several tributaries which would have drained the eastern side of Ontario Island. The total drainage basin could have been as large as 6000 km² in area with a total relief of over 330 m. Local relief would have exceeded 30 m along several of the end-moraine ridges.

A variety of materials, from gravelly outwash through sandy silt tills to silty clay tills such as the Port Stanley Till, would have served as source material. Recently drained sandy lake plains would dominate the landscape along the edge of the glacial lake. Variations in local relief and source materials were probably sufficient to allow for the development of both well drained and poorly drained sites, often in close proximity. Three sides of the exposed land area were bordered by the glacier; along the southern edge was a glacial lake. Conditions would have been harsh, as is suggested by the presence of relict patterned ground (Morgan 1982, 1988). Middle Wisconsinan and possibly older organic deposits outcrop within this drainage basin at Innerkip and along the glacial lake shoreline in the Plum Point–Port Talbot area. Prior to the Late Wisconsinan ice

Table 6. List of plant taxa, LP736.*

Dwarf shrub meadows and fellfield:	
<i>Dryas integrifolia</i> leaves	68
<i>Dryas hypanthia</i>	3
cf. <i>Salix</i> leaves	4
<i>Salix</i> male catkins	3
Boreal and temperate, open bog woodland and fen:	
cf. <i>Larix</i> cone	1
<i>Menyanthes</i>	1
Pinaceae and scales	3
<i>Viola</i>	1
Wet or damp mineral mud flats, lakeshores and depressions:	
<i>Ranunculus trichophyllus</i> -type	6
<i>Scirpus</i>	5
<i>Eleocharis</i>	1
Submersed and floating-leaved aquatic macrophytes:	
<i>Brasenia schreberi</i>	2
<i>Myriophyllum</i> (warty type)	1
<i>Myriophyllum</i> (smooth type)	2
<i>Najas flexilis</i>	40
<i>Zannichelia palustris</i>	3
<i>Potamogeton filiformis</i>	17
<i>Potamogeton zosteriformis</i>	2
<i>Potamogeton</i> sp.	2
Open prairie woodland and grassland:	
<i>Thalictrum venulosum</i> -type	1
Indifferent, wide-range habitats:	
<i>Carex</i> (lenticular-type)	4
<i>Cerastium</i>	3
<i>Potentilla</i>	4
<i>Silene</i>	1
cf. <i>Arenaria</i>	1

* Seeds unless otherwise specified. Numbers per 75 cm³ fresh sediment greater than 0.250 mm mesh sieve.

Identifications and interpretations by B.G. Warner, University of Waterloo.

advance, such organic deposits were probably much more widespread.

The sediments of the Jacksonburg delta rest conformably on Port Stanley Drift and interfinger with layers and lenses of Wentworth Till. These stratigraphic relationships place their deposition after the Port Bruce Stade and probably within the Mackinaw Interstade. The Mackinaw Interstade was a period of ice recession believed to have occurred about 13 300 years BP in the Lake Erie and Lake Huron basins (Dreimanis and Karrow 1972).

The radiocarbon date of 25 800 ± 600 BP (BGS-884) is incompatible with this regional stratigraphy. The sedimentology and paleogeography do not point to *in situ* deposition for any of the organic remains. This date may therefore be attributed to redeposition of wood that originated from Middle Wisconsinan (Plum Point Interstade) deposits elsewhere in the region, possibly by currents of both proglacial streams and longshore drift in the glacial

Table 7. List of plant taxa, LP732.*

Dwarf shrub meadows and fellfield:	
<i>Dryas integrifolia</i> leaves	33
cf. <i>Salix herbacea</i> leaves	4
<i>Salix</i> bud scales	1
<i>Salix</i> male catkins	3
Boreal and temperate, open bog woodland and fen:	
<i>Viola</i>	1
Wet or damp mineral mud flats, lakeshores and depressions:	
<i>Ranunculus trichophyllus</i> -type	6
<i>Scirpus</i>	1
Submersed and floating-leaved aquatic macrophytes:	
<i>Brasenia schreberi</i>	3
<i>Myriophyllum</i>	1
<i>Najas flexilis</i>	2
<i>Potamogeton alpinus</i>	2
<i>Potamogeton filiformis</i>	7
<i>Potamogeton</i> sp.	6
Indifferent, wide-range habitats:	
<i>Cerastium</i> (Coryophyllaceae)	2
<i>Potentilla</i>	1
cf. <i>Moehringia</i> (Coryophyllaceae)	1
Undeterminable	5

* Seeds unless otherwise specified. Numbers per 50 cm³ fresh sediment greater than 0.250 mm mesh sieve.

Identifications and interpretations by B.G. Warner, University of Waterloo.

lake (Warner and Barnett 1986). The rounded, water-worn nature of the wood pieces supports this interpretation. Re-working of Middle Wisconsinan deposits may be responsible for the presence of several other plants on the plant taxa lists (see Tables 4, 5, 6 and 7).

The second date of 13 360 ± 440 years BP (BGS-929) on *Dryas integrifolia* leaves fits with the regional chronology. These delicate leaves probably would not have survived intact if they had been eroded from pre-existing Middle Wisconsinan deposits, then redeposited.

Dryas integrifolia is a plant that is a pioneer species. It grows in gravelly places such as braided stream plains (Porsild and Cody 1979). Its tolerance of cold, combined with its ability to grow in newly exposed gravelly and sandy environments, may explain its relatively high abundance in the 4 sites studied. The environments proximal to the depositional area would have included newly exposed sandy lake plains and the braided stream network that flowed along the ice margin. Karrow and Warner (1988) suggested that *Dryas integrifolia* along with *Salix herbacea* and *Taraxacum* cf. *T. lacerium* probably were confined to areas of patterned ground near the ice front. They suggested that “isolated forest groves of spruce and tamarack were scattered farther away from the periglacial influence of the ice” (Karrow and Warner 1988).

Dry, open, herbaceous grasslands and herb meadows may have existed in areas less protected from winds and temperature changes as suggested by the fossil occurrence

of *Thalictrum venulosum* (Karrow and Warner 1988). Warner (Karrow and Warner 1988) suggested that *Menyanthes trifoliata* and *Cornus stolonifera* occupied “minerotrophic peatlands and poorly drained soils in lowlands”.

If the spruce needles originated from the newly exposed landscape and not from older Middle Wisconsin deposits or by way of lake ice or longshore currents from the areas south or west of the glacial lake, then these sites provide the earliest record of post-glacial spruce in southern Ontario. The occurrence of spruce needles within sediments interpreted as delta distributary channel fills, however, strongly suggests that they originated from spruce trees growing on the newly exposed landscape of Ontario Island.

WENTWORTH DRIFT

Sediments of the Wentworth Drift dominate the eastern half of the study area (the Long Point map area and the eastern part of the Port Burwell area). The Wentworth Drift exposed in the Lake Erie shore bluffs (see Figures 10 and 11) can be divided into 2 main components, the Wentworth Till and stratified sediments of the Simcoe delta. The upper 2 facies associations of the Jacksonburg delta, facies associations 3 and 4, interfinger with Wentworth Till in the vicinity of Jacksonburg and can also be considered to be part of the Wentworth Drift. The nature of the sediments that compose the Galt moraine is discussed in detail in the section entitled “Sediments of the Galt Moraine”.

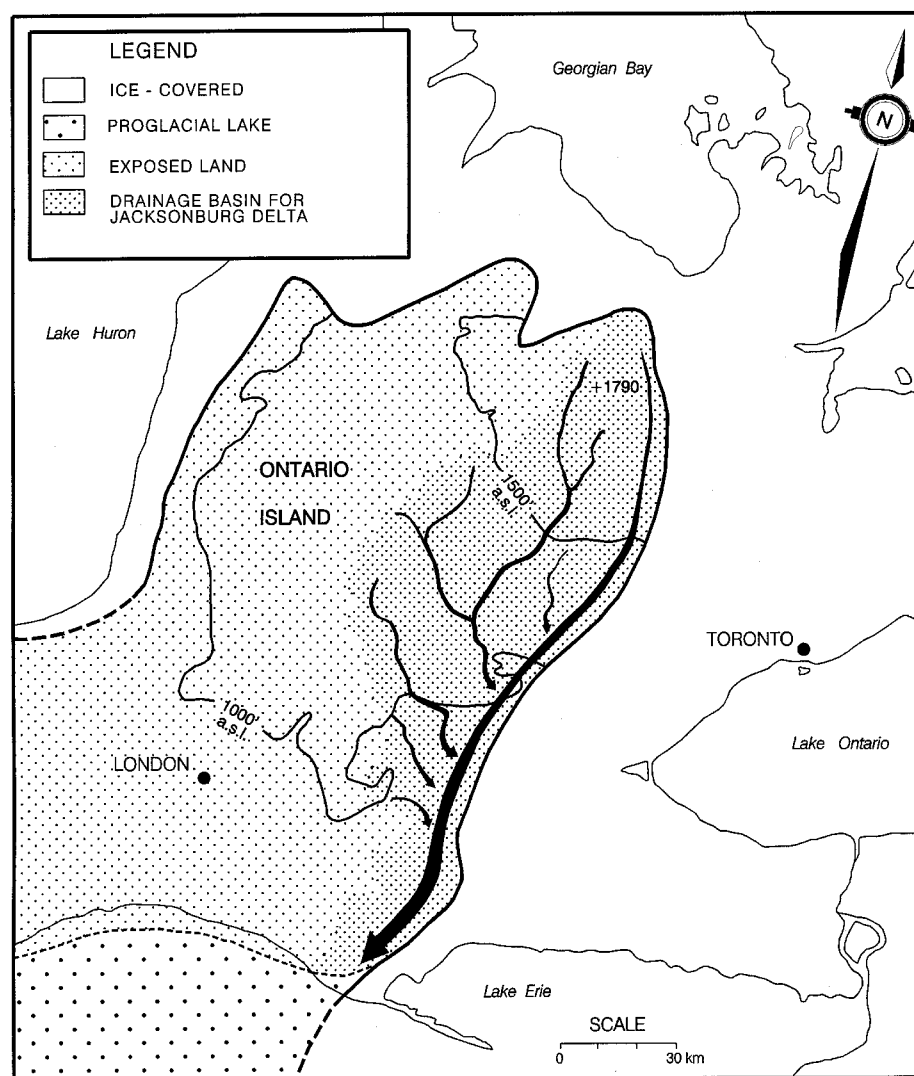


Figure 21. Paleogeography of southern Ontario about 13 400 years BP.

Wentworth Till

Wentworth Till makes up a large part of the Lake Erie shore bluffs between Jacksonburg and Erie View (see Figure 10) and occurs sporadically in exposures east of Turkey Point (see Figure 11). In the lake bluff exposures between Jacksonburg and Erie View, the Wentworth Till is a massive clayey silt to silty clay containing a minor amount of very coarse sand, pebbles, cobbles and boulders (Figure 22). It is very poorly sorted, platykurtic, and near symmetrical to fine skewed. It is substantially finer than the Wentworth Till described in the Brantford (Cowan 1975) and Simcoe (Barnett 1978) areas to the north.

The change in the texture of the Wentworth Till along the Paris moraine from northeast to southwest (Figure 23) occurs in a series of steps and probably reflects the incorporation of various-textured glaciofluvial and glaciolacustrine sediments into the base of the glacier prior to deposition. The steps may indicate the approximate locations of major textural changes in the overridden sediments. The step-like change from sand-dominated to silt-dominated matrix texture coincides with the projected Lake Arkona shoreline (see Figure 23) and could represent the change from a glaciofluvial-dominated (sand) to a more glaciolacustrine-dominated (silt) environment which would have occurred in the vicinity of the shoreline.

The coincidence of the step-like change in texture in the Wentworth Till and the projected location of the glacial Lake Arkona shoreline may indicate a direct association of these 2 events, in that the glacial advance that deposited the Wentworth Till of the Paris moraine occurred within, or slightly after, glacial Lake Arkona. The area where a

change from silt-dominated to clay-dominated basal sediments of glacial Lake Arkona occurred may be indicated by the second step-like change in the matrix texture of the Wentworth Till (see Figure 23).

The Wentworth Till matrix also becomes finer-textured from east to west across the study area (see Figure 23). The textural change, however, appears to be gradual and not as extreme as the change from north to south (see Figure 23). The easternmost sample of Wentworth Till contains 24% sand and 15% clay (sample 82-10-48, Figures 23 and 24; Appendix 3A). Because of the rapid fining from north to south and east to west (see Figure 24) within the study area, mean values of the textural properties of the Wentworth Till have little value. Properties of individual samples of Wentworth Till are presented in Appendixes 3, 4, 5 and 6. In general, most properties are similar to those of Port Stanley Till samples taken in the area to the west. Wentworth Till is associated with the Paris and Galt moraines.

Sediments of the Galt Moraine

The Galt moraine can be traced from north of Orangeville southward to the Lake Erie shore near Jacksonburg, a distance of some 160 km. It is composed of Wentworth Till and associated stratified sediments which interfinger with radiocarbon-dated, organic-bearing sediments of the Jacksonburg delta ($13\,360 \pm 440$ years BP, BGS-929).

During the formation of the Galt moraine, water levels in the Lake Erie basin were dropping from Arkona levels to that of the Jacksonburg delta. Water depth at The Sand Hills Park site would not have exceeded 60 m and could have been as low as 1 or 2 m during the formation of this moraine. The source of sediment inflow could have been up to 30 km north of The Sand Hills Park site, but it was most likely nearer.

DESCRIPTION OF SEDIMENTS

The materials exposed along the Lake Erie bluffs at The Sand Hills Park are summarized graphically in Figure 25. A thinly bedded diamicton layer outcrops rarely along the base of the bluffs and is related to the formation of the Paris moraine.

Overlying this diamicton is a unit of rhythmically bedded sand (facies A, part of Facies Association 3 of the Jacksonburg delta) composed of couplets which generally fine upward from ripple cross-stratified, fine sand to silty clay or clay. Couplets over 10 m thick were observed.

The coarse component of the couplets consists predominantly of thick, stacked sequences (1 to 2 m) of Type A and Type B climbing ripple drift, fine and very fine sand (Jopling and Walker 1968). The climbing ripple drift sequences generally fine upward, accompanied by an increase in the angle of climb. The increase in angle of climb results from an increase in the amount of sediment being deposited from suspension relative to the rate of traction sediment transport. This indicates a waning of the current during deposition (Jopling and Walker 1968). Irregularly shaped clay clasts up to 1.5 cm in diameter and detrital or-

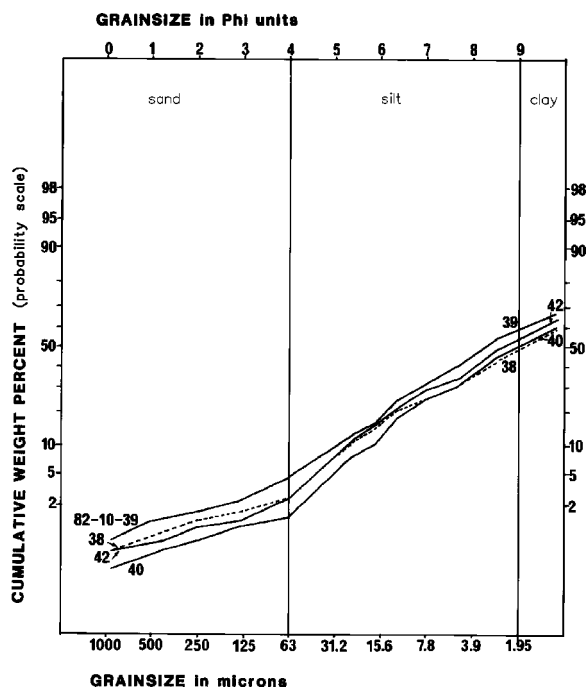


Figure 22. Cumulative weight percent probability plots of samples of Wentworth Till from the Galt moraine.

ganic material including seeds, leaves and twigs, can be present. The clay component of the couplet is up to 1.5 cm thick, laterally extensive and probably deposited from suspension during the winter months.

Within the couplets, there are, in some places, several smaller fining-upward sequences. Paleocurrent measurements indicate strong, unidirectional flow within each layer and a gradual shifting upward through the unit from flow toward the west-southwest to flow toward the south-southeast.

Facies A contains lens-shaped inclusions of thinly to thickly bedded diamicton (facies B, Photo 6).

The diamicton lenses are composed of individual beds, 5 cm to 1 m thick, of massive silty clay containing some very coarse sand, pebbles, cobbles and occasional boulders. The diamicton beds are usually separated by discontinuous, faint laminations of fine sand and/or silt within the lens-shaped inclusions. Several of the massive diamicton layers contain discrete clasts of diamicton, rounded inclusions of rippled sands, and boulders “floating” or protruding above the diamicton’s upper surface. The lower

contact of facies B can be erosional, brecciated or gradational.

The thinly bedded diamictons, facies B, increase in abundance toward the southeast, or toward the paleo-ice marginal position of the Galt moraine, where individual massive beds are commonly 0.5 to 1 m thick and the entire stratified diamicton sequence reaches a thickness of about 15 m (see Figure 25, Station LP 340). In this area, dewatering structures, such as dish structures, occur within the stratified sands. Sand dikes penetrate up through some of the diamicton layers as a result of fluidization of the sands during rapid deposition of the sands and loading by the overlying debris flow.

Overlying facies A or facies B at the southeastern end of The Sand Hills Park area is up to 19 m of dark red-brown, massive, silty clay diamicton, containing less than 5% clasts (facies C, Photo 7). This unit exhibits conchoidal fracture when broken and has a near-vertical set of joints. Conchoidal fracture commonly develops in massive, fine-grained sediments which lack oriented features such as bedding planes or shear planes. Near-vertical jointing is

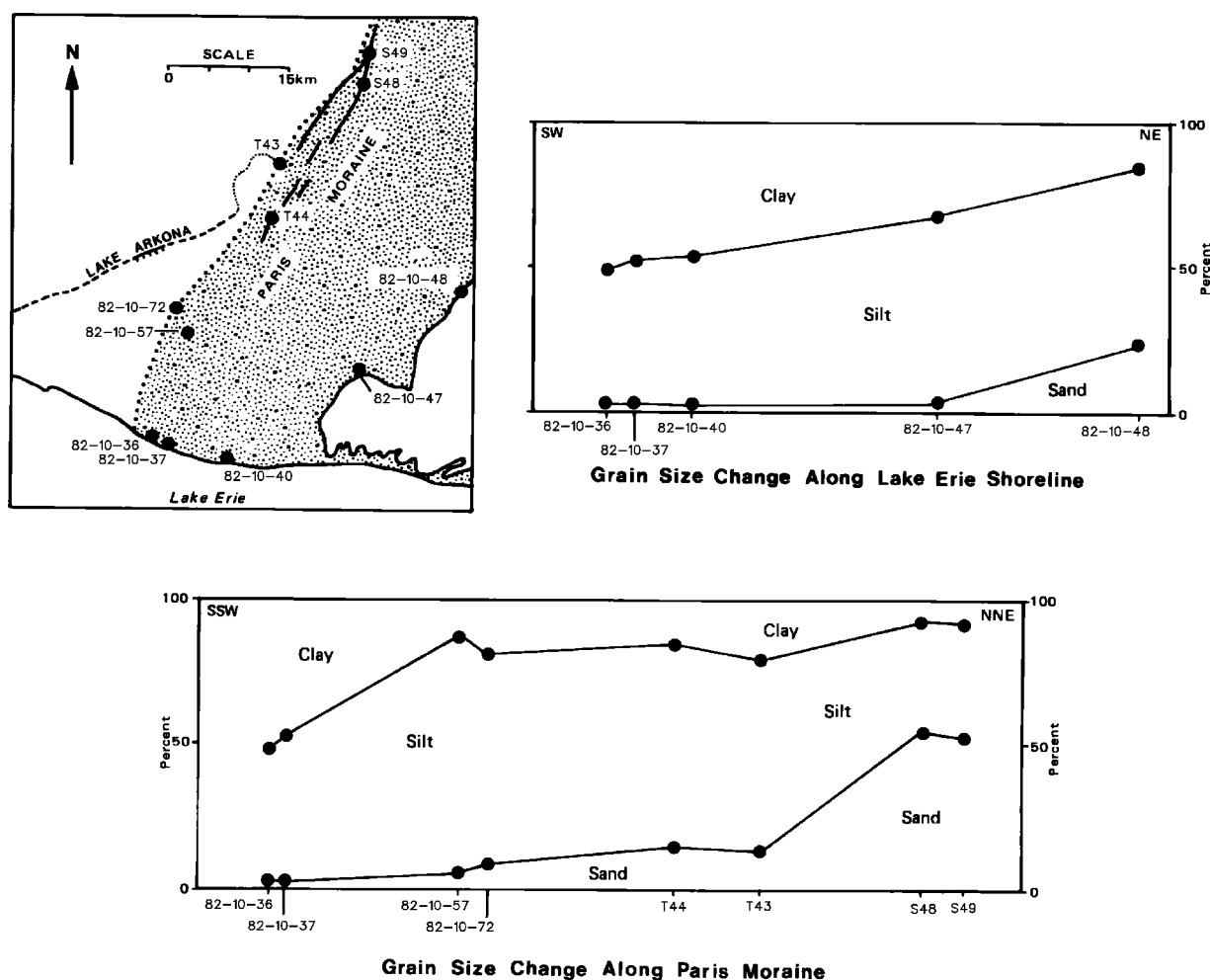


Figure 23. Variation in texture of Wentworth Till samples along the Paris moraine.

commonly associated with the desiccation of fine-grained sediments and is suggested here to indicate a lack of strong structural control in the sediment, such as well-developed shear planes. The lower contact of facies C with the rhythmically bedded sand unit (facies A) or the thinly bedded diamict unit (facies B) is usually sharp, with evidence of erosion. Gradational contacts, however, can also be observed at some sites. The upper contact is gradational with facies B where present, and sharp and erosional with facies D, often marked by a lag concentration of pebbles.

Facies D of The Sand Hills Park area (part of Facies Association 4 of the Jacksonburg delta) is dominated by flat-bedded or low-angle cross-stratified, fine sand. It is well sorted, platykurtic and fine to strongly fine skewed, and the stratification is accentuated by well developed heavy mineral concentrations. Rarely, beds of ripple cross-laminated sand and isolated areas of trough cross-stratified sands occur.

In places, the ripples are oscillatory, or wave ripples, and indicate that the dominant wave current direction was toward the southeast during their formation (see Figure 19). The trough cross-stratified sand units indicate that flow during their deposition was generally toward the south. Lenses of thinly bedded diamict (facies B) also occur within facies D. They sometimes contain protruding or "floating" boulders. Adjacent to the trough cross-stratified sands, erosion of the diamict beds has occurred and a lag of pebbles and clasts of diamict remains along the bottom of the troughs.

Eolian sand that forms The Sand Hills cliff top dunes overlies facies D.

INTERPRETATION

Facies A of The Sand Hills Park area, the rhythmically bedded sand, like Facies A of the McConnell's Nursery sediment sequence associated with the Lakeview moraine, is probably glaciolacustrine, varved sand. It was deposited primarily by quasi-continuous underflows. Facies A at The Sand Hills Park, however, probably formed closer to the sediment source and possibly higher up the delta foresets than facies A at McConnell's Nursery. The sediments are quite similar to those described by Ashley (Gustavson et al. 1975) in glacial Lake Hitchcock, Massachusetts.

Facies B, the thinly bedded diamict, can be found interbedded with facies A and D. Its stratified nature, discontinuous, lens-shaped distribution with rounded terminations of layers, the presence of rounded inclusions of stratified sediments, the block inclusions of diamict and "floating" boulders suggest deposition by debris flows. The texture of the stratified diamict is similar to that of the Wentworth Till of the area and to facies C. This suggests that the debris originated from the glacier or glacially deposited sediments.

Facies C, the massive diamict, can be traced north-westward only as far as the Galt moraine, where it becomes interfingering with facies B sediments. Like facies D at McConnell's Nursery, it is thought that the massive diamict facies is subglacial till.

Facies D at The Sand Hills Park, which is really an assemblage of facies, is predominantly the result of deposition in shallow water. The isolated trough cross-beds probably represent the former position of distributary channels on the delta top or front. The heavy mineral concentrations and the symmetrical ripples are evidence of wave activity in this environment.

Sediments of the Simcoe Delta

A large body of stratified sediments overlies the Wentworth Till and is well exposed in the Lake Erie shore bluffs east of Turkey Point (see Figure 11). This body of stratified sediments consists of 2 main units: a thick sequence of silt and sand rhythmites overlain by a thick unit of silt and clay rhythmites.

The sequence of silt and sand rhythmites is similar to those described as facies associations 2 and 3 of the Jacksonburg delta. The sand and silt rhythmites are thickest in the vicinity of Turkey Point (Photo 8). They are replaced laterally and vertically by the silt and clay rhythmites in the Lake Erie bluff sections but are overlain by gravelly-sand foreset beds and trough cross-bedded gravelly sands further inland along Fishers Creek. Several lenses of sandy-textured diamict occur within the sand and silt rhythmite facies. These diamict units are interpreted as debris flows of Wentworth Till and have characteristics similar to the Wentworth Till exposed elsewhere in this area (Appendices 3, 4 and 5).

The silt and clay rhythmites are very similar to those described as Facies Association 1 of the Jacksonburg delta.

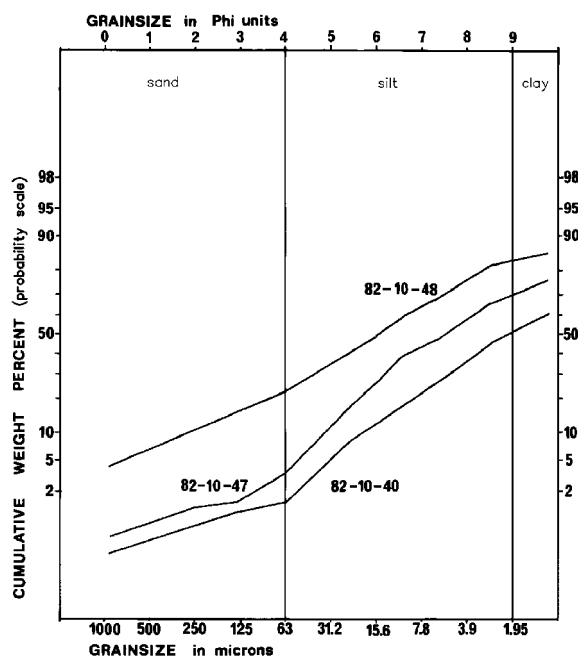


Figure 24. Cumulative weight percent probability plots illustrating textural changes in Wentworth Till samples from east to west across the study area: sample 82-10-48 taken from near Normandale in east, sample 82-10-47 taken from near St. Williams, and sample 82-10-40 taken from the Galt Moraine near Jacksonburg.

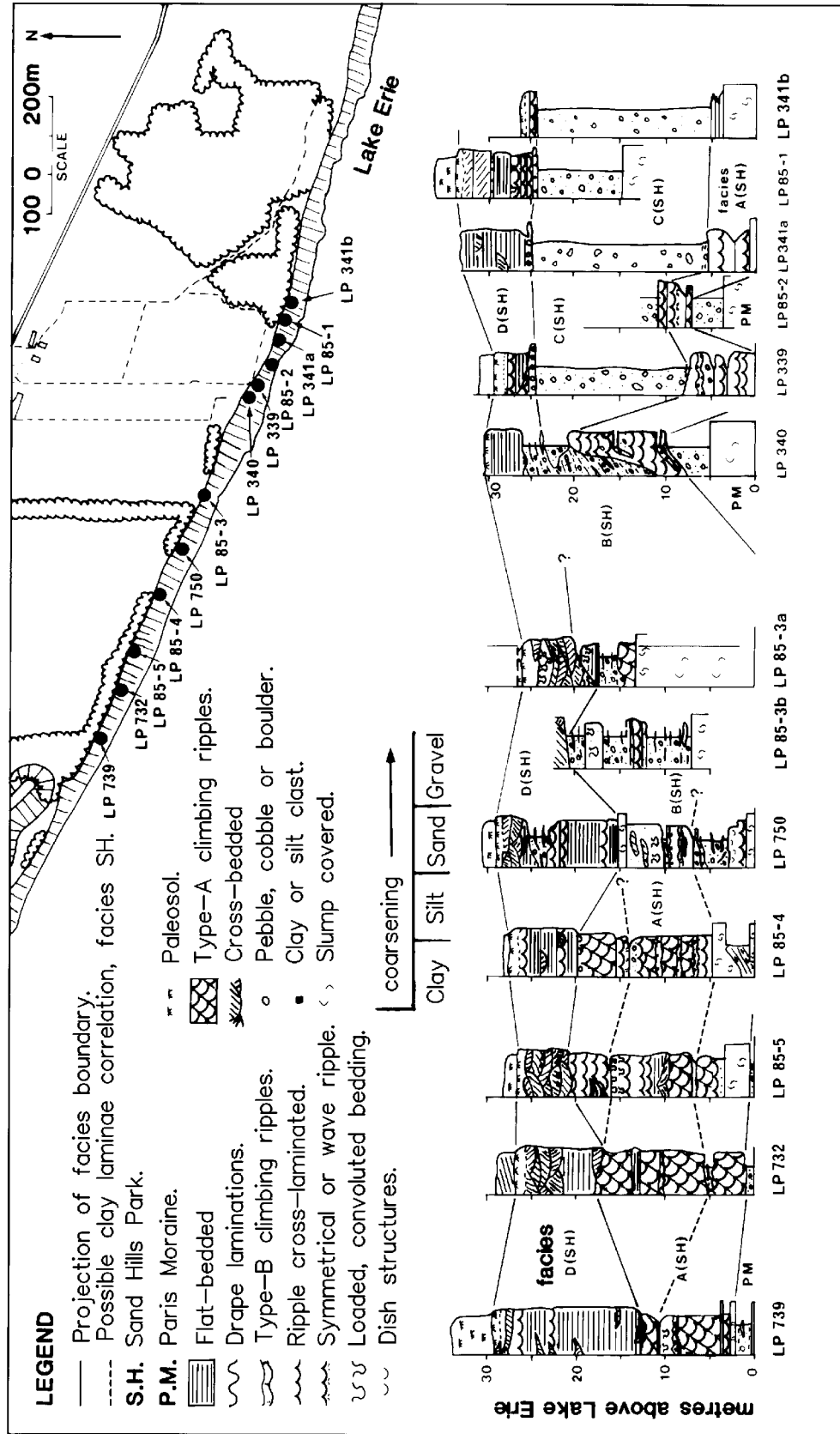


Figure 25. Sediments exposed along the Lake Erie bluffs near The Sand Hills Park (Galt moraine).

The silt and clay rhythmite unit forms high-angle to near-vertical slopes making them difficult to study in detail. However, at the Norfolk Conservation Park, 3.5 km north-east of Fishers Creek, this unit is well exposed and accessible. Unfortunately, recent and penecontemporaneous slumping of the silt and clay rhythmites makes studies, such as varve counting, difficult.

Gravelly-sand foreset beds overlain by trough cross-bedded gravelly sands underlie rhythmically bedded silts and clays north of the lakeshore along Fishers Creek and an unnamed creek to the northeast. The

coarse-grained deposits are believed to be a part of the topset beds of the Simcoe delta (Barnett 1978, 1979). The Simcoe delta was first recognized by Taylor (1913). An attempt to outline the distribution of the coarser facies of this feature was presented in the report on the Quaternary geology of the Simcoe area (Barnett 1978, Figure 12, p.50). Based on the exposures along Fishers Creek, an extension in the distribution of the coarser facies of the Simcoe delta to the southwest is indicated. The rhythmically bedded silts and sands and the silt and clay rhythmites are thought to be the lower delta-front



Photo 6. Lens-shaped inclusion of a thinly bedded diamicton (facies B), The Sand Hills Park.



Photo 7. Massive diamicton, facies C, The Sand Hills Park.



Photo 8. Rhythmically bedded sands and silts of the Simcoe delta exposed east of Turkey Point.

and basinal sediments of the Simcoe delta, respectively (Barnett 1978, 1979).

GLACIOLACUSTRINE DEPOSITS

The rhythmically bedded silts and clays overlying the deposits of the Simcoe delta may represent the deepening of waters in the Lake Erie basin during the rise to the Lake Whittlesey level (Port Huron Stadial). Above this unit is a coarsening-upward sequence of silts and sands, possibly representing the post-Whittlesey shallowing of lake levels in the Lake Erie basin. Most of the surficial sand deposits, which form part of the Norfolk sand plain, were deposited in Lake Whittlesey and younger lakes. These sands are generally fine to medium grained and structureless within the upper metre as a result of soil-forming processes. Below this level, they are often laminated with fine sand, heavy mineral concentrations or silt. The thickness of these surficial sands is difficult to determine because of their continuity with older, underlying sands; however, up to 27 m have been reported by drillers in water wells in the Tillsonburg area (Barnett 1982). In the study area, these sands are generally between 5 and 10 m thick.

Small areas of gravel and gravelly sand are associated with abandoned shoreline deposits of lakes Whittlesey and

Arkona along the Tillsonburg moraine, and with glacial Lake Warren beneath dune sand at Straffordville.

OLDER ALLUVIUM

Alluvium is a sediment which is deposited by rivers. Deposition occurs primarily by lateral growth of point bars within the river's channel or by vertical accretion on the river's flood plain. Older alluvium is alluvium deposited and preserved on abandoned fluvial terraces.

Four sets of abandoned river terraces were identified along Big Creek and Big Otter Creek in the study area. The terraces are underlain primarily by fine- to coarse-grained sand with usually less than 10% gravel content. The terraces probably grade to high proglacial lake levels that once existed in the Lake Erie basin. Identification of the particular lake to which each terrace grades is difficult. However, the fanning out of the lower 2 terrace sets at the projected levels of glacial lakes Grassmere and Lundy, make these correlations reasonable. The upper 2 terraces probably relate to intermediate lake levels above Lake Grassmere and below Lake Whittlesey, and may be related to levels of glacial Lake Warren.

Older alluvium occurs along some of the minor creeks in the report area. Two interesting fluvial terraces are exposed along the Lake Erie shore cliffs east of Port Burwell. At the first locality, 3 km east of Port Burwell, the base of the older alluvium occurs approximately 19 m above the present level of Lake Erie. The older alluvium consists of orange-brown, fine-grained sand with thin laminations of organic matter. Small twigs, fragments of wood and peat are present at the base of the older alluvium. Preliminary pollen analysis of the older alluvium indicates deposition prior to the spruce to pine transition (approximately 10 500 years BP in this part of Ontario). Spruce pollen (*Picea*) make up over 80% of the tree pollen while non-tree (non-aboreal) pollen ranges from 8 to 21% of all pollen (C.E. Winn, private consultant, personal communication, 1983). A radiocarbon age of $11\,070 \pm 140$ years BP (BGS-882) was obtained on wood from within the alluvial sediments and appears reasonable with respect to the pollen spectra.

At the second locality, 8 km southeast of Port Burwell, the base of the older alluvium is marked by a gravel lag and occurs about 15 m above the present level of Lake Erie. Here, the older alluvium consists of orange-brown and grey, fine-grained sand with heavy mineral laminations and thin laminations containing organic matter. Logs, small twigs and molluscs were present within the older alluvium. Pollen analysis indicates that the deposition of the older alluvium occurred during the spruce to pine transition (C.E. Winn, private consultant, personal communications, 1983). A large log taken from near the base of the alluvium was dated at 9750 ± 150 years BP (BGS-883). The date is not unreasonable for this site.

Neither of the 2 terraces can be related directly to the water level that existed in the Lake Erie basin during their formation because terrace remnants are small and gradients difficult to determine. However, the water levels in the Lake Erie basin were probably lower than 189 m asl and

the shoreline must have been located much farther out in the Lake Erie basin than at present.

At Clear Creek, hand borings revealed an abandoned channel of Clear Creek, the base of which occurs 5 m below the present level of Lake Erie. The channel, excavated into Wentworth Till, is filled by a fining-upward sequence of sediments consisting of grey, fine-to medium-grained sand, interbedded fine-grained sand and silty clay containing organic detritus, faintly stratified silty clay with organ-

ic matter, and dark brown to brown fibrous peat becoming very woody at the top (Figure 26). This sediment sequence has been interpreted as an alluvial channel cut-and-fill sequence (Barnett et al. 1985). The sand unit has been interpreted as the product of active sediment transport in the channel. The faintly stratified silty clay was possibly deposited in a cut-off meander (oxbow lake) environment. Because oxbow lakes eventually become sites of dense vegetation and organic matter accumulation (Collinson

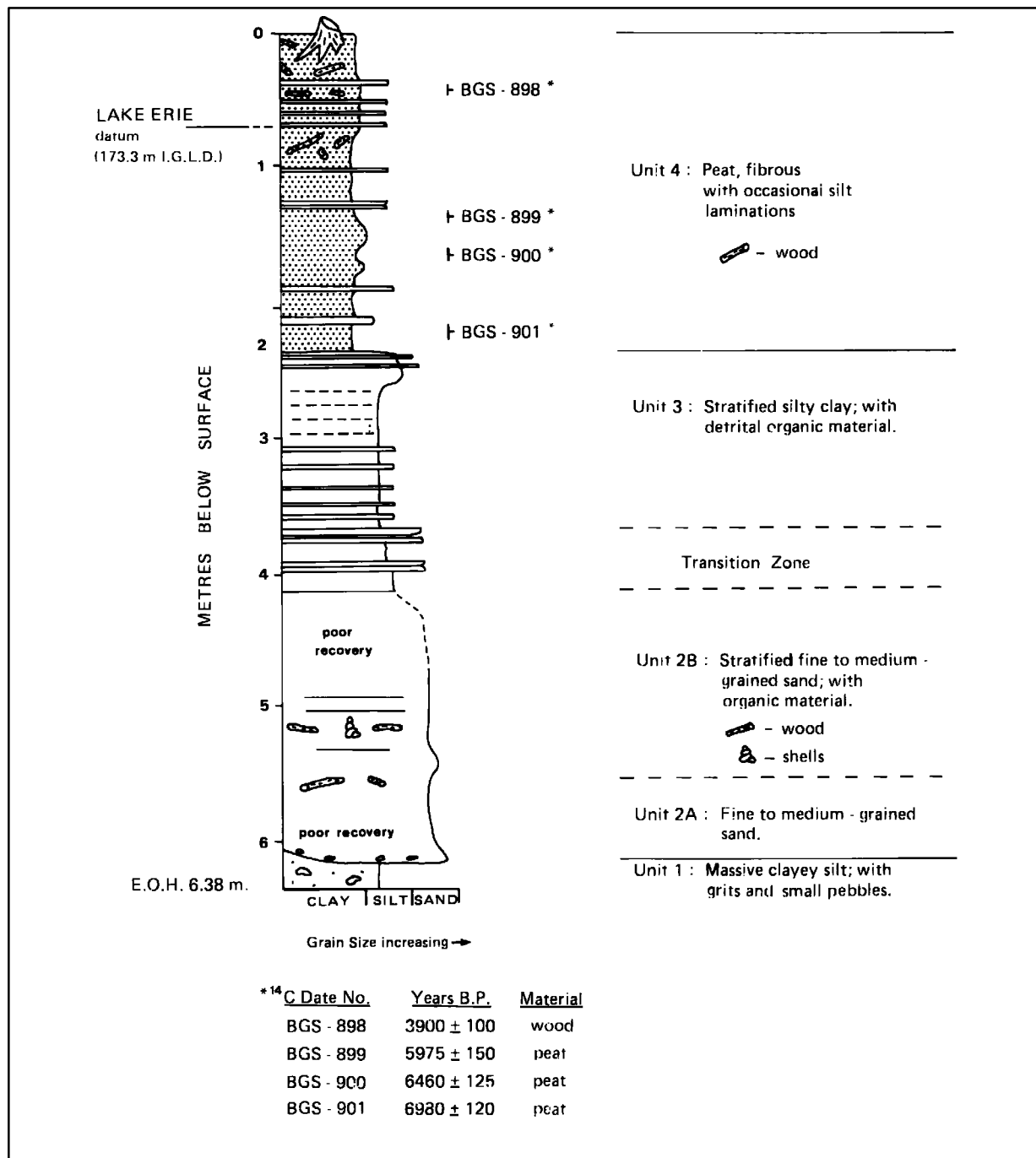


Figure 26. Sketch of sediment profile and location of radiocarbon dates, Clear Creek site (from Barnett et al. 1985). I.G.L.D. - International Great Lakes Datum; E.O.H. - end of hole.

1978), the upper part of the fill sequence is interpreted as the late stages of oxbow lake sedimentation (Barnett et al. 1985).

A study of the palynology of the sediment fill suggests that the infilling began approximately 9500 to 9000 years ago. Infilling was complete sometime after 3900 ± 100 years BP (BGS-898) based on a radiocarbon date on wood near the top of the channel fill. The sediment and pollen records (Barnett et al. 1985, Figure 3) suggest that the water level in the Lake Erie basin was lower than the present level during this time interval.

Several fan-shaped features occur approximately 5 m above the present level of Lake Erie along the stretch of Lake Erie bluffs protected by Long Point (Barnett and Zilans 1983). It is difficult to confirm whether these features are deltas or alluvial fans because of the lack of exposure of their internal characteristics. However, the coincidence of elevation to which these features are built, combined with the associated older alluvial terraces that grade to their top surfaces, strongly suggest that these features are deltas.

The upper 2 m of the sediment in these features is gravelly sand to gravel with the occasional silt interbed. Shells were reported by the land owner from 2 wells dug in one of the deltas; the thickness of the deltaic sediments exceeds 6 m. Older alluvium graded to the deltas consists of thinly interbedded, very fine-grained sand and silty fine-grained sand, with the occasional lens of silty, small pebbly gravel and clayey silt debris flows. Toward the base, very coarse sand and pebbly gravel occur above the till surface. Shells, wood fragments, and charcoal are present throughout the sequence. Older alluvium that graded to one of the deltas was observed to be up to 4 m thick. Several logs were collected from the base of this thick sequence of older alluvium; one of them was dated at 1900 ± 80 years BP (BGS-928). Radiocarbon dating of organic detritus from another older alluvial sequence yielded a date of 960 ± 80 years BP (BGS-980). Samples were collected from several sites and analyzed for pollen content. Pollen grains were very poorly preserved, hindering identification (C.E. Winn, private consultant, personal communication, 1983).

The deltas, which define a water level in the Lake Erie basin of approximately 180 m asl, are relatively young features, based on the radiocarbon dates. If the interpretation of the channel fill sediments at Clear Creek is correct, in that postglacial water levels in the Lake Erie basin were lower than present between 9500 and 4000 years BP, then the deltas must have formed sometime between 4000 and 1000 years BP.

Near Fort Erie, abandoned terraces of the Niagara River occur at an elevation of approximately 180 m. They cut across the Fort Erie moraine, where they may represent the controlling outlet sill for the lake level defined by the deltas near Port Rowan. Shoreline features identified by Feenstra (1981) at Erie Beach south of Fort Erie at 180 m and at Shisler Point at 181 m may also define this lake level. However, Feenstra (1981) related these shoreline features to pre-Early Lake Erie falling water-levels in the Lake Erie basin. Contrary to the ideas of Coakley and Lewis (1985), the Fort Erie moraine may have controlled

water levels in the Lake Erie basin up until about 1000 years BP, before downcutting of this morainic dam to the level of the present bedrock sill occurred.

EOLIAN DEPOSITS

Sands found in the surface dunes of the report area are well sorted to moderately well sorted, normal kurtic to slightly leptokurtic or platykurtic and near symmetrical through fine skewed to strongly fine skewed (positive skewed) (see Appendix 6). The average graphic mean of 11 samples of dune sand is 2.7ϕ with a standard deviation of 0.2ϕ . Cumulative weight percentage probability plots of dune sand samples are presented in Figure 27. Samples of dune sands

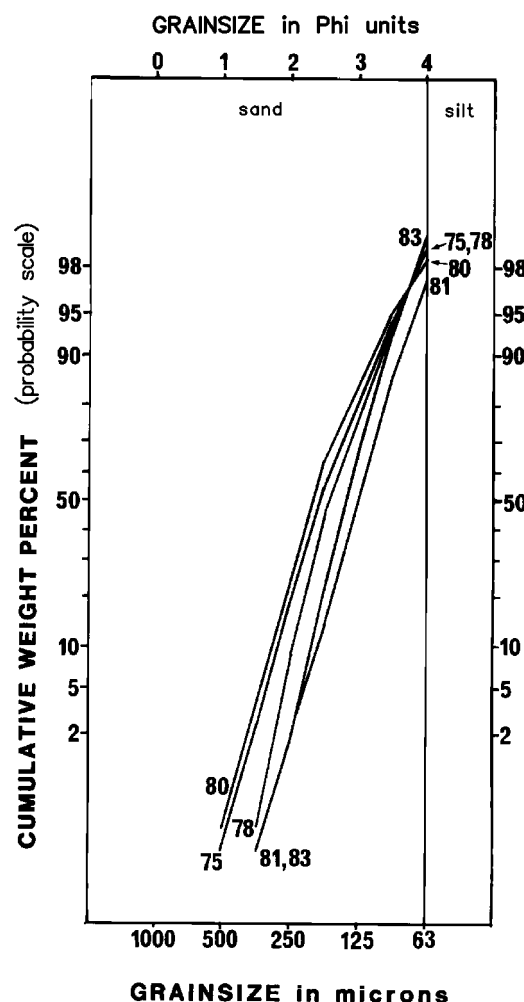


Figure 27. Cumulative weight percent probability plots of dune sand samples.

from the Simcoe and Tillsonburg areas (Barnett 1982) have similar grain-size distributions.

BOG AND SWAMP DEPOSITS

Only 2 major areas of organic accumulation occur in the report area. These are in the Turkey Point and Long Point marshes. Elsewhere, organic accumulation is thin and

often the result of deposition in small seasonal ponds that have developed in depressions underlain by fine-grained soils. Bog iron has formed in broad, shallow depressions in areas where sands containing abundant heavy minerals occur above finer-textured sediments.

MODERN ALLUVIUM

Modern alluvium is forming along most of the creeks in the report area but its areal extent is often too small to depict on Quaternary geology maps at a scale of 1:50 000. The texture of the modern alluvium is variable, depending on the type of deposits being eroded within the drainage basin. In the report area, modern alluvium is commonly silt, sandy

silt, or sand, with varying amounts of organic debris. Modern alluvium up to 7 m thick was observed along Big Otter Creek; however, it is usually much thinner along the smaller creeks in the area (i.e., up to 2 m thick).

LAKE ERIE DEPOSITS

Along most of the shoreline of Lake Erie in the report area, the accumulation of sand at the base of the bluffs in beaches is minimal. Large accumulations of sand occur at Port Burwell and in the Turkey Point and Long Point spits. The sedimentology of the latter has been described in detail by Coakley (1985).

Glacial History

The sediments observed in the study area were deposited during Late Wisconsinan and Recent times, from approximately 23 000 years BP to the present. In southwestern Ontario, the initial period of ice advance during the Late Wisconsinan, the Nissouri Stade, is represented by the Catfish Creek Drift (Figure 28). Catfish Creek Drift does not outcrop within the study area; however, it has been encountered at depth directly overlying the bedrock surface (borehole OGS-82-M-8, Appendix 2). Its distribution in the subsurface is discontinuous. And it is most likely to be found in the western half of the Port Burwell map area.

During the Nissouri Stade, the margin of the continental glacier extended into Ohio and Indiana where its limit is marked by the Cuba and Hartwell moraines (Goldthwait et al. 1965; Dreimanis and Goldthwait 1973). Indications from the Woodstock area (Cowan 1975) are that initial ice movement was controlled by the Great Lakes basins, but then changed to a more regional flow during this stadial maximum. During recession, as the ice thinned, the direction of ice flow was once again controlled by the Great Lakes basins (Dreimanis 1961; Cowan 1975).

During the Erie Interstade, as the ice front receded, several high-level lakes occupied the Lake Erie basin (Dreimanis 1969; Mörner and Dreimanis 1973). At the maximum retreat, Lake Leverett existed in the Lake Erie

basin (Mörner and Dreimanis 1973). The sediments deposited during these high-level lakes are, for the most part, missing from the sediment record but are inferred from the fine-grained texture of the Port Stanley Till.

The Port Stanley Till and Drift represent the Port Bruce Stade, or the period of ice advance that followed the Erie Interstade. The direction of ice flow was once again controlled by the Lake Erie basin. Overriding of the Erie Interstadial glaciolacustrine sediments occurred. The incorporation of these fine-grained sediments into the base of the glacier as it overrode them must have been extensive, based on their effect on the grain-size distribution of the fine-grained Port Stanley Till.

During the Port Bruce Stade, the Erie lobe eventually coalesced with the Huron lobe and advanced to the Union City–Powell moraine in the United States (Mickelson et al. 1983; see Figure 28). The northern extent of the Erie lobe in southwestern Ontario is marked by the Ingersoll moraine (see Figure 5). This moraine is, in part, palimpsest and cored by Catfish Creek Drift (Dreimanis 1964; Terasmae et al. 1972; Barnett 1982). Recession and oscillations probably occurred at the western extremity of the Erie lobe prior to the actual deposition of Port Stanley Drift in the Ingersoll moraine. The entire report area remained ice cov-

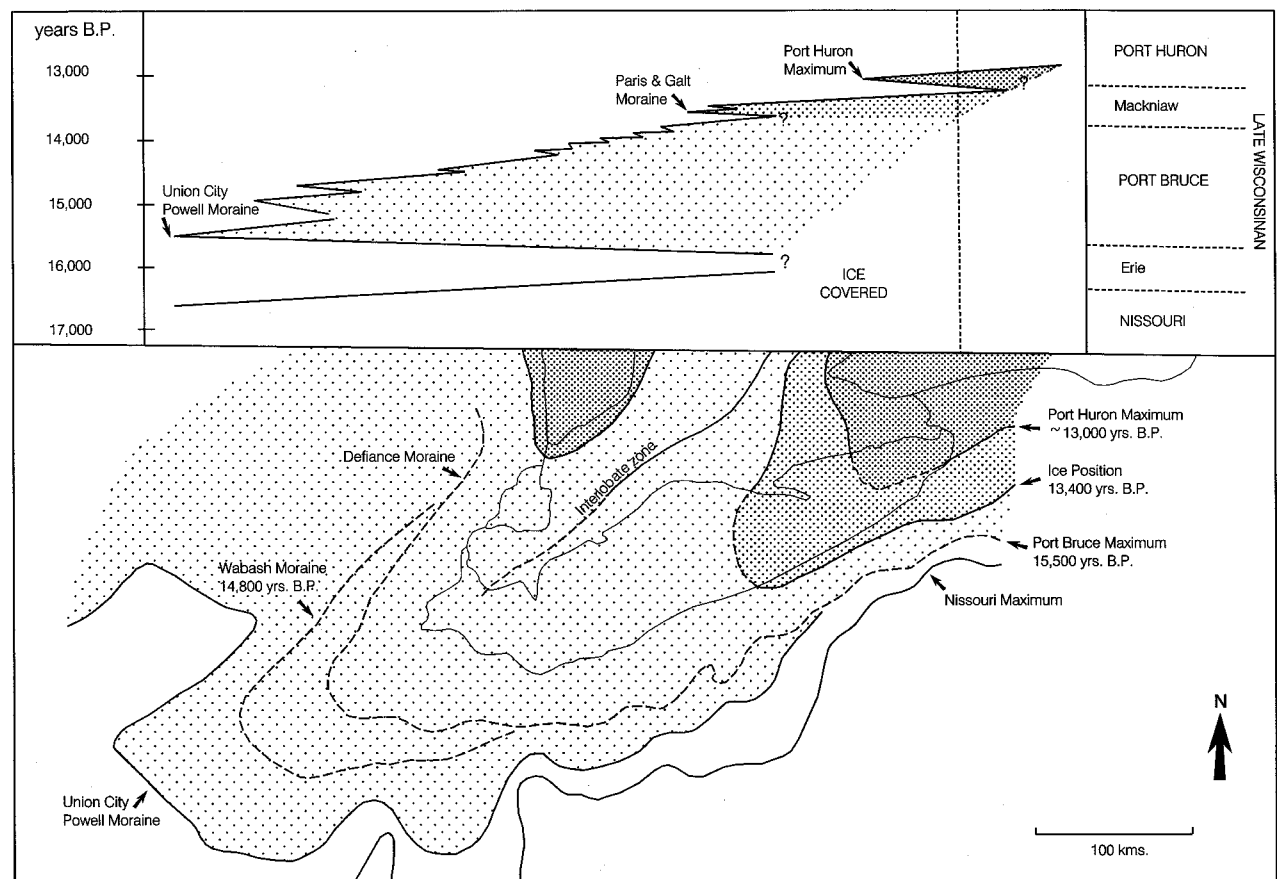


Figure 28. Time-space diagram of the Erie lobe (from Barnett 1985).

ered while glacial Lake Maumee I inundated the western end of the Lake Erie basin.

During ice-marginal recession from the Ingersoll moraine, the ice margin paused and readvanced slightly to form the Westminster, St. Thomas, and Norwich moraines (see Figure 5). Meltwater flowed freely from these ice margins northward to the Thames River, then southwestward along the Ingersoll moraine to the Komoka delta at London (Barnett 1982). The Komoka delta was built into Lake Maumee I and Lake Maumee II. Dreimanis (1970) suggested that the glacial Lake Maumee II phase occurred in the lakes Erie and Huron basins during ice marginal fluctuations along the St. Thomas moraine. The report area remained ice covered at this time.

As the glacier retreated from the Norwich moraine (see Figure 5), a high-level glacial lake (Lake Maumee II or III) flooded the ground between this moraine and the ice front (Barnett 1982, 1985). At this time the rivers draining the ice margin flowed southward along the margin carrying sediment into the lake. Deltaic sands were deposited along the ice margin where it entered the lake and silts and clays were carried farther out into the basin. The ice front receded to a position south of the Tillsonburg moraine, then readvanced, overriding the glaciolacustrine sediments to form the northern limb of the Tillsonburg moraine. Similar oscillations formed the middle and southern limbs of this moraine (Barnett 1982). The southern limb of the Tillsonburg moraine is the most northerly moraine in the report area.

The ice front then receded to a position south of the Courtland moraine. Deltaic sediments continued to be de-

posited along the ice margin. Glacial Lake Maumee III existed in the Lake Erie basin by this time, flooding the area between the St. Thomas moraine and the ice margin. A minor readvance of the ice margin formed the Courtland moraine. The Mabee and Lakeview moraines (see Figure 5) formed in a similar manner, probably during glacial Lake Maumee IV.

Deposition of the main body of deltaic sediments in this report area followed the receding ice margin south-eastward, while the finer-textured clays continued to be deposited farther out into the basin. The subsequent readvance to the Lakeview moraine overrode these sediments and deposited the uppermost layer of Port Stanley Till exposed west of Port Burwell (see Figure 8). The series of off-flapping Port Stanley Till layers separated by glaciolacustrine sediments present in the Port Burwell area and Tillsonburg area to the north (Barnett 1982) are a result of small ice oscillations. The readvance associated with the formation of the Lakeview moraine covered a distance of about 2 to 3 km over about a period of 10 to 15 years. Ice velocities at the glacier bed were about 0.6 metres per day, similar to those of ice streams in Antarctica (Sugden and John 1976). Fluctuations and ice flows of similar magnitudes probably occurred during the formation of the other moraines in the report area.

With the subsequent retreat of the ice margin toward the eastern end of the Lake Erie basin during the initial part of the Mackinaw Interstade, a regional lowering of the lake level in the lakes Huron and Erie basins occurred (Figure 29). Lake Arkona features are well developed on Port Bruce Stadial sediments, such as those forming the Mabee

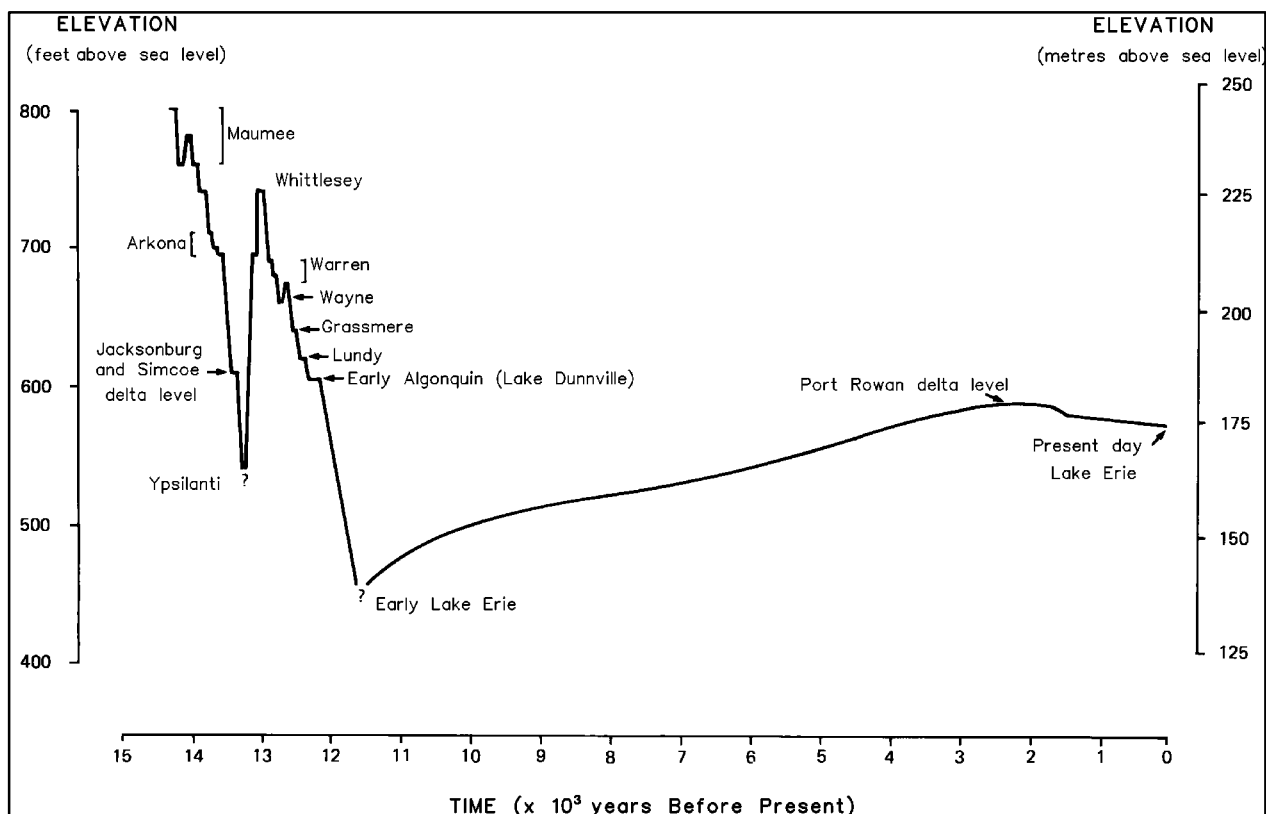


Figure 29. Sequence of ancestral lakes in the Lake Erie basin (modified after Barnett 1985).

moraine (Barnett 1982). They were probably formed during the initial stages of ice retreat. The Paris and Galt moraines, composed of Wentworth Drift, represent a period of readjustments of the Erie lobe during the Mackinaw Interstade. The relationship of Lake Arkona to the Paris moraine still remains unclear.

During the formation of the Galt moraine, however, water levels had fallen to between 181 and 185 m elevation in the Lake Erie basin as recorded by the sediments of the Jacksonburg delta. Because the Erie lobe blocked eastward drainage, the Michigan and Huron lobes must have receded northward far enough to uncover the Indian River Lowlands or the Straits of Mackinac, in order to form a lake at this level (Figure 30). Deglaciation of most of Michigan must have occurred at the time of the formation of the Jacksonburg delta about 13 400 years BP. This is supported by dates on the Cheyboygan Bryophyte Bed (Miller and Benninghoff 1969). However, dates on the Cheyboygan site range from $13\,300 \pm 400$ years BP to as young as 9960 ± 350 years BP and their interpretation is controversial (see Fullerton 1980).

During this time the deglaciated portion of southern Ontario (Ontario Island) supported a wide variety of plant taxa with modern arctic, boreal and prairie affinities. As suggested by Terasmae (1981, p.84) “a major proportion of migration of the pioneer vegetation into southwestern Ontario occurred in late Port Bruce Stadial . . . and during the following Mackinaw Interstadial (about 13 500 to 13 000 years BP)”. His contention that initial populations of spruce could have been established at this time is supported by the identification of spruce (*Picea*) needles from Jacksonburg delta sediments (Warner and Barnett 1986).

Immediately following the formation of the Galt moraine, the Simcoe delta was built into a Lake Erie basin wa-

ter body at about the same level as that into which the Jacksonburg delta was built (Taylor 1913; Barnett 1978, 1991). Again, westward drainage, possibly along the Indian River lowlands or Straits of Mackinac, must have occurred. The sandy rhythmites east of Turkey Point (see Figure 11) and the gravels along Fishers Creek and the unnamed creek to the northeast are a part of the Simcoe delta. With further ice margin retreat into the Lake Ontario basin, eastward outlets were opened, resulting in falling water levels in the Lake Erie basin and eventually Lake Ypsilanti formed (Kunkle 1963).

During the subsequent Port Huron Stade and the deposition of the Halton Till, ice re-entered the eastern end of the Lake Erie basin and raised the water level in the basin to that of glacial Lake Whittlesey (Barnett 1979). The silt and clay unit containing ice-rafted debris exposed along the Lake Erie shore bluff east of Turkey Point (see Figure 11) may represent this deepening of the water in the Lake Erie basin. The overlying, coarsening-upward sequence of silts and sands record the post-Whittlesey lowering of lake levels in the Lake Erie basin and, indirectly, the recession of the ice margin from the Port Huron Stade maximum as lower eastern outlets were uncovered.

Abandoned shoreline features of glacial lakes Whittlesey, Warren, Grassmere and Lundy are present within the study area. Early Lake Erie, or at least lakes with shorelines south of the present Lake Erie shore, are represented in the study area by the 2 hanging fluvial terraces east of Port Burwell and by the abandoned channel cut and fill at Clear Creek.

The Port Rowan deltas record a water level about 5 m above the present level of Lake Erie. These features appear to have formed after 4000 years BP, sometime around 2000 to 3000 years BP.

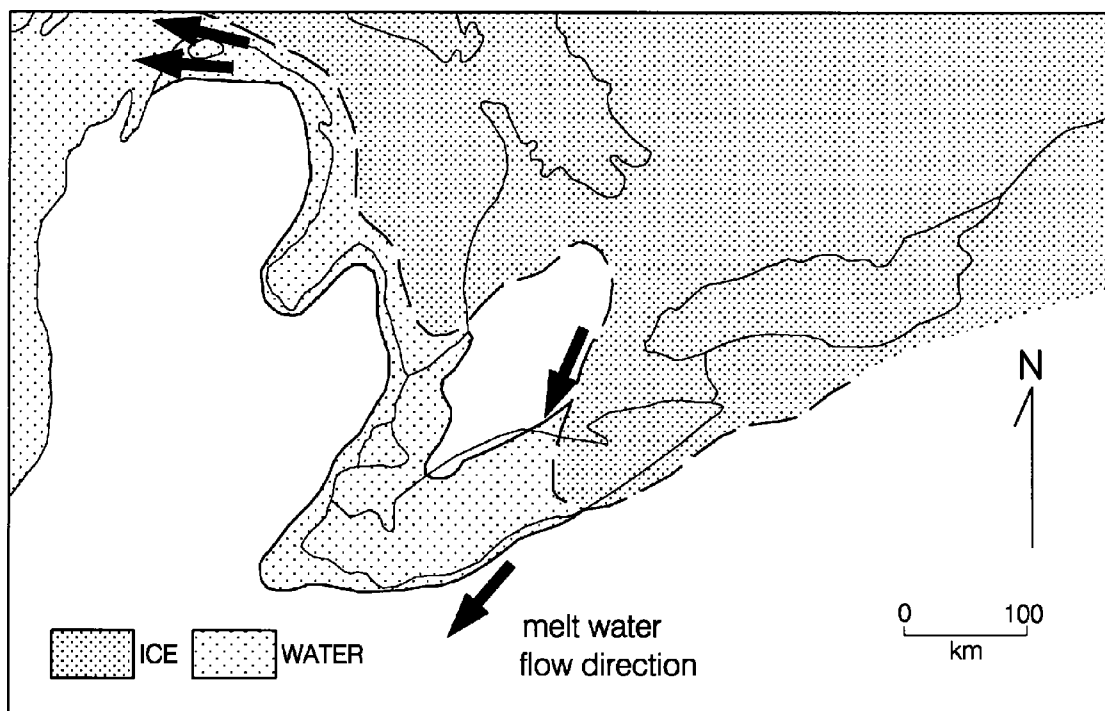


Figure 30. Paleogeographic map of the Lake Erie basin 13 400 years ago during the Jacksonburg delta level (from Barnett 1985).

Applied Quaternary Geology

AGRICULTURAL SOILS

The soils within the map area have developed in Quaternary deposits of Lake Wisconsin and Recent age. Soil development is estimated to have begun between approximately 12 600 and 12 000 years ago, following the lowering of postglacial lakes and exposure of the relatively flat lake plains. The small part of the Tillsonburg moraine that rises above the Lake Whittlesey level has probably been exposed to soil forming processes for at least 13 500 years. Other parts of the map area, such as areas within the sand plains that have been modified by eolian processes and older alluvial terraces, may have been subjected to weathering processes for a much shorter length of time. In the case of the large cliff-top dunes at The Sand Hills Park, soil formation probably began within the last hundred years.

Soil maps for the previous counties of Norfolk (*circa* 1928) and Elgin (*circa* 1929) were prepared by staff of the Ontario Agricultural College. These were updated by the Ontario Institute of Pedology. Preliminary maps for the Regional Municipality of Haldimand–Norfolk (Langway 1980a, 1980b; Montgomery 1980; Patterson 1980; Presant 1980) and Bayham Township (Aspinal and Schut 1984) have been released.

A report entitled *Soils of the Regional Municipality of Haldimand–Norfolk* (Presant and Acton 1984) discusses soil types, properties and distributions within the eastern

half of the present map area. The relationship of soil type to parent material is summarized in Table 8 and discussed in greater detail by Presant and Acton (1984).

ECONOMIC GEOLOGY

Sand and Gravel

Extraction of sand and gravel has occurred throughout the map area in abandoned beach deposits, shallow water glaciolacustrine deposits and the topset beds of the Jacksonburg and Simcoe deltas.

Gravel resources are scarce. In the past, gravel and gravelly sand has been extracted along the 3 creeks located north of Turkey Point in Simcoe delta deposits and from glacial Lake Whittlesey beach deposits in Bayham Township. Further extraction of the Simcoe delta deposits is hindered by a thick cover of glaciolacustrine, fine-grained sediments and the relatively low gravel content. The Lake Whittlesey beach deposits are thin and narrow.

Sand has been excavated from the large dunes throughout the sand plain area, predominantly for fill and to increase the amount of level acreage available for cropland.

An assessment of the mineral aggregate potential for the Township of Delhi has been prepared by the Ontario Geological Survey (1984).

Table 8. Relationship of soil series to Quaternary deposits of the Long Point–Port Burwell map area (*modified from* Presant and Acton 1984).

Geological Unit	Good Drainage	Soil Series Imperfect Drainage	Poor Drainage
Till:			
Port Stanley Till	Muriel	Gobbles	Kelvin
Wentworth Till	Muriel	Gobbles	Kelvin
Glaciolacustrine sediments:			
clay, silt and clay	Muriel	Gobbles	Kelvin
clayey silt	Brantford	Beverly	Toledo
very fine sandy silt	Brant	Tuscola	Colwood
sand	Fox	Brady	Granby
	Wattford	Normandale	St. Williams
	Plainfield	Walsingham	Waterin
sand and gravel	Burford		
thin (40 to 100 cm) sandy textures over Port Stanley Till	Bookton (till phase)	Berrien (till phase)	Wauseon (till phase)
thin (40–100 cm) sandy textures over silty clay	Bookton	Berrien	Wauseon
thin (40–100 cm) silty textures over silty clay		Tavistock	Maplewood

Clay

Glaciolacustrine clay and Wentworth Till have been used in the past as the raw material for hollow bricks and drain tiles (Keele 1924). A clay pit was located at Port Rowan and a description of the material used was given by Keele (1924). Keele (1924) and Guillet (1977) have evaluated clay and till deposits of the map area for their potential as raw material for brick and tile.

Iron

Iron was produced between 1848 and 1923 at the Van Norman Foundry located at Normandale. Local sources of bog iron ore and oak (for firing) from Delhi and Norfolk townships municipalities were used in the smelting process.

ENVIRONMENTAL AND ENGINEERING GEOLOGY

General

Within the Long Point–Port Burwell area, there are several geological factors which may affect the construction of roads and buildings. Large flood plain areas, such as those along Big Otter and Big creeks, and several smaller flood plains along minor creeks, should be avoided when constructing buildings that would be adversely affected by flood waters. Sibul (1969, p.73) suggested that the bankfull stage (when stream discharge exceeds 6200 ft³/sec) of Big Otter Creek at Vienna probably occurs on the average of once in 13 years, and a flood level of 6400 ft³/sec, as recorded March 6, 1965, has a recurrence interval estimated to be 17 years.

The surface of the Port Stanley Till is, in places, susceptible to frost heaving as is the surface of glaciolacustrine silt deposits.

The complex stratigraphy and the many steep valley walls in the map area may also pose problems to construction. Seepage and contact springs along valley walls where relatively impermeable fine-textured tills, silts and/or clays are interbedded with permeable sands may increase the potential for slope failure. Piping of the sands along valley walls may cause land subsidence. Novakovic and Farvolden (1974) suggested a very close association of springs with slumps and minor landslides in the Big Creek and Big Otter Creek drainage basins. Construction should be avoided near the valley edges in these areas when possible, otherwise detailed engineering, groundwater and geological investigations should be undertaken.

Along with the numerous other considerations in the selection of waste disposal sites, caution should be used in the map area to avoid contamination of the groundwater aquifers in the confined, wedge-shaped, deltaic sand bodies (Barnett 1982). The aquifers possibly recharge from the surface in the intermorainal areas of the sand plain.

Another problem in the map area is the susceptibility of the topsoil to wind erosion, enhanced by mismanagement of the land. In contrast, some land owners have practiced good land management by removing the topsoil from stabilized dunes, excavating the dune sand for fill, then replacing the topsoil on the now-level field to increase the workable acreage of the property.

Shoreline Erosion

The Lake Erie coast within the Long Point–Port Burwell area can be divided into 2 main types of shorelines: 1) erodible bluffs composed of a variety of Quaternary sediment types, and 2) large sand and gravel spits (Long Point and Turkey Point spits). The erodible bluffs of the area can be further divided into naturally protected and unprotected bluff segments. The main area of naturally protected bluffs occurs along Inner Bay, where the bluffs are protected from the full force of Lake Erie waves by Long Point and Turkey Point spits.

The unprotected, erodible bluffs of the Long Point–Port Burwell area have one of the highest erosion rates along the Canadian shoreline of the Great Lakes (up to 5.4 m³/m/yr, Boyd 1981). It is, in part, for this reason that the detailed study of bluff stratigraphy and sedimentology was undertaken for this report (see Figure 7a–g, back pocket).

Knowledge of the properties of the Quaternary sediments and of the stratigraphy (the vertical distribution of the sediment types) within the shore bluffs and foreshore area is essential for shore erosion, shore protection and shore management studies. The properties of the Quaternary sediments affect: 1) the erodibility of the foreshore area and, therefore, bluff toe recession rates (Kamphuis 1986, 1987); 2) the types of processes that are effective in the degradation of the shore bluff (weathering, wind, surface runoff, groundwater, etc.); 3) the amount and flow paths of surface runoff (number and types of gullies, sheet wash, etc.); and 4) the distribution and flow paths of groundwater (seepage zones, piping, sand volcanoes). Groundwater distribution can affect, in turn, the strengths of the materials making up the bluff. Increases of water pressures within bluff material decreases material strength (cohesion) which tends to decrease bluff stability (slumping and sliding) (Clemens 1977).

The shore bluffs of the Long Point–Port Burwell area contain excellent examples of how bluff composition and stratigraphy affect coastal outline at various scales. On the regional scale, the large promontory in the central part of the Lake Erie shoreline, between Jacksonburg and Erie View (see Figures 7 and 10), corresponds to the area where the shore bluffs are composed predominantly of a cohesive, fine-grained till (Wentworth Till of the Paris and Galt moraines). Bluffs to the east and west of the promontory, are composed of noncohesive, stratified sediments of glaciolacustrine origin (see Figures 7, 9 and 11).

On a smaller scale, headlands occur east of Turkey Point (see Figures 7 and 11), where Wentworth Till is exposed at the base of the shore bluff and within the

foreshore zone. Here, the Wentworth Till is a silt till containing 5 to 10% clasts. Boulders are common and provide a natural armour in the nearshore zone.

The shore bluffs of the Long Point–Port Burwell area also display excellent examples of how bluff composition and stratigraphy affect bluff profile. In the report area, bluffs composed entirely of till can form steep bluffs which are commonly undercut and which recede by a combination of cliff-toe erosion and mass wasting. Bluffs composed primarily of coarse silt and sand (The Sand Hills Park area, *see* Figures 7 and 9) are commonly well drained in their upper parts, often dry and susceptible to wind erosion. The formation of cliff-top dunes is the result (example, The Sand Hills). Locally, wind is also an effective erosion agent of silt and sand units exposed elsewhere along the shore bluffs.

The stretch of lake bluffs between Port Burwell and Port Bruce (*see* Figures 7a and 7b) illustrates the effects that bluff stratigraphy, or the position of various cohesive and noncohesive materials in the bluffs, has on bluff profile.

In the area approximately 6 km west of Port Burwell (immediately east of Tate Drain, McConnell's Nursery area; *see* Figure 7b), the types of sediments exposed in the shore bluffs are similar, but their arrangement or stratigraphic position is different. At several sites (*see* Figure 7a, Stations LP34 to LP85-17) a layer of Port Stanley Till outcrops at the base of the bluffs. It is overlain by a thick unit of silt and sand rhythmites which is in turn overlain by silt and clay rhythmites and Port Stanley flowtills. To the east, the layer of Port Stanley Till dips below lake level and the silt and sand rhythmite unit forms the base of the bluff (*see* Figure 7a, Stations LP25, LP719 and LP24). Excepting the lower till unit, the bluffs are composed of similar sediments; however, the flowtill unit is replaced, in part, by a unit of subglacially deposited Port Stanley Till at the latter example.

The bluff profiles are quite different (Figure 31). The sections with till at the base have horizontal distances between the toe and crest of bluffs on the order of 40 m. The sections with the silt and sand rhythmites outcropping along the base have gentle lower slopes. Horizontal distances from bluff toe to bluff crest can be as large as 100 m.

The cohesive units in both profiles in Figure 31 (the Port Stanley Till, flowtills and silt and clay rhythmites) form near vertical bluff faces. Bluff profiles are less steep where the silt and sand rhythmites occur, due primarily to groundwater seepage and piping within the noncohesive sediments. Seepage and piping is concentrated in the lower parts of the silt and sand rhythmite unit (*see* Figure 31).

Additional features that contribute to shore bluff recession in the area, in addition to groundwater seepage and piping related to the noncohesive materials, are the complex relationships of toe erosion by wave attack, cliff steepening, sheet sloughing and landsliding (Photo 9). Quigley et al. (1977) discuss in some detail these pro-

cesses, including recurrence intervals, that bluffs immediately to the west of the Long Point–Port Burwell area are undergoing.

Gullying is also affected by bluff composition. The types of gullies vary across the report area. In areas of thick till at surface or in areas of complex stratigraphy, gullies are often steep-walled and “v”-shaped. Gullies are absent along bluffs composed primarily of noncohesive sediments.

Large theater-shaped gullies occur east of Port Burwell (*see* Figure 7c) within the silt and sand rhythmite facies of the Jacksonburg delta. Groundwater seepage and piping of the silt and very fine sand components of the rhythmites contribute greatly to erosion and allow rapid formation (over a period of a few days to weeks) of these theater-shaped gullies. Gully bases are commonly located along the contact between the silt rhythmites and underlying clay rhythmite facies, particularly if this contact is within a few metres of the base of the bluff. Clay rhythmite units are commonly highly deformed and occur higher in section than expected based on an examination of the lateral positions of these units. It is believed that the theater-shaped gullies are the result of a “one time” rapid release of stored groundwater.

A proposed mechanism to store the groundwater near the face of the bluff and to allow it to drain rapidly includes an initial stage of deep-seated plastic deformation of the clay rhythmite unit, causing bulging at the toe of the bluff. The bulging could form a natural dam along the base of the bluff to hold back or retain groundwater within the lower part of the silt and sand rhythmites, until the dam was breached, and the stored water allowed to drain.

The deep-seated bulging and deformation of the bluff may explain the deformed nature and position (i.e., higher in the bluff than expected) of the clay rhythmites in the area of the theater-shaped gullies. Displaced modern shoreline deposits (up to 3 m above lake level) are found on the top of crescent-shaped ridges of deformed clay rhythmites. The layers of the clay rhythmites generally dip toward the bluff and lend support to the suggestion of an initial stage of deep-seated plastic deformation.

Human activities along the shore bluffs can alter many of the natural processes and the factors that control the stability of the bluffs. For example, several gullies along the bluffs, head at the ends of drainage tile lines where the flow of water is concentrated. Several brochures and pamphlets have been prepared discussing shoreline erosion processes and shoreline protection methods (Clemens 1977; Ontario Ministry of Natural Resources 1981 and references therein). Philpott (1986) lists a series of studies done for the federal government on shore erosion in the Port Burwell area. These studies provide additional data, such as wave conditions, that pertain directly to the Port Burwell area. Care must be taken in shoreline management operations and consideration taken of the repercussion to neighbouring land.

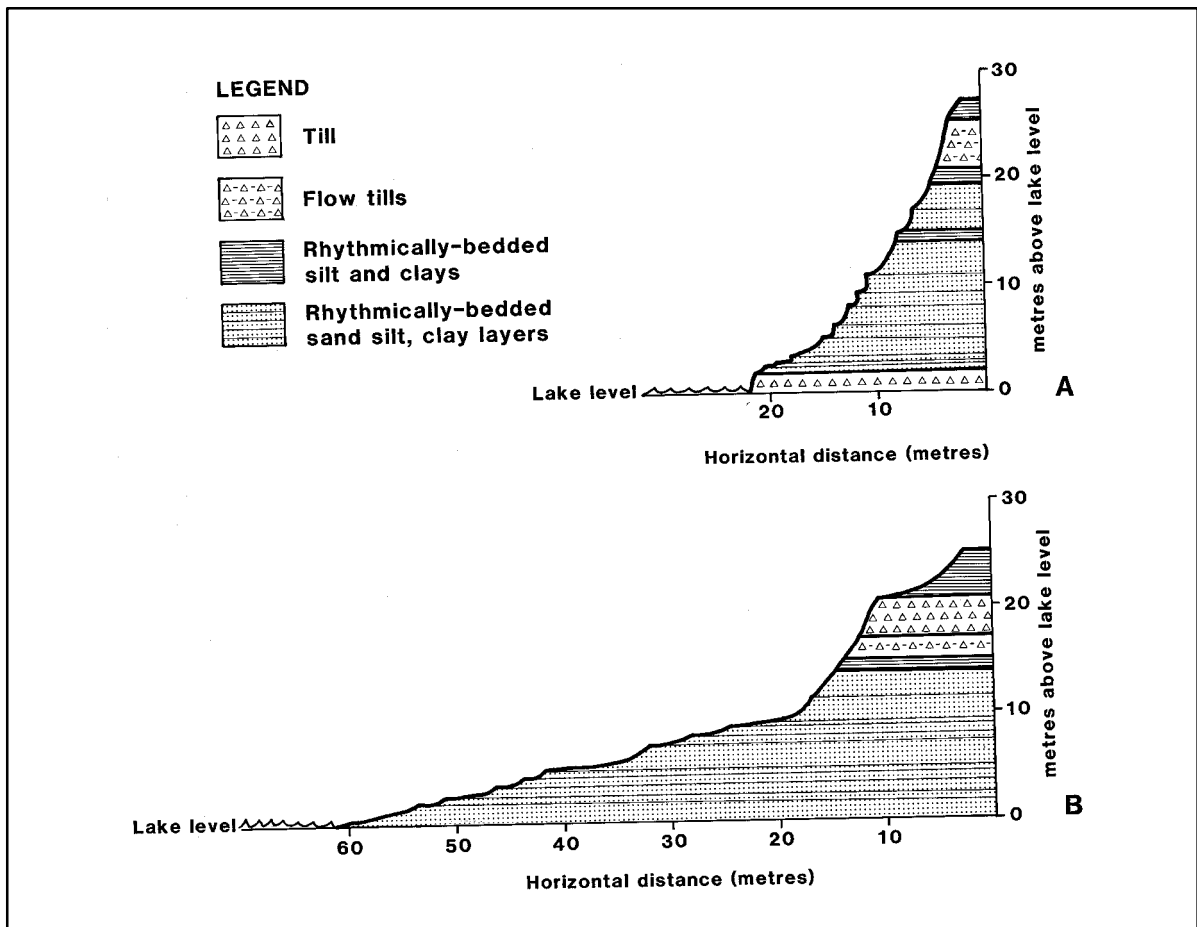


Figure 31. Sketch of bluff profiles: A) at LP 14, and B) in the vicinity of LP 719 (see Figure 7); measurements are approximate.



Photo 9. Large rotational slide along Lake Erie bluff, Port Burwell, Ontario.

Appendix 1. Descriptions of Selected Sections*

Appendix 1 contains detailed section descriptions and paleocurrent and grain size variability information for the following sections (listed in order of occurrence in the text).

LP 85-1

LP 85-2

LP 85-3

LP 85-4

LP 85-5

LP 85-6

LP 85-7

LP 85-8

LP 85-9

LP 85-10

LP 85-11

LP 85-12

LP 85-13

LP 85-14

LP 85-15

LP 85-16

LP 85-17

LP 85-18

LP 339

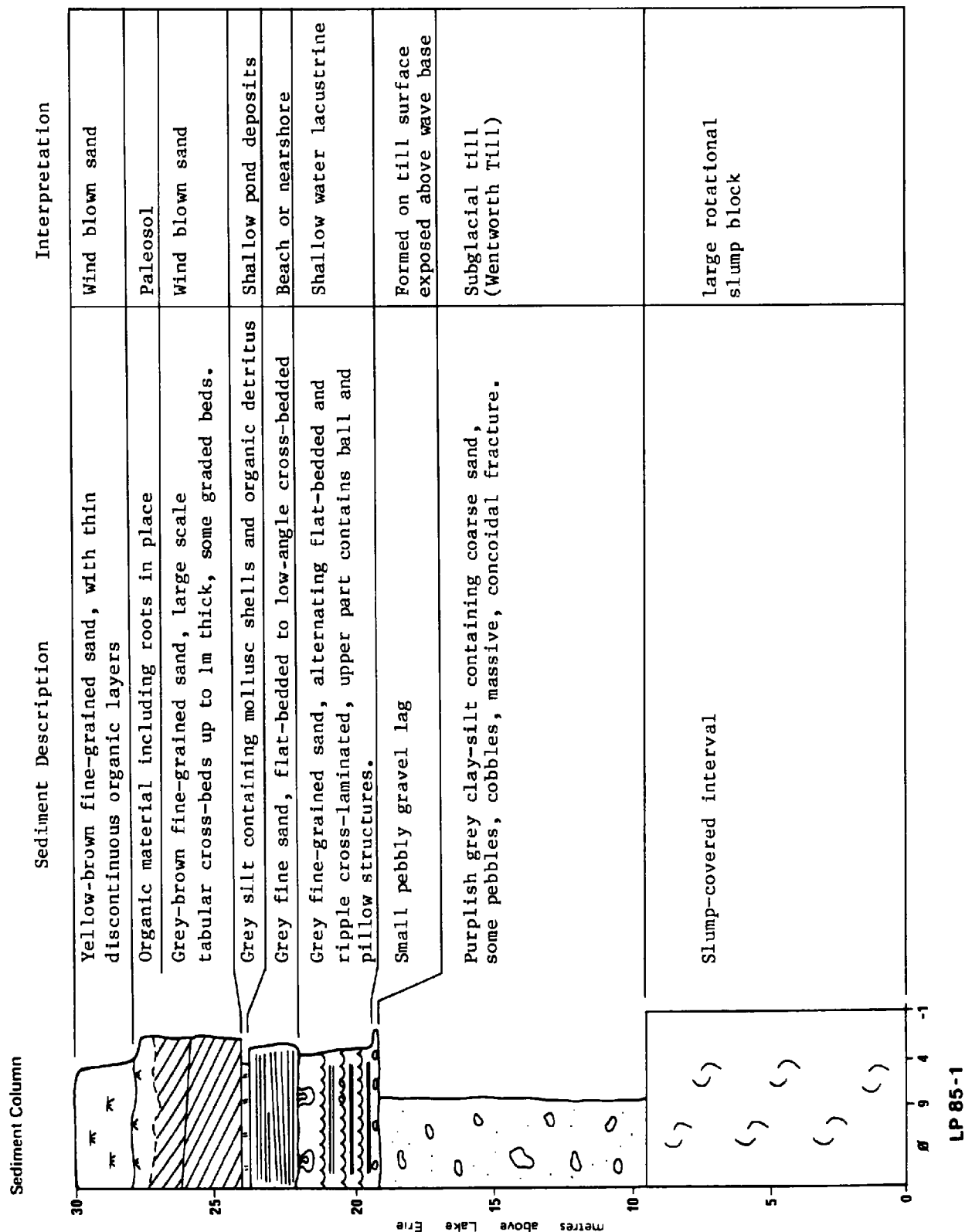
LP 739

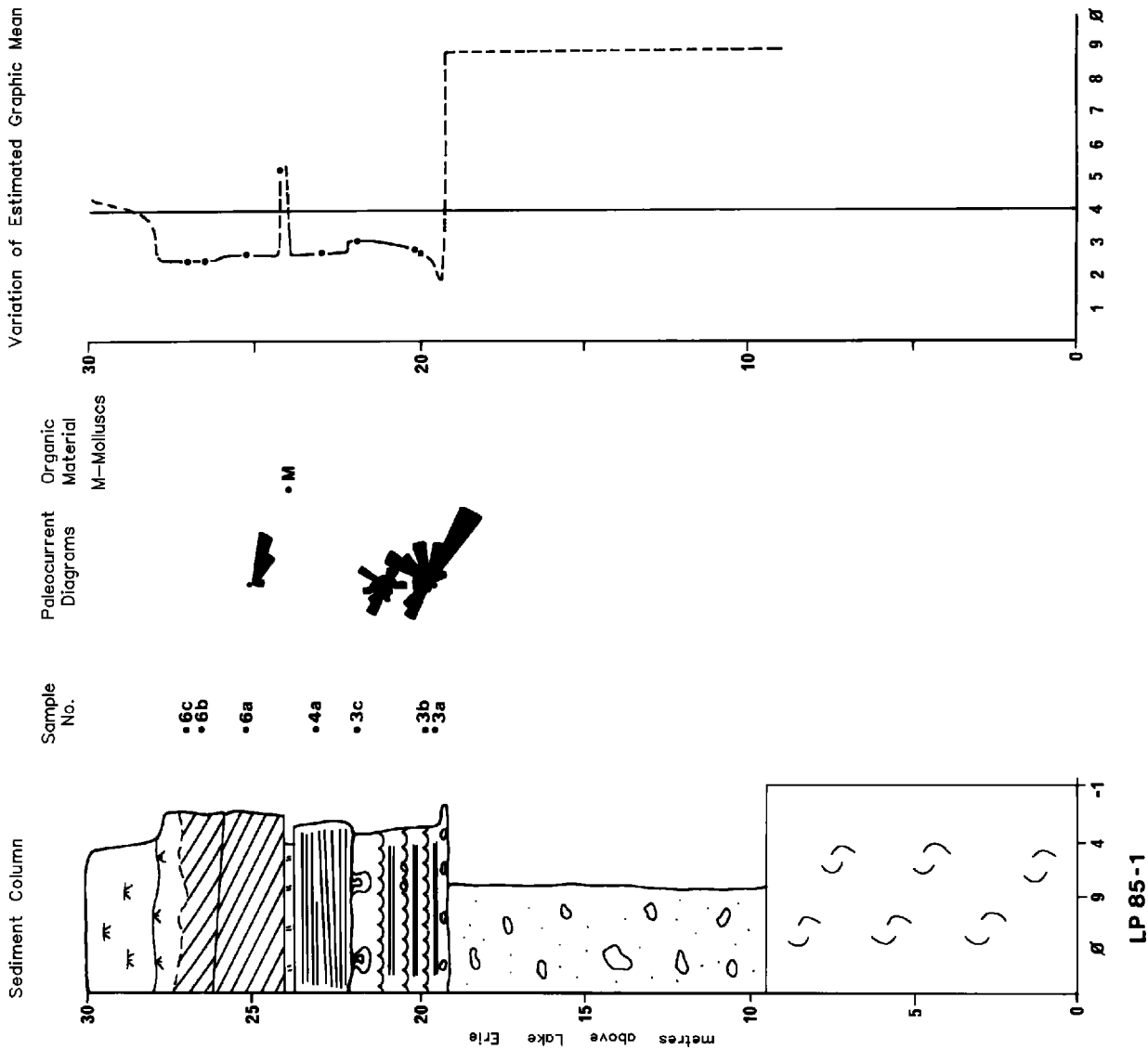
LP 750

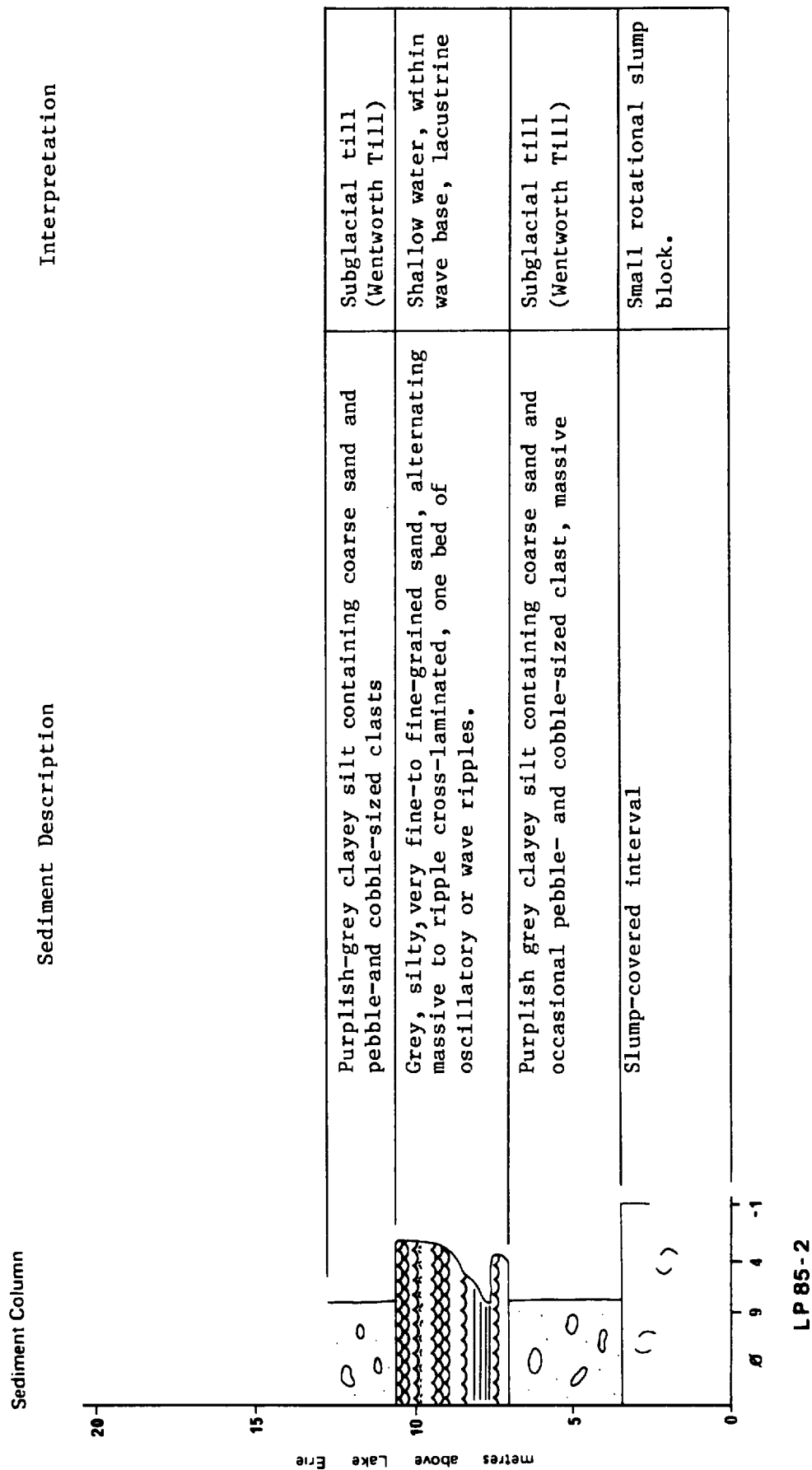
*See Figure 7a-f for section locations.

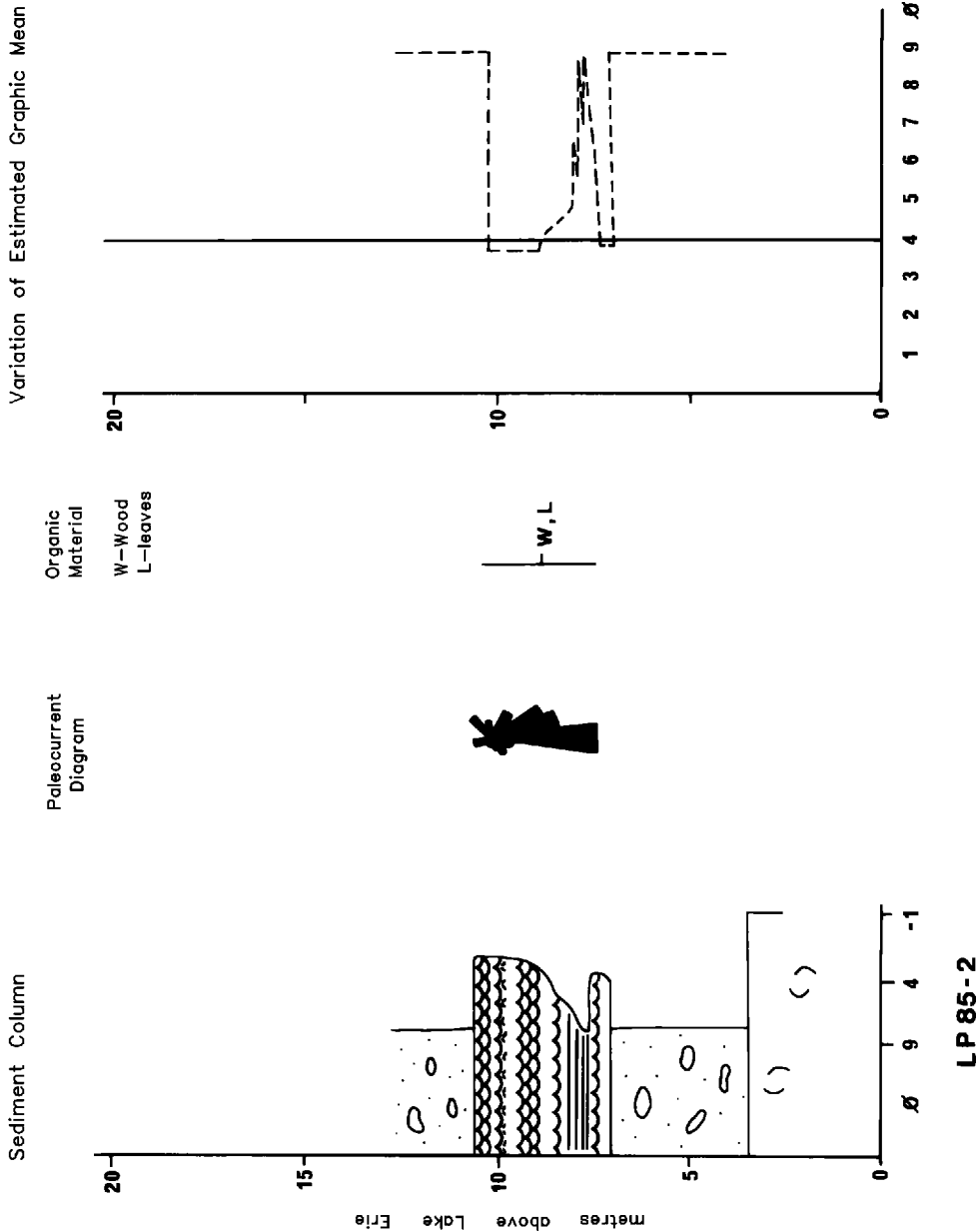
Legend for sedimentary columns

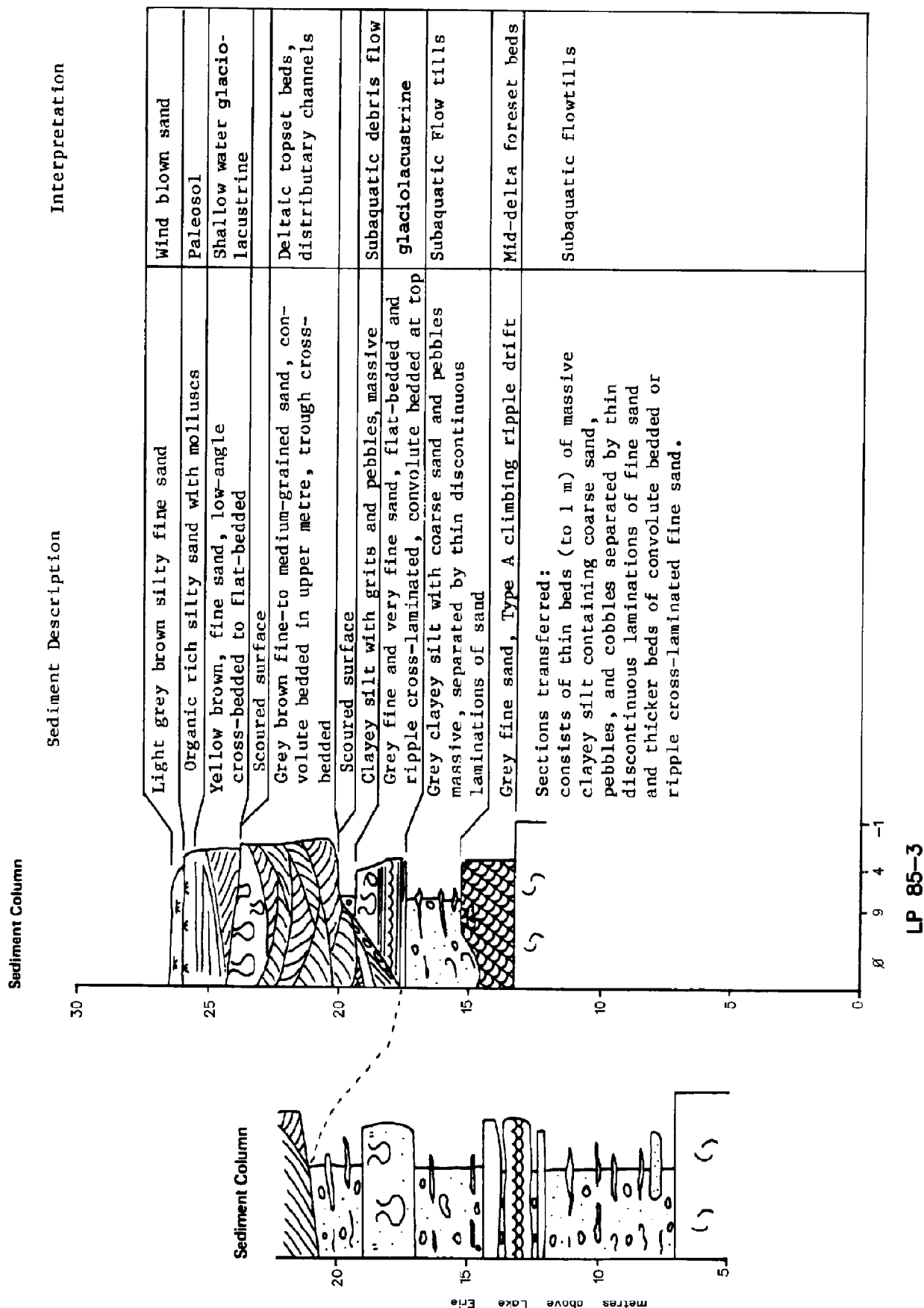
	Flat-bedded.
	
	Low-angle cross-beds.
	Cross-bedded.
	Ripple cross-laminated.
	
	Type-A Climbing Ripples.
	Type-B Climbing Ripples.
	Sinusoidal or drape laminations.
	Symmetrical or wave ripple
	Loaded, convolute bedding.
	Flame structures.
	Deformed, folding dominant.
	Deformed, faulting dominant.
	Dish structures.
	Pebble, cobble or boulder.
	Clay or silt clast.
	Slump covered.
	Paleosol.
	Silt.

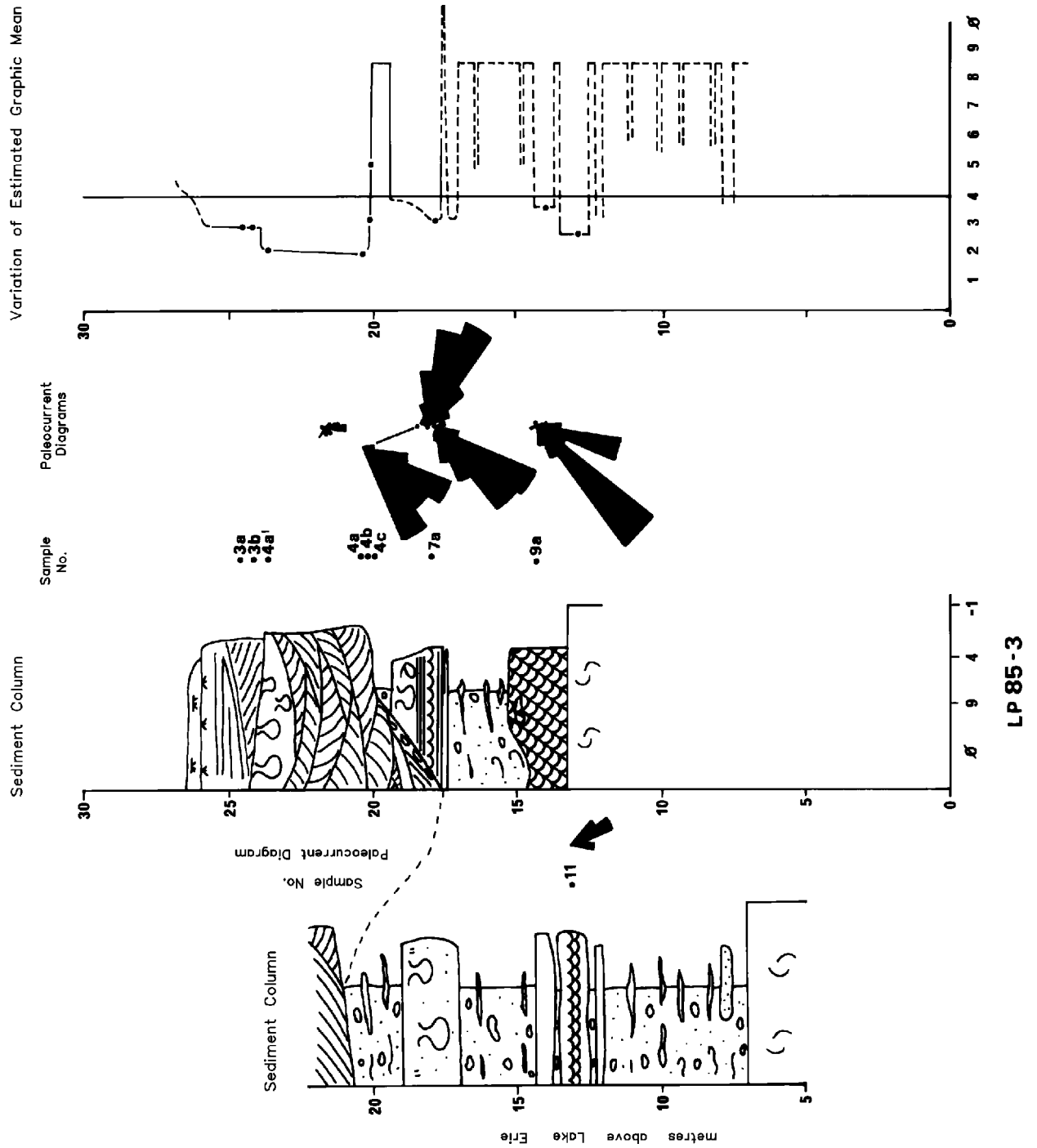


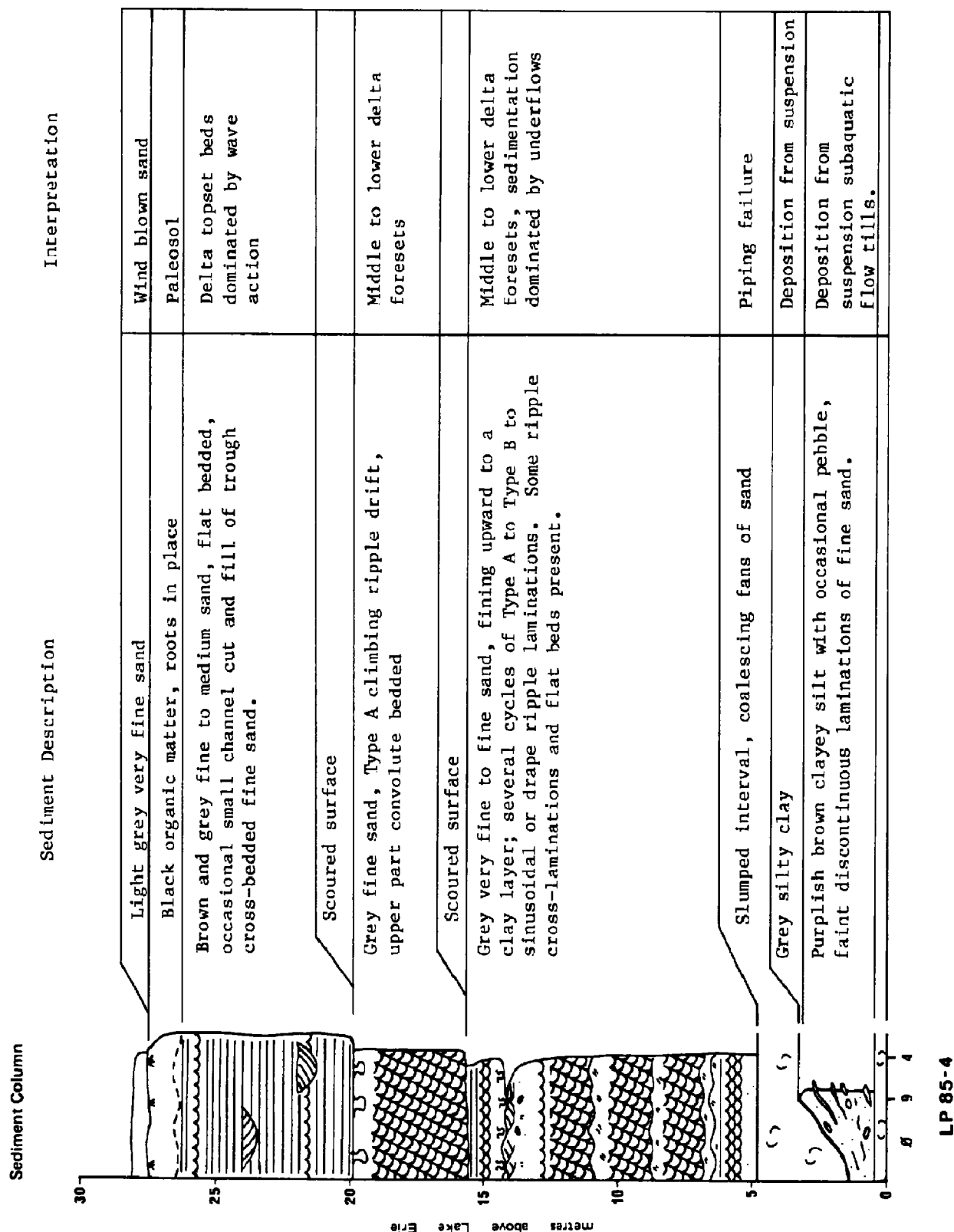


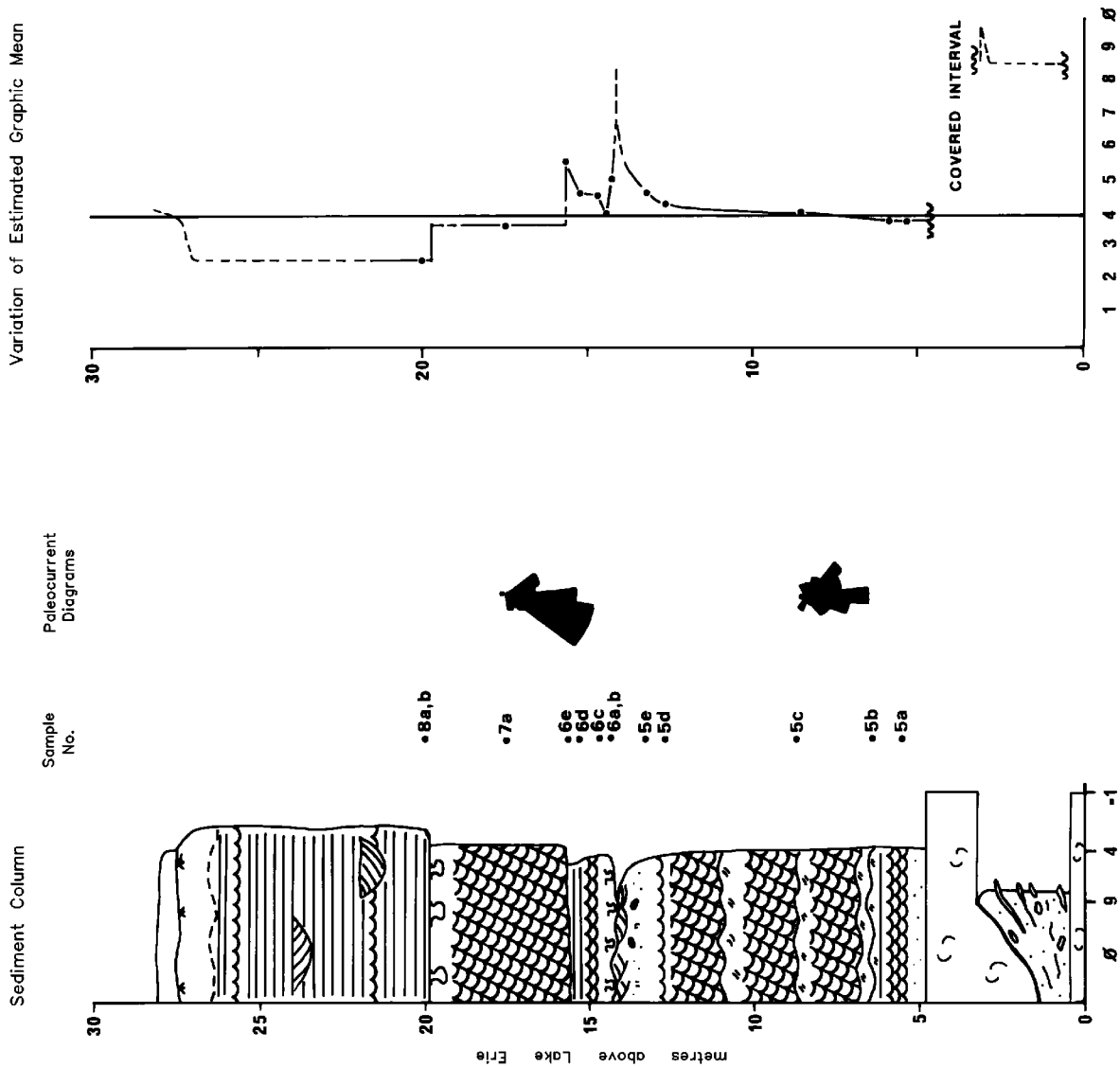




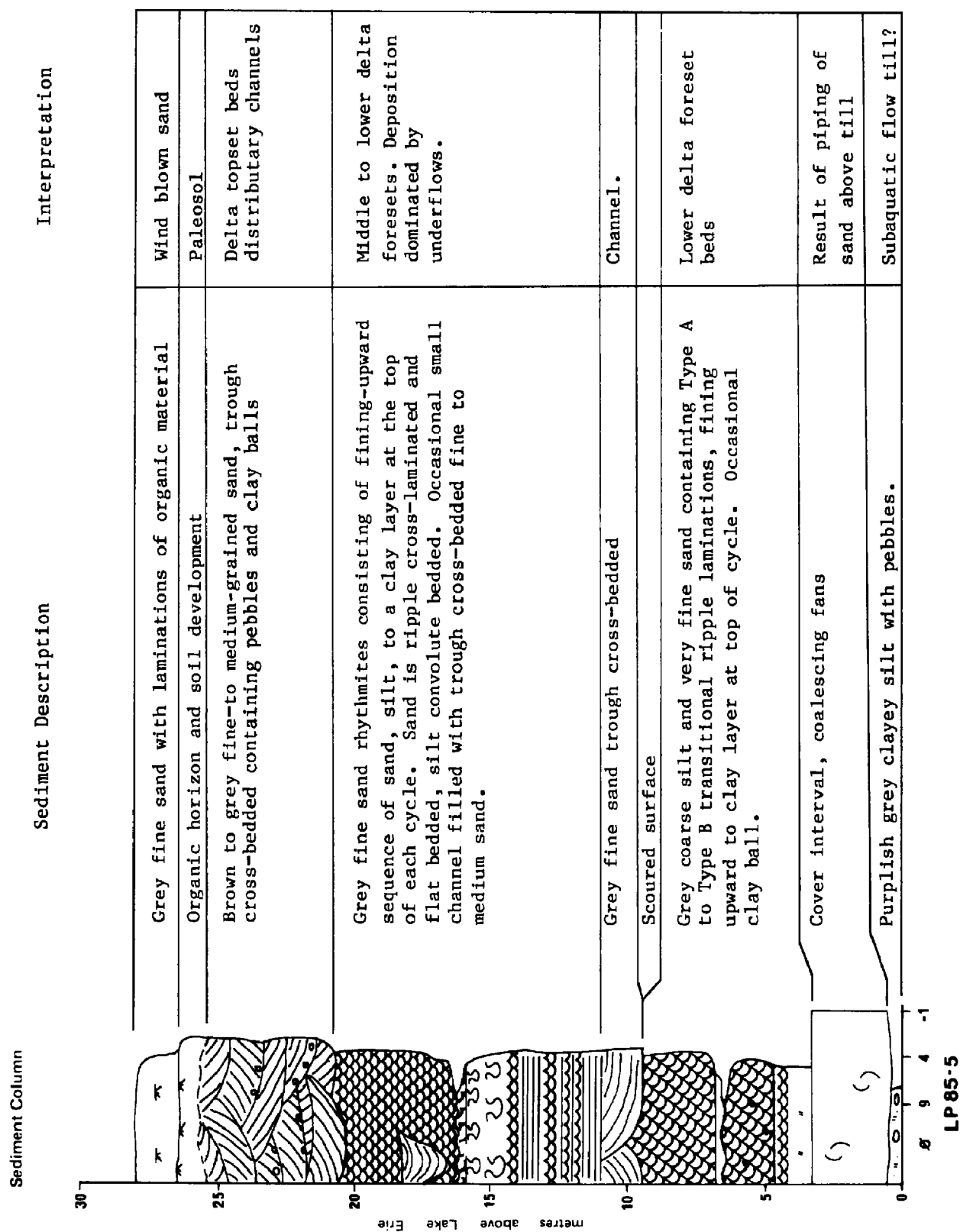


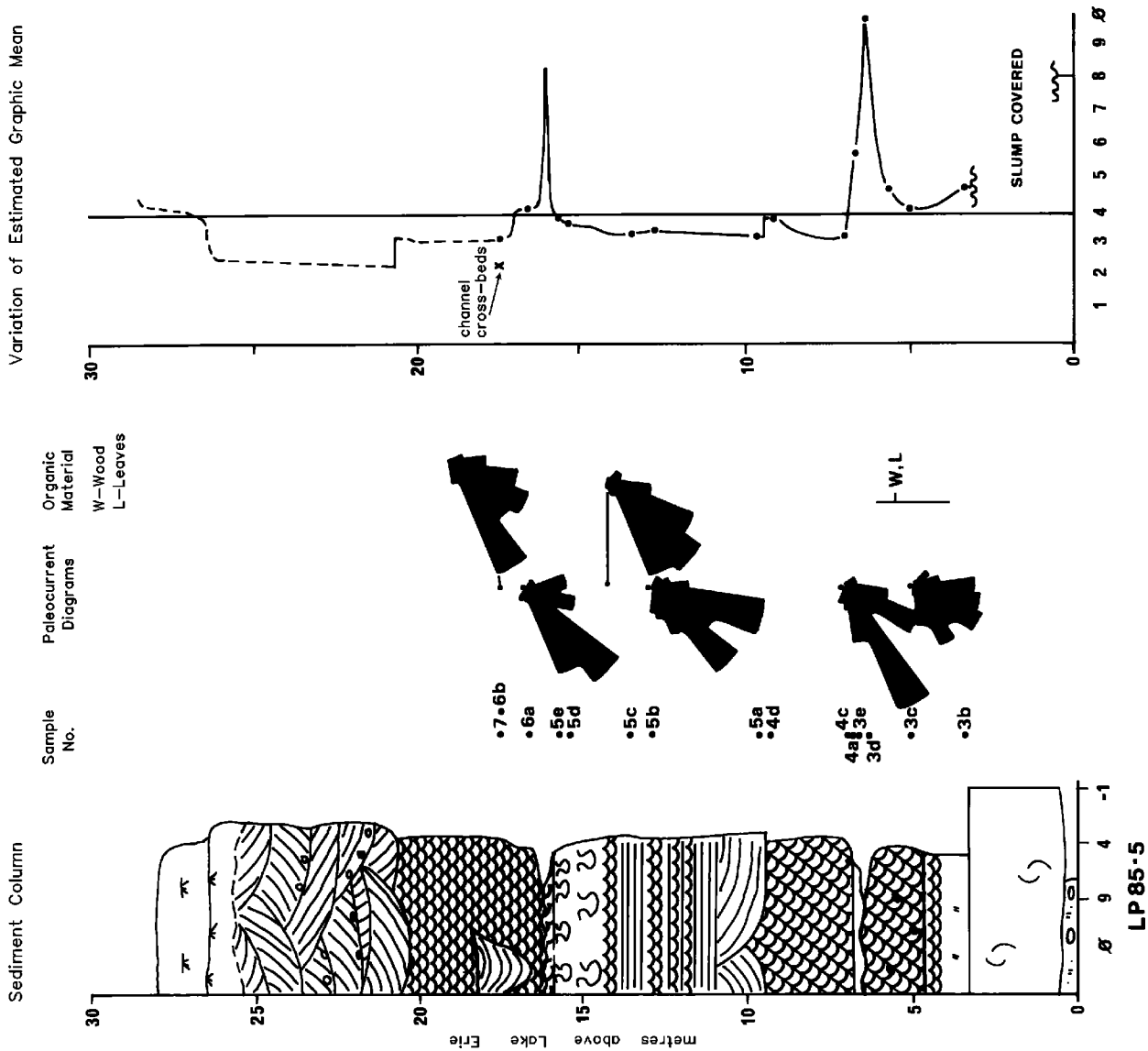




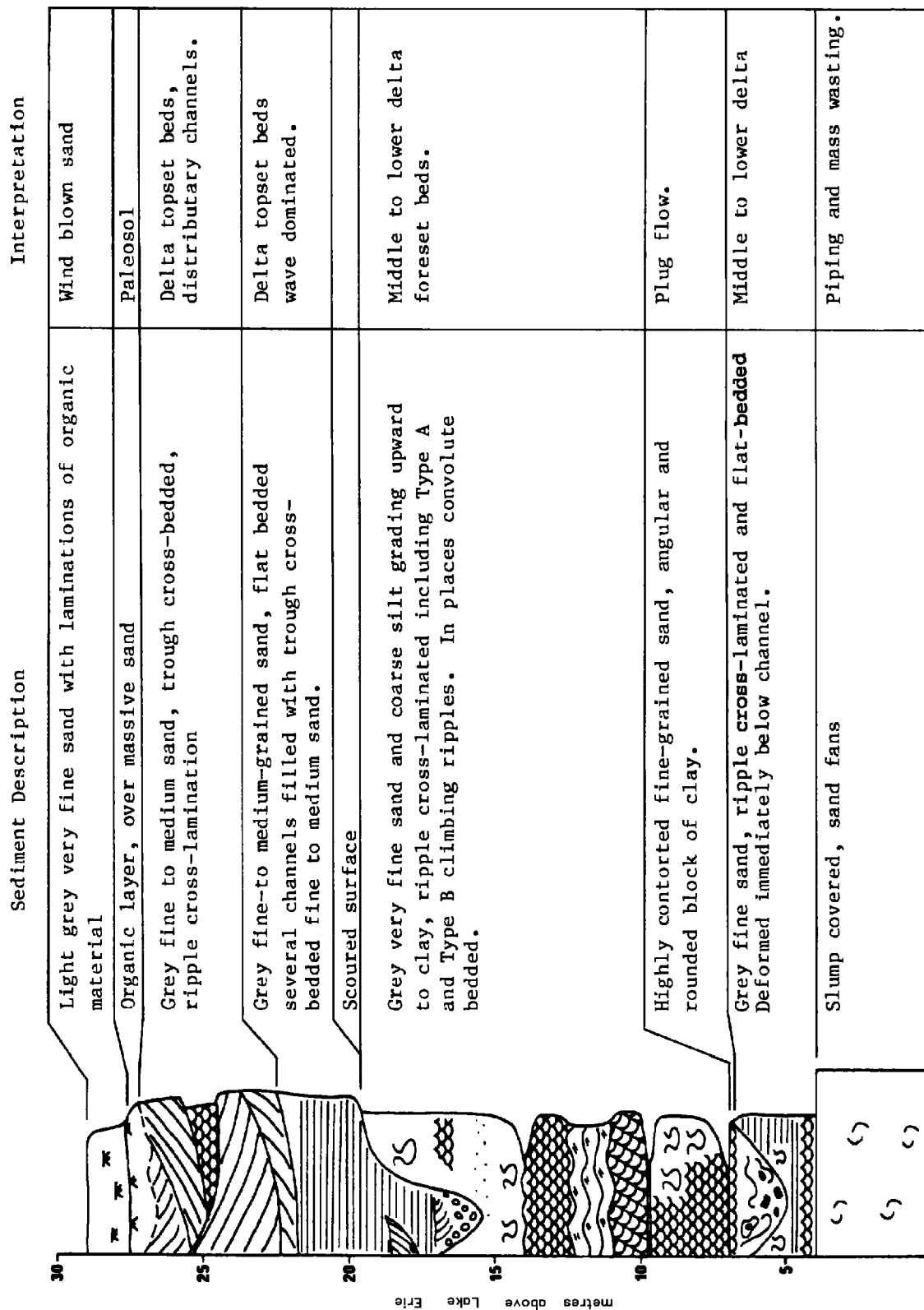


LP 85-4





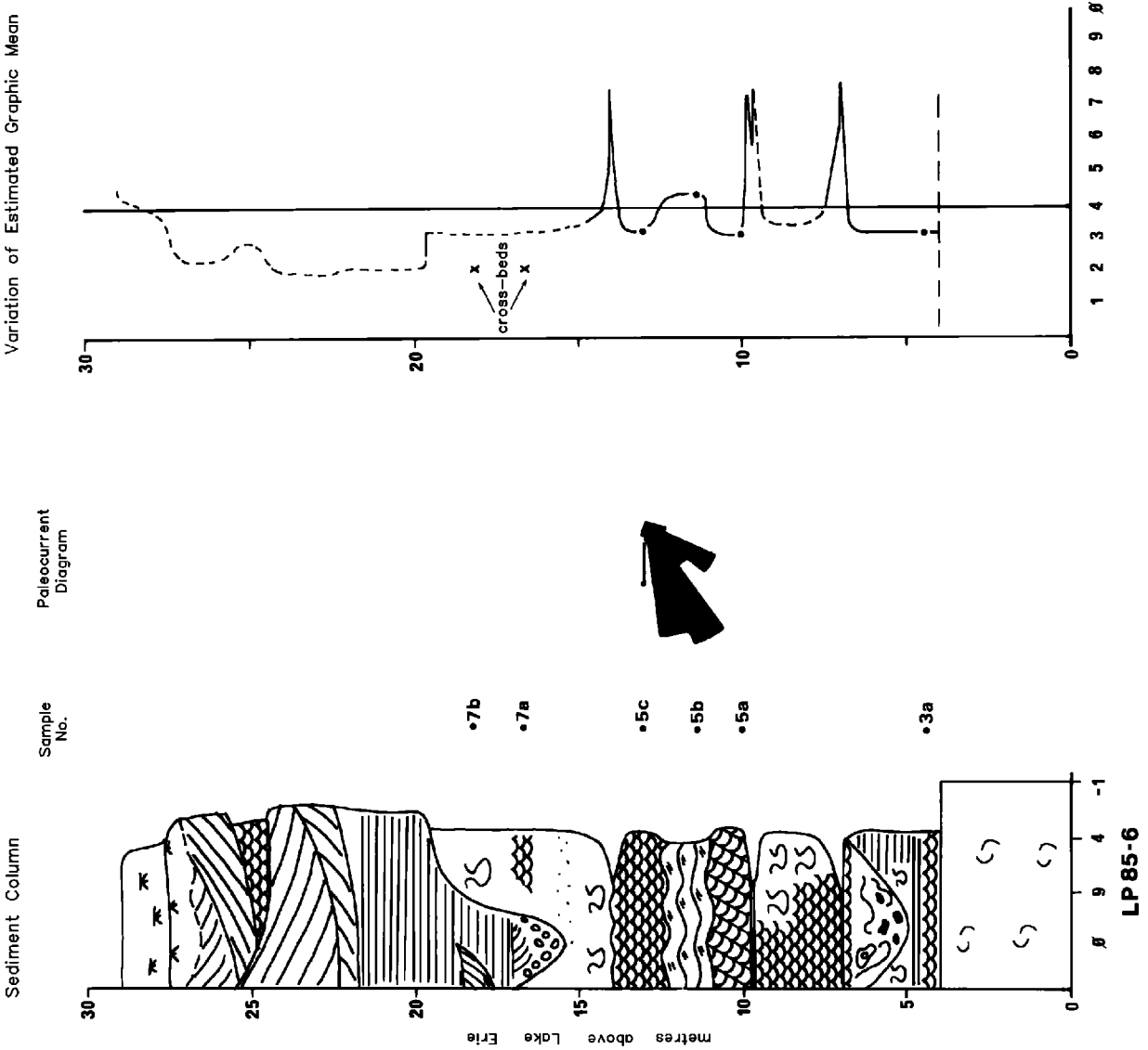
Sediment Column

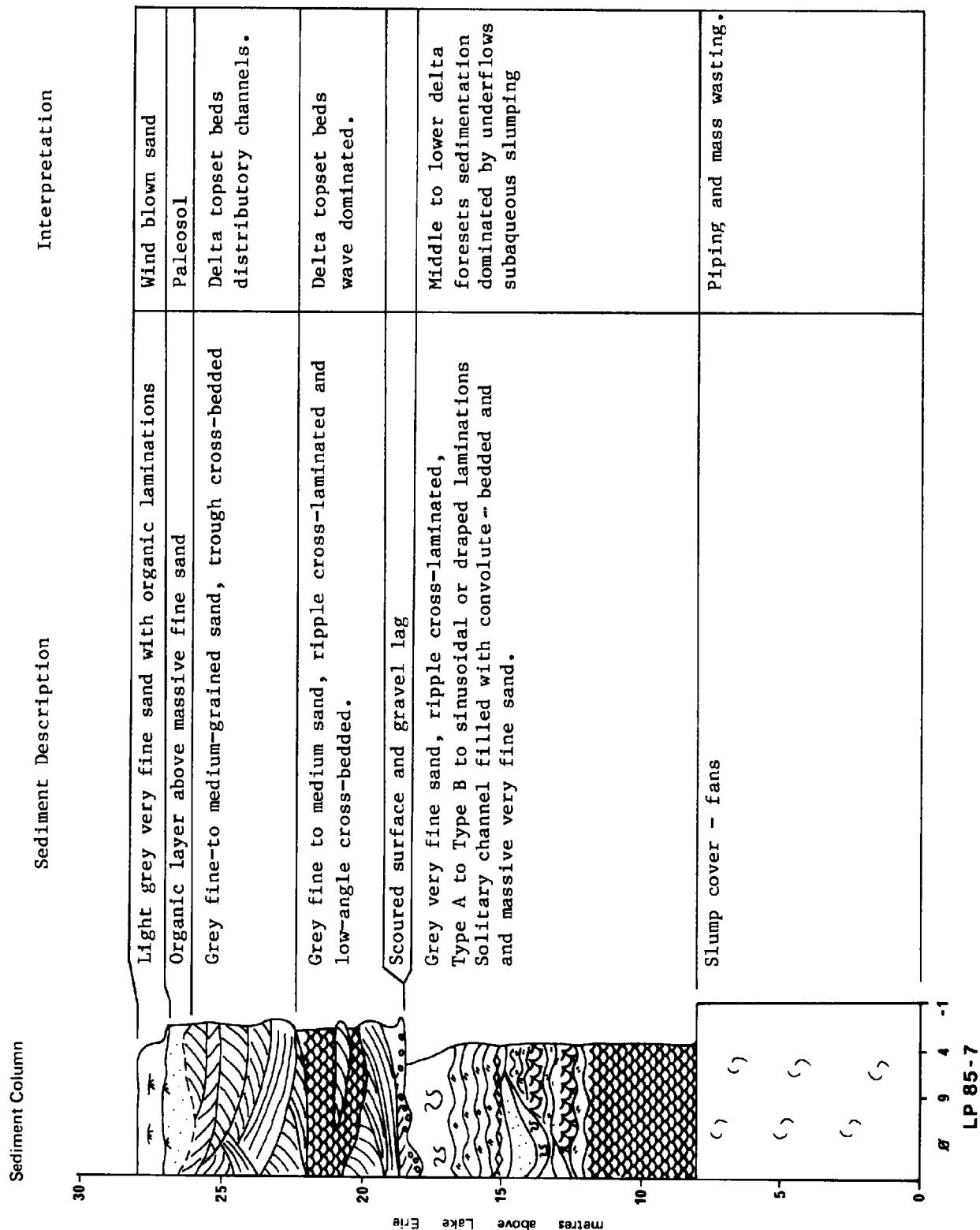


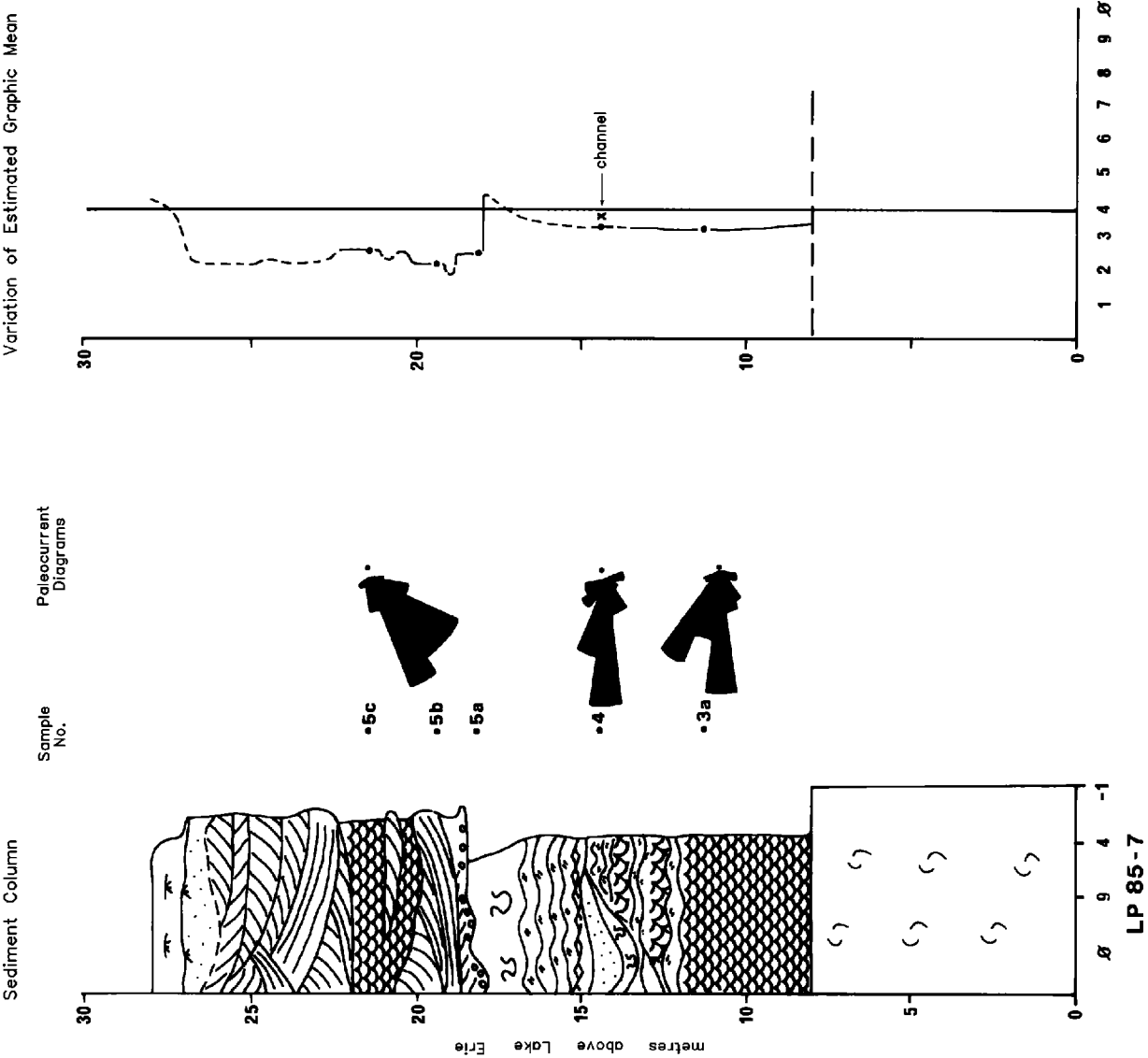
Interpretation

Sediment Description

Wind blown sand	Light grey very fine sand with laminations of organic material
Paleosol	Organic layer, over massive sand
Delta topset beds, distributary channels.	Grey fine to medium sand, trough cross-bedded, ripple cross-lamination
Delta topset beds wave dominated.	Grey fine-to medium-grained sand, flat bedded several channels filled with trough cross-bedded fine to medium sand.
	Scoured surface
Middle to lower delta foreset beds.	Grey very fine sand and coarse silt grading upward to clay, ripple cross-laminated including Type A and Type B climbing ripples. In places convolute bedded.
Plug flow.	Highly contorted fine-grained sand, angular and rounded block of clay.
Middle to lower delta	Grey fine sand, ripple cross-laminated and flat-bedded Deformed immediately below channel.
Piping and mass wasting.	Slump covered, sand fans



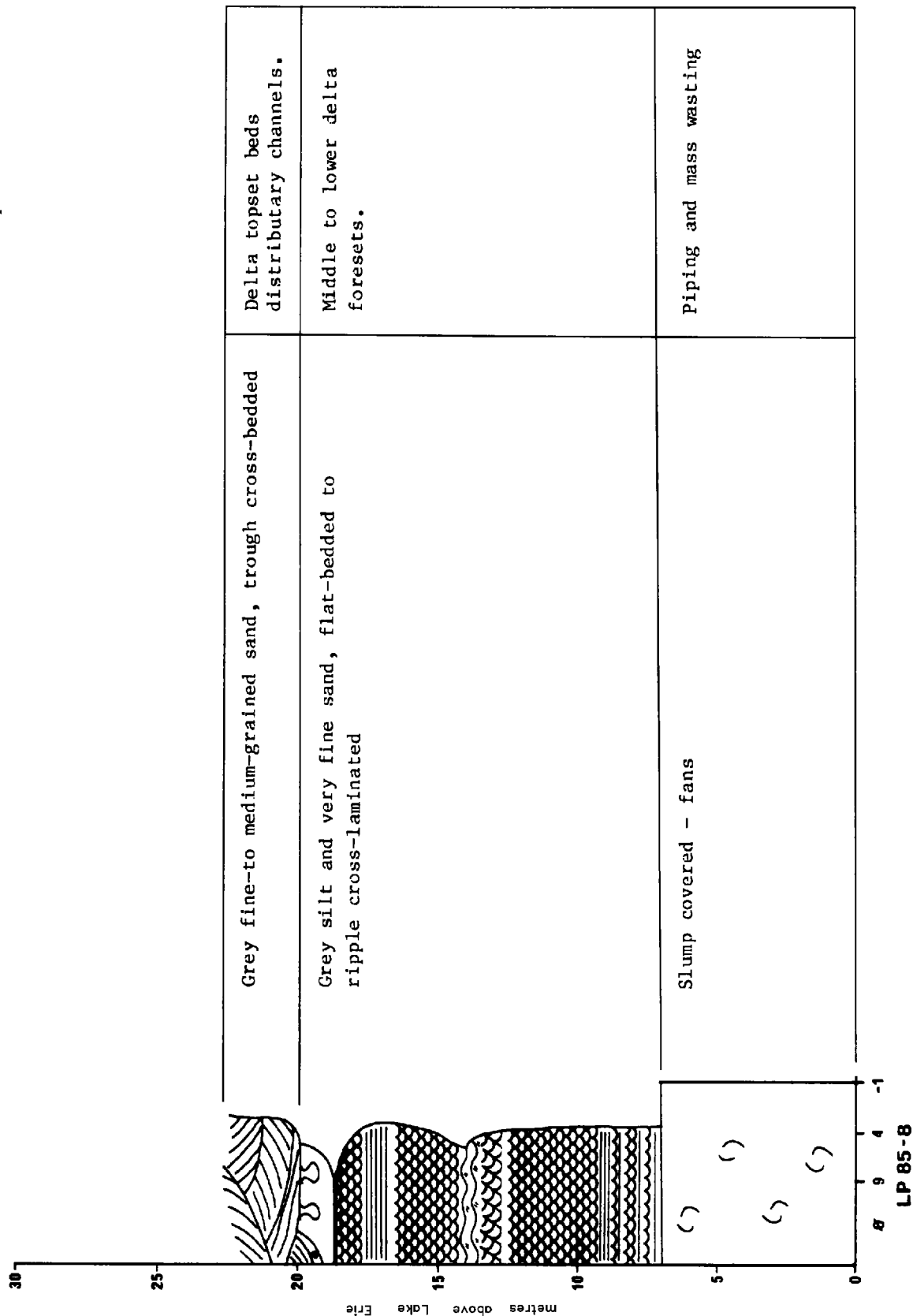


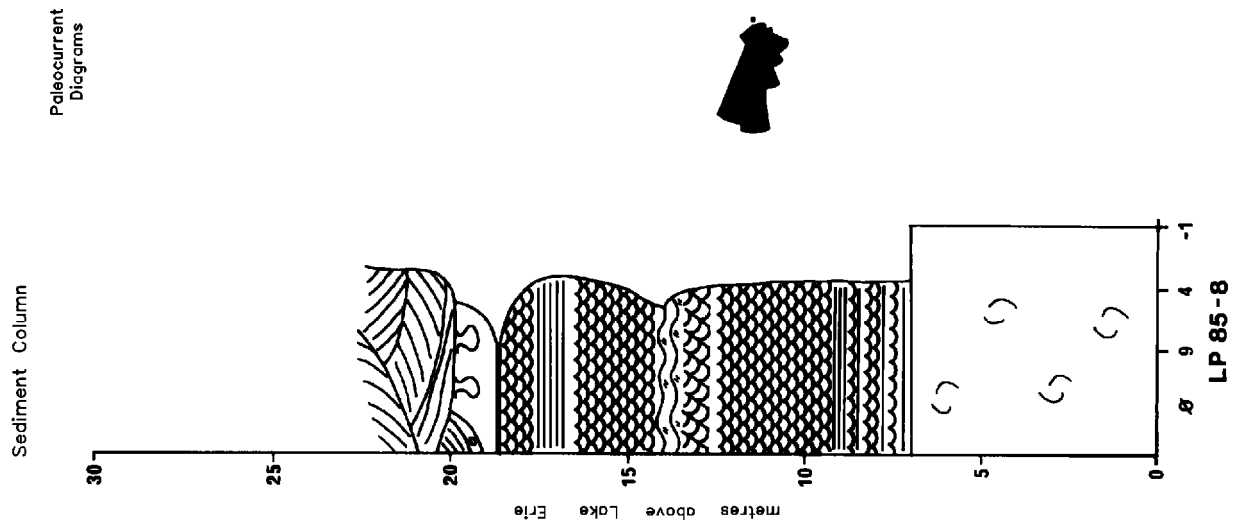


Sediment Column

Sediment Description

Interpretation

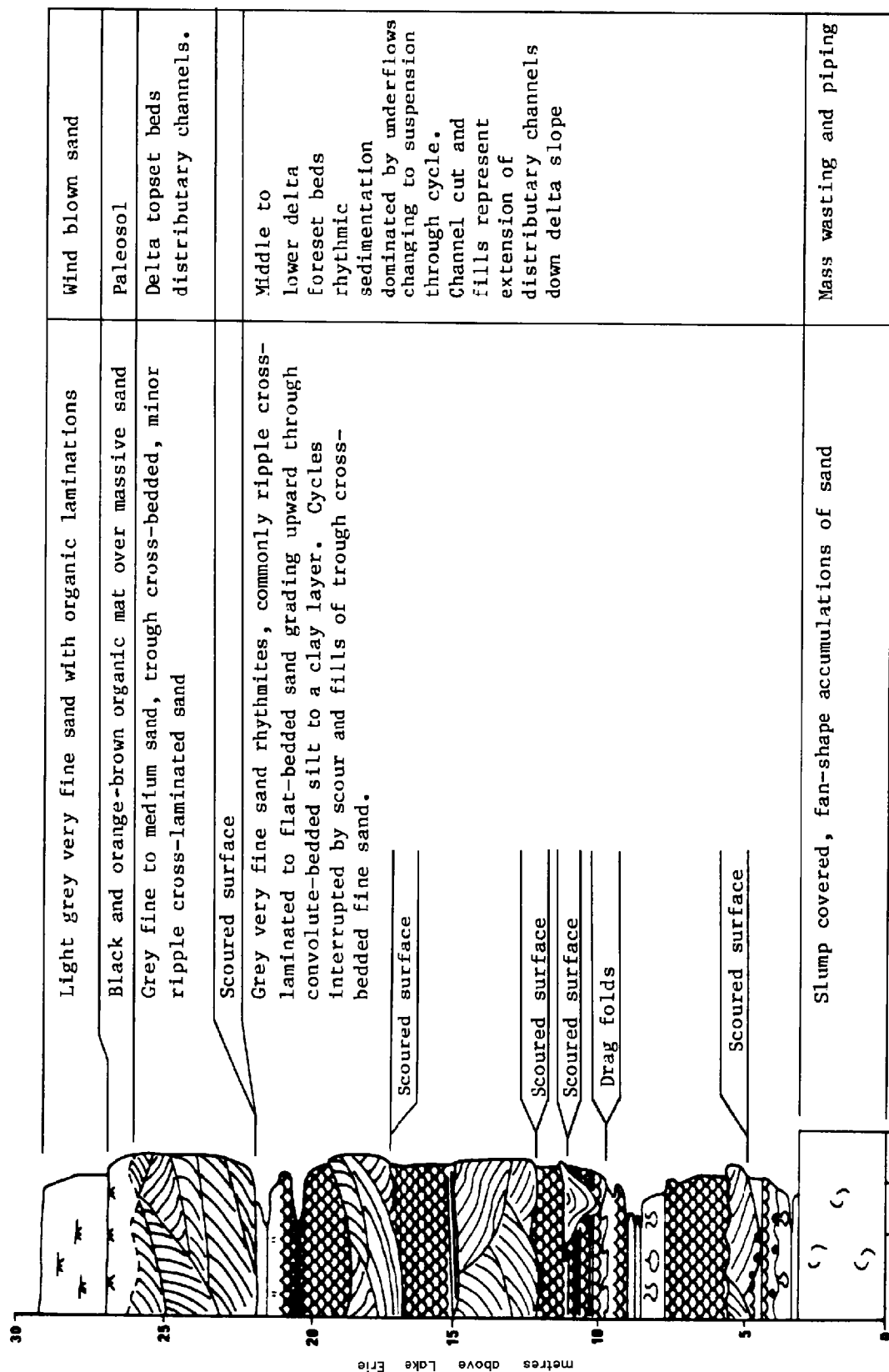




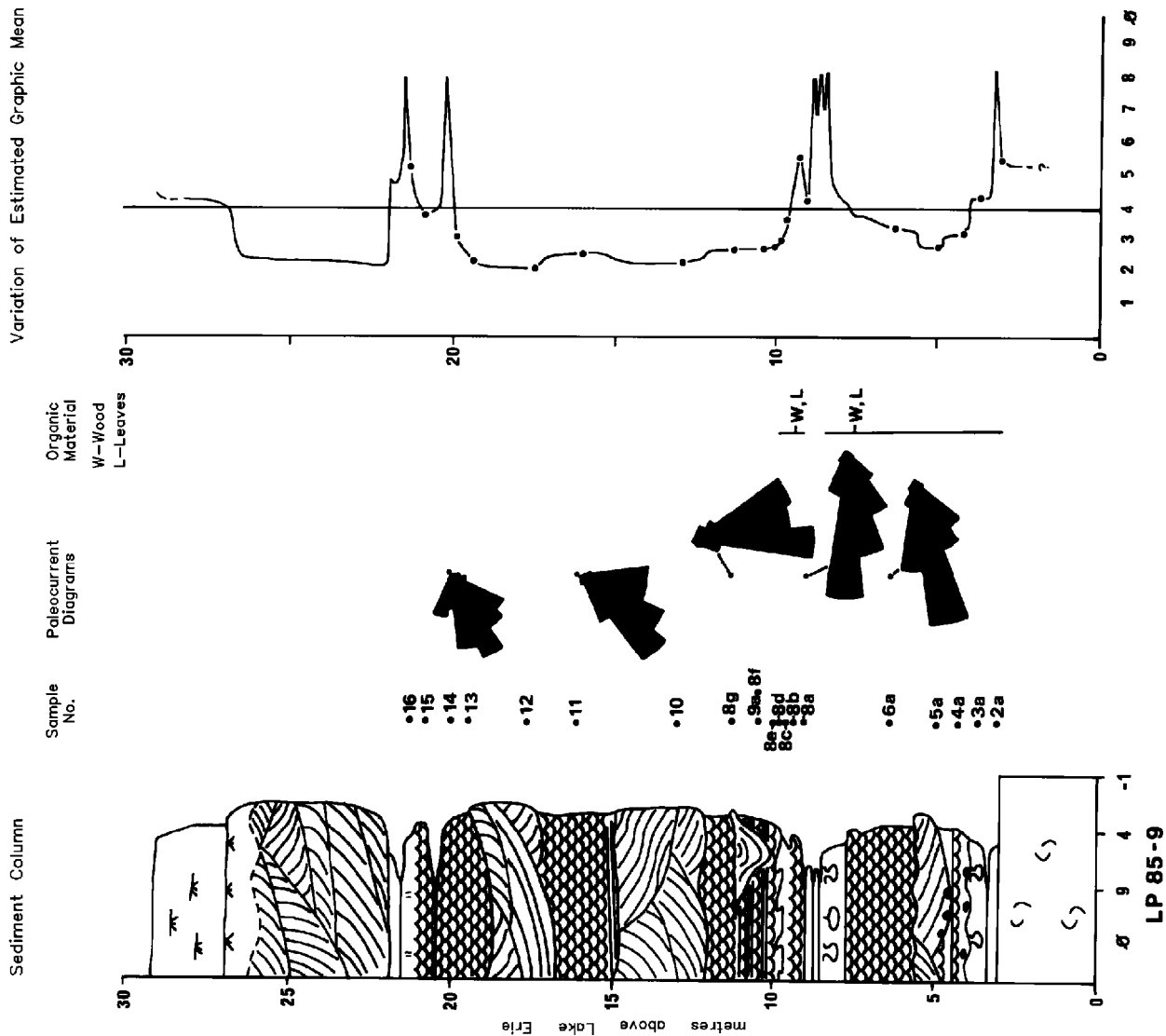
Sediment Column

Sediment Description

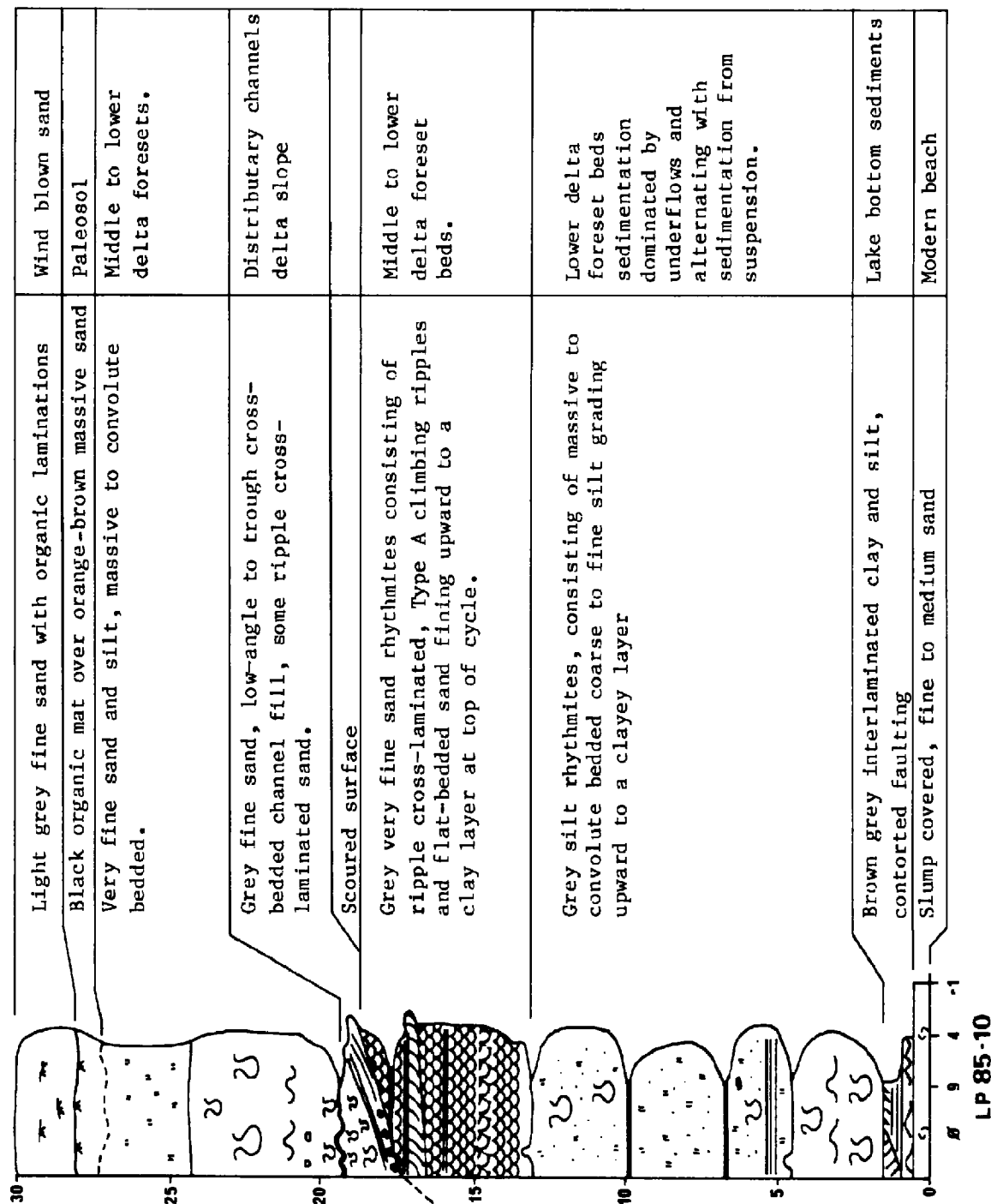
Interpretation



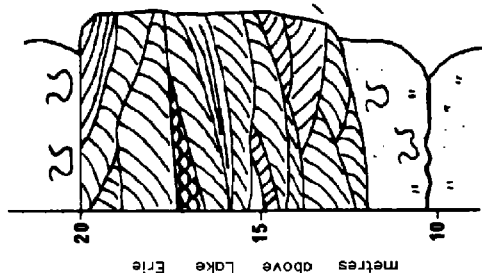
0 9 4 -1
LP 85-9

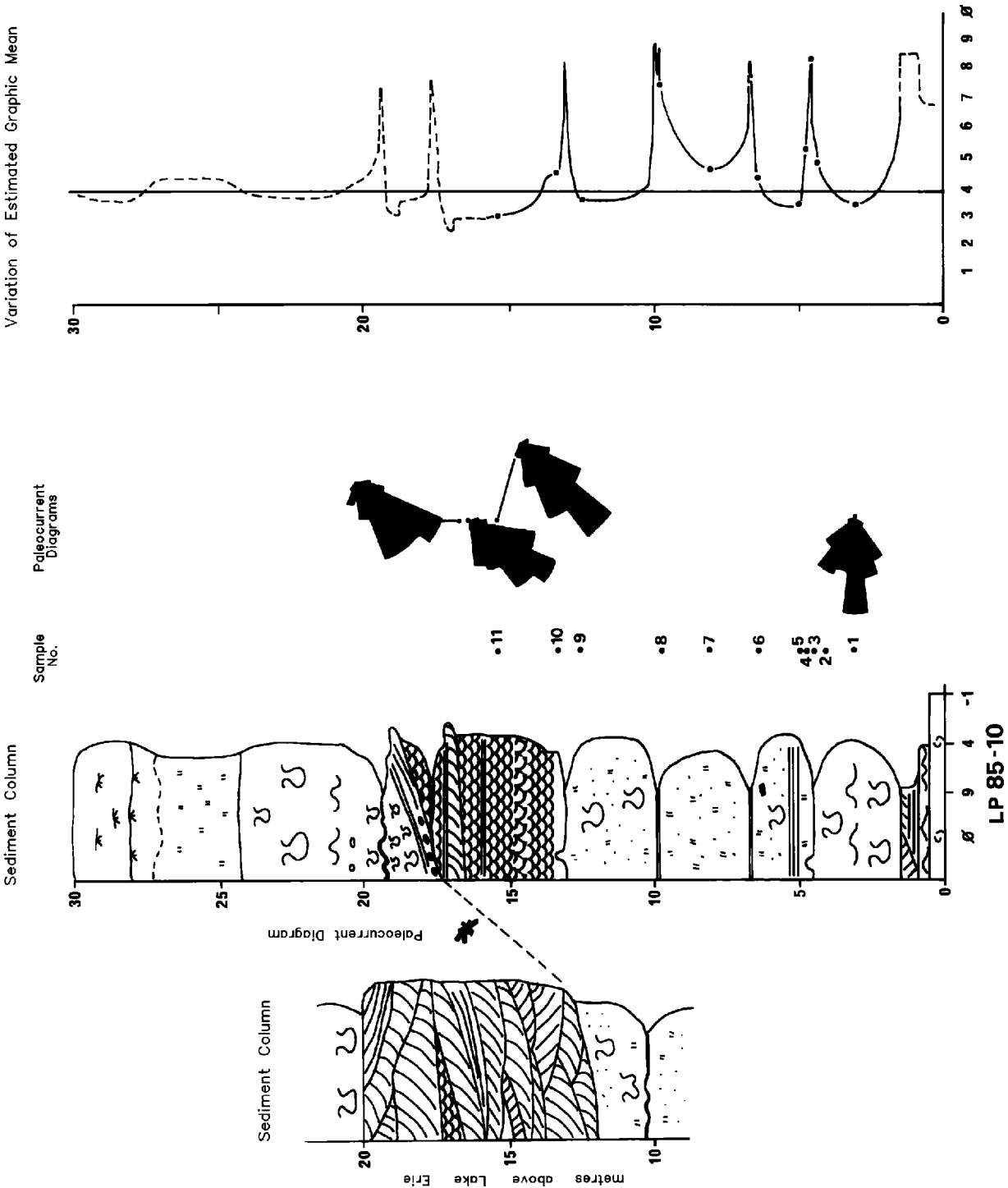


Sediment Column



Sediment Column

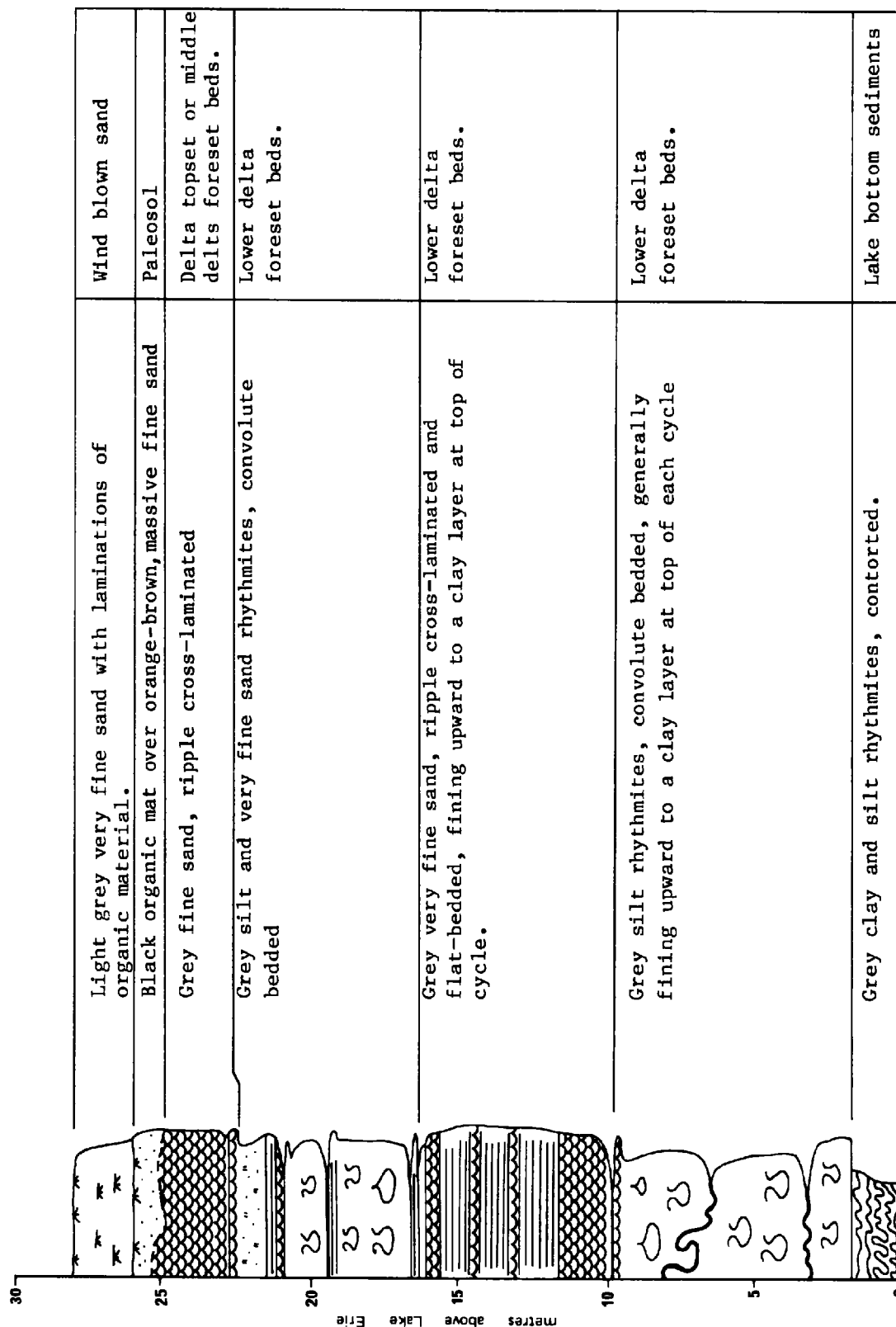




Sediment Column

Sediment Description

Interpretation

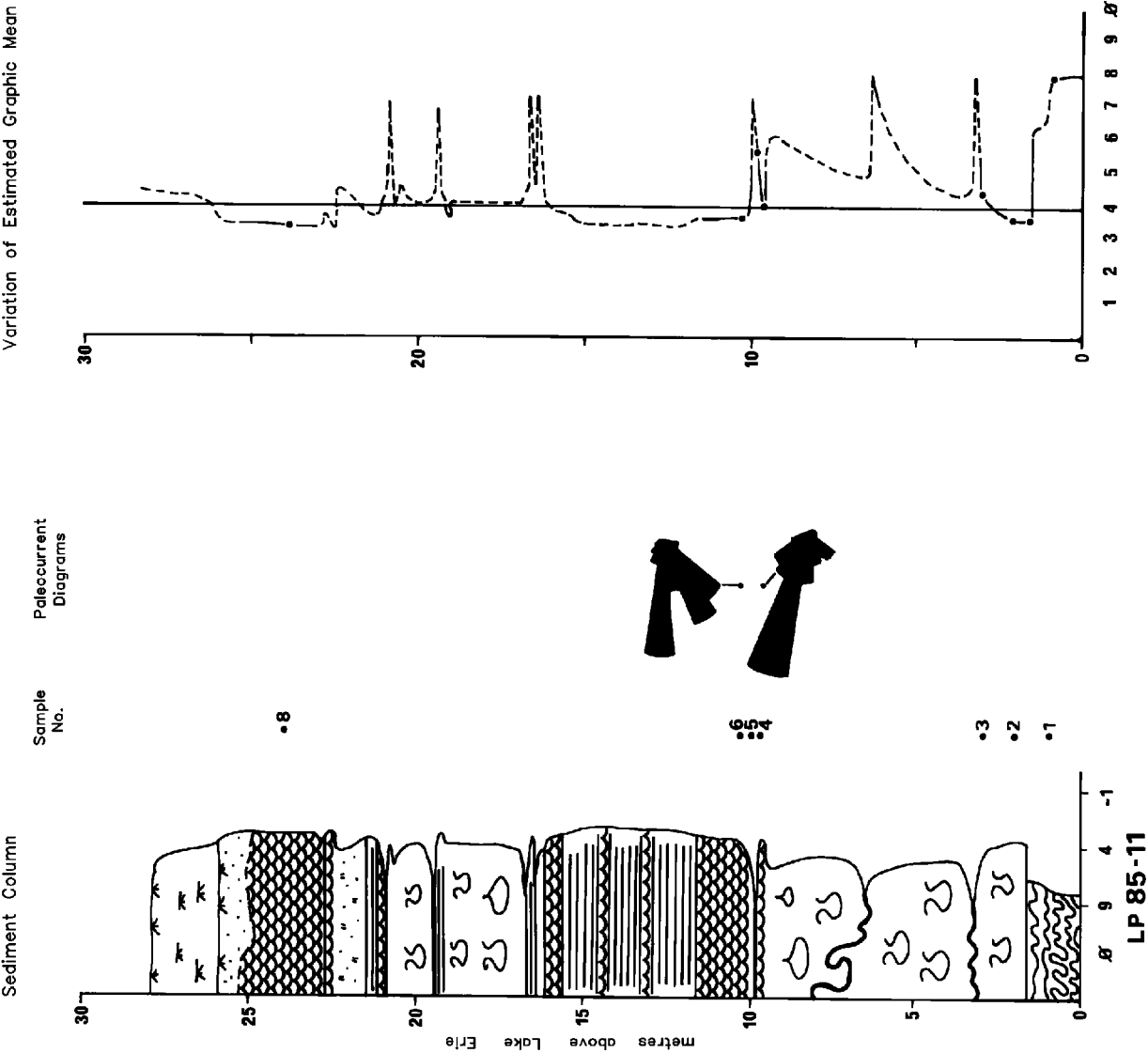


metres above Lake Erie

30 25 20 15 10 5 0

8 9 4 -1

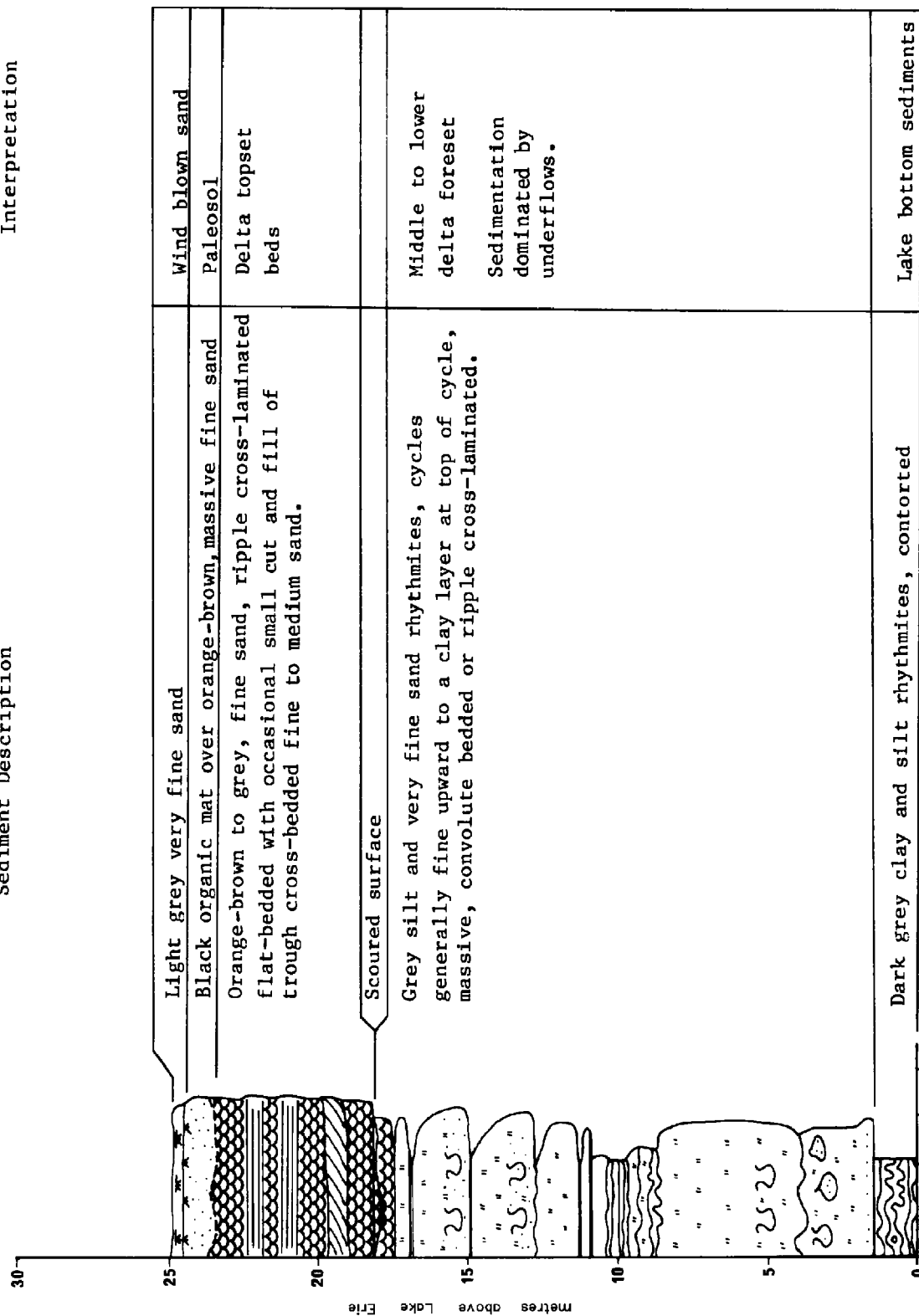
LP 85-11



Sediment Column

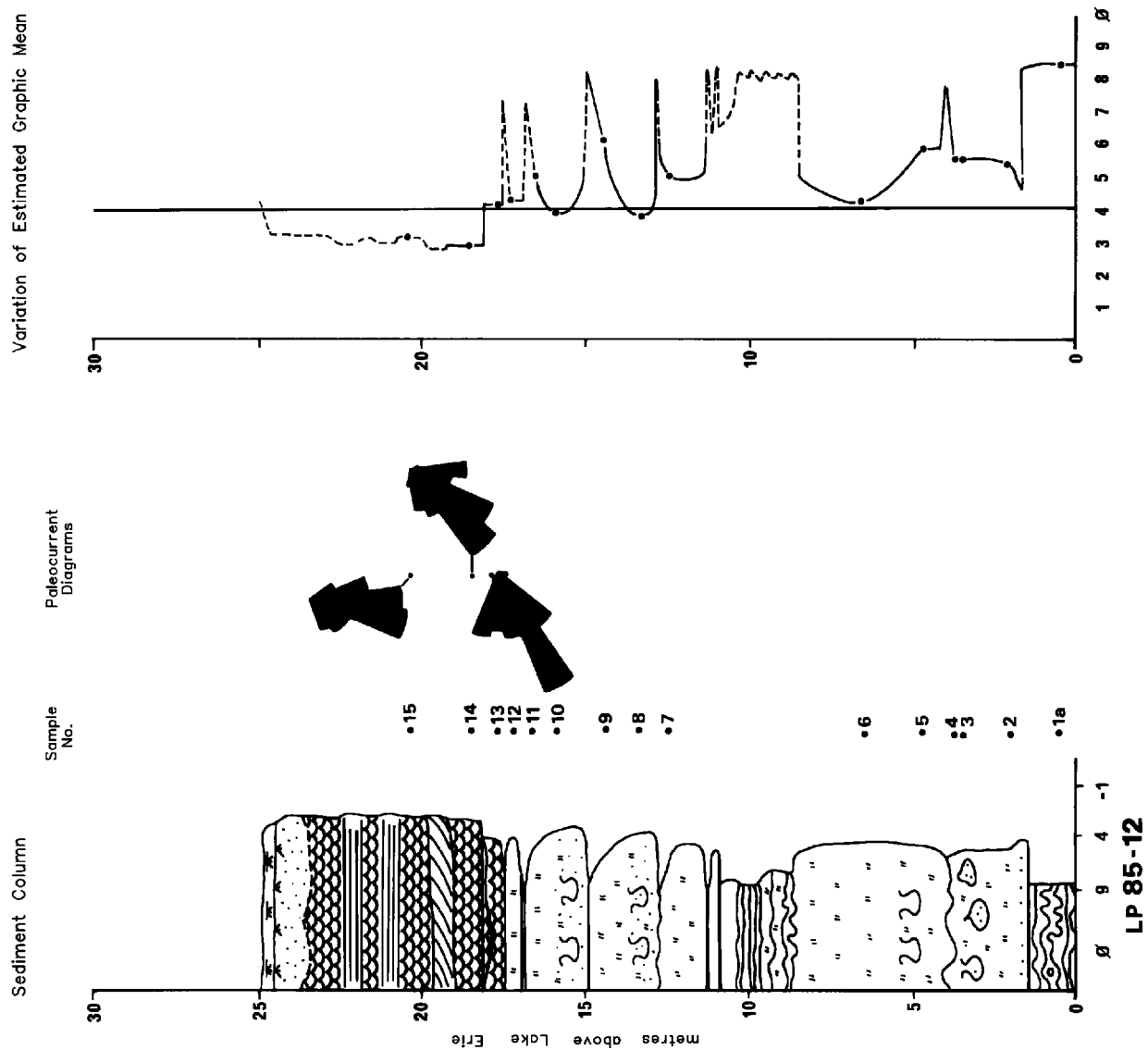
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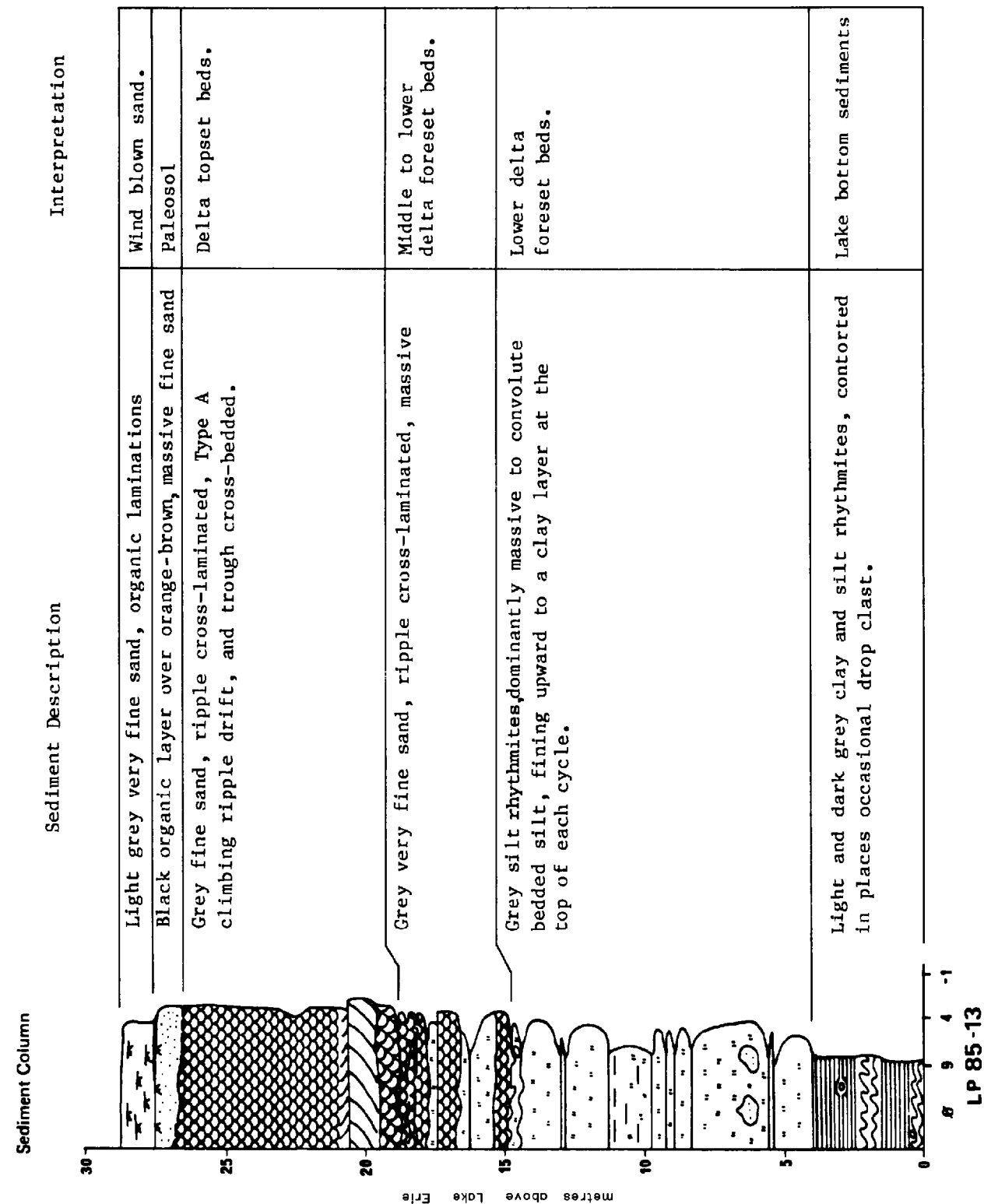
Interpretation

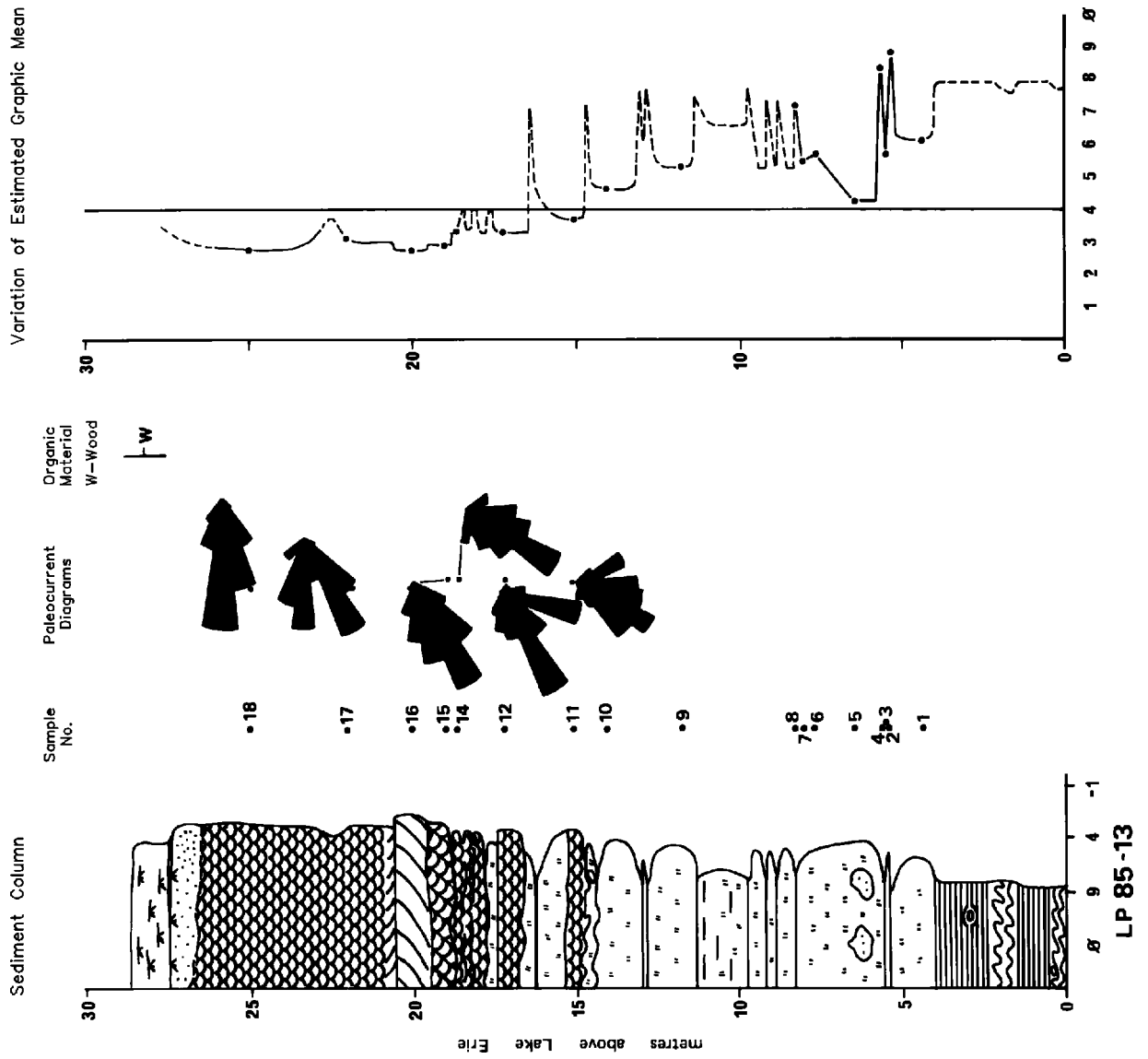


0 5 10 15 20 25 30
metres above Lake Erie

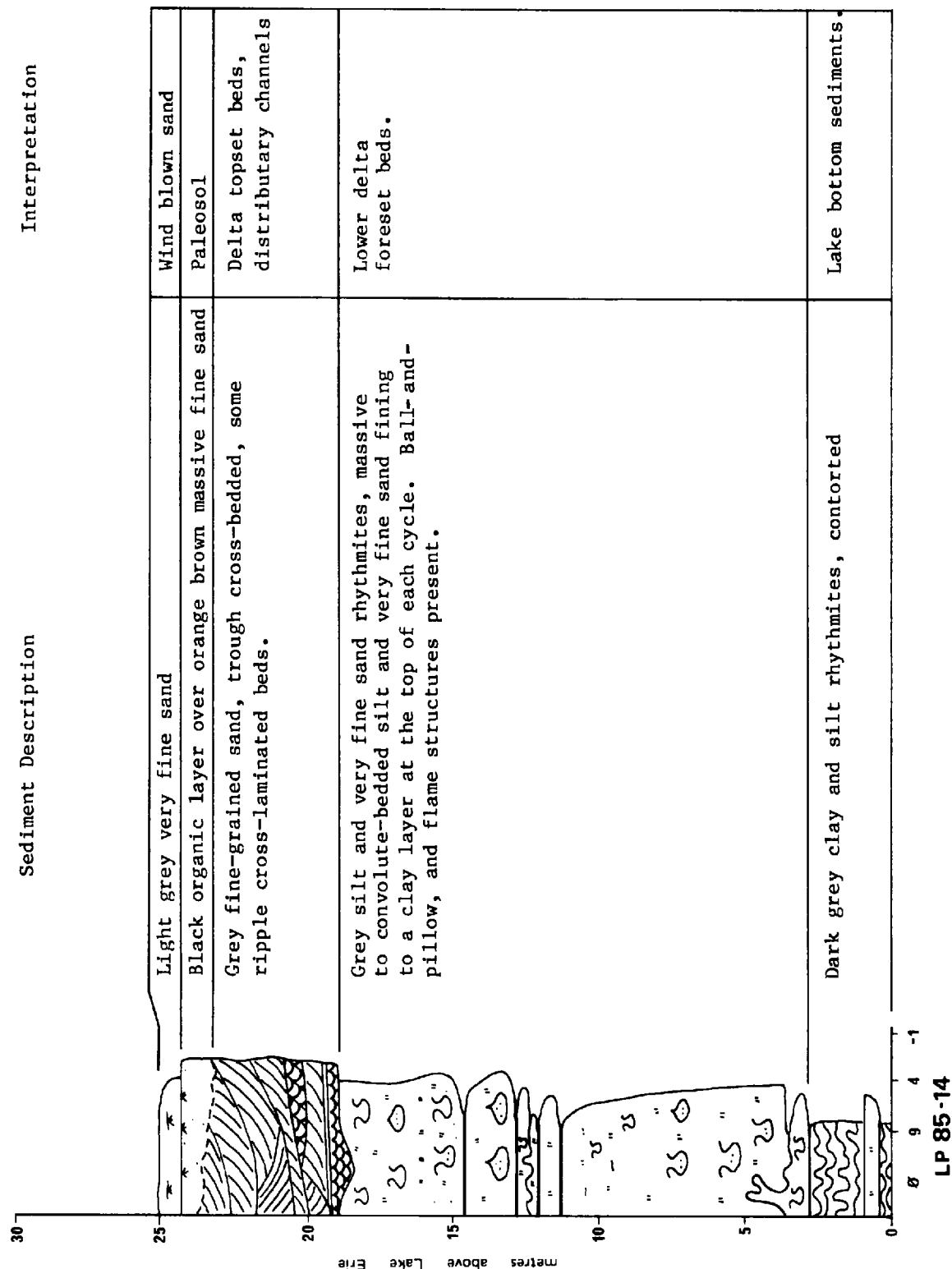
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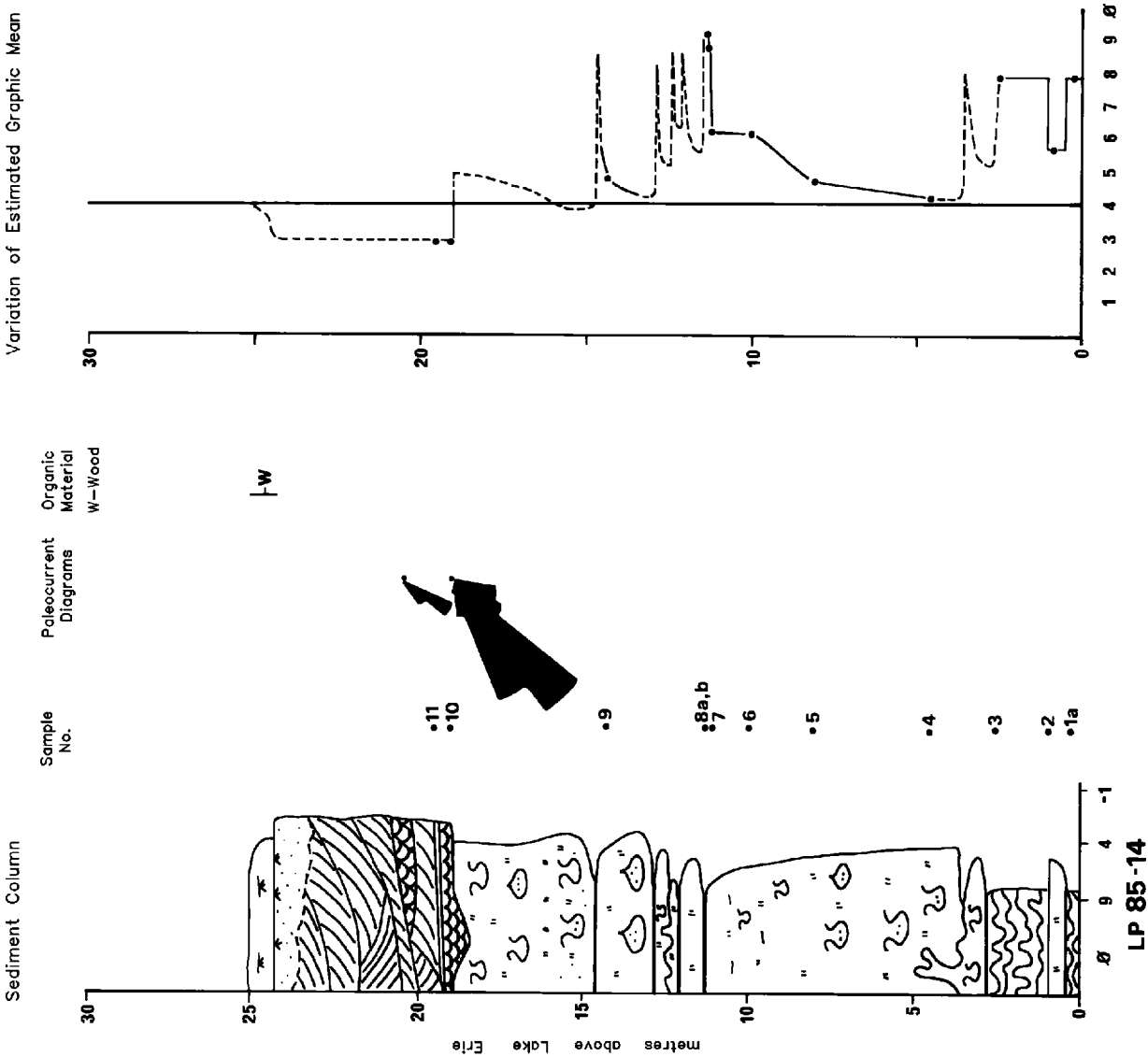






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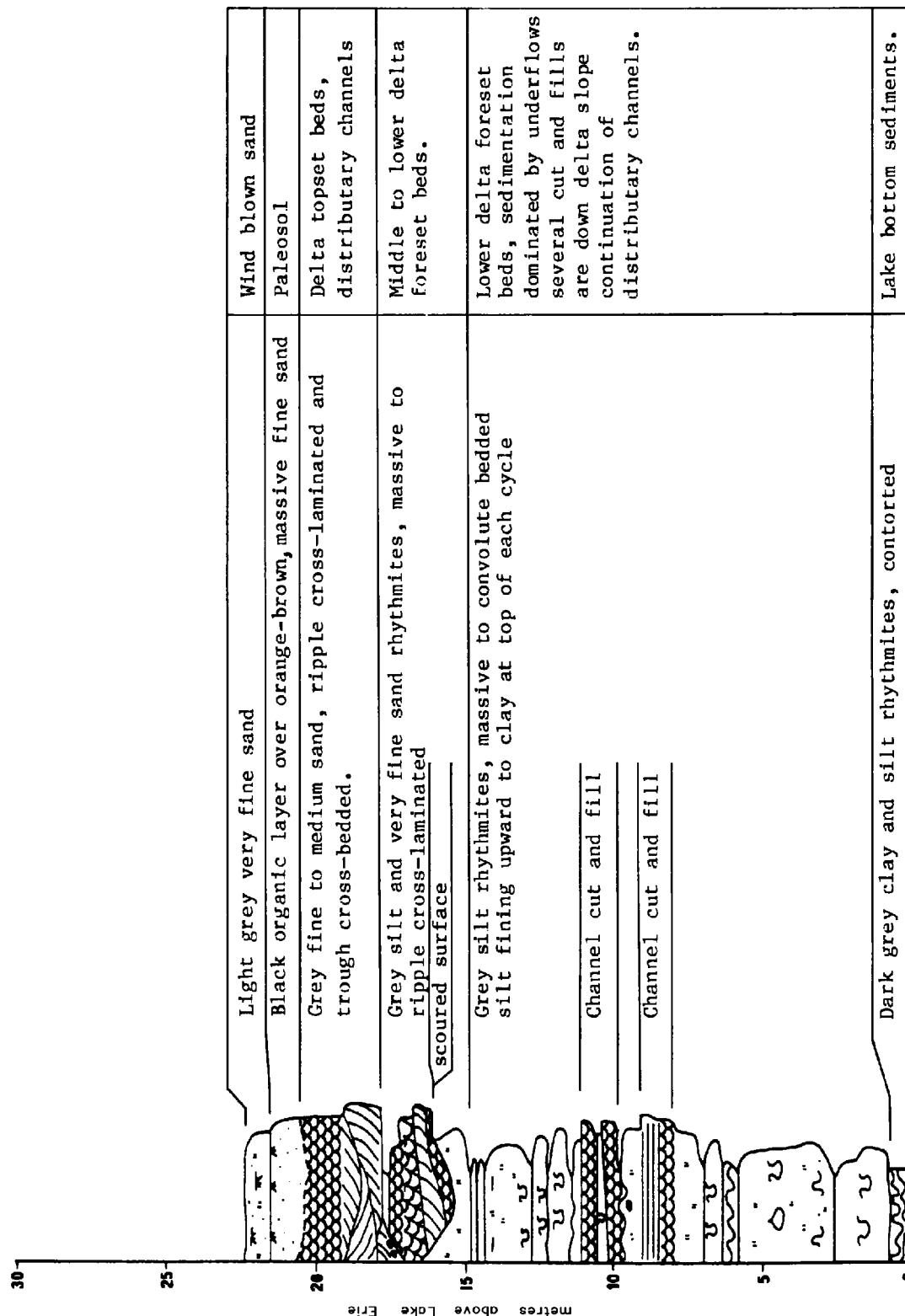




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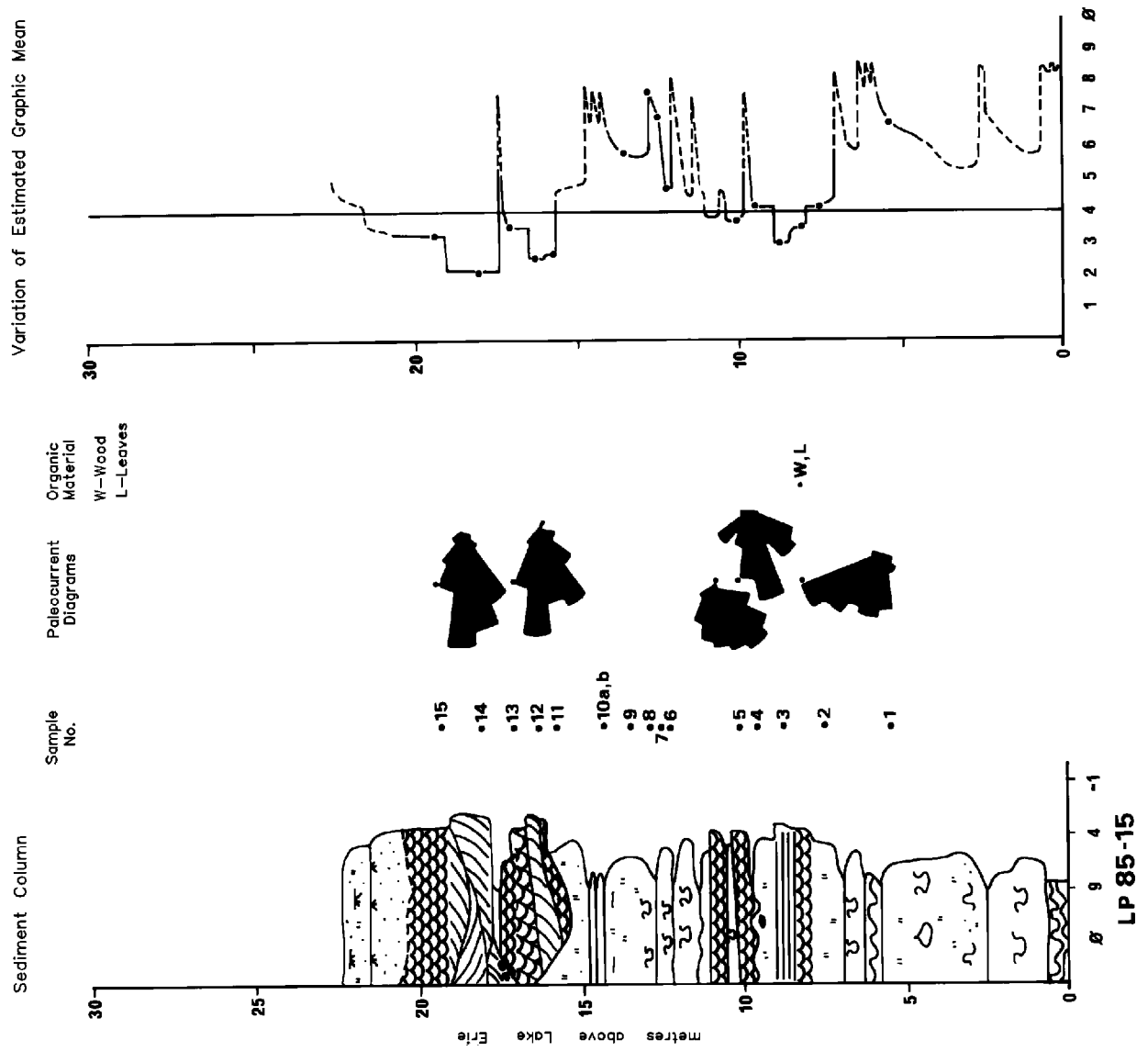
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Interpretation

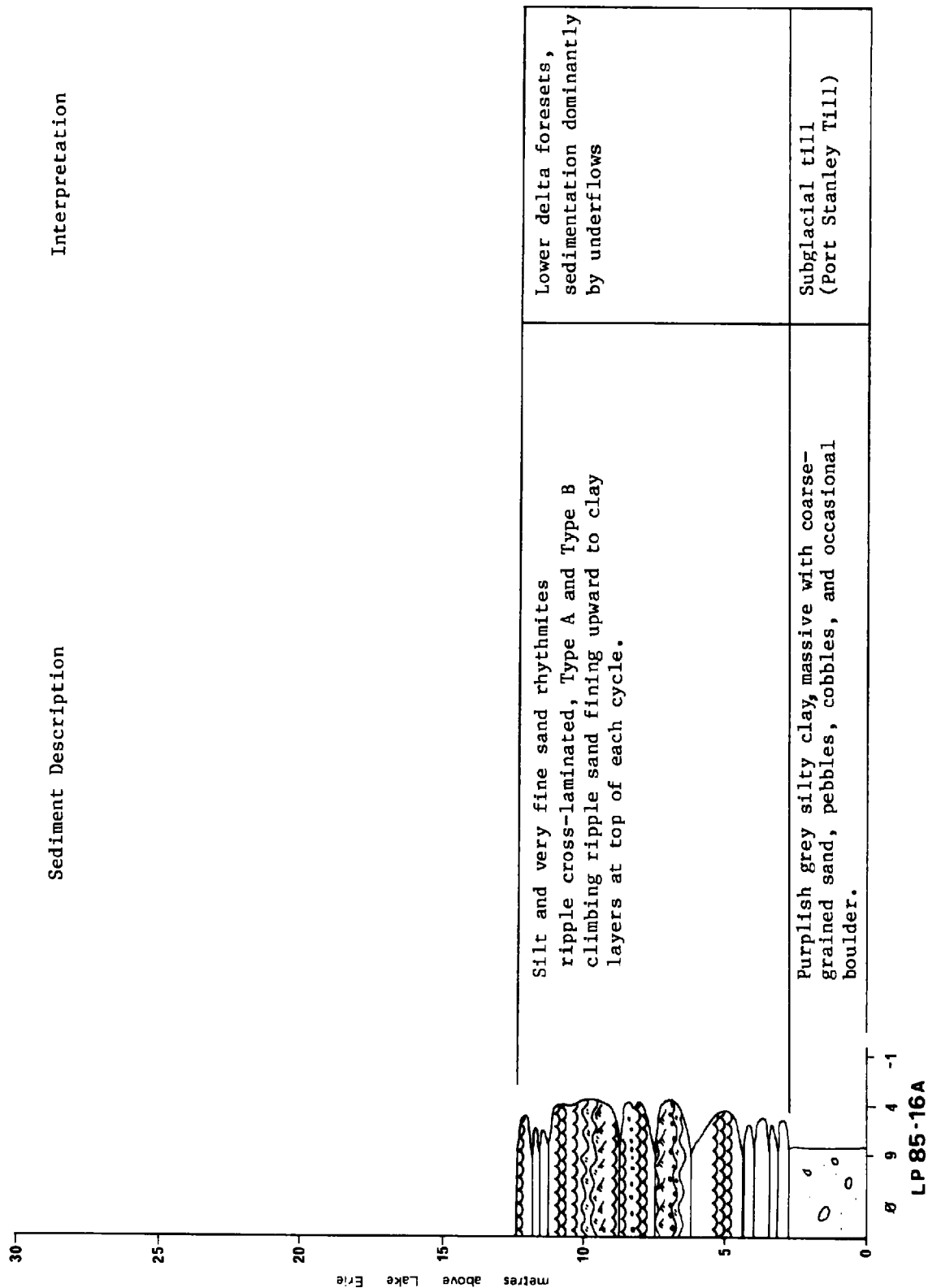


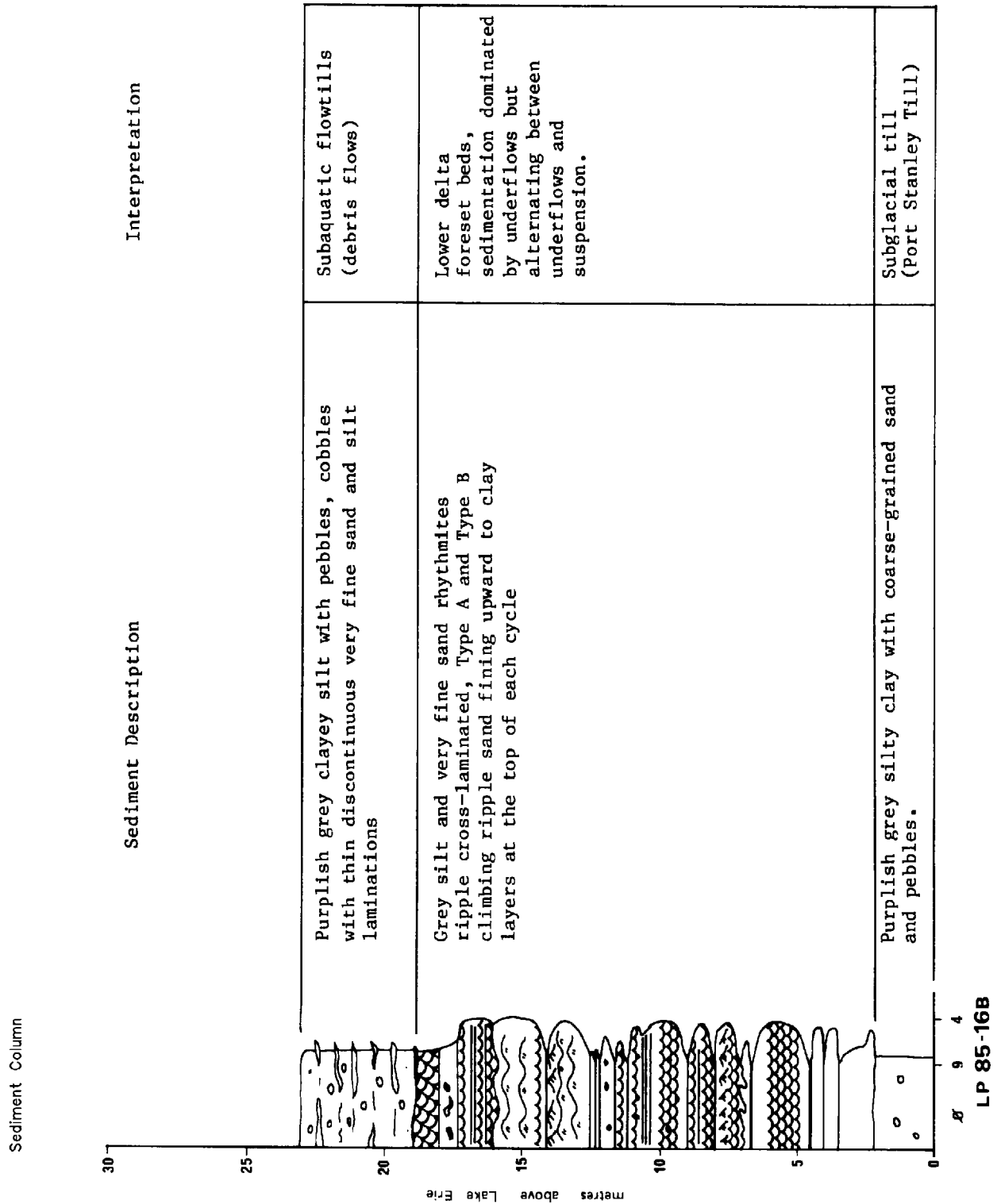
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metres above Lake Erie

LP 85-15

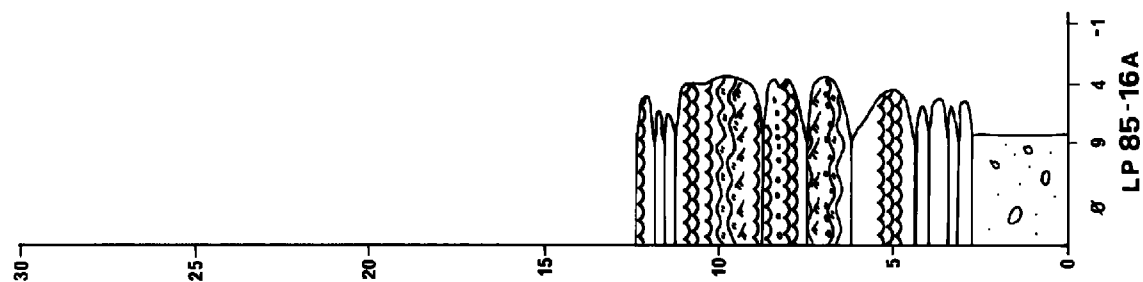


Sediment Column





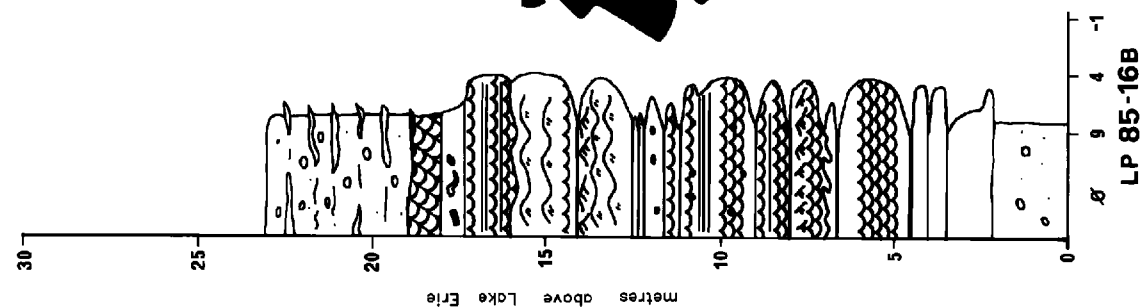
Sediment Column



Paleocurrent Diagrams

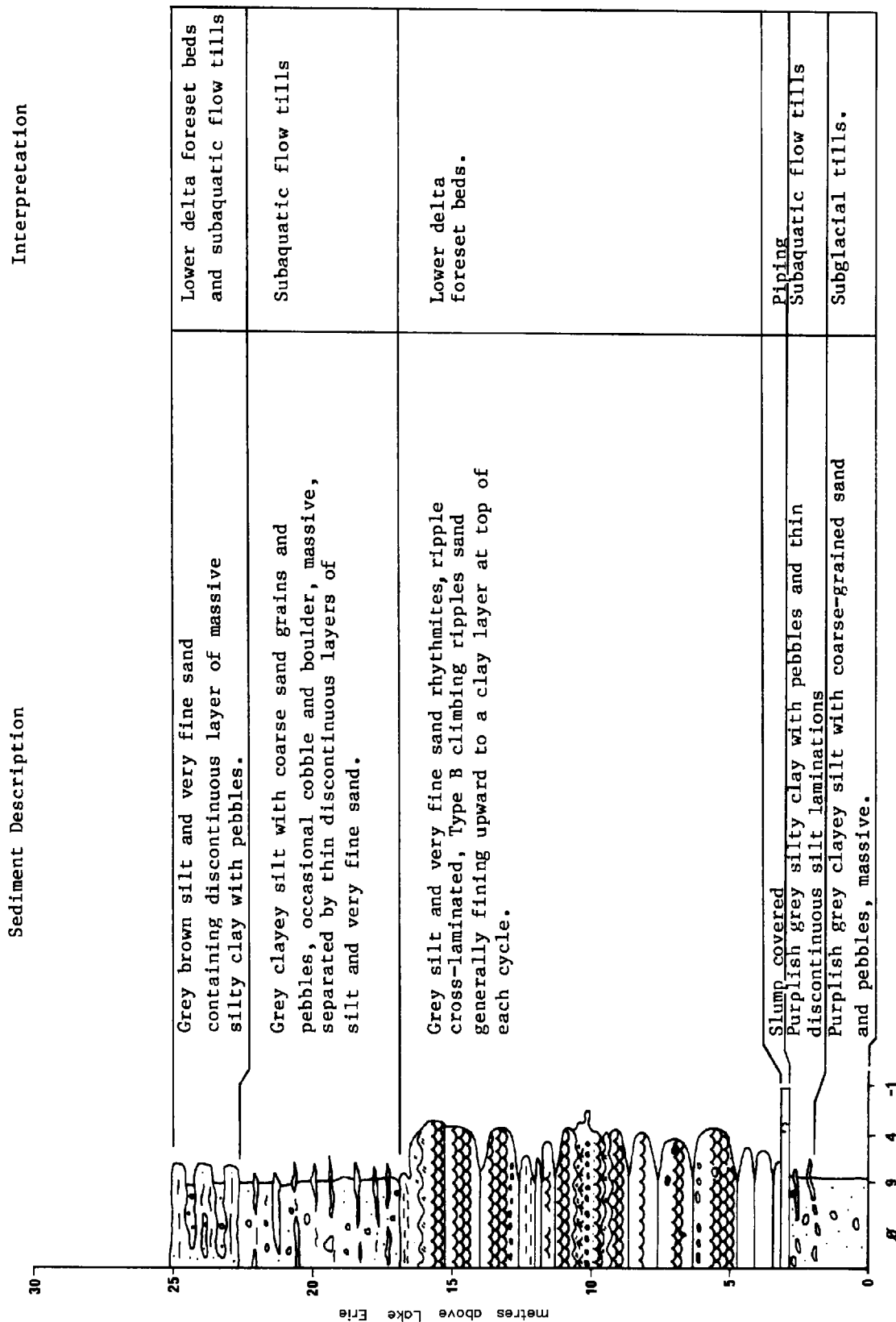


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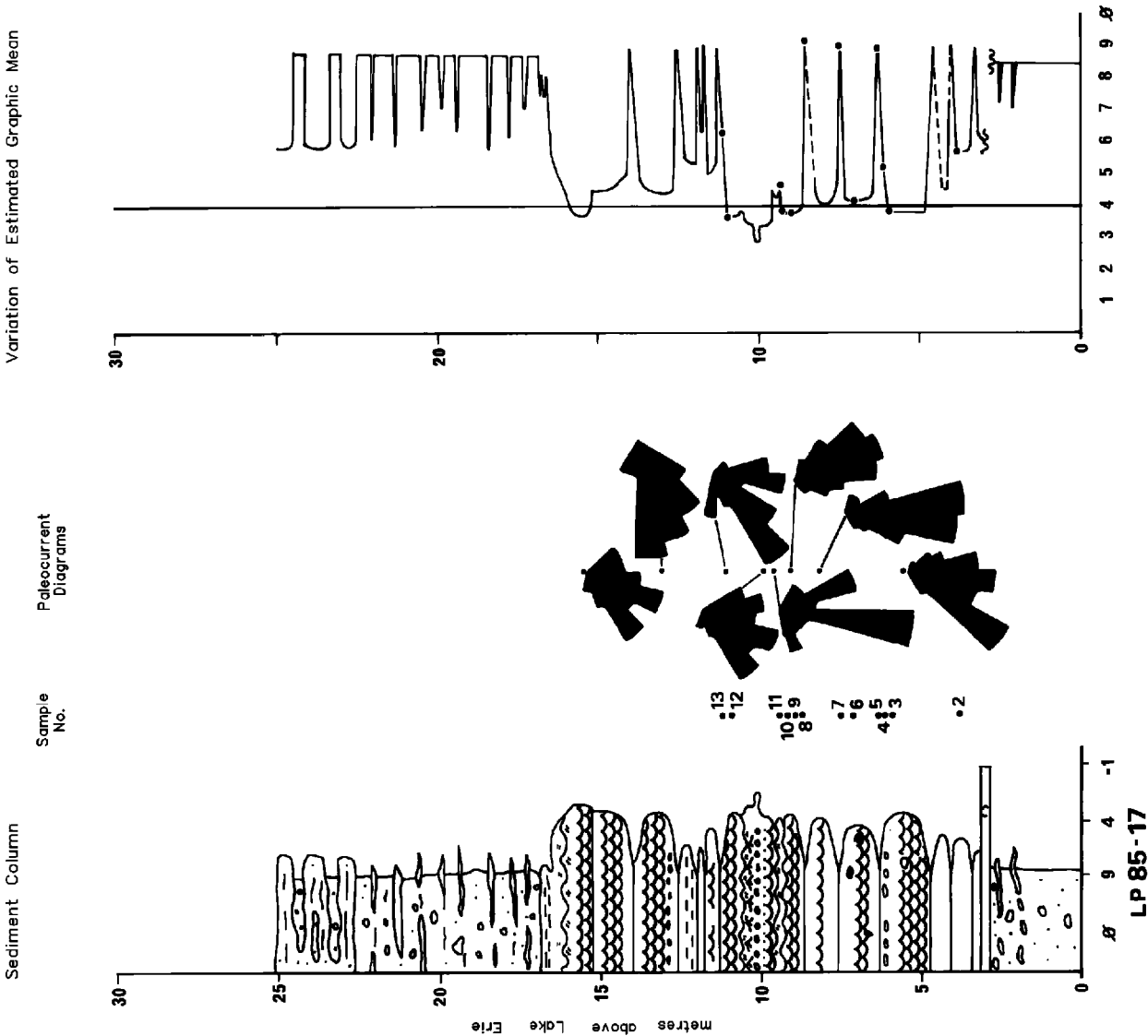


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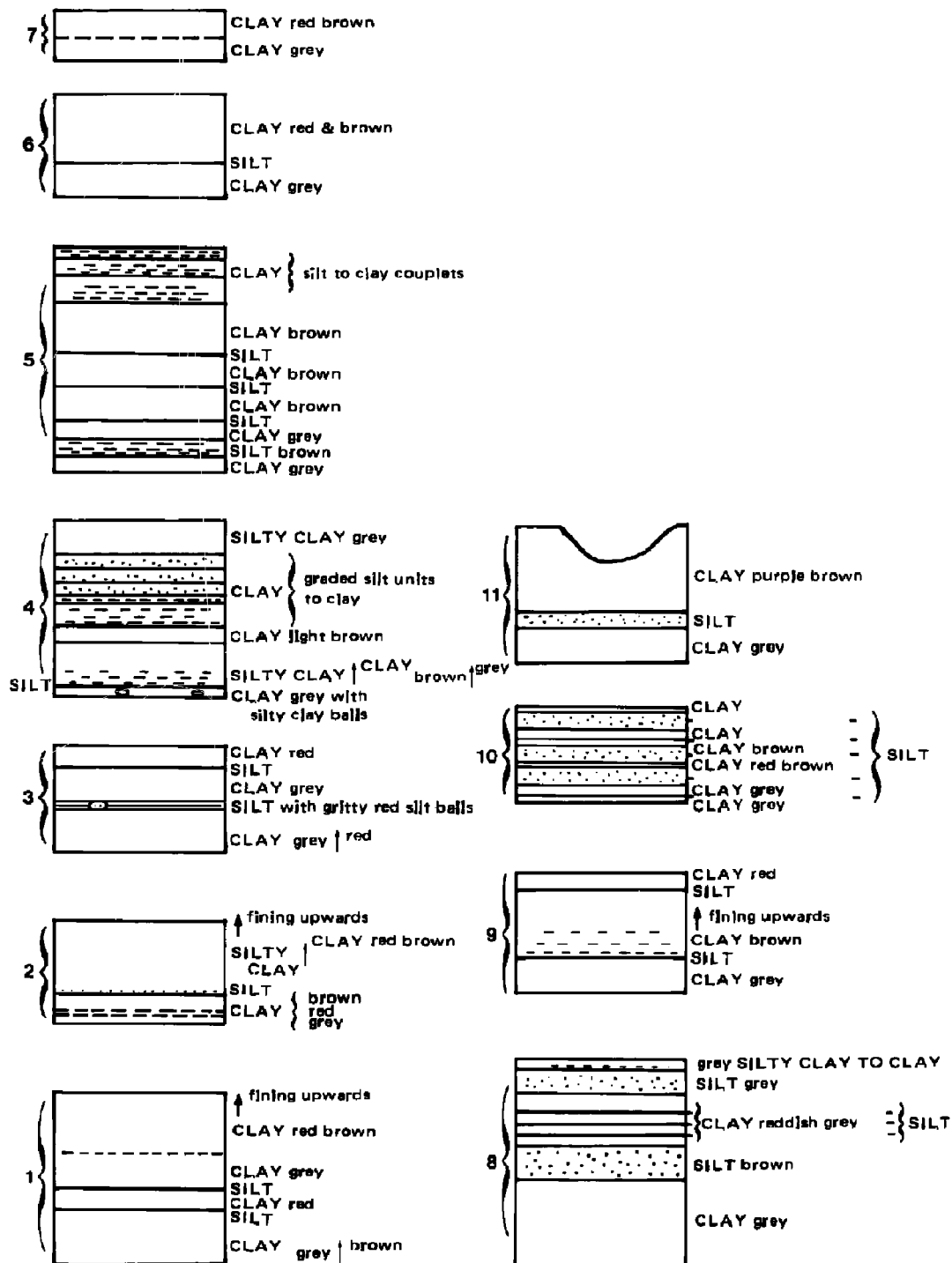
Sediment Column



LP 85-17

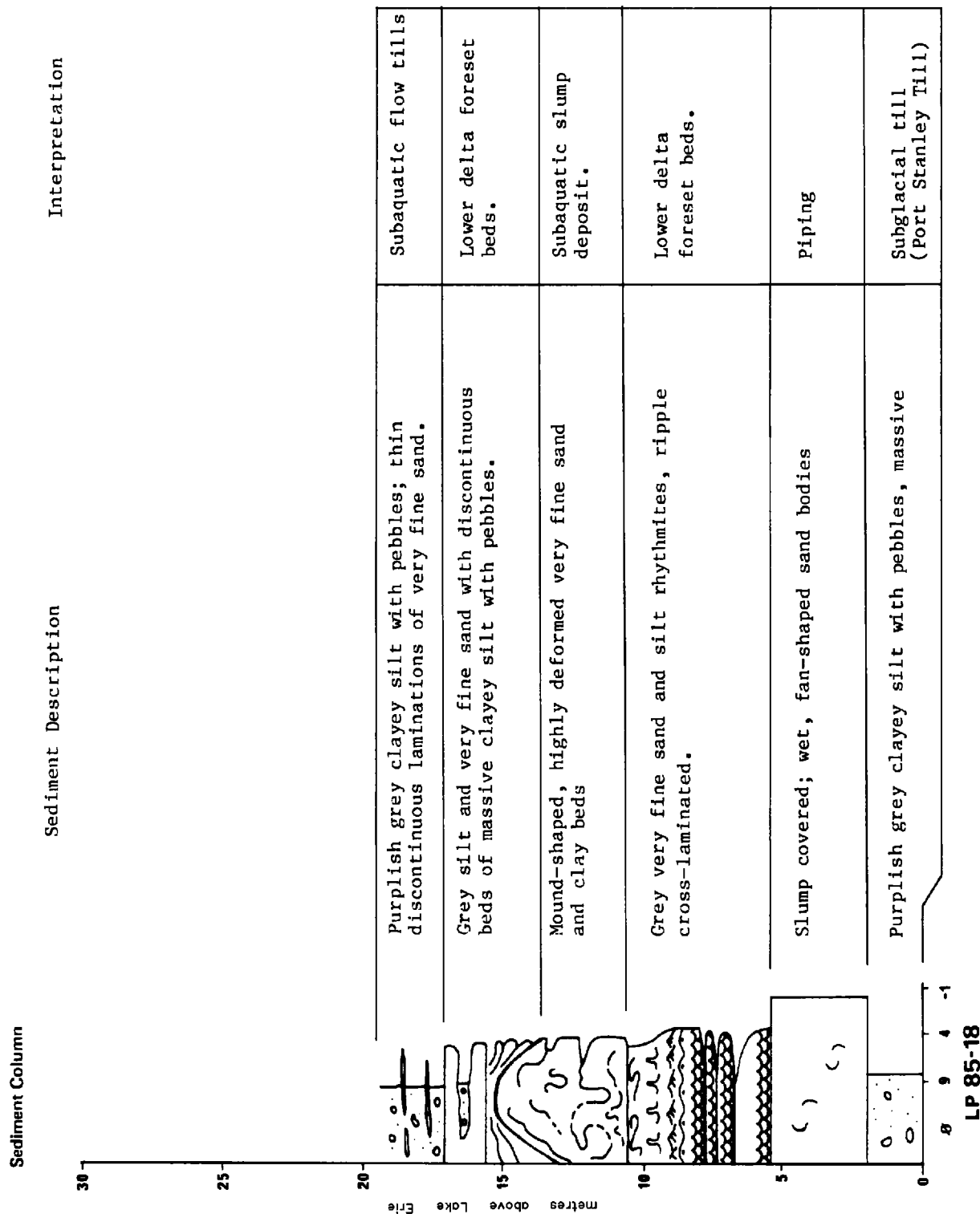


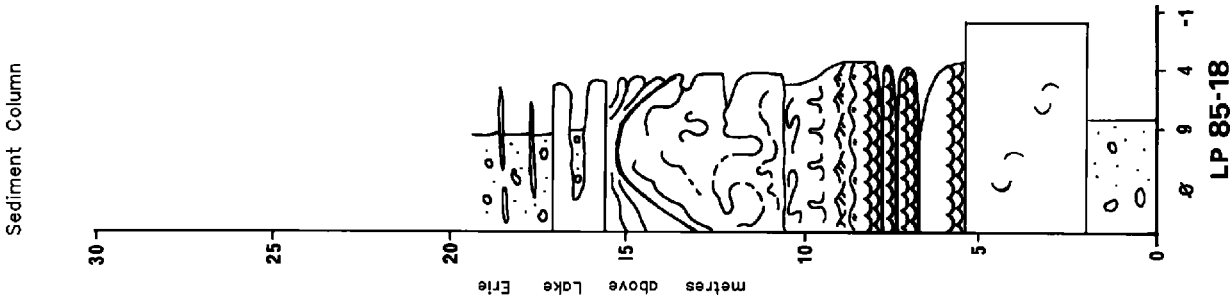
Details of Winter Layer LP-85-17



See previous page for sample positions.

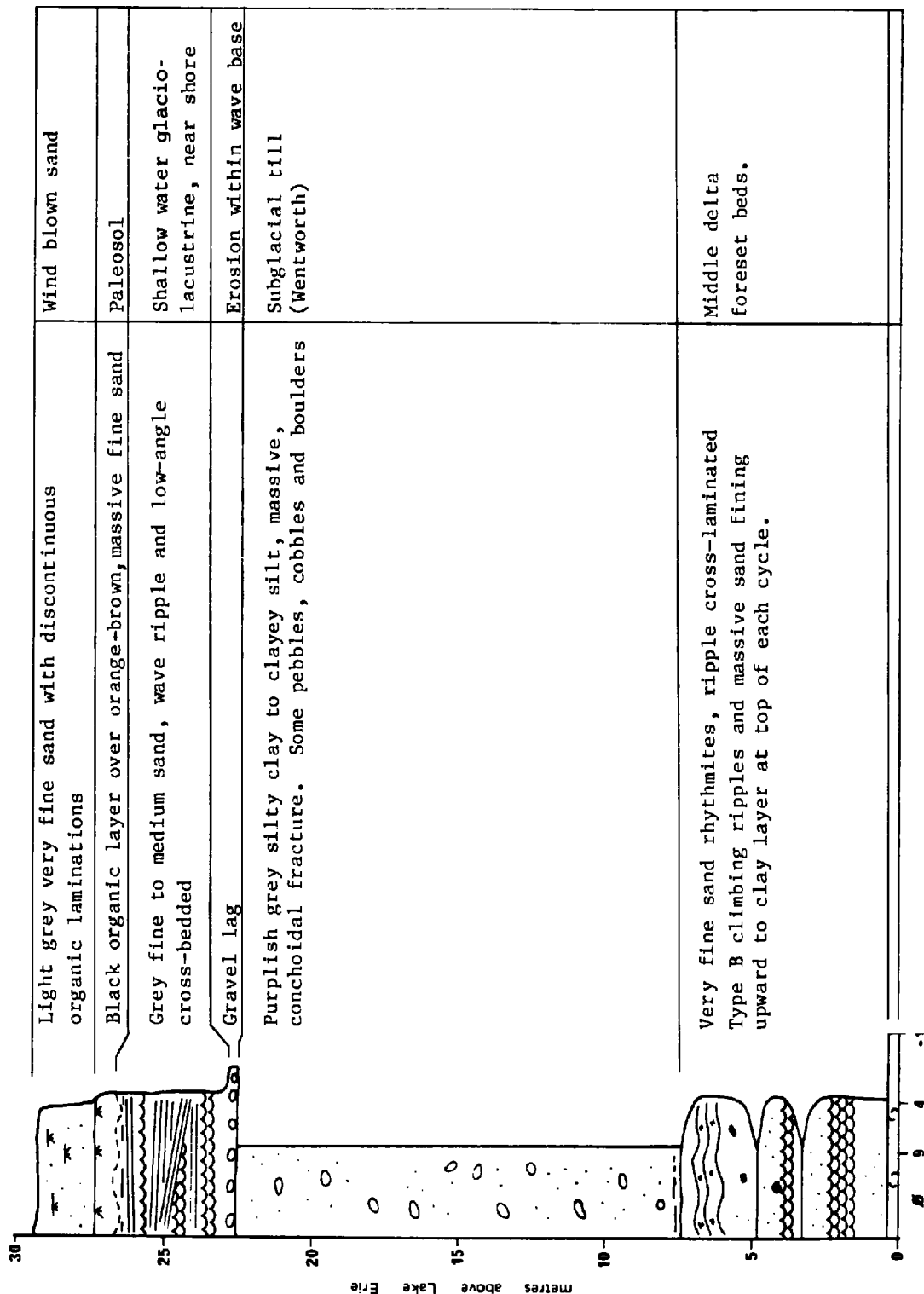
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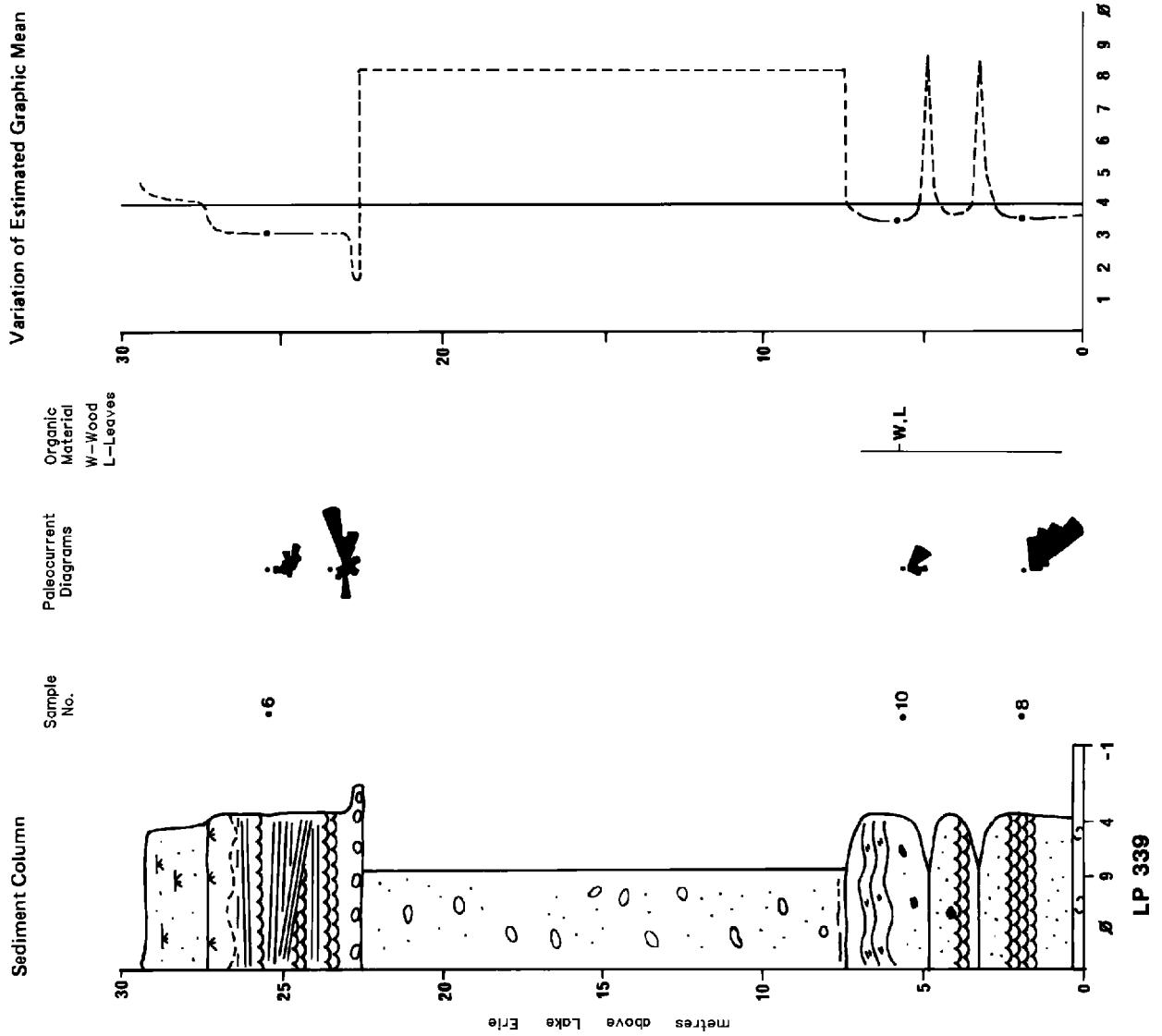


Sediment Column

Sediment Description Interpretation



LP 339

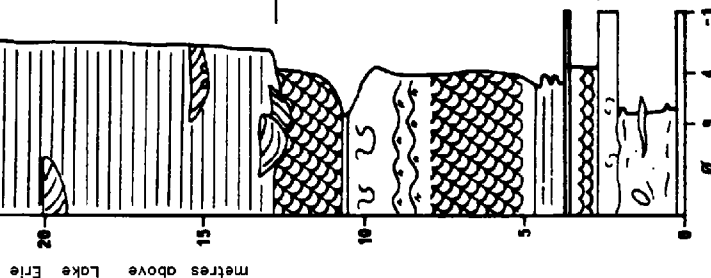


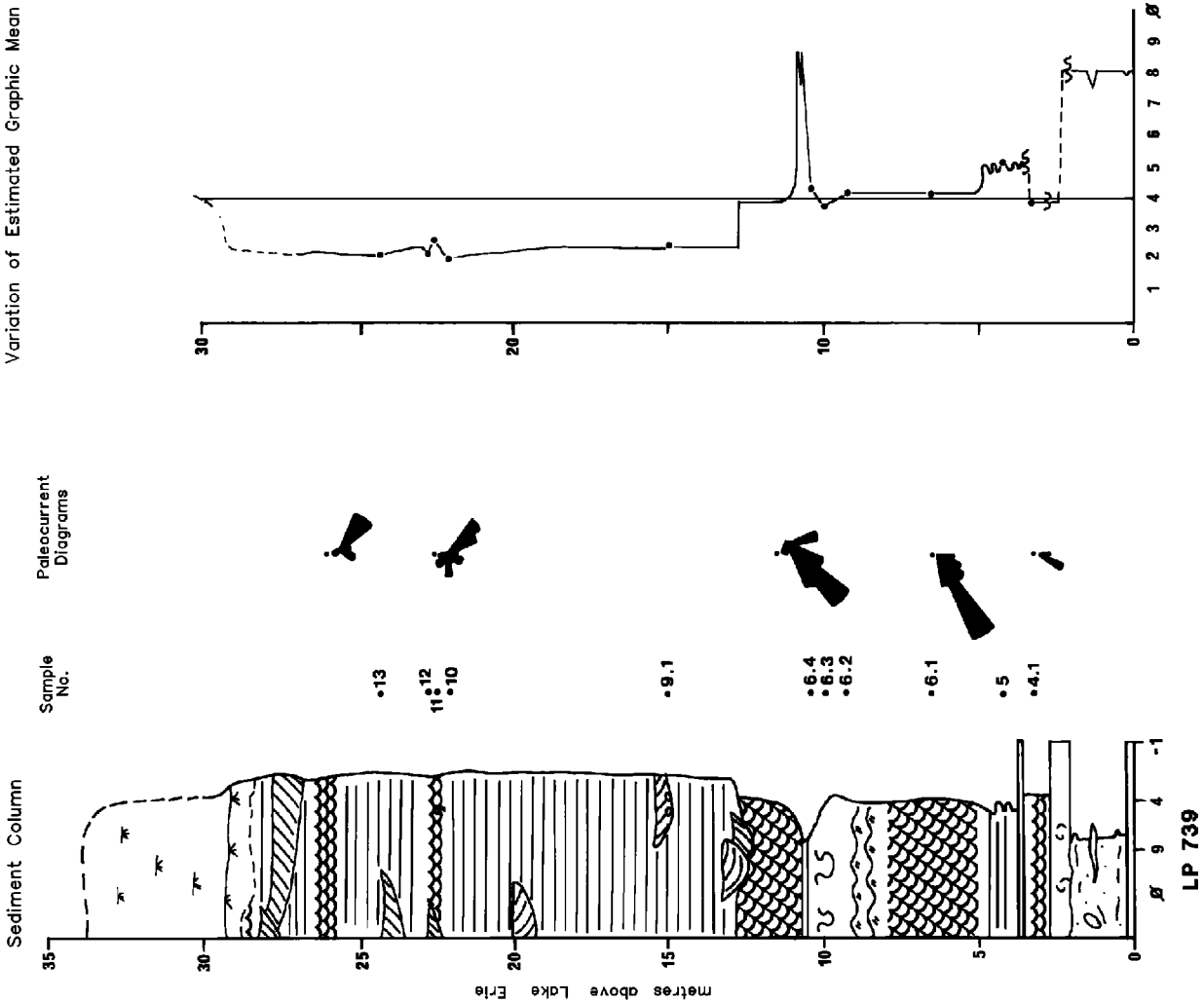
Sediment Column

Sediment Description

Interpretation

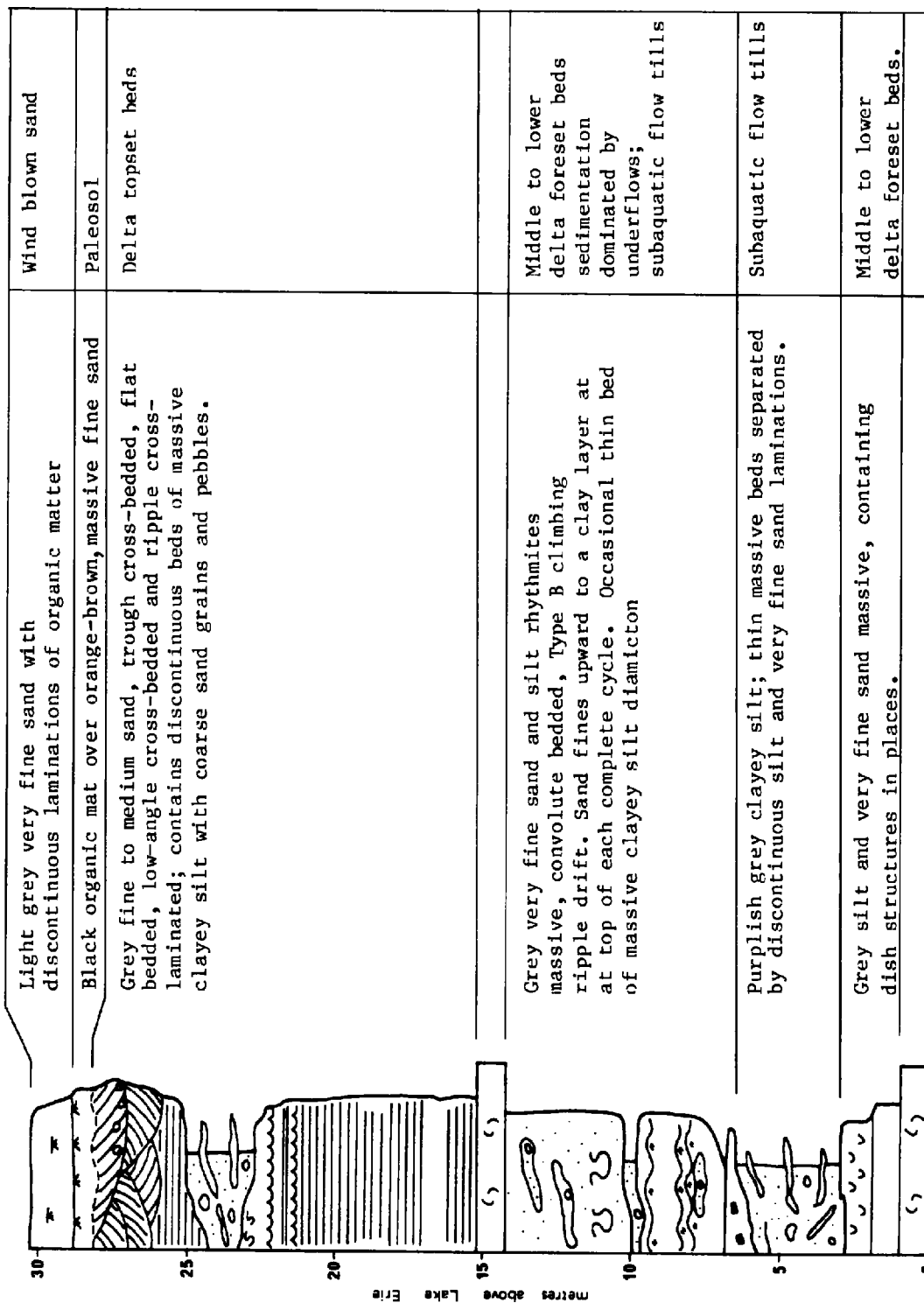
Light grey very fine sand with discontinuous laminations of organic material.	Wind blown sand
Black organic layer over orange-brown, massive fine sand	Paleosol
Grey fine to medium sand, flat-bedded, low-angle cross-bedded, ripple cross-laminated and isolated channel cut and fills of trough cross-bedded sand	Delta topset beds, wave dominated with occasional distributary channel.
Grey very fine to fine sand rhythmites; Type A to Type B climbing ripple sand fining upward into convolute-bedded silts and a clay layer at top of each cycle.	Middle delta foreset beds
Slump covered	Piping
Purplish grey clayey silt with pebbles, interbedded with discontinuous laminations of very fine sand.	Subaquatic flow tills





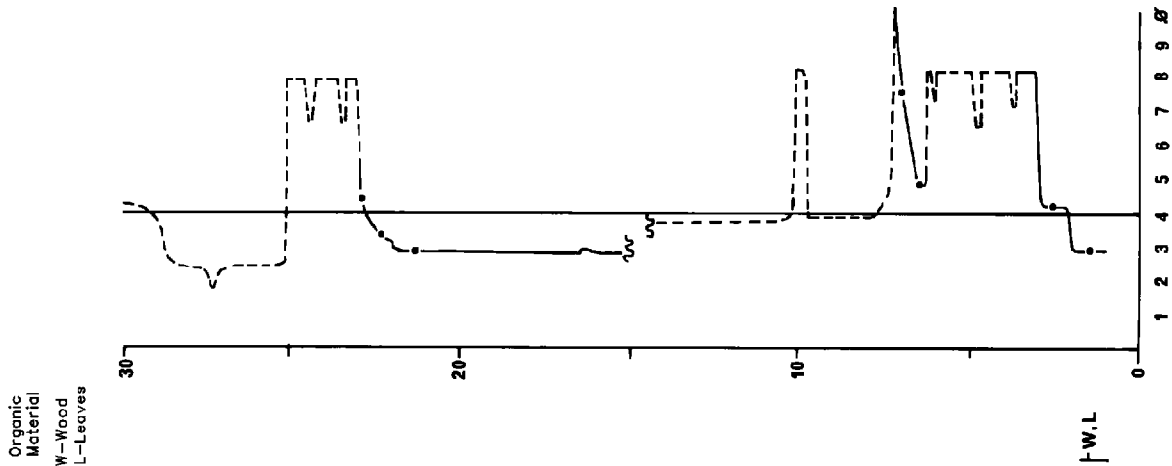
Sediment Column

Sediment Description Interpretation



LP 750

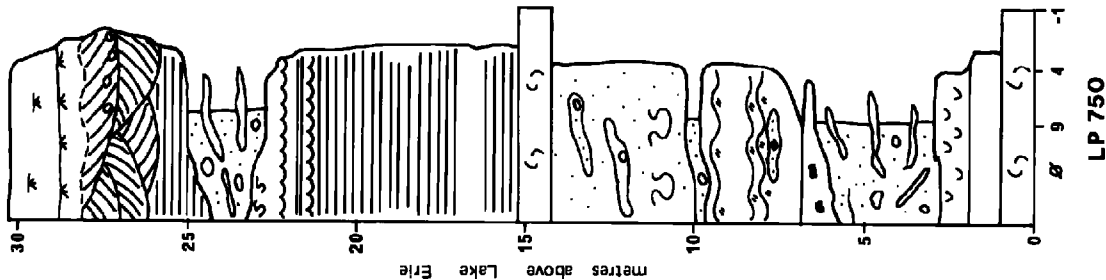
Variation of Estimated Graphic Mean



Paleocurrent Diagrams



Sediment Column



Appendix 2. Reverse Circulation Borehole Logs

Descriptions of Quaternary sediments by K.L. Bradshaw and A.F. Bajc.

Descriptions and interpretations of Paleozoic rocks by K.L. Bradshaw and M.D. Johnson.

Borehole: OGS-82-M-5

Drilling Company: Heath and Sherwood Ltd.

Location: Lot 1, Concession 9, Township of Norfolk, Regional Municipality of Haldimand–Norfolk (UTM Grid 3574E 1518N)

Elevation of top of hole: 190.26 m.

Depth below surface (m)	Thickness (m)	Description of material (interpretation)
0 to 28.7	28.7	Purplish-brown to grey clayey silt to silty clay containing small pebbles and sand grains. Stratification not observed. Samples analyzed: M-5-6 depth 9 to 10 m M-5-13 depth 18 to 19 m M-5-18 depth 26 to 27 m (Wentworth Till)
8.7 to 83.5	54.8	Grey silty clay with occasional very coarse sand grains. Faint to well developed colour banding (red and grey) and occasional lamination of sand, silt and clay. Small pebbles rare. Lower 6 m contains several thin beds of gritty silty clay with small pebbles. Samples analyzed: M-5-31 depth 46 to 47 m M-5-45 depth 69.5 to 70 m (Glaciolacustrine silty clay, lower 6 m may contain subaquatic flowtills.)
83.5 to 95.92	12.42	Brownish-grey to grey clayey silt with occasional small pebbles and very coarse sand grains. No bedding or laminations observed. Lower 2 m is gritty, light greyish brown with numerous limestone and shale pebbles. Samples analyzed: M-5-51 depth 87 to 88 m M-5-53 depth 93 to 93.5 m M-5-54 depth 94 to 95 m (Port Stanley Till)
95.92 to 111.37	15.45	Dark brown calcareous shale becoming interbedded with limestone below 105.53 m. (Marcellus Formation.)
111.37 to 117.73	6.36	Grey-brown, very fine to sublithographic limestone, fossiliferous. (Dundee Formation).

Borehole: OGS-82-M-6

Drilling Company: Heath and Sherwood Ltd.

Location : In road between Lots 1 and 2, Concession 4, Township of Norfolk, Regional Municipality of Haldimand–Norfolk (UTM Grid 2912E 1709N)

Elevation of top of hole: 194.89 m.

Depth below surface (m)	Thickness(m)	Description of material (interpretation)
0 to 20.4	20.4	Orange-brown to grey fine sand with some small pebbles becoming finer grained downward. Red and grey clay balls probably represent thin clay layers within a fine to very fine sand. A few wood fragments between 12 and 14 m depth. Several thin beds of clayey silt containing very coarse sand grains are interbedded with sand in lower 2 m. (Glaciolacustrine sand, probably rhythmites; clayey silt beds may be subaquatic flowtills.)
20.4 to 35.4	15	Brownish-grey to grey silty clay to clayey silt interbedded with grey silty clay containing some small pebbles and coarse sand grains. Faint laminations of silt, and red and dark grey clay laminations are present. Samples analyzed: M-6-4 depth 23 to 24 m (flowtill) M-6-6 depth 26 to 27 m (Glaciolacustrine clay with possible subaquatic flowtills of Wentworth Till.)

Borehole: OGS-82-M-6 (cont'd)

Depth below surface (m)	Thickness(m)	Description of material (interpretation)
35.4 to 64.3	28.9	Grey silt to clayey silt with red clay laminations. Below 50 m laminated silt and clay become gritty, containing small red shale fragments and small pebbles increasing in abundance downward. Samples analyzed: M-6-10 depth 42 to 43 m M-6-13 depth 46 to 46.3 m (Glaciolacustrine clay and silt rhythmites.)
64.3 to 74.7	10.4	Grey, massive, silty clay to clayey silt with occasional pebbles and coarse sand grains. Samples analyzed: M-6-15 depth 64.6 to 65.5 m M-6-17 depth 70 to 71 m (Port Stanley Till)
74.7 to 78.0	3.3	Red clay and silty clay interlaminated with grey silty clay to clayey silt containing small pebbles (Glaciolacustrine clay and silt rhythmites with interbeds of subaquatic flowtills.)
78.0 to 87.96	9.96	Grey-brown to grey, massive, gritty clayey silt with pebbles. In thin zone between depths of 84.7 and 86 m material contains fewer pebbles and is less gritty. Samples analyzed: M-6-19 depth 79 to 79.5 m M-6-23 depth 83 to 84 m M-6-26 depth 86 to 87 m (Port Stanley Till)
87.96 to 96.42	8.46	Dark grey, horizontally laminated, calcareous shale (Marcellus Formation)
96.42 to 101.26	4.84	Grey-brown sublithographic to very finely crystalline, richly fossiliferous limestone. (Dundee Formation.)

Borehole: OGS-82-M-7**Drilling Company:** Heath and Sherwood Ltd.**Location:** Lot 6, Concession 3, Township of Bayham, Elgin County (UTM Grid 1397E 2719N)**Elevation of top of hole:** 180.75 m.

Depth below surface (m)	Thickness (m)	Description of material (interpretation)
0 to 7.6	7.6	Fine-grained sand with organic debris, becoming gravelly below a depth of 6 m. (Alluvium.)
7.6 to 15	7.4	Greyish-brown clay and silty clay, colour banded toward base of interval. Sample analyzed: M-7-7 depth 8 to 9 m (Glaciolacustrine clay and silty clay.)
15 to 25.6	10.6	Greyish-brown silty clay containing occasional small pebbles and coarse sand-sized grains. Massive appearance. Samples analyzed: M-7-13 depth 17 to 18 m M-7-15 depth 23 to 23.5 m (Port Stanley Till)
25.6 to 26	0.4	Grey fine sand interbedded with red clay. (Glaciolacustrine sand rhythmites.)
26 to 28	2	Grey gritty silty clay, structureless (Flow Till or Port Stanley Till)
28 to 28.4	0.4	Grey sand with small pebbles (Glaciolacustrine sand)
28.4 to 36.7	8.3	Greyish-brown silty clay with sand-sized and pebble-sized clasts, structureless. Samples analyzed: M-7-19 depth 29 to 30 m M-7-22 depth 34 to 35 m (Port Stanley Till)
36.7 to 39.5	2.8	Brownish-grey and red, well stratified clayey silt and clay, occasional small pebble. (Glaciolacustrine silt and clay)

Borehole: OGS-82-M-7 (cont'd)

Depth below surface (m)	Thickness(m)	Description of material (interpretation)
39.5 to 43.8	4.3	Light-brownish-grey silty clay with numerous sand-sized grains and small pebbles, a boulder encountered at a depth of 41.3 m. Sample analyzed: M-7-25 depth 40.5 to 41 m (Port Stanley Till)
43.8 to 44.7	0.9	Gravel containing clasts of shale, limestone, granite and marble (Glaciolacustrine gravel)
44.7 to 45.0	0.3	Grey silty clay (Glaciolacustrine clay)
45.0 to 48.8	3.8	Light-greyish-brown clayey silt becoming very gritty below a depth of 46 m. Large boulder hit at 47 m depth. Sample analyzed: M-7-32 depth 46 to 47 m (Port Stanley Till)
48.8 to 63.14	14.34	Grey-brown to pale buff-brown, very finely crystalline limestone (Dundee Formation).

Borehole: OGS-82-M-8**Drilling Company:** Heath and Sherwood Ltd.**Location:** Part of Lot 26, Concession 1, Township of Malahide, Elgin County (UTM Grid 0770E 2308N)**Elevation of top of hole:** 204.48 m.

Depth below surface (m)	Thickness (m)	Description of material (interpretation)
0 to 0.6	0.6	Light-orange-brown fine sand. (Glaciolacustrine sand).
0.6 to 3.7	3.1	Light-greyish-brown to brownish-grey clayey silt with few pebbles and sand-sized grains, massive to faintly stratified. (Port Stanley subaquatic flowtills)
3.7 to 10.2	6.5	Brownish-grey to grey clayey silt to silt, faintly stratified with occasional red clay layer and a couple of thin beds of clayey silt containing pebbles and sand-sized grains. (Glaciolacustrine silt and clay with occasional Port Stanley sub-aquatic flowtill)
10.2 to 24.8	12.6	Light-brownish-grey silt and very fine sand beds separated by red and grey clay layers. Very occasional pebble or cobble encountered and wood fragments occurred between 12 and 14 m depth. (Glaciolacustrine silt and very fine sand rhythmities).
24.8 to 30.2	5.4	Greyish-brown clayey silt to silty clay with a few coarse sand grains and small pebbles, appears massive. Sample analyzed: M-8-12 depth 29.5 to 30 m (Port Stanley Till)
30.2 to 31.5	1.3	Grey clayey silt, very little sand-sized or pebble-sized fragments (Glaciolacustrine clayey silt)
31.5 to 34.0	2.5	Grey very fine sand with thin layers of red and greyish brown clay (Glaciolacustrine sand rhythmities)
34.0 to 56.7	22.7	Light brown to greyish-brown, structureless, clayey silt, numerous sand-sized grains and pebbles. Samples analyzed: M-8-14 depth 35.8 to 36.5 m M-8-23 depth 52.5 to 53 m M-8-25 depth 55.5 to 56 m (Port Stanley Till)
56.7 to 59.5	2.8	Thin layer of sand underlain by greyish-brown silty clay, containing laminations of clay in lower 1.6 m. (Glaciolacustrine sand over glaciolacustrine clay and silt)
59.5 to 74.0	14.5	Light-greyish-brown clayey silt, gritty with numerous small pebbles. Samples analyzed: M-8-28 depth 60.5 to 61 m M-8-33 depth 68 to 69 m M-8-36 depth 73 to 73.5 m (Port Stanley Till)

Borehole: OGS-82-M-8 (cont'd)

Depth below surface (m)	Thickness(m)	Description of material (interpretation)
74.0 to 84.18	10.18	Brownish-grey to grey, very gritty, sandy, clayey silt. Pebbly with one granitic boulder encountered at 77.5 m depth. Gravel layer present between 78.6 and 79 m depth. Light-brownish-grey to grey gritty sand, clayey, silt, numerous small pebbles and a few shale boulders. Petroliferous odour in lower 1.6 m of unit. Samples analyzed: M-8-38 depth 75.9 to 76.5 m M-8-39 depth 77.6 to 78 m M-8-41 depth 80 to 81 m M-8-42 depth 82.3 to 83 m (Catfish Creek Till)
84.18 to 87.36	3.18	Calcareous shale interbedded with very fine-grained to sublithographic limestone (Marcellus Formation)
87.36 to 99.87	12.51	Brown grey, very fine- to medium-crystalline, highly fossiliferous limestone (Dundee Formation)

Appendix 3. Properties of Samples

3A : Colour, Grain Size, Carbonate Content, Heavy Minerals

3B : Pebble Lithologies

3C : Heavy Mineral Assemblages

Explanation of Texture and Material Interpretation Abbreviations:

C.C.	-	Catfish Creek Till
P.S.	-	Port Stanley Till
W.T.	-	Wentworth Till
M.N.	-	McConnell's Nursery (<i>see</i> "Sediments of the Lakeview Moraine")
S.H.	-	The Sand Hills Park (<i>see</i> "Sediments of the Galt Moraine")
cb	-	convolute bedded
crd	-	climbing ripple drift
fb	-	flat bedded
rcl	-	ripple cross-laminated
tcb	-	trough cross-bedded
md(μ)	-	mean diameter (in microns)

Appendix 3A. Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (µ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
82-10-1	till (P.S.)	10YR4/2	40	56	4	4	24	12	36	2.0	3.5	9.5	998 226	LP116-TM3
82-10-2	till (P.S.)	10YR4/2	38	58	4	4	22	13	35	1.7	4.7	11.6	1050 2285	LP40B-TM2
82-10-3	till (P.S.)	10YR4/2	43	53	4	3	22.5	14	36.5	1.6	4.2	9.0	1760 2290	LP39-TM1
82-10-4	till (P.S.)	10YR4/2	42	55	3	3	21.5	15	36.5	1.4	4.2	10	0294 2304	LP17-TM2
82-10-5	till (P.S.)	10YR4/2	36	62	2	4	22.5	13	35.6	1.8	4.2	11.8	9960 2240	LP115-TM2
82-10-6	till (P.S.)	10YR4/2	38	59	3	4	25.3	13.3	38.6	1.9	3.3	10.3	0560 2285	LP42-TM2
82-10-7	till (P.S.)	10YR4/2	39	57	4	3.6	21.5	14.5	36.1	1.5	3.8	11.1	0115 2290	LP40-TM1
82-10-8	till (P.S.)	10YR4/2	40	55	5	3.6	24.3	10.4	34.7	2.3	1.7	8.9	0294 2304	LP17-TM1
82-10-9	till (P.S.)	10YR4/2	42	54	4	3	23.2	10.8	34.0	2.2	2.3	9.5	0435 2300	LP46-TM1
82-10-10	till (P.S.)	10YR4/2	41	57	2	3.3	23.2	14.5	37.7	1.6	4.5	10	0545 2295	LP15-TM
82-10-11	till (P.S.)	10YR4/2	42	56	2	3	24.2	10.4	34.6	2.3	4.7	8.5	0750 2285	LP34-TM1
82-10-12	till (P.S.)	10YR4/2	43	55	2	3	22.7	13.5	36.2	1.7	4.2	9.3	0772 2279	LP14-TM1
82-10-13	till (P.S.)	10YR4/2	45	53	2	2.8	26.8	12.7	39.5	2.1	4.7	9.9	0868 2267	LP26-TM1
82-10-14	till (P.S.)	10YR4/2	25	71	4	9	25.3	15.4	40.7	1.6	4.7	8.6	0835 2280	LP33-TM1
82-10-15	till (P.S.)	10YR4/2	34	61	5	5	26.3	15.1	41.4	1.7	5.1	9.2	1011 2348	LP21-TM
82-10-16	till (P.S. Mabec M.)	10YR4/2	38	58	4	2.5	28.3	11.7	40.0	2.4	4.2	6.7	0010 2363	PB125-TM
82-10-17	till (P.S. Mabec M.)	10YR5/5	34	63	3	4.4	26.1	11.3	37.4	2.3	3.8	9.1	0375 2445	PB115-BTM
82-10-18	till (P.S. Mabec M.)	10YR4/2	36	61	3	4.5	23.9	14.6	38.5	1.6	4.6	8.6	0852 2643	PB160-TM
82-10-19	till (P.S. Mabec M.)	10YR4/2	30	65	5	6	26.2	14.3	40.5	1.8	5.0	8.2	1290 2850	LP144-TM1
82-10-20	till (P.S. Mabec M.)	10YR4/2	27	68	5	6.5	23.4	13.9	37.3	1.7	4.3	6.5	1290 2850	LP144-TM4
82-10-21	till (P.S. Courtland M.)	10YR4/2	26	69	5	9	22.3	15.3	37.6	1.5	4.0	8.5	0225 2760	PB240TM
82-10-22	till (P.S. Tillsonburg M.)	10YR4/2	30	55	15	7	25.7	13.7	39.4	1.9	2.8	10.4	0327 2990	P823
82-10-23	till (P.S. Courtland M.)	10YR4/2	42	54	4	3	23.9	13.2	37.1	1.8	5.3	8.7	1175 3072	PB158-TM1
82-10-24	till (P.S. Courtland M.)	10YR4/2	36	59	5	4.5	26.1	14.9	41.0	1.8	5.5	9.5	1330 3160	LP127-TM1

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
82-10-25	till (P.S. Tillsonburg M.)	10YR4/2	27	60	13	10	19.8	16.5	36.3	1.2	2.4	5.9	0954 3285	LP220-TM1
82-10-26	flow till (P.S. Mabee M.)	10YR4/2	41	57	2	3	27.7	11.3	39.0	2.5	5.3	7.6	1290 2850	LP144-TM2
82-10-27	flow till (P.S. Mabee M.)	10YR5/4	26	69	5	6.5	26.1	12.6	38.7	2.1	6.9	7.9	1290 2850	LP144-TM3
82-10-28	till ? (P.S.)	10YR4/2	21	66	13	11	21.3	13.3	34.6	1.6	6.7	10.6	9960 2240	LP115-TM1
82-10-29	flow till (P.S.)	10YR4/2	22	54	24	12	16.6	11.8	28.4	1.4	6.1	9	0560 2285	LP42-TM1
82-10-30	flow till (P.S. Tillsonburg M.)	10YR4/4	35	60	5	4.8	24.0	14.9	38.9	1.6	5.5	7.8	1330 3160	LP127-TM
82-10-31	till (P.S.)	10YR4/2	37	61	2	3.8	21.2	13.2	34.4	1.61			1210 2220	LP240-TM1
82-10-32	till (P.S.)	10YR4/2	37	61	2	3.9	21.5	12.9	34.4	1.67			1305 2205	LP250-TM1
82-10-33	till (P.S.)	10YR4/2	41	57	2	3	17.9	13.8	31.7	1.30			1735 2085	LP273-TM1
82-10-34	till (P.S. Lakeview M.)	10YR4/2	39	58	3	3.2	18.2	15.9	34.1	1.14			1560 2605	LP266-TM1
82-10-35	till (P.S. Mabee M.)	10YR4/2	40	55	3	3	24.6	12.2	36.8	2.02	8.1	10.8	1567 3016	LP29-TM1
82-10-36	flow till (W.T. Paris M.)	10YR4/2	51	46	3	1.9	17.5	11.8	29.3	1.48			2965 1475	LP337-TM1
82-10-37	flow till (W.T. Paris M.)	10YR4/2	47	50	3	2.05	19.8	13.2	33.0	1.50			3045 1440	LP340-TM1
82-10-38	till (W.T. Galt M.)	10YR4/2	49	48	3	2.0	17.4	13.8	31.2	1.26			3045 1445	LP339-TM
82-10-39	till (W.T. Galt M.)	10YR4/2	38	57	5	3.5	18.7	15.9	34.6	1.18	6.5	7.8	3295 1395	LP348-TM1
82-10-40	till (W.T. Galt M.)	10YR4/2	46	52	2	2.3	19.7	15.2	34.9	1.30			3440 1380	LP388-TM1
82-10-41	till (W.T. Galt M.)	10YR4/2	42	55	3	2.8	22.2	14.1	36.3	1.57			3710 1350	LP384BTM
82-10-42	till (W.T. Galt M.)	10YR4/2	43	54	3	2.8	20.9	15.7	36.6	1.33			3770 1340	LP382-TM
82-10-43	till (W.T. Galt M.)	10YR4/2	38	58	4	3.3	24.1	15.0	39.1	1.6			3845 1825	PB335-TM
82-10-44	till (W.T. Galt M.)	10YR4/3	37	61	2	3.9	24.1	14.5	38.6	1.7			4305 2240	PB352-TM
82-10-45	till (W.T. Galt M.)	10YR4/3	35	61	4	4	23.7	13.2	36.9	1.8	5.7	10.8	4320 2295	PB356-TM
82-10-46	till (W.T. Galt M.)	10YR4/2	32	64	4	5	22.1	16.8	38.9	1.3			4460 2215	PB423-TM
82-10-47	till (W.T. Galt M.)	10YR4/3	28	68	4	6.2	22.6	14.7	37.3	1.5	6.1	6.1	4855 2265	PB450-TM

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
82-10-48	till (W.T. Normandale)	10YR4/2	15	61	24	19	23.2	18.9	42.1	1.2	5.9	7.1	5965 3190	LP467-TM
82-10-49	flow till (W.T. Normandale)	10YR4/2	11	80	9	18	19.4	18.3	37.7	1.0	5.5	6.7	5564 2746	LP4TM4
82-10-50	flow till (W.T. Normandale)	2.5Y4/2	21	67	12	8	22.3	16.1	38.4	1.4	6.6	7.4	586 2778	LP8TM
82-10-51	flow till (W.T. Normandale)	10YR5/4	7	64	29	38	16.6	17.5	34.1	0.9	2.8	6.9	5590 2795	LP6TM1
82-10-52	flow till (W.T. Normandale)	10YR4/2	9	62	29	20	19.9	21.2	41.1	0.9	4.9	7.9	5745 2930	LP459B-TM2
82-10-53	flow till (W.T. Normandale)	10YR4/4	8	47	45	52	18.7	16.3	35.0	1.1	3.8	10.8	5760 2945	LP458-TM1
82-10-54	flow till (W.T. Normandale)	2.5Y5/2	10	51	39	43	21.6	20.1	41.7	1.0	2.7	5.6	5755 2940	LP458-TM2
82-10-55	flow till (W.T. Normandale)	10YR5/2	30	62	8	5.2	26.2	13.4	39.6	1.9	6.4	7.8	5825 3025	LP463-TM1
82-10-56	flow till (W.T. Normandale)	10YR4/2	11	66	23	30	17.7	20.0	37.7	0.9	5.4	7.8	5840 3050	LP464-TM1
82-10-57	flow till (W.T. Paris M.)	10YR4/2	12	82	6	23	15.6	19.4	35.0	0.8	4.4	9.2	3125 2755	PB289-TM
82-10-58	flow till (P.S. Mabee M.)	10YR4/2	35	62	3	3.9	20.7	16.1	36.8	1.3			1565 2915	LP202-TM
82-10-59	till bell (W.T. Normandale)	10YR4/3	21	63	21	16	21.8	17.9	39.7	1.2	3.2	6.7	5569 2750	LP5-TM
82-10-60	clay and silt (glaciolacustrine)	10YR4/2	24	73	3	5	23.0	12.7	35.7	1.8			5564 2746	LP4-Gl
82-10-61	clay and silt (glaciolacustrine)	10YR4/2	41	56	3	2.8	22.7	14.5	37.2	1.6	5.1	11.3	5745 2930	LP459-TM1
82-10-62	flow till (W.T. Normandale)	10YR5/2	9	66	25	29	19.2	16.8	36.0	1.1	3.0	7.0	5598 2796	LP68-TM2

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (µ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
82-10-63	flow till (W.T. Normandale)	10YR4/2	10	80	10	21	18.0	18.9	36.9	0.9	5.0	6.7	5255 2565	LP530-TM
82-10-64	till (P.S. Courtland M.)	10YR4/2	34	60	6	4.2	23.4	15.0	38.4	1.6			1070 3170	LP198-TM
82-10-65	till (P.S. Courtland M.)	10YR4/2	33	60	7	4.4	22.6	16.3	38.9	1.4	6.3	7.8	1260 3170	LP191-TM
82-10-66	till (P.S. Tillsonburg M.)	10YR4/2	31	65	4	4.9	20.2	16.8	37.0	1.20			2600 2865	PB55B-TM
82-10-67	till (P.S. Tillsonburg M.)	10YR4/2	27	68	5	6.0	22.6	16.6	39.2	1.37	5.7	8.2	0327 2902	PB20A
82-10-68	till (P.S. Mabee M.)	10YR4/2	29	60	11	6.1	19.4	15.8	35.2	1.2	4.5	5.3	1493 3025	LP309-TM
82-10-69	clay (glaciolacustrine)	10YR4/2	82	18	0		19.2	14.9	34.1	1.3			7720 2279	LP14CLY
82-10-70	till (W.T. Paris M.)		1	25	74	83					1.0	4.5	5840 3050	LP464
82-10-71	sand (gravel)		-	1	99						8.8	11.6	5515 3105	LP513
82-10-72	till (W.T. Paris M.)		19	72	9	8	16.7	17.3	34.0	0.9	7.4	7.8	2965 3085	PB269
82-10-73	sand (glaciolacustrine)		1	24	75	84					0.2	8.3	1675 3190	PB494
82-10-74	sand (glaciolacustrine)		-	1	99	259					7.9	5.7	3650 2130	PB488
82-10-75	dune sand		-	1	99	190					4.6	6.0	0016 2956	PB496
82-10-76	dune sand		-	10	90	120					5.25	4.9	1535 3105	PB495
82-10-77	dune sand		-	2	98	145					5.5	6.3	1650 3205	PB493
82-10-78	dune sand		-	2	98	168					5.65	6.4	1670 3140	PB492
82-10-79	dune sand		-	2	98	179					3.1	4.8	1750 3180	PB491
82-10-80	dune sand		-	1	99	190					7.2	6.2	2990 3140	PB490
82-10-81	dune sand		-	-	100	125					3.6	4.7	2910 2255	PB489

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetite %		
82-10-82	dune sand		-	-	100	177					5.5	6.7	4295 2505	PB358
82-10-83	dune sand		-	5	95	143					3.3	2.6	4305 2880	PB487A
82-10-84	dune sand		-	2	98	152					3.9	3.3	4305 2880	PB487B
82-10-85	dune sand		-	4	96	125					3.5	4.0	4700 2855	PB486
82-10-86	till (P.S.)	10YR4/2	31	65	4	5.5	23.2	14.4	37.6	1.61			1065 2240	LP243-TM1
82-10-88	till (C.C. Sparta M.)	10YR4/4	17	49	34	25	19.9	15.0	34.9	1.3	3.9	10.0	9355 2865	
82-10-89	till (W.T. Galt M.)		26	71	3	7.5	18.2	16.9	35.1	1.08	5.0	8.1	4975 2380	LP727-TM
82-10-91	flow till (P.S.)		27	70	3	7	21.6	14.5	36.1	1.49	3.9	8.0	0772 2279	LP14-1
82-10-92	flow till (P.S.)		26	70	4	8	19.4	16.3	35.7	1.19	2.4	6.8	0772 2279	LP14-2
82-10-93	flow till (P.S.)		19	78	3	14	21.9	12.4	34.3	1.77	4.0	7.0	0770 2335	PB133-4
82-10-94	clay and silt (glaciolacustrine)		37	62	1	3.5	22.5	14.0	36.5	1.61			0770 2335	PB133-3
82-10-95	clay and silt (glaciolacustrine)		50	49	1	2	22.2	12.4	34.6	1.79			0770 2335	PB133-2
82-10-96	sand (glaciolacustrine)						10.3	13.8	24.1	0.75	1.1	1.7	0770 2335	PB133-1
82-10-97	sand (facies A.M.N.)		2	50	48	60	11.6	21.2	32.8	0.55	1.5	2.8	0772 2279	LP14-1
82-10-98	sand (facies A.M.N.)		2	37	61	65	10.6	22.4	33.0	0.47	0.8	3.3	0772 2279	LP14-2
82-10-99	sand (facies A.M.N.)		2	36	63	65	12.4	19.2	31.6	0.65	0.8	3.7	0772 2279	LP14-3
82-10-100	silt (facies A.M.N.)		3	92	5	40	11.6	21.8	33.4	0.54	1.8	4.9	0772 2279	LP14-4
82-10-101	clay (facies A.M.N.)		80	20	0	-	20.5	6.3	26.8	3.24			0772 2279	LP14-5
82-10-102	silt (facies A.M.N.)		2	73	25	51	11.6	21.4	33.0	0.54	2.2	3.0	0772 2279	LP14-6
82-10-103	sand (facies A.M.N.)		1	53	46	60	15.3	17.6	32.9	0.87	1.0	6.3	0772 2279	LP14-7
82-10-104	silt (facies A.M.N.)		2	78	20	45	14.5	19.9	34.4	0.73	2.8	2.6	0772 2279	LP14-8

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
82-10-105	silt (facies A.M.N.)		14	84	14	15	18.7	16.5	35.2	1.13	5.6	8.8	0772 2279	LP14-9
82-10-106	clay (facies A.M.N.)		36	64	0	3.5	23.2	14.2	37.4	1.63			0772 2279	LP14-10
82-10-107	silt (facies A.M.N.)		2	66	32	52	11.5	19.7	31.2	0.59	2.5	3.9	0772 2279	LP14-11
82-10-108	silt (facies (A.M.N.)		3	80	17	41	9.4	22.6	32.0	0.42	1.6	2.4	0772 2279	LP14-12
82-10-109	silt (facies A.M.N.)		2	52	46	60	11.7	19.9	31.6	0.59	0.7	5.9	0772 2279	LP14-13
82-10-110	clay (facies A.M.N.)		41	59	0	3	18.6	18.1	36.7	1.03			0772 2279	LP14-14
82-10-111	silt (facies A.M.N.)		3	94	3	30	12.8	21.0	33.8	0.61	1.5	1.1	0772 2279	LP14-15
82-10-112	sand (facies A.M.N.)		2	35	63	70	11.8	22.2	34.0	0.53	0.5	5.9	0772 2279	LP14-16
82-10-113	sand (facies A.M.N.)		2	89	9	39	14.4	17.1	31.5	0.84	2.2	2.5	0772 2279	LP14-17
82-10-115	sand (facies A.S.H.) rel		1	39	60	70							2950 1475	LP739-4-1
82-10-116	silt (facies A.S.H.)		2	95	3	31.2							2950 1475	LP739-5-1
82-10-117	sand (facies A.S.H.) crd		2	46	52	65							2950 1475	LP739-6-1
82-10-118	silt (facies A.S.H.)		2	52	46	60							2950 1475	LP739-6-2
82-10-119	sand (facies A.S.H.) cb		1	23	76	80							2950 1475	LP739-6-3
82-10-120	silt (facies A.S.H.)		2	63	35	50							2950 1475	LP739-6-4
82-10-121	sand (facies D.S.H.) fb		0	1	99	200							2950 1475	LP739-9-1
82-10-122	sand (facies D.S.H.) tcb		0	0.5	99.5	200							2950 1475	LP739-9-2
82-10-123	sand (facies D.S.H.) fb		0	0.5	99.5	250							2950 1475	LP739-10
82-10-124	sand (facies D.S.H.) rel		0	3	97	180							2950 1475	LP739-11
82-10-125	sand (facies D.S.H.) tcb		0	1	99	225							2950 1475	LP739-12
82-10-126	sand (facies D.S.H.) fb		0	0.5	99.5	225							2950 1475	LP739-13
82-10-127	sand (facies D.S.H.) fb		0	0.5	99.5	235							2875 1512	LP740-Sd1a
82-10-128	sand (facies D.S.H.) fb		0	2	98	185							2875 1512	LP740-Sd2
82-10-129	sand (facies D.S.H.) fb		0	5	95	150							2875 1512	LP740-Sd3
82-10-130	sand (facies A.S.H.) rel		1	20	79	95							3045 1445	LP339-8
82-10-131	sand (facies A.S.H.) rel		2	18	80	105							3045 1445	LP339-19
82-10-132	sand (facies D.S.H.) rel		1	11	88	120							3045 1445	LP339-6

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetite %		
82-10-133	sand (facies A.S.H.) rcl		0	5	95	135							3005 1455	LP750-1
82-10-134	silt (facies A.S.H.)		1.5	31.5	47	60							3005 1455	LP750-2
82-10-135	silt (facies A.S.H.) rcl		2	91	7	40							3005 1455	LP750-3
82-10-136	sand (facies D.S.H.) fb		0	6	94	160							3005 1455	LP750-6
82-10-137	sand (facies D.S.H.) rcl		1	14	86	100							3005 1455	LP750-7
82-10-138	silt (facies D.S.H.) cb		2	71	27	40							3005 1455	LP750-8
82-10-139	silt (facies A.S.H.)		30	70	-	5	20.2	17.7	37.9	1.2			3005 1455	LP750-4a
82-10-140	clay (facies A.S.H.)		79	21	-	-	19.7	16.6	36.3	1.2			3005 1455	LP750-4b
82-10-141	flow till (P.S.)		37	59	4	4	20.2	16.3	36.5	1.2			0905 2270	LP719-FT1
82-10-142	flow till (P.S.)		26	70	4	9	19.2	17.5	36.7	1.1			0905 2270	LP719-FT2
82-10-143	till (P.S.)		26	69	5	9	20.2	16.1	36.3	1.3			0905 2270	LP719-TM
M-5-6	till (W.T. Galt M.)		43	55	2	2.7	19.1	16.5	35.6	1.16			3574 1518	M-5-6
M-5-13	till (W.T. Galt M.)		39	57	4	3.2	18.8	16.9	35.7	1.11			3574 1518	M-5-13
M-5-18	till (W.T. Galt M.)		47	50	3	2.1	22.1	13.5	35.6	1.64			3574 1518	M-5-18
M-5-31	silt and clay		42	58	0	2.8	22.5	14.9	37.4	1.51			3574 1518	M-5-31
M-5-45	silt and clay		39	61	0	3	24.1	12.2	36.3	1.98			3574 1518	M-5-45
M-5-51	till (P.S.)		44	53	3	2.4	25.3	13.1	38.4	1.93			3574 1518	M-5-51
M-5-53	till (P.S.)		43	46	11	2.8	24.8	13.8	38.6	1.80	2.1	4.6	3574 1518	M-5-53
M-5-54	till (P.S.)		34	43	23	4.2	25.9	15.1	41.0	1.72	2.0	9.5	3574 1518	M-5-54
M-6-4	till (W.T. Paris M.)		43	53	4	2.5	18.1	12.9	31.0	1.40			2912 1709	M-6-4
M-6-6	silt and clay		40	60	0	2.8	26.4	11.5	37.9	2.30			2912 1709	M-6-6
M-6-10	silt and clay		43	57	0	2.5	25.9	12.2	38.1	2.12			2912 1709	M-6-10
M-6-13	silt and clay		65	35	0	1.8	19.9	15.3	35.2	1.30			2912 1709	M-6-13
M-6-15	till (P.S.)		40	58	2	2.9	21.2	13.4	34.6	1.58			2912 1709	M-6-15

Appendix 3A. (cont'd) Colour, grain size, carbonate content, heavy materials.

Sample No.	Material Interpretation	Colour	Texture				Carbonates				Heavy Minerals		Sample Location (UTM Grid)	Field No.
			Clay %	Silt %	Sand %	md (μ)	Calcite %	Dolomite %	Total %	Ratio Ca/Dol	Total %	Magnetics %		
M-6-17	till (P.S.)		36	61	1	3.5	21.1	15.4	36.5	1.37			2912 1709	M-6-17
M-6-19	till (P.S.)		41	49	10	3	24.0	14.1	38.1	1.72	3.1	6.4	2912 1709	M-6-19
M-6-23	till (P.S.)		40	52	8	3.1	24.8	13.9	38.7	1.78	3.4	6.4	2912 1709	M-6-23
M-6-26	till (P.S.)		43	50	7	2.8	26.8	10.4	37.2	2.58			2912 1709	M-6-26
M-7-7	clay and silt		42	56	2	2.8	25.9	12.0	37.9	2.16			1397 2719	M-7-7
M-7-13	till (P.S.)		46	51	3	2.2	24.6	14.3	38.9	1.72			1397 2719	M-7-13
M-7-15	till (P.S.)		50	46	4	2	25.7	12.4	38.1	2.07			1397 2719	M-7-15
M-7-19	till (P.S.)		56	56	8	3.8	28.2	11.9	40.1	2.37			1397 2719	M-7-19
M-7-22	till (P.S.)		56	58	6	3.6	25.5	14.5	40.0	1.76			1397 2719	M-7-22
M-7-25	till (P.S.)		55	40	5	1.8	25.9	8.63	34.5	2.99			1397 2719	M-7-25
M-7-32	till (P.S.)		37	59	4	3.6	22.6	15.2	37.8	1.49			1397 2719	M-7-32
M-8-12	till (P.S.)		50	48	2	2	22.2	11.8	34.0	1.88			0770 2308	M-8-12
M-8-14	till (P.S.)		44	51	5	2.5	22.1	15.0	37.1	1.47			0770 2308	M-8-14
M-8-23	till (P.S.)		40	52	8	3	23.0	11.3	34.3	2.04	3.4	6.4	0770 2308	M-8-23
M-8-25	till (P.S.)		40	56	4	3.1	23.7	13.2	36.9	1.80			0770 2308	M-8-25
M-8-28	till (P.S.)		42	49	9	2.8	23.2	13.2	36.4	1.76	3.5	5.9	0770 2308	M-8-28
M-8-33	till (P.S.)		38	48	14	3.2	26.4	13.4	39.8	1.97	3.2	8.5	0770 2308	M-8-33
M-8-36	till (P.S.)		37	59	4	3.3	24.1	11.8	35.9	2.04			0770 2308	M-8-36
M-8-38	till (C.C.)		24	39	37	19	23.9	18.1	42.0	1.32	3.9	8.7	0770 2308	M-8-38
M-8-39	till (C.C.)		28	41	31	9	26.6	12.6	39.2	2.11	4.3	9.6	0770 2308	M-8-39
M-8-41	till (C.C.)		35	42	23	4.8	25.7	14.4	40.1	1.78			0770 2308	M-8-41
M-8-42	till (C.C.)		32	66	2	3.1	31.4	9.01	40.5	3.49	3.1	11.9	0770 2308	M-8-42

Appendix 3B. Pebble lithologies.

Field No.	Sample No.	Material Interpretation	Pebble Lithologies (percent)							Sample Location
			Limestone	Dolostone	Chert	Sandstone	Siltstone	Shale	Precambrian	
LP406-TM2	82-10-2	till (P.S.)	31	21	4	8	4	29	4	1050 2285
LP46-TM1	82-10-9	till (P.S.)	51	11	7	4	3	19	5	0435 2300
LP14-TM1	82-10-12	till (P.S.)	50	8	-	4	-	27	12	0772 2279
LP33-TM1	82-10-14	till (P.S.)	56	15	6	-	2	9	10	0835 2280
LP127-TM1	82-10-24	till (P.S.)	72	3	6	1	5	8	5	1330 3160
LP42-TM1	82-10-29	flow till (P.S.)	32	11	-	9	39	4	4	0560 2285
LP250-TM1	82-10-32	till (P.S.)	65	5	5	2	5	16	4	1305 2205
LP29-TM1	82-10-35	till (P.S.)	65	7	7	2	2	-	15	1567 3016
LP339-TM	82-10-38	till (W.T. Galt M.)	66	18	4	-	-	2	10	3045 1445
LP348-TM1	82-10-39	till (W.T. Galt M.)	45	28	9.5	2.5	-	-	15	3295 1395
LP388-TM1	82-10-40	till (W.T. Galt M.)	57	21	6	-	-	7	9	3440 1380
LP384BTM	82-10-41	till (W.T. Galt M.)	52	14	9	4	7	6	7	3710 1350
PB335-TM	82-10-43	till (W.T. Galt M.)	60	14	8	8	2	2	4	4305 2240
PB356-TM	82-10-45	till (W.T. Galt M.)	59	20	4	13	-	1	3	4320 2295
PB450-TM	82-10-47	till (W.T. Galt M.)	52	32	4	-	4	4	5	4855 2265
LP467-TM	82-10-48	till (W.T. Normandale)	85	7	2	-	2	-	4	5965 3190
LP458-TM1	82-10-53	flow till (W.T. Normandale)	58	5	22	-	-	-	14	5760 2945
LP464-TM1	82-10-56	flow till (W.T. Normandale)	64	12	18	1.5	1.5	-	3	5840 3050

Appendix 3C. Heavy mineral assemblages.

Field No.	Sample Location (UTM Grid)	Sample No.	Material Interpretation	Total Grains Counted	hbl	opx	cpx	tr/act	bt	ap	ep	spn	zrn	qtz	fel	c	O	HA	U	Gr _T	Gr _P	Gr _R	
LP116-TM3	998 226	82-10-1	till (P.S.)*	351																10.5	4	6.5	1.6
LP116-TM3	998 226	82-10-1	till (P.S.)+	459																14	4.5	9.5	2.0
LP40B-TM2	1050 2285	82-10-2	till (P.S.)*	261	34	6.5	26.5	2.5	1	2.5	T**	1.5	-	T	-	T	2	2	1	19.5	7.5	12	1.6
LP39-TM1	1760 2290	82-10-3	till (P.S.)*	292	38	2	28	4	-	2	-	1	T	-	T	3	1.5	2	-	18	8	10	1.3
LP17-TM2	2940 2304	82-10-4	till (P.S.)*	374																11	3.5	7.5	2.2
LP17-TM2	2940 2304	82-10-4	till (P.S.)+	187																15.5	6	9.5	1.6
LP115-TM2	9960 2240	82-10-5	till (P.S.)*	215	34.5	7	27	1.5	-	4	1.5	1	T	-	-	-	4	1	T	18	8	10	1.25
LP40-TM1	0115 2290	82-10-7	till (P.S.)*	188	34.5	6	30	1	-	4	0.5	2	0.5	-	-	1	-	1.5	0.5	16.5	7.5	9	1.2
LP26-TM1	0868 2267	82-10-13	till (P.S.)*	227	41	5	25	4	-	2	0.5	2	0.5	-	0.5	2	-	0.5	-	16.6	6	10.6	1.7
LP21-TM	1011 2348	82-10-15	till (P.S.)*	222	44	3	25	2	-	1	0.5	0.5	-	-	-	1	-	1	-	21.7	7.7	14	1.8
PB450-TM	4855 2265	82-10-47	till (W.T. Normandale)*	268	41	4	27.5	1	1	1.5	-	2	-	-	-	-	1.5	-	-	21.5	7.5	14	1.9
M-8-33	0770 2308	M-8-33	till (P.S.)*	297	36	3	31	2	-	1	0.5	1	0.5	-	-	1.5	4	2	-	16.5	6	10.5	1.8
M-8-39	0770 2308	M-8-39	till (C.C.)*	282	44	7	26	1	1	3	-	2	-	-	-	2.5	3	1	-	10.5	7	3.5	0.5
LP14-3	0772 2279	82-10-99	sand (facies A, M.N.)*	135	30	1.5	17	-	40	-	-	1.5	-	-	1	-	4	1	1	3	1.5	1.5	1
* counts done on the -60 mesh + 120 mesh fraction																							
+ counts done on the -120 mesh + 120 mesh fraction																							
*** present but in trace amounts less than 0.5 %																							
hbl	Homblende	opx	Orlthopyroxene	cpx	Clinopyroxene	tr/act	Tremolite/Actinolite	bt	Biotite														
ap	Apatite	ep	Epidotite	spn	Sphene	zrn	Zircon	qtz	Quartz														
Feldspar		c	Carbonate	o	Opaque	HA	Highly Altered	U	Unknown														
Gr _T	Total Garnet	Gr _T	Garnet (red)	Gr _P	Garnet (purple)	Gr _R	Garnet ratio																

* counts done on the -60 mesh + 120 mesh fraction

+ counts done on the -120 mesh + 120 mesh fraction

** present but in trace amounts less than 0.5 %

hbl	Hornblende	opx	Orthopyroxene	cpx	Clinopyroxene	tr/act	Tremolite/Actinolite	bt	Biotite
ap	Apatite	ep	Epidote	spn	Sphene	zrn	Zircon	qtz	Quartz
fel	Feldspar	c	Carbonate	0	Opaque	HA	Highly Altered	U	Unknown
Gr _T	Total Garnet	Gr _T	Garnet (red)	Gr _P	Garnet (purple)	Gr _R	Garnet ratio		

Appendix 4. Geochemical Properties of Samples

Explanation of Material Interpretation Codes:

C.C. - Catfish Creek Till
P.S. - Port Stanley Till
W.T. - Wentworth Till

Appendix 4. Geochemical properties of samples.

Field No.	Sample No.	Material Interpretation	Clay %	Trace Element Content (ppm)								Sample Location (UTM grid)
				Cu	Co	Cr	Ni	Zn	Pb	Ba	Li	
LP116-TM3	82-10-1	till (P.S.)	40	26	10	56	23	72	10	380	26	9980 2260
LP40B-TM2	82-10-2	till (P.S.)	38	26	10	56	22	74	10	340	25	1050 2285
LP39-TM1	82-10-3	till (P.S.)	43	28	11	59	26	86	10	310	28	1760 2290
LP17-TM2	82-10-4	till (P.S.)	42	26	11	57	25	78	10	410	27	2940 2304
LP115-TM2	82-10-5	till (P.S.)	36	27	10	53	22	70	10	370	24	9960 2240
LP42-TM2	82-10-6	till (P.S.)	38	26	10	54	22	68	-10	360	25	0560 2285
LP40-TM1	82-10-7	till (P.S.)	39	28	10	54	23	74	10	370	26	0115 2290
LP17-TM1	82-10-8	till (P.S.)	40	28	10	59	25	76	11	410	26	0294 2304
LP46-TM1	82-10-9	till (P.S.)	42	26	10	57	22	72	10	390	26	0435 2300
LP15-TM	82-10-10	till (P.S.)	41	26	11	55	22	74	10	340	26	0545 2295
LP34-TM1	82-10-11	till (P.S.)	42	26	11	55	23	78	10	360	26	0750 2285
LP14-TM1	82-10-12	till (P.S.)	43	26	11	58	25	75	10	370	26	0772 2279
LP26-TM1	82-10-13	till (P.S.)	45	27	11	57	24	76	10	370	26	0868 2267
LP33-TM1	82-10-14	till (P.S.)	25	26	10	49	19	67	10	380	22	0835 2280
LP21-TM	82-10-15	till (P.S.)	34	26	10	52	21	70	10	380	24	1011 2348
PB125-TM	82-10-16	till (P.S. Mabee M.)	38	27	10	54	22	72	10	360	26	0010 2363
PB115-BTM	82-10-17	till (P.S. Mabee M.)	34	25	9	51	21	70	-10	370	23	0375 2445
BP160-TM	82-10-18	till (P.S. Mabee M.)	36	27	10	53	22	72	10	350	25	0852 2643
LP144-TM1	82-10-19	till (P.S. Mabee M.)	30	26	9	50	20	65	10	380	23	1240 2850
LP144-TM4	82-10-20	till (P.S. Mabee M.)	27	24	8	51	18	67	-10	360	21	1290 2850
PB240-TM	82-10-21	till (P.S. Courtland M.)	26	26	10	50	20	72	10	380	24	0225 2760
PB23	82-10-22	till (P.S. Tillsonburg M.)	30	28	10	60	22	77	10	340	24	0327 2990
PB158-TM1	82-10-23	till (P.S. Courtland M.)	42	26	10	54	22	70	10	370	26	1175 3072
LP127-TM1	82-10-24	till (P.S. Courtland M.)	36	27	10	52	21	72	10	370	24	1330 3160
LP220-TM1	82-10-25	till (P.S. Tillsonburg M.)	27	26	9	46	19	66	10	350	22	0954 3285
LP144-TM2	82-10-26	flow till (P.S. Mabee M.)	41	28	9	50	20	68	10	330	23	1290 2850
LP144-TM3	82-10-27	flow till (P.S. Mabee M.)	26	24	7	44	16	62	-10	330	20	1290 2850
LP115-TM1	82-10-28	till ? (P.S.)	21	26	9	48	20	64	10	360	15	9960 2240
LP42-TM1	82-10-29	flow till (P.S.)	22	32	11	51	24	76	10	350	18	0560 2285
LP127-TM	82-10-30	flow till (P.S. Tillsonburg M.)	35	27	10	53	20	77	10	380	16	1330 3160
LP240-TM1	82-10-31	till (P.S.)	37	30	12	54	23	68	11	400	29	1210 2220
LP250-TM1	82-10-32	till (P.S.)	37	28	10	53	23	67	10	400	28	1305 2205
LP273-TM1	82-10-33	till (P.S.)	41	28	12	60	24	74	-10	440	31	1735 2085
LP266-TM1	82-10-34	till (P.S.)	39	28	11	54	24	68	-10	360	30	1560 2605
LP29-TM1	82-10-35	till (P.S. Mabee M.)	40	30	10	52	20	70	-10	420	26	1567 3016
LP337-TM1	82-10-36	flow till (W.T. Paris M.)	51	30	13	68	29	77	10	400	36	2965 1475
LP340-TM1	82-10-37	flow till (W.T. Paris M.)	47	30	12	59	27	76	-10	420	35	3045 1440
LP339-TM	82-10-38	till (W.T. Paris M.)	49	28	13	65	27	74	-10	400	35	3045 1440
LP348-TM1	82-10-39	till (W.T. Galt M.)	38	28	10	53	25	64	10	360	30	3295 1395
LP388-TM1	82-10-40	till (W.T. Galt M.)	46	29	13	61	29	72	10	340	34	3440 1380

Appendix 4. (cont'd) Geochemical properties of samples.

Field No.	Sample No.	Material Interpretation	Clay %	Trace Element Content (ppm)								Sample Location (UTM grid)
				Cu	Co	Cr	Ni	Zn	Pb	Ba	Li	
LP384BTM	82-10-41	till (W.T. Galt M.)	42	102	12	60	24	82	10	360	30	3710 1350
LP382-TM	82-10-42	till (W.T. Galt M.)	43	127	13	60	24	88	-10	420	32	3770 1340
PB335-TM	82-10-43	till (W.T. Galt M.)	38	162	11	55	21	91	-10	400	30	3845 1825
PB352-TM	82-10-44	till (W.T. Galt M.)	37	122	10	54	24	84	10	350	28	4305 2240
PB356-TM	82-10-45	till (W.T. Galt M.)	35	112	11	55	21	81	11	390	28	4320 2295
PB423-TM	82-10-46	till (W.T. Galt M.)	32	113	11	48	21	78	10	360	28	4460 2215
PB450-TM	82-10-47	till (W.T. Galt M.)	28	94	9	48	18	74	10	380	26	4855 2265
LP467-TM	82-10-48	till (W.T. Normandale)	15	81	8	38	15	60	-10	310	21	5966 3190
LP4-TM4	82-10-49	till (W.T. Normandale)	11	80	9	39	14	58	10	310	19	5564 2746
LP8-TM	82-10-50	till (W.T. Normandale)	21	112	11	49	20	74	12	360	24	5586 2778
LP6-TM1	82-10-51	flow till (W.T. Normandale)	7	63	6	38	14	68	-10	350	16	5590 2795
LP459B-TM2	82-10-52	flow till (W.T. Normandale)	9	50	6	32	11	51	-10	350	16	5745 2930
LP458-TM1	82-10-53	flow till (W.T. Normandale)	8	79	7	40	14	80	-10	360	18	5760 2945
LP458-TM2	82-10-54	flow till (W.T. Normandale)	10	76	6	35	14	61	-10	330	18	5755 2940
LP463-TM1	82-10-55	flow till (W.T. Normandale)	30	83	8	45	17	72	-10	360	26	5825 3025
LP464-TM1	82-10-56	flow till (W.T. Normandale)	11	47	6	36	13	54	-10	400	18	5840 3050
PB289-TM	82-10-57	flow till (W.T. Paris M.)	12	52	7	43	17	61	-10	380	21	3125 2755
LP202-TM	82-10-58	flow till (P.S. Mabee M.)	35	90	10	53	19	81	10	360	29	1565 2915
LP5-TM	82-10-59	till ball (W.T. Normandale)	21	58	8	45	16	76	10	350	24	5569 2750
LP4-GL	82-10-60	clay and silt	24	68	10	53	22	73	11	360	26	5564 2746
LP459-TM1	82-10-61	clay and silt	41	140	13	63	27	114	10	380	27	5745 2930
LP68-TM2	82-10-62	flow till (W.T. Normandale)	9	68	8	37	16	58	-10	330	16	5598 2796
LP530-TM	82-10-63	flow till (W.T. Normandale)	10	52	8	38	15	62	-10	340	16	5255 2565
LP198-TM	82-10-64	till (P.S. Courtland M.)	34	146	10	53	24	104	11	280	25	1070 3170
LP191-TM	82-10-65	till (P.S. Courtland M.)	34	89	11	54	23	84	-10	330	25	1260 3170
PB558-TM	82-10-66	till (P.S. Tillsonburg M.)	31	107	11	54	24	85	-10	330	24	2600 2865
PB20A	82-10-67	till (P.S. Tillsonburg M.)	27	135	11	53	24	92	-10	421	24	0327 2902
LP309-TM	82-10-68	till (P.S. Mabee M.)	29	122	11	52	23	86	-10	380	24	1493 3025
PB269	82-10-72	clay and silt	82	98	10	50	23	75	10	430	24	2965 3085
LP243-TM1	82-10-86	till (P.S.)	31	91	11	53	21	84	-10	450	24	1065 2240
	82-10-87	till (C.C. Sparta M.)	17	70	8	42	15	88	11	350	16	9355 2865
	82-10-88	till (W.T. Galt M.)	26	92	10	59	24	86	-10	400	24	4975 2380
LP719-FT1	82-10-141	flow till (P.S.)	37	120	12	53	21	83	16	430	25	0905 2270
LP719-FT2	82-10-142	flow till (P.S.)	26	82	10	47	17	72	14	400	22	0905 2270
LP719-TM	82-10-143	till (P.S.)	26	58	9	45	18	68	12	410	21	0905 2270

Appendix 4. (cont'd) Geochemical properties of samples.

Field No.	Sample No.	Material Interpretation	Clay %	Trace Element Content (ppm)								Sample Location (UTM grid)
				Cu	Co	Cr	Ni	Zn	Pb	Ba	Li	
M-5-6	M-5-6	till (W.T. Galt M.)	43	80	11	56	26	86	15	440	30	3574 1518
M-5-13	M-5-13	till (W.T. Galt M.)	39	48	11	54	25	84	14	400	30	3574 1518
M-5-18	M-5-18	till (W.T. Galt M.)	47	310	12	59	28	136	14	390	32	3574 1518
M-5-31	M-5-31	silt and clay	42	370	12	51	25	145	13	420	30	3574 1518
M-5-45	M-5-45	silt and clay	39	176	10	48	24	98	13	400	28	3574 1518
M-5-51	M-5-51	till (P.S.)	44	205	12	52	25	106	12	380	30	3574 1518
M-5-53	M-5-53	till (P.S.)	43	270	11	50	24	120	13	390	31	3574 1518
M-5-54	M-5-54	till (P.S.)	34	265	11	49	24	114	14	370	32	3574 1518
M-6-4	M-6-4	till (W.T. Paris M.)	43	159	12	57	27	104	16	420	32	2912 1709
M-6-6	M-6-6	clay and silt	40	158	11	50	24	94	18	390	28	2912 1709
M-6-10	M-6-10	clay and silt	43	340	12	53	24	134	20	370	28	2912 1709
M-6-13	M-6-13	clay and silt	65	162	14	62	27	110	15	400	32	2912 1709
M-6-15	M-6-15	till (P.S.)	40	172	12	53	23	100	16	380	28	2912 1709
M-6-17	M-6-17	till (P.S.)	36	96	11	51	23	86	15	390	27	2912 1709
M-6-19	M-6-19	till (P.S.)	41	137	12	56	26	96	16	400	30	2912 1709
M-6-23	M-6-23	till (P.S.)	40	108	13	54	25	90	16	380	30	2912 1709
M-6-26	M-6-26	till (P.S.)	43	118	13	55	26	92	17	400	30	2912 1709
M-7-7	M-7-7	clay and silt	42	103	11	53	24	92	16	400	28	1397 2719
M-7-13	M-7-13	till (P.S.)	46	126	12	56	24	96	18	370	30	1397 2719
M-7-15	M-7-15	till (P.S.)	50	104	13	66	28	100	45	420	31	1397 2719
M-7-19	M-7-19	till (P.S.)	36	103	11	55	26	93	19	380	29	1397 2719
M-7-22	M-7-22	till (P.S.)	36	124	12	54	24	94	30	330	28	1397 2719
M-7-25	M-7-25	till (P.S.)	55	139	13	73	33	112	27	410	36	1397 2719
M-7-32	M-7-32	till (P.S.)	37	124	11	55	25	89	18	380	29	1397 2719
M-8-12	M-8-12	till (P.S.)	50	132	12	62	27	101	22	400	30	0770 2308
M-8-14	M-8-14	till (P.S.)	44	179	12	59	25	107	22	400	30	0770 2308
M-8-23	M-8-23	till (P.S.)	40	164	12	62	28	104	25	380	32	0770 2308
M-8-25	M-8-25	till (P.S.)	40	114	11	55	23	92	20	400	30	0770 2308
M-8-28	M-8-28	till (P.S.)	42	139	12	62	28	96	20	420	32	0770 2308
M-8-33	M-8-33	till (P.S.)	38	130	12	64	30	94	17	390	33	0770 2308
M-8-36	M-8-36	till (P.S.)	37	127	11	59	25	91	17	400	29	0770 2308
M-8-38	M-8-38	till (C.C.)	24	164	11	65	30	88	19	370	30	0770 2308
M-8-39	M-8-39	till (C.C.)	28	132	11	60	28	85	21	350	30	0770 2308
M-8-41	M-8-41	till (C.C.)	35	91	11	63	29	82	17	350	32	0770 2308
M-8-42	M-8-42	till (C.C.)	32	72	11	90	34	62	12	300	40	0770 2308

Appendix 5. Geotechnical Properties of Samples

Explanation of Material Interpretation Abbreviations:

C.C. - Catfish Creek Till
P.S. - Port Stanley Till
W.T. - Wentworth Till

Appendix 5. Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
LP116-TM3	82-10-1	till (P.S.)	4	56	40	29	16	13	0.3	Cl	lean clay	9980 2260
LP406-TM2	82-10-2	till (P.S.)	4	58	38	27	16	11	0.3	Cl	lean clay	1050 2285
LP39-TM1	82-10-3	till (P.S.)	4	53	43	29	17	12	0.3	Cl	lean clay	1760 2290
LP17-TM2	82-10-4	till (P.S.)	3	55	42	29	16	13	0.3	Cl	lean clay	2940 2304
LP115-TM2	82-10-5	till (P.S.)	2	62	36	27	16	11	0.3	Cl	lean clay	9960 2240
LP42-TM2	82-10-6	till (P.S.)	3	59	38	27	16	11	0.3	Cl	lean clay	0560 2285
LP40-TM1	82-10-7	till (P.S.)	4	57	39	27	16	11	0.3	Cl	lean clay	0115 2290
LP17-TM1	82-10-8	till (P.S.)	5	55	40	27	16	11	0.3	Cl	lean clay	0294 2308
LP46-TM1	82-10-9	till (P.S.)	4	54	42	28	16	12	0.3	Cl	lean clay	0435 2300
LP15-TM	82-10-10	till (P.S.)	2	57	41	29	16	13	0.3	Cl	lean clay	0545 2295
LP34-TM1	82-10-11	till (P.S.)	2	56	42	30	18	12	0.3	Cl	lean clay	0750 2285
LP14-TM1	82-10-12	till (P.S.)	2	55	43	30	17	13	0.3	Cl	lean clay	0772 2279
LP26-TM1	82-10-13	till (P.S.)	2	53	45	31	17	14	0.3	Cl	lean clay	0868 2267
LP33-TM1	82-10-14	till (P.S.)	4	71	25	22	14	8	0.3	Cl	lean clay	0835 2280
LP21-TM	82-10-15	till (P.S.)	5	61	34	25	15	10	0.3	Cl	lean clay	1011 2348
PB125-TM	82-10-16	till (P.S. Mabee M.)	4	58	38	28	15	13	0.3	Cl	lean clay	0010 2363
PB115-8TM	82-10-17	till (P.S. Mabee M.)	3	63	34	32	18	14	0.4	Cl	lean clay	0375 2445
PB160-TM	82-10-18	till (P.S. Mabee M.)	3	61	36	26	16	10	0.3	Cl	lean clay	0852 2643
LB144-TM1	82-10-19	till (P.S. Mabee M.)	5	65	30	24	14	10	0.3	Cl	lean clay	1290 2850
LP144-TM4	82-10-20	till (P.S. Mabee M.)	5	68	27	27	16	11	0.4	Cl	lean clay	1290 2850
PB240-TM	82-10-21	till (P.S. Courtland M.)	5	69	26	22	13	9	0.4	Cl	lean clay	0225 2760
PB23	82-10-22	till (P.S. Tillsonburg M.)	15	55	30	24	13	11	0.4	Cl	lean clay with sand	0327 2990
PB158-TM1	82-10-23	till (P.S. Courtland M.)	4	54	42	29	16	13	0.3	Cl	lean clay	1175 3072
LP127-TM1	82-10-24	till (P.S. Courtland M.)	5	59	36	26	15	11	0.3	Cl	lean clay	1330 3160

Appendix 5. (cont'd) Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
LP144-TM4	82-10-25	till (P.S. Tillsonburg M.)	13	60	27	21	13	8	0.3	Cl	lean clay	0954 3285
PB158-TM1	82-10-26	flow till (P.S. Mabee M.)	2	57	41	32	17	15	0.4	Cl	lean clay	1290 2850
LP127-TM1	82-10-27	flow till (P.S. Mabee M.)	5	69	26	27	16	11	0.4	Cl	lean clay	1290 2850
LP220-TM1	82-10-28	till ? (P.S.)	13	66	21	21	13	8	0.4	Cl	lean clay	9960 2240
LP144-TM2	82-10-29	flow till (P.S.)	24	54	22	19	12	7	0.3	Cl-MI	lean clay with sand	0560 2285
LP144-TM3	82-10-30	flow till (P.S. Tillsonburg M.)	5	60	35	29	16	13	0.4	Cl	lean clay	1330 3160
LP42-TM1	82-10-31	till (P.S.)	2	61	37	27	16	11	0.3	Cl	lean clay	1210 2220
LP127-TM	82-10-32	till (P.S.)	2	61	37	27	16	11	0.3	Cl	lean clay	1305 2205
LP240-TM1	82-10-33	till (P.S.)	2	57	41	32	17	15	0.4	Cl	lean clay	1735 2085
LP250-TM1	82-10-34	till (P.S.)	3	58	39	28	16	12	0.3	Cl	lean clay	1560 2605
LP273-TM1	82-10-35	till (P.S. Mabee M.)	5	55	40	33	18	15	0.4	Cl	lean clay	1567 3016
LP29-TM1	82-10-36	flow till (W.T. Paris M.)	3	46	51	34	18	16	0.3	Cl	lean clay	2965 1475
LP337-TM1	82-10-37	flow till (W.T. Paris M.)	3	50	47	31	18	13	0.3	Cl	lean clay	3045 1440
LP340-TM1	82-10-38	till (W.T. Galt M.)	3	48	49	32	18	14	0.3	Cl	lean clay	3045 1445
LP339-TM	82-10-39	till (W.T. Galt M.)	5	57	38	27	16	11	0.3	Cl	lean clay	3295 1395
LP348-TM1	82-10-40	till (W.T. Galt M.)	2	52	46	31	17	14	0.3	Cl	lean clay	3440 1380
LP388-TM1	82-10-41	till (W.T. Galt M.)	3	55	42	30	17	13	0.3	Cl	lean clay	3710 1350
LP384-8TM	82-10-42	till (W.T. Galt M.)	3	54	43	30	17	13	0.3	Cl	lean clay	3770 1340
LP382-TM	82-10-43	till (W.T. Galt M.)	4	58	38	28	16	12	0.3	Cl	lean clay	3845 1825
PB335-TM	82-10-44	till (W.T. Galt M.)	2	61	37	31	17	14	0.4	Cl	lean clay	4305 2240
PB352-TM	82-10-45	till (W.T. Galt M.)	4	61	35	31	18	13	0.4	Cl	lean clay	4320 2295
PB356-TM	82-10-46	till (W.T. Galt M.)	4	64	32	26	15	11	0.3	Cl	lean clay	4460 2215
PB423-TM	82-10-47	till (W.T. Galt M.)	4	68	28	25	16	9	0.3	Cl	lean clay	4855 2265

Appendix 5. (cont'd) Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
PB450-TM	82-10-48	till (W.T. Normandale)	24	61	15	17	12	5	0.3	Cl-MI	silty clay with sand	5965 3190
LP467-TM	82-10-49	flow till (W.T. Normandale)	9	80	11	18	15	3	0.3	MI	silt	5564 2746
LP8TM	82-10-50	flow till (W.T. Normandale)	12	67	21	21	14	7	0.3	Cl-MI	silty clay	5586 2778
LP6TM1	82-10-51	flow till (W.T. Normandale)	29	64	7		non plastic		-	MI	silt with clay	5590 2795
LP6TM1	82-10-52	flow till (W.T. Normandale)	29	62	9	17	15	2	2	MI	silt with sand	5745 2930
LP459B-TM2	82-10-53	flow till (W.T. Normandale) M.)	45	47	8		non plastic		-	MI	sandy silt	5760 2945
LP458-TM1	82-10-54	flow till (W.T. Normandale)	39	51	10		non plastic		-	MI	sandy silt	5755 2940
LP458-TM2	82-10-55	flow till (W.T. Normandale)	8	62	30	22	14	8	0.3	CI	lean clay	5825 3025
LP463-TM1	82-10-56	flow till (W.T. Normandale)	23	66	11	15	14	1	0.1	MI	silt with sand	5840 3050
LP464-TM1	82-10-57	flow till (W.T. Paris M.)	6	82	12	19	17	2	0.2	MI	silt	3125 2755
PB289-TM	82-10-58	flow till (P.S. Mabec M.)	3	62	35	26	15	11	0.3	CI	lean clay	1565 2915
LP202-TM	82-10-59	till ball (W.T. Normandale)	21	63	21	19	13	6	0.3	Cl-MI	silty clay with sand	5569 2750
LP5-TM	82-10-60	glaciolacustrine clay and silt	3	75	24	26	16	8	0.3	CI	lean clay	5564 2746
LP4-9GL	82-10-61	glaciolacustrine clay and silt	3	56	41	31	17	14	0.3	CI	lean clay	5745 2930
P459-TM1	82-10-62	flow till (W.T.Normandale)	25	66	9	15	13	2	0.2	MI	silt with sand	5598 2796

Appendix 5. (cont'd) Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
LP68-TM2	82-10-63	flow till (W.T. Normandale)	10	80	10	17	14	3	0.3	MI	silt	5255 2565
LP530-TM	82-10-64	till (P.S. Courtland M.)	6	60	34	26	15	11	0.3	CI	lean clay	1070 3170
LP198-TM	82-10-65	till (P.S. Courtland M.)	7	60	34	26	14	12	0.4	CI	lean clay	1260 3170
LP191-TM	82-10-66	till (P.S. Tillsontburg M.)	4	65	31	26	15	11	0.4	CI	lean clay	2600 2865
PB558-TM	82-10-67	till (P.S. Tillsontburg M.)	5	68	27	25	15	10	0.4	CI	lean clay	0327 2902
PB20A	82-10-68	till (P.S. Mabec M.)	11	60	29	22	13	9	0.3	CI	lean clay	1493 3025
LP309-TM	82-10-69	glaciolacustrine clay	0	18	82	66	24	42	0.5	CH	fat clay	7720 2279
LP140	82-10-72	till (W.T. Paris M.)	9	72	19	21	14	7	0.4	CI-MI	silty clay	2965 3085
LP469	82-10-86	till (P.S.)	4	65	31	24	14	10	0.3	CI	lean clay	1065 2240
LP727-TM	82-10-88	till (C.C. Sparta M.)	34	49	17	21	13	8	0.5	CI	lean clay with sand	9355 2865
LP727-TM	82-10-89	till (W.T. Galt M.)	3	71	26	22	14	8	0.3	CI	lean clay	4475 2380
LP14-1	82-10-91	flow till (P.S.)	3	70	27	23	14	9	0.	CI	lean clay	0772 2279
PB14-2	82-10-92	flow till (P.S.)	4	70	26	22	13	9	0.4	CI	lean clay	0772 2279
PB133-4	82-10-93	flow till (P.S.)	3	78	19	20	14	6	0.3	CI-MI	silty clay	0770 2335
PB133-3	82-10-94	glaciolacustrine clay and silt	1	62	37	29	16	13	0.4	CI	lean clay	0770 2335
PB133-2	82-10-95	glaciolacustrine clay and silt	1	49	50	37	18	19	0.4	CI	lean clay	0770 2335
LP133-1	82-10-101	glaciolacustrine clay	0	20	80	70	25	45	0.6	CH	fat clay	0772 2279
LP14-10	82-10-106	glaciolacustrine clay	0	64	36	30	15	15	0.4	CI	lean clay	0772 2279
LP14-14	82-10-110	glaciolacustrine clay	0	59	41	31	15	16	0.4	CI	lean clay	0772 2279

Appendix 5. (cont'd) Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
LP750-4a	82-10-139	glaciolacustrine silt	0	70	30	26	16	10	0.3	Cl	lean clay	3005 1455
LP750-4b	82-10-140	glaciolacustrine clay	0	21	79	62	27	35	0.4	CH	fat clay	3005 1455
LP719-FT1	82-10-141	flow till (P.S.)	4	59	37	26	15	11	0.3	Cl	lean clay	0905 2270
LP719-FT2	82-10-142	flow till (P.S.)	4	70	26	22	14	8	0.3	Cl	lean clay	0905 2270
LP719-TM	82-10-143	till (P.S.)	5	69	26	21	14	7	0.3	Cl-MI	silty clay	0905 2270
M-5-16	M-5-16	till (W.T. Galt M.)	2	55	43	33	17	16	0.4	Cl	lean clay	3574 14518
M-5-13	M-5-13	till (W.T. Galt M.)	4	57	39	29	16	13	0.3	Cl	lean clay	3574 1518
M-5-18	M-5-18	till (W.T. Galt M.)	3	50	47	34	17	17	0.4	Cl	lean clay	3574 1518
M-5-31	M-5-31	glaciolacustrine silt and clay	0	58	42	31	17	14	0.3	Cl	lean clay	3574 1518
M-5-45	M-5-45	glaciolacustrine silt and clay	0	61	39	29	16	13	0.3	Cl	lean clay	3574 1518
M-5-51	M-5-51	till (P.S.)	3	53	44	32	17	15	0.3	Cl	lean clay	3574 1518
M-5-53	M-5-53	till (P.S.)	11	46	43	31	16	15	0.4	Cl	lean clay	3574 1518
M-5-54	M-5-54	till (P.S.)	23	43	34	27	15	12	0.4	Cl	lean clay with sand	3574 1518
M-6-4	M-6-4	till (W.T. Paris M.)	4	53	43	33	17	16	0.4	Cl	lean clay	2912 1709
M-6-6	M-6-6	glaciolacustrine silt and clay	0	60	40	30	16	14	0.4	Cl	lean clay	2912 1709
M-6-10	M-6-10	glaciolacustrine silt and clay	0	57	43	30	17	13	0.3	Cl	lean clay	2912 1709
M-6-13	M-6-13	glaciolacustrine silt and clay	0	35	65	36	19	17	0.3	Cl	lean clay	2912 1709
M-6-15	M-6-15	till (P.S.)	2	58	40	29	16	13	0.3	Cl	lean clay	2912 1709
M-6-17	M-6-17	till (P.S.)	1	63	36	27	16	11	0.3	Cl	lean clay	2912 1709
M-6-19	M-6-19	till (P.S.)	10	49	41	29	15	14	0.3	Cl	lean clay	2912 1709
M-6-23	M-6-23	till (P.S.)	8	52	40	27	16	11	0.3	Cl	lean clay	2912 1709
M-6-26	M-6-26	till (P.S.)	7	50	43	30	16	14	0.3	Cl	lean clay	2912 1709

Appendix 5. (cont'd) Geotechnical properties of samples.

Field No.	Sample No.	Material	Textural Analysis			Atterberg Limits				Unified Soil Classification System		Sample Location (UTM grid)
			Sand %	Silt %	Clay %	Liquid Limit	Plastic Limit	Plasticity Index	Activity Ratio	Group Symbol	Group Name	
M-7-7	M-7-7	glaciolacustrine clay and silt	2	56	43	29	17	12	0.3	Cl	lean clay	1397 2719
M-7-13	M-7-13	till (P.S.)	3	51	46	31	17	14	0.3	Cl	lean clay	1397 2719
M-7-15	M-7-15	till (P.S.)	4	46	50	33	18	15	0.3	Cl	lean clay	1397 2719
M-7-19	M-7-19	till (P.S.)	8	56	36	26	15	11	0.3	Cl	lean clay	1397 2719
M-7-22	M-7-22	till (P.S.)	6	58	36	27	15	12	0.3	Cl	lean clay	1397 2719
M-7-25	M-7-25	till (P.S.)	5	40	55	36	19	17	0.3	Cl	lean clay	1397 2719
M-7-32	M-7-32	till (P.S.)	4	59	37	28	15	13	0.4	Cl	lean clay	1397 2719
M-8-12	M-8-12	till (P.S.)	2	48	50	34	17	17	0.3	Cl	lean clay	0770 2308
M-8-14	M-8-14	till (P.S.)	5	51	44	30	16	14	0.3	Cl	lean clay	0770 2308
M-8-23	M-8-23	till (P.S.)	8	52	40	28	16	12	0.3	Cl	lean clay	0770 2308
M-8-25	M-8-25	till (P.S.)	4	56	40	28	15	13	0.3	Cl	lean clay	0770 2308
M-8-28	M-8-28	till (P.S.)	9	49	42	30	16	14	0.3	Cl	lean clay	0770 2308
M-8-33	M-8-33	till (P.S.)	14	48	38	28	16	12	0.3	Cl	lean clay	0770 2308
M-8-36	M-8-36	till (P.S.)	4	59	37	28	15	13	0.4	Cl	lean clay	0770 2308
M-8-38	M-8-38	till (C.C.)	37	39	24	22	12	10	0.4	Cl	lean clay with sand	0770 2308
M-8-39	M-8-39	till (C.C.)	31	41	28	24	13	11	0.4	Cl	lean clay with sand	0770 2308
M-8-41	M-8-41	till (C.C.)	23	42	35	26	14	12	0.3	Cl	lean clay with sand	0770 2308
M-8-42	M-8-42	till (C.C.)	2	66	32	30	17	13	0.4	Cl	lean clay	0770 2308

Appendix 6. Statistical Parameters of Grain Size

Explanation of Symbols:

1) ϕ_5 , 16, etc.: values of phi at the 5th, 16th, etc., percentiles

2) M_z : Graphic Mean (Folk 1968)

$$\text{where } M_z = (\phi_{16} + \phi_{50} + \phi_{84}) / 3$$

3) σ_I : Inclusive Graphic Standard Deviation (Folk 1968)

$$\text{where } \sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

under 0.35ϕ , very well sorted

between 0.35 and 0.5ϕ , well sorted

between 0.5 and 0.71ϕ , moderately well sorted

between 0.71 and 1.0ϕ , moderately sorted

between 1.0 and 2.0ϕ , poorly sorted

between 2.0 and 4ϕ , very poorly sorted

over 4ϕ , extremely poor sorted.

4) Sk_I : Inclusive Graphic Skewness (Folk 1968)

$$\text{where } Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

Sk_I values between 1.0 and 0.3, strongly fine skewed

between 0.3 and 0.1, fine skewed

between 0.1 and -0.1, near symmetrical

between -0.1 and -0.3, coarse skewed

between -0.3 and -1.0, strongly coarse skewed

5) K_G : Graphic Kurtosis

$$\text{where } K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

$K_G \approx 1.00$, normal curves

$K_G > 1.00$, leptokurtic curves

$K_G < 1.00$, platykurtic curves

6) Material interpretation

C.C. - Catfish Creek Till

P.S. - Port Stanley Till

W.T. - Wentworth Till

M.N. - McConnell's Nursery (*see* "Sediments of the Lakeview Moraine")

S.H. - The Sand Hills Park (*see* "Sediments of the Galt Moraine")

f.a.1 - facies association 1 (*see* "Sediments of the Jacksonburg Delta")

f.a.2 - facies association 2 (*see* "Sediments of the Jacksonburg Delta")

f.a.3 - facies association 3 (*see* "Sediments of the Jacksonburg Delta")

f.a.4 - facies association 4 (*see* "Sediments of the Jacksonburg Delta")

c.b. - convolute bedded

c.r.d. - climbing ripple drift

f.b. - flat bedded

r.c.l. - ripple cross-laminated

t.c.b. - trough cross-bedded

l.a.c.b. - low-angle cross-bedded

Appendix 6. Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ ₁	Sk ₁	K _G	Sample Location (UTM grid)
LP116-TM3	82-10-1	till	3.9	5.5	6.3	7.8	12.1*	15.0*	20.0*	9.5*	4.8*	0.5*	1.1*	9980 2260
LP406-TM2	82-10-2	till	4.2	5.4	6.1	7.6	12*	16.5*	21*	9.9*	5.3*	0.6*	5.3*	1050 2285
LP39-TM1	82-10-3	till	4.5	5.8	6.9	8.4	11*	12.3*	14.8*	8.8*	3.2*	0.2*	1.0*	1760 2290
LP17-TM2	82-10-4	till	4.5	5.6	6.6	8.3	10.8*	12*	14.5*	8.6*	3.1*	0.2*	1.0*	2940 2304
LP115-TM2	82-10-5	till	4.8	5.9	6.5	8.2	10.1*	11.1*	13.2*	8.4*	2.6*	0.2*	1.0*	9960 2240
LP40-TM1	82-10-7	till	4.4	5.5	6.4	8.2	10.5*	11.7*	14*	8.5*	3.0*	0.2*	1.0*	0115 2290
LP14-TM1	82-10-12	till	4.8	6.7	7.8	9.4	10.5*	11*	12.1*	9.0*	2.2*	-0.3*	1.1*	0772 2279
LP33-TM1	82-10-14	till	4.2	5.1	5.6	6.7	9.1	10.5*	13.2*	7.4*	2.7*	0.4*	1.1*	0835 2280
LP21-TM5	82-10-15	till	4.1	5.6	6.0	7.8	9.9*	11.1*	13.3*	8.2*	2.8*	0.2*	1.0*	1011 2348
PB125-TM	82-10-16	till	4.6	5.6	6.4	8.2	10.5*	11.8*	14.4*	8.5*	3.0*	0.2*	1.0*	0010 2363
LP144-TM1	82-10-19	till (P.S. Mabee M.)	4.2	5.2	5.8	7.6	9.8	11.2*	14*	8.0*	3.0*	0.3*	1.0*	1290 2850
LP144-TM4	82-10-20	till (P.S. Mabee M.)	4.0	5.1	5.8	7.5	9.3	10.5*	12.9*	7.7*	2.7*	0.2*	1.0*	1290 2850
LP144-TM2	82-10-26	flow till (P.S. Mabee M.)	4.8	6.0	6.7	8.4	9.6	11.7*	13.8*	8.7*	2.8*	0.2*	1.3*	1290 2850
LP42-TM1	82-10-29	flow till (P.S.)	0.6	3.2	4.2	6.3	8.5	10.3*	13.7*	6.6*	3.8*	0.1*	1.3*	0560 2285
LP273-TM1	82-10-33	till (P.S.)	4.9	6.2	6.7	8.5	10.9*	11.9*	14.2*	8.9*	2.8*	0.2*	0.9*	1735 2085
LP339-TM	82-10-38	till (W.T. Galt M.)	4.6	6.0	7.0	9.1	11.3*	12.3*	14.4*	9.1*	3.1*	0.1*	0.9*	3045 1445
LP348-TM1	82-10-39	till (W.T. Galt M.)	4.1	5.9	6.4	8.2	10.7*	12*	14.5*	8.7*	3.1*	0.2*	1.0*	3295 1395
LP388-TM1	82-10-40	till (W.T. Galt M.)	5.0	6.3	7.0	9.0	11.2*	12.3*	14.4*	9.2*	2.9*	0.1*	0.9*	3440 1380
PB450-TM	82-10-47	till (W.T. Galt M.)	4.3	5.4	6.0	7.5	9.7	11.1	14*	8.0*	2.9*	0.3*	1.1*	4855 2265
LP467-TM	82-10-48	till (W.T. Normandale)	0.4	3.0	4.2	6.1	7.8	9.3	14*	6.1	3.6*	0.1*	1.6*	5965 3190
LP202-TM	82-10-58	flow till (P.S. Mabee M.)	4.6	5.8	6.5	8.2	9.4	11.5*	13.8*	8.5*	2.8*	0.2*	1.3*	1565 2915
LP464	82-10-70	glaciolacustrine sand	2.8	3.1	3.2	3.6	4.0	4.3	4.8	3.6	0.5	0.2	1.0	5840 3050
LP513	82-10-71	delaic gravel	-4.2	-3.6	-2.7	-1.4	0.1	0.6	1.4	-1.7	1.8	-0.1	0.8	5515 3105
PB494	82-10-73	glaciolacustrine sand	2.9	3.1	3.3	3.6	4.1	4.3	4.9	3.7	0.6	0.3	1.1	1675 3190
PB488	82-10-74	glaciolacustrine sand	1.5	1.6	1.7	1.9	2.2	2.3	2.9	1.9	0.4	0.4	1.3	3650 2130
PB496	82-10-75	dune sand	1.6	2.0	2.1	2.4	2.9	3.1	3.5	2.5	0.6	0.2	1.0	0016 2956
PB495-76	82-10-76	dune sand	2.0	2.3	2.4	2.7	3.1	3.3	3.7	2.8	0.5	0.1	1.0	1535 3105
PB493-77	82-10-77	dune sand	2.0	2.5	2.4	2.7	3.1	3.3	3.7	2.8	0.5	0.3	0.9	1650 3205
PB492-78	82-10-78	dune sand	1.9	2.2	2.3	2.6	2.0	3.2	3.6	2.7	0.5	0.2	1.0	1670 3140

**extrapolated data point; determination involves extrapolated data point.*

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ _I	Sk _I	K _G	Sample Location (UTM grid)
PB491-79	82-10-79	dune sand	1.6	2.0	2.1	2.5	2.9	3.1	3.6	2.5	0.6	0.1	1.0	1750 3180
PB490	82-10-80	dune sand	1.5	1.8	2.0	2.3	2.8	3.0	3.5	2.4	0.6	0.2	1.1	2990 3140
PB489	82-10-81	dune sand	2.2	2.5	2.7	3.0	3.3	3.4	3.8	3.0	0.5	-0.03	1.1	2910 2255
PB358	82-10-82	dune sand	1.7	1.9	2.1	2.5	3.0	3.2	3.7	2.5	0.6	0.1	0.9	4295 2505
PB487A	82-10-83	dune sand	2.2	2.4	2.6	2.8	3.1	3.3	3.6	2.8	0.4	0.1	1.1	4305 2880
PB487B	82-10-84	dune sand	2.1	2.4	2.5	2.8	3.1	3.2	3.7	2.8	0.5	0.1	1.2	4305 2880
PB486	82-10-85	dune sand	2.0	2.3	2.5	2.7	3.0	3.1	3.4	2.7	0.4	0.01	1.0	4700 2855
LP14-1	82-10-91	flow till (P.S. layer D)	4.5	5.4	5.8	7.4	9.7	11.3*	14.6*	8.0*	3.0*	0.4*	1.1*	0772 2279
LP14-2	82-10-92	flow till (P.S. layer D)	4.2	5.1	5.6	7.1	9.4	11.1*	14.5*	7.8*	3.1*	0.4*	1.1*	0772 2279
PB133-4	82-10-93	flow till (P.S. layer d)	4.4	5.1	5.4	6.3	8.3	10.2*	14.5*	7.2*	2.8*	0.6*	1.4*	0770 2335
PB133-3	82-10-94	glaciolacustrine silt and clay	5.2	6.1	6.8	8.3	10.7*	11.8*	14.3*	8.7*	2.8*	0.3*	1.0*	0770 2335
PB133-2	82-10-95	glaciolacustrine silt and clay	5.4	6.9	7.8	9.4	10.9*	12*	14.4*	9.4*	2.7*	0.1*	1.2*	0770 2335
PB133-1	82-10-96	glaciolacustrine sand	2.2	2.4	2.5	2.8	3.1	3.2	3.6	2.8	0.4	0.1	1.0	0770 2335
LP14-1	82-10-97	sand (facies A, M.N.)	3.2	3.4	3.6	3.9	4.5	4.8	5.7	4.0	0.7	0.4	1.1	0772 2279
LP14-2	82-10-98	sand (facies A, M.N.)	3.0	3.2	3.3	3.6	4.1	4.5	5.6	3.8	0.7	0.4	1.3	0772 2279
LP14-3	82-10-99	sand (facies A, M.N.)	2.9	3.2	3.3	3.5	4.0	4.3	5.8	3.7	0.7	0.5	1.7	0772 2279
LP14-4	82-10-100	silt (facies A, M.N.)	3.6	4.1	4.3	4.7	6.0	6.4	7.9	5.1	1.2	0.5	1.0	0772 2279
LP14-6	82-10-102	silt (facies A, M.N.)	3.4	3.7	3.8	4.2	4.7	5.0	6.1	4.3	0.8	0.3	1.2	0772 2279
LP14-7	82-10-103	sand (facies A, M.N.)	3.0	3.3	3.4	3.8	4.4	4.8	6.2	3.9	0.9	0.4	1.3	0772 2279
LP14-8	82-10-104	silt (facies A, M.N.)	3.2	3.6	3.8	4.4	5.1	5.6	7.1	4.5	1.1	0.3	1.2	0772 2279
LP14-9	82-10-105	silt (facies A, M.N.)	4.5	5.1	5.3	6.1	7.5	8.7	12.3*	6.6	2.1*	0.5*	1.5*	0772 2279
LP14-11	82-10-107	silt (facies A, M.N.)	3.1	3.4	3.6	4.0	4.6	4.9	6.1	4.1	0.8	0.3	1.2	0772 2279
LP14-12	82-10-108	silt (facies A, M.N.)	2.7	3.2	3.4	4.2	5.1	5.5	7.3	4.3	1.3	0.3	1.1	0772 2279
LP14-13	82-10-109	silt (facies A, M.N.)	3.0	3.4	3.5	3.8	4.4	4.7	5.9	4.0	0.8	0.4	1.4	0772 2279
LP14-15	82-10-111	silt (facies A, M.N.)	4.1	4.5	4.7	5.0	5.6	6.1	7.6	5.2	0.9	0.4	1.5	0772 2279
LP14-16	82-10-112	sand (facies A, M.N.)	2.9	3.2	3.3	3.6	3.9	4.3	5.3	3.7	0.7	0.4	1.5	0772 2279
LP14-17	82-10-113	sand (facies A, M.N.)	3.5	3.9	4.0	4.6	5.3	5.7	7.0	4.7	1.0	0.3	1.1	0772 2279
LP739-4-1	82-10-115	sand (facies A, S.H.) r.c.l.	3.1	3.4	3.6	3.9	4.3	4.5	5.0	3.9	0.6	0.2	1.2	2950 1475
LP739-5-1	82-10-116	silt (facies A, S.H.)	4.1	4.5	4.5	5.0	5.4	5.7	6.9	5.1	0.7	0.3	1.2	2950 1475

*extrapolated data point; determination involves extrapolated data point.

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ ₁	Sk ₁	K _G	Sample Location (UTM grid)
LP739-6-1	82-10-117	sand (facies A, S.H.) c.r.d.	3.2	3.5	3.6	4.0	4.4	4.6	5.4	4.0	0.6	0.2	1.2	2950 1475
LP739-6-2	82-10-118	silt (facies A, S.H.)	3.3	3.6	3.8	4.1	4.7	4.8	5.7	4.2	0.7	0.3	1.1	2950 1475
LP739-6-3	82-10-119	sand (facies A, S.H.) c.b.	2.9*	3.2	3.4	3.7	4.0	4.2	4.7	3.7	0.5*	0.1*	1.2*	2950 1475
LP739-6-4	82-10-120	silt (facies A, S.H.)	3.4	3.7	3.9	4.3	4.7	5.0	6.0	4.3	0.7	0.2	1.2	2950 1475
LP739-9-1	82-10-121	sand (facies D, S.H.) f.b.	1.8	2.1	2.2	2.5	2.8	3.0	3.4	2.5	0.5	0.2	1.1	2950 1475
LP739-9-2	82-10-122	sand (facies D, S.H.) t.c.b.	1.6	2.0	2.2	2.4	2.7	2.9	3.2	2.4	0.5	0.1	1.3	2950 1475
LP739-10	82-10-123	sand (facies D, S.H.) f.b.	1.5	1.7	1.8	1.9	2.3	2.4	2.8	2.0	0.4	0.3	1.1	2950 1475
LP739-11	82-10-124	sand (facies D, S.H.) r.c.l.	1.9	2.2	2.3	2.5	2.9	3.1	3.5	2.6	0.5	0.3	1.0	2950 1475
LP739-12	82-10-125	sand (facies D, S.H.) t.c.b.	1.6	1.8	1.9	2.2	2.5	2.7	3.2	2.2	0.5	0.2	1.1	2950 1475
LP739-13	82-10-126	sand (facies D, S.H.) f.b.	1.5	1.7	1.9	2.2	2.5	2.7	3.1	2.2	0.5	0.2	1.0	2950 1475
LP740-Sd1a	82-10-127	sand (facies D, S.H.) f.b.	1.5	1.8	1.9	2.1	2.4	2.5	2.9	2.1	0.4	0.1	1.1	2875 1512
LP740-Sd2	82-10-128	sand (facies D, S.H.) f.b.	1.6	2.0	2.2	2.5	2.9	3.1	3.6	2.5	0.6	0.2	1.1	2875 1512
LP740-Sd3	82-10-129	sand (facies D, S.H.) f.b.	1.9	2.3	2.5	2.9	3.3	3.5	4.1*	2.9	0.6*	0.1*	1.2*	2875 1512
LP339-8	82-10-130	sand (facies A, S.H.) r.c.l.	2.7	3.0	3.1	3.5	3.9	4.2	4.8	3.6	0.6	0.2	1.1	3045 1445
LP339-10	82-10-131	sand (facies A, S.H.) r.c.l.	2.7	3.0	3.1	3.4	3.8	4.2	5.2	3.5	0.7	0.4	1.4	3045 1445
LP339-6	82-10-132	sand (facies D, S.H.) r.c.l.	2.0	2.5	2.7	3.1	3.7	4.0	4.6	3.2	0.8	0.1	1.0	3045 1445
LP750-1	82-10-133	sand (facies A, S.H.) r.c.l.	2.2	2.5	2.6	2.9	3.2	3.4	3.9	2.9	0.5	0.1	1.1	3005 1455
LP750-2	82-10-134	silt (facies A, S.H.)	3.3	3.6	3.7	4.1	4.6	4.8	5.6	4.1	0.6	0.3	1.1	3005 1455
LP750-3	82-10-135	silt (facies A, S.H.) r.c.l.	3.9	4.2	4.4	4.7	5.2	5.6	6.6	4.8	0.8	0.3	1.5	3005 1455
LP750-6	82-10-136	sand (facies D, S.H.) f.b.	2.1	2.3	2.4	2.7	3.2	3.5	4.1*	2.8	0.6*	0.4*	1.1*	3005 1455
LP750-7	82-10-137	sand (facies D, S.H.) r.c.l.	2.6	2.9	3.1	3.3	3.7	4.0	4.7	3.4	0.6	0.3	1.5	3005 1455
LP750-8	82-10-138	silt (facies D, S.H.) c.b.	3.4	3.8	4.0	4.4	4.9	5.3	6.3	4.5	0.8	0.2	1.3	3005 1455
LP750-4a	82-10-139	silt (facies A, S.H.)	5.3	6.2	6.6	7.7	9.8	11.2*	14*	8.3*	2.6*	0.4	1.1*	3005 1455
LP750-4b	82-10-140	clay (facies A, S.H.)	5.3	8.2	9.3	12.2*	13.5*	14.6*	16.5*	11.7*	3.3*	-0.2*	1.1*	3005 1455
LP719-FT1	82-10-141	flow till (P.S. layer D)	4.1	5.5	6.3	8.0	10.2	11.5*	13.8*	8.3*	3.0*	0.2*	1.0*	0906 2262
LP719-FT2	82-10-142	flow till (P.S. layer D)	4.1	4.9	5.3	6.8	9.2	10.4*	12.5*	7.4*	2.7*	0.3*	0.9*	0906 2262
LP719-TM	82-10-143	till (P.S. layer D)	4.0	4.8	5.3	6.8	9.2	10.4*	12.6*	7.3*	2.7*	0.3*	0.9*	0906 2262
M-5-31	M-5-31	glaciolacustrine clay and silt	5.6	6.8	7.5	8.6	10.8*	11.8*	14*	9.1*	2.5*	0.3*	1.0*	3574 1518
M-5-45	M-5-45	glaciolacustrine clay and silt	5.5	6.8	7.4	8.5	10.4*	11.3*	13.2*	8.9*	2.3*	0.2*	1.0*	3574 1518

*extrapolated data point; determination involves extrapolated data point.

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ _I	Sk _I	K _G	Sample Location (UTM grid)
M-6-6	M-6-6	glaciolacustrine clay and silt	5.5	6.9	7.4	8.7	10.8*	11.9*	14.1*	9.1*	2.6*	0.3*	1.0*	2912 1709
M-6-10	M-6-10	glaciolacustrine clay and silt	5.5	6.7	7.5	8.8	10.5*	11.3*	13*	8.9*	2.3*	0.1*	1.0*	2912 1709
M-6-13	M-6-13	glaciolacustrine clay and silt	4.7	7.5	7.8	9.5	11.2*	12*	13.6*	9.7*	2.5*	0.01*	1.1*	2912 1709
M-8-14	M-8-14	till (P.S. layer B)	4.2	6.1	7.0	8.8	10.9*	11.9*	14*	8.9*	3.0*	0.1*	1.0*	0770 2308
M-8-23	M-8-23	till (P.S. layer B)	2.7	5.7	6.8	8.5	10.8*	11.9*	14.1*	8.7*	3.3*	0.1*	1.2*	0770 2308
M-8-25	M-8-25	till (P.S. layer B)	5.4	6.0	6.7	8.4	10.6*	11.7*	13.9*	8.7*	2.7*	0.2*	0.9*	0770 2308
M-8-28	M-8-28	till (P.S. layer A)	2.1	5.7	6.8	8.6	10.5*	11.4*	13.1*	8.6*	3.1*	-0.1*	1.2*	0770 2308
M-8-33	M-8-33	till (P.S. layer A)	1.0	4.6	6.1	8.3	10.4*	11.3*	13.3*	8.1*	3.5*	-0.2*	1.2*	0770 2308
M-8-36	M-8-36	till (P.S. layer A)	4.2	6.0	6.6	8.3	10.5*	11.7*	14*	8.6*	2.9*	0.2*	1.0*	0770 2308
M-8-38	M-8-38	till (C.C.)	-1.2*	1.3	2.5	5.9	8.9	10.8*	14*	6.0*	4.7*	0.1*	1.0*	0770 2308
M-8-39	M-8-39	till (C.C.)	-0.8*	1.7	3.1	6.8	9.7	11*	13.8*	6.5*	4.5*	-0.1*	0.9*	0770 2308
M-8-41	M-8-41	till (C.C.)	1.7*	2.5	4.8	7.8	10.3*	11.6*	14.1*	7.3*	4.2*	-0.1*	0.9*	0770 2308
M-8-42	M-8-42	till (C.C.)	4.8	5.6	6.2	7.9	10	10.9*	13*	8.1*	2.6*	0.2*	0.9*	0770 2308
	85-1-3a	sand (facies association 4) r.c.l.	2.2	2.5	2.6	2.8	3.0	3.2	3.6	2.8	0.4	0.1	1.6	3060 1430
	85-1-3b	sand (f.a. 4) f.b.	2.1	2.5	2.7	2.9	3.2	3.4	3.8	2.9	0.5	0.1	1.2	3060 1430
	85-1-3c	sand (f.a. 4) c.b.	2.2	2.6	2.7	3.1	3.7	3.8	4.4	3.2	0.7	0.2	1.0	3060 1430
	85-1-4a	sand (f.a. 4) f.b.	2.0	2.3	2.5	2.8	3.2	3.4	4.0	2.8	0.6	0.1	1.2	3060 1430
	85-1-6a	dune sand	2.0	2.3	2.4	2.7	3.1	3.3	3.7	2.8	0.5	0.1	1.1	3060 1430
	85-1-6b	dune sand	1.7	2.0	2.1	2.6	2.9	3.1	3.5	2.6	0.6	-0.1	0.9	3060 1430
	85-1-6c	dune sand	1.9	2.1	2.2	2.5	2.9	3.1	3.7	2.6	0.5	0.2	1.2	3060 1430
	85-3-3a	sand (post-Mackinaw) l.a.c.b.	1.8	2.0	2.1	2.4	2.8	2.9	3.5	2.4	0.5	0.1	1.1	3020 1450
	85-3-3b	sand (post-Mackinaw) f.b.	2.1	2.5	2.6	2.9	3.3	3.6	4.0	3.0	0.6	0.2	1.1	3020 1450
	85-3-4a1	sand (facies association 4) c.b.	1.7	1.8	1.8	1.9	2.2	2.4	3.0	2.0	0.4	0.5	1.3	3020 1450
	85-4-4a2	sand (f.a. 4) t.c.b	1.6	1.7	1.8	1.9	2.1	2.3	2.6	2.0	0.3	0.3	1.2	3020 1450
	85-3-4b	silt (f.a. 4) c.r.d.	3.7	4.3	4.6	5.1	5.6	6.1	7.1	5.1	1.0	0.2	1.3	3020 1450
	85-3-4c	sand (f.a. 4) r.c.l.	2.4	2.7	2.8	3.1	3.3	3.7	4.5	3.2	0.6	0.3	1.7	3020 1450
	85-3-7a	sand (f.a. 4) r.c.l.	2.2	2.6	2.7	3.0	3.5	3.7	4.2	3.1	0.6	0.3	1.1	3020 1450

*extrapolated data point; determination involves extrapolated data point.

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ _I	Sk _I	K _G	Sample Location (UTM grid)
	85-3-9a	sand (f.a. 4) r.c.l.	2.8	3.1	3.2	3.5	3.9	4.2	4.7	3.6	0.6	0.3	1.2	3020 1450
	85-3-11	sand (f.a. 3) r.c.l.	1.8	2.0	2.1	2.5	2.9	3.1	3.8	2.5	0.6	0.2	1.1	3020 1450
	85-4-5a	sand (f.a. 3) r.c.l.	2.8	3.1	3.3	3.8	4.3	4.5	5.3	3.8	0.7	0.2	1.1	2995 1460
	85-4-5b	sand (f.a. 3) c.r.d. (b-type)	3.1	3.3	3.5	3.8	4.3	4.5	5.1	3.9	0.6	0.3	1.0	2995 1460
	85-4-5c	silt (f.a. 3)	3.2	3.5	3.6	3.9	4.4	4.7	5.4	4.0	0.6	0.3	1.1	2995 1460
	85-4-5d	silt (f.a. 3) r.c.l.	3.5	3.8	4.0	4.3	4.7	4.9	6.0	4.3	0.7	0.2	1.4	2995 1460
	85-4-5e	silt(f.a. 3)	3.7	4.0	4.2	4.6	5.1	5.4	6.5	4.7	0.8	0.2	1.3	2995 1460
	85-4-6a	silt (f.a. 3) c.b.	4.0	4.3	4.5	4.9	5.8	6.1	7.1	5.1	0.9	0.4	1.1	2995 1460
	85-4-6b	silt (f.a. 3) c.b.	3.2	3.5	3.8	4.0	4.5	4.7	5.6	4.1	0.7	0.3	1.4	2995 1460
	85-4-6c	silt (f.a. 3)	3.7	4.0	4.2	4.5	4.9	5.1	6.3	4.5	0.7	0.2	1.5	2995 1460
	85-4-6d	silt (f.a. 3)	3.7	4.0	4.1	4.5	4.9	5.3	6.3	4.6	0.7	0.3	1.4	2995 1460
	85-4-6e	silt (f.a. 3)	4.1	4.6	4.9	5.4	6.1	6.6	8.6	5.6	1.2	0.3	1.5	2995 1460
	85-4-7a	sand (f.a. 3) r.c.l.	2.8	3.1	3.2	3.5	4.1	4.4	5.2	3.6	0.7	0.3	1.1	2995 1460
	85-4-8a	sand (f.a. 4) f.b.	1.7	2.0	2.2	2.6	2.8	3.0	3.4	2.5	0.5	-0.1	1.1	2995 1460
	85-4-8b	sand (f.a.) f.b.	2.1	2.3	2.5	2.7	2.9	3.0	3.4	2.7	0.4	-0.03	1.2	2995 1460
	85-5-3b	silt (f.a. 3)	3.8	4.2	4.3	4.7	5.0	5.5	6.5	4.8	0.7	0.3	1.6	2990 1470
	85-5-3c	silt (f.a. 3)	3.4	3.6	3.7	4.1	4.6	4.8	5.6	4.2	0.6	0.2	1.1	2990 1470
	85-5-3d	silt (f.a. 3)	3.7	4.0	4.2	4.6	5.0	5.4	6.4	4.7	0.8	0.2	1.3	2990 1470
	85-5-3e	silt (f.a. 3)	5.1	6.3	7.7	10.4	-	-	-	-	-	-	-	2990 1470
	85-5-4a	silt (f.a. 3)	4.7	5.0	5.2	5.7	6.3	6.7	8.1	5.8	0.9	0.3	1.3	2990 1470
	85-5-4c	sand (f.a. 3)	2.6	2.9	3.0	3.3	3.7	3.9	4.6	3.4	0.6	0.2	1.3	2990 1470
	85-4-d	sand (f.a. 3)	2.8	3.2	3.4	3.9	4.4	4.7	5.6	3.9	0.8	0.2	1.1	2990 1470
	85-5-5a	sand (f.a. 3) channel t.c.b.	2.7	2.8	2.9	3.1	3.6	3.8	4.5	3.2	0.5	0.4	1.0	2990 1470
	85-5-5b	sand (f.a. 3) r.c.l.	2.7	3.0	3.1	3.4	3.7	4.1	4.7	3.5	0.6	0.3	1.3	2990 1470
	85-5-5c	sand (f.a. 3) f.b.	2.7	2.9	3.0	3.3	3.7	4.0	4.6	3.4	0.6	0.3	1.0	2990 1470
	85-5-5d	silt (f.a. 3)	3.4	3.9	4.1	4.5	4.9	5.3	6.2	4.5	0.8	0.2	1.3	2990 1470
	85-5-5e	silt (f.a. 3)	3.8	4.1	4.3	4.7	5.2	5.7	6.9	4.8	0.8	0.3	1.4	2990 1470
	85-5-6a	silt (f.a. 3)	3.2	3.5	3.6	4.1	4.5	4.8	5.8	4.1	0.7	0.2	1.1	2990 1470
	85-5-6b	sand (f.a. 3)	2.5	2.6	2.7	2.9	3.4	3.6	4.1	3.1	0.5	0.4	1.1	2990 1470

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ ₁	Sk ₁	K _G	Sample Location (UTM grid)
	85-5-7	sand channel fill	1.9	2.1	2.3	2.6	2.9	3.2	3.7	2.6	0.5	0.1	1.2	2990 1470
	85-6-3a	sand (f.a. 3) r.c.l.	2.6	2.8	2.9	3.2	3.6	3.8	4.6	3.3	0.6	0.3	1.3	2785 1560
	85-6-5a	sand (f.a. 3)	2.5	2.7	2.8	3.1	3.5	3.7	4.4	3.2	0.5	0.3	1.1	2785 1560
	85-6-5b	silt (f.a. 3)	3.6	3.9	4.1	4.5	4.8	5.0	6.1	4.5	0.6	0.2	1.4	2785 1560
	85-6-5c	sand (f.a. 3)	2.7	2.8	2.9	3.3	3.7	3.9	4.6	3.3	0.6	0.3	1.0	2785 1560
	85-6-7a	sand (f.a. 4) l.a.c.b.	1.2	1.7	1.8	2.2	2.7	2.9	3.6	2.3	0.7	0.2	1.1	2785 1560
	85-6-7b	sand (f.a. 4) f.b.	1.8	1.9	2.0	2.4	2.7	2.9	3.4	2.4	0.5	0.2	0.9	2785 1560
	85-7-3a	sand (f.a. 3) r.c.l.	2.7	2.9	3.0	3.3	3.8	4.1	4.7	3.4	0.6	0.3	1.1	2850 1530
	85-7-4	sand (f.a. 3)	2.9	3.3	3.5	3.9	4.5	4.8	5.7	4.0	0.8	0.2	1.2	2850 1530
	85-7-5a	sand (f.a. 4) t.c.b.	1.9	2.2	2.3	2.6	2.8	3.0	3.5	2.6	0.5	0.1	1.2	2850 1530
	85-7-5b	sand (f.a. 4) l.a.c.b.	1.7	1.8	1.9	2.2	2.6	2.8	3.2	2.3	0.5	0.2	0.9	2850 1530
	85-7-5c	sand (f.a. 4) r.c.l.	2.1	2.3	2.4	2.6	2.8	3.0	3.6	2.6	0.4	0.3	1.4	2850 1530
	85-9-2a	silt (f.a. 3)	4.2	4.7	4.9	5.4	6.1	6.5	9.0	5.5	1.2	0.4	1.6	2720 1598
	85-9-3a	silt (f.a. 3)	3.7	3.9	4.2	4.4	4.8	4.9	5.9	4.4	0.6	0.2	1.6	2720 1598
	85-9-4a	sand (f.a. 3) channel r.c.l.	2.4	2.7	2.8	3.2	3.7	3.9	4.6	3.3	0.6	0.3	1.1	2720 1598
	85-9-5a	sand (f.a. 3) channel t.c.b.	2.1	2.3	2.5	2.8	3.1	3.3	3.8	2.8	0.5	0.1	1.2	2720 1598
	85-9-6a	sand (f.a. 3) r.c.l.	2.7	2.9	3.0	3.4	3.9	4.1	4.7	3.5	0.6	0.2	1.0	2720 1598
	85-9-8a	silt (f.a. 3)	3.3	3.6	3.8	4.3	4.7	5.0	5.8	4.3	0.7	0.1	1.1	2720 1598
	85-9-8b	silt (f.a. 3)	4.3	4.7	4.9	5.4	6.1	6.5	8.5	5.5	1.1	0.4	1.5	2720 1598
	85-9-8c	sand (f.a. 3)	2.5	2.8	2.9	3.3	3.6	3.9	4.5	3.3	0.6	0.3	1.2	2720 1598
	85-9-8d	sand (f.a. 3) r.c.l.	2.8	3.1	3.2	3.7	4.1	4.4	4.8	3.7	0.6	0.1	1.0	2720 1598
	85-9-8e	sand (f.a. 3) f.b.	2.3	2.6	2.7	2.9	3.3	3.5	4.1	3.0	0.5	0.3	1.3	2720 1598
	85-9-8f	sand (f.a. 3)	2.3	2.5	2.7	2.9	3.1	3.4	3.9	2.9	0.5	0.2	1.4	2720 1598
	85-9-8g	silt (f.a. 3) r.c.l.	2.2	2.5	2.6	2.8	3.1	3.3	3.9	2.9	0.5	0.2	1.3	2720 1598
	85-9-9a	sand (f.a. 3) channel l.a.c.b.	2.1	2.4	2.5	2.8	3.1	3.4	3.9	2.8	0.5	0.2	1.2	2720 1598
	85-9-10	sand (f.a. 3) channel t.c.b.	1.9	2.1	2.2	2.5	2.8	2.9	3.3	2.5	0.4	0.1	1.0	2720 1598
	85-9-11	sand (f.a. 3) r.c.l.	2.1	2.3	2.4	2.5	2.8	2.9	3.3	2.6	0.3	0.2	1.1	2720 1598
	85-9-12	sand (f.a. 3) channel t.c.b.	1.4	1.7	1.8	2.1	2.5	2.7	3.3	2.2	0.5	0.3	1.0	2720 1598
	85-9-13	sand (f.a. 3)	2.0	2.1	2.2	2.5	2.8	2.9	3.2	2.5	0.4	0.1	1.0	2620 1598
	85-9-14	sand (f.a. 3)	2.2	2.5	2.6	2.9	3.5	3.8	4.6	3.1	0.7	0.4	1.2	2720 1598

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ _I	Sk _I	K _G	Sample Location (UTM grid)
	85-9-15	sand (f.a. 3)	2.8	3.1	3.3	3.7	4.2	4.5	6.3	3.8	0.7	0.2	1.1	2720 1598
	85-9-16	silt (f.a. 3)	3.5	4.2	4.5	5.1	6.0	6.4	7.9	5.2	1.2	0.2	1.2	2720 1598
	85-10-1	sand (f.a. 3)	2.7	3.0	3.1	3.5	3.9	4.0	4.6	3.5	0.6	0.1	1.0	2630 1640
	85-10-2	silt (f.a. 3)	3.6	4.0	4.3	4.8	5.6	6.1	7.8	5.0	1.2	0.3	1.3	2630 1640
	85-10-3	clay (f.a. 3)	5.3	6.3	7.0	8.6	-	-	-	-	-	-	-	2630 1640
	85-10-4	silt (f.a. 3)	4.4	4.7	4.8	5.1	5.9	6.2	7.8	5.3	0.9	0.5	1.3	2630 1640
	85-10-5	silt (f.a. 3)	2.7	3.0	3.1	3.4	3.7	4.0	4.5	3.5	0.5	0.3	1.2	2630 1640
	85-10-6	silt (f.a. 3)	3.0	3.6	3.8	4.4	5.0	5.5	6.7	4.5	1.1	0.2	1.3	2630 1640
	85-10-7	silt (f.a. 3)	3.5	4.0	4.2	4.6	5.2	5.7	7.3	4.7	1.0	0.3	1.5	2630 1640
	85-10-8	silt (f.a. 3)	4.6	5.4	5.8	6.7	8.0	9.1	-	7.1	-	-	-	2630 1640
	85-10-9	sand (f.a. 3)	2.8	3.0	3.2	3.5	4.1	4.4	5.1	3.6	0.7	0.3	1.1	2630 1640
	85-10-10	silt (f.a. 3)	3.2	3.7	4.0	4.5	5.0	5.4	6.7	4.5	0.9	0.2	1.4	2630 1640
	85-10-11	sand (f.a. 3)	2.2	2.6	2.7	3.0	3.5	3.7	4.5	3.1	0.6	0.3	1.2	2630 1640
	85-11-1	clay (f.a. 1)	5.4	6.3	6.8	8.0	10.1	-	-	-	-	-	-	2575 1678
	85-11-2	sand (f.a. 2)	2.9	3.1	3.3	3.6	4.0	4.2	4.8	3.6	0.6	0.2	1.1	2575 1678
	85-11-3	silt (f.a. 2)	3.3	3.7	3.9	4.4	4.9	5.4	6.4	4.5	0.9	0.2	1.2	2575 1678
	85-11-4	silt (f.a. 2)	3.0	3.4	3.6	4.0	4.5	4.7	5.7	4.0	0.7	0.2	1.2	2575 1678
	85-11-5	silt (f.a. 2) r.c.l.	4.3	4.7	4.9	5.4	6.1	6.5	8.4	5.5	1.1	0.3	1.4	2575 1678
	88-11-6	sand (f.a. 3) r.c.l.	2.8	3.0	3.2	3.6	4.1	4.3	4.9	3.6	0.6	0.2	1.0	2575 1678
	88-11-8	sand (f.a. 3) r.c.l.	2.8	3.0	3.1	3.3	3.7	4.0	4.7	3.4	0.6	0.4	1.3	2575 1678
	85-12-1a	clay (f.a. 1)	5.5	6.8	7.25	8.4	7.6	-	-	-	-	-	-	2155 1915
	85-12-2	silt (f.a. 2)	4.0	4.4	4.6	5.2	6.2	6.8	8.9	5.5	1.4	0.5	1.3	2155 1915
	85-12-3	silt (f.a. 2)	4.0	4.5	4.7	5.2	6.3	6.8	9.6	5.5	1.4	0.5	1.4	2155 1915
	85-12-4	silt (f.a. 2)	4.1	4.6	4.8	5.3	6.2	6.6	8.4	5.5	1.2	0.3	1.3	2155 1915
	85-12-5	silt (f.a. 2)	4.1	4.6	4.8	5.6	6.7	7.4	-	5.8	-	-	-	2155 1915
	85-12-6	silt (f.a. 2)	3.2	3.6	3.7	4.3	4.9	5.2	6.4	4.4	0.9	0.3	1.2	2155 1915
	85-12-7	silt (f.a. 2)	3.7	4.0	4.3	4.8	5.7	6.2	8.0	5.0	1.2	0.4	1.3	2155 1915
	85-12-8	sand (f.a. 2)	2.9	3.2	3.4	3.7	4.3	4.6	5.3	3.8	0.7	0.3	1.1	2155 1915
	85-12-9	silt (f.a. 2)	4.2	4.8	5.2	5.9	6.7	7.4	10.3	6.0	1.6	0.3	1.6	2155 1915
	85-12-10	sand (f.a. 2)	3.1	3.3	3.4	3.7	4.3	4.5	5.3	3.8	0.7	0.4	1.1	2155 1915

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ ₁	Sk ₁	K _G	Sample Location (UTM grid)
	85-12-11	silt (f.a. 2)	3.2	3.7	4.0	4.9	6.1	6.7	9.6	5.1	1.7	0.3	1.3	2155 1915
	85-12-12	silt (f.a. 2)	3.4	3.6	3.8	4.2	4.7	4.9	6.0	4.2	0.7	0.2	1.1	2155 1915
	85-12-13	silt (f.a. 2)	3.2	3.5	3.7	4.0	4.5	4.7	5.8	4.1	0.7	0.3	1.3	2155 1915
	85-12-14	sand (f.a. 4) r.c.l.	2.2	2.4	2.6	2.8	3.2	3.4	3.9	2.9	0.5	0.2	1.2	2155 1915
	85-12-15	sand (f.a. 4) r.c.l.	2.4	2.7	2.8	3.0	3.3	3.5	5.3	3.0	0.7	0.5	2.2	2155 1915
	85-13-1	silt (f.a. 2)	4.2	4.4	4.6	5.6	7.2	8.1	11.3	6.0	2.0	0.5	1.2	2025 1975
	85-13-2	clay (f.a. 2)	5.4	6.8	7.4	8.9	10.9	-	-	-	-	-	-	2025 1975
	85-13-3	silt (f.a. 2)	4.6	4.8	5.0	5.5	6.3	6.8	-	5.7	-	-	-	2025 1975
	85-13-4	clay (f.a. 2)	5.3	6.5	7.4	8.4	10.0	-	-	-	-	-	-	2025 1975
	85-13-5	silt (f.a. 2)	3.3	3.6	3.8	4.2	4.7	4.9	5.6	4.2	0.7	0.1	1.1	2025 1975
	85-13-6	silt (f.a. 2)	3.9	4.3	4.6	5.3	6.8	7.4	-	5.7	-	-	-	2025 1975
	85-13-7	silt (f.a. 2)	3.8	4.3	4.6	5.1	6.5	7.2	-	5.5	-	-	-	2025 1975
	85-13-8	clay (f.a. 2)	4.3	4.7	5.3	6.9	8.8	9.9	-	7.2	-	-	-	2025 1975
	85-13-9	silt (f.a. 2)	4.0	4.4	4.6	5.0	6.1	6.6	8.4	5.3	1.2	0.5	1.2	2025 1975
	85-13-10	silt (f.a. 2)	3.8	4.0	4.2	4.6	5.0	5.3	6.2	4.6	0.7	0.2	1.3	2025 1975
	85-13-11	sand (f.a. 3) r.c.l.	3.0	3.2	3.3	3.6	4.1	4.3	4.9	3.7	0.6	0.4	1.0	2025 1975
	85-13-12	sand (f.a. 3) r.c.l.	2.6	2.9	3.0	3.3	3.6	3.8	4.5	3.3	0.5	0.2	1.3	2025 1975
	85-13-13	sand (f.a. 3) r.c.l.	2.8	2.9	3.0	3.3	3.6	3.9	4.6	3.4	0.5	0.3	1.3	2025 1975
	85-13-14	sand (f.a. 4) r.c.l.	2.3	2.5	2.7	2.9	3.2	3.4	3.9	2.9	0.5	0.2	1.2	2025 1975
	85-13-16	sand (f.a. 4) channel t.c.b.	2.1	2.4	2.5	2.8	3.0	3.2	3.7	2.8	0.5	0.1	1.3	2025 1975
	85-13-17	sand (f.a. 4)	2.4	2.7	2.8	3.0	3.3	3.5	4.1	3.0	0.5	0.3	1.2	2025 1975
	85-13-18	sand (f.a. 4)	2.3	2.5	2.7	2.9	3.1	3.3	3.9	2.9	0.4	0.3	1.4	2025 1975
	85-14-1a	clay (f.a. 1)	5.6	6.5	7.0	8.0	9.7	-	-	-	-	-	-	2280 1830
	85-14-2	silt (f.a. 1)	4.2	4.7	4.9	5.5	6.4	6.9	-	5.7	-	-	-	2280 1830
	85-14-3	clay (f.a. 1)	5.2	6.2	6.8	8.0	10.2	-	-	-	-	-	-	2280 1830
	85-14-4	silt (f.a. 2)	3.1	3.5	3.7	4.2	4.8	5.0	5.9	4.2	0.8	0.2	1.1	2280 1830
	85-14-5	silt (f.a. 2)	3.1	3.6	3.9	4.5	5.3	6.0	8.3	4.7	1.4	0.4	1.6	2280 1830
	85-14-6	silt (f.a. 2)	4.3	4.8	5.1	5.9	6.9	7.5	10.8	6.1	1.7	0.4	1.5	2280 1830
	85-14-7	silt (f.a. 2)	4.8	5.4	5.8	6.7	8.3	-	-	-	-	-	-	2280 1830
	85-14-8a	clay (f.a. 2)	6.0	7.4	7.7	8.8	10.5	-	-	-	-	-	-	2280 1830

Appendix 6. (cont'd) Statistical parameters of grain size.

Field No.	Sample No.	Material Interpretation	φ5	φ16	φ25	φ50	φ75	φ84	φ95	M _z	σ ₁	Sk ₁	K _G	Sample Location (UTM grid)
	85-14-8b	clay (f.a. 2)	5.6	7.0	7.6	9.2	-	-	-	-	-	-	-	2280 1830
	85-14-9	silt (f.a. 2)	3.9	4.2	4.3	4.6	4.9	5.3	6.6	4.7	0.7	0.4	1.8	2280 1830
	85-14-10	sand (f.a. 4) r.c.l.	2.3	2.5	2.6	2.8	3.1	3.3	3.8	2.9	0.4	0.2	1.2	2280 1830
	85-14-11	sand (f.a. 4) t.c.b.	2.3	2.5	2.6	2.8	3.2	3.4	3.8	2.9	0.4	0.2	1.2	2280 1830
	85-15-1	silt clay (f.a. 2)	4.3	5.1	5.4	6.5	7.7	8.7	-	6.8	-	-	-	2360 1795
	85-15-2	silt (f.a. 4)	3.1	3.5	3.6	4.1	4.6	4.8	5.7	4.1	0.7	0.1	1.1	2360 1795
	85-15-3	sand (f.a. 2) f.b.	2.2	2.6	2.7	3.0	3.3	3.5	4.1	3.0	0.5	0.2	1.3	2360 1795
	85-15-4	silt (f.a. 2)	3.0	3.4	3.6	4.2	4.7	5.0	6.3	4.2	0.9	0.2	1.2	2360 1795
	85-15-5	sand (f.a. 2)	3.0	3.3	3.4	3.6	4.2	4.4	5.0	3.8	0.6	0.4	1.1	2360 1795
	85-15-6	silt (f.a. 2)	3.6	4.0	4.2	4.6	5.1	5.7	6.9	4.8	0.9	0.3	1.5	2360 1795
	85-15-7	silt (f.a. 2)	4.8	5.6	6.0	7.0	8.7	-	-	-	-	-	-	2360 1795
	85-15-8	silty clay (f.a. 2)	-	6.3	6.7	7.8	9.8	-	-	-	-	-	-	2360 1795
	85-15-9	silt (f.a. 2)	4.4	4.8	5.0	5.7	6.7	7.4	-	6.0	-	-	-	2360 1795
	85-15-10a	silty clay (f.a.)	4.9	5.6	6.1	7.3	8.9	-	-	-	-	-	-	2360 1795
	85-15-10b	clay (f.a. 2)	5.7	6.9	7.2	8.8	-	-	-	-	-	-	-	2360 1795
	85-15-11	sand (f.a. 4) r.c.l.	2.1	2.3	2.4	2.6	2.9	3.2	3.7	2.7	0.5	0.3	1.2	2360 1795
	85-15-12	sand (f.a. 4) t.c.b.	1.9	2.1	2.2	2.5	2.9	3.1	3.6	2.6	0.5	0.2	1.1	2360 1795
	85-15-13	sand (f.a. 2) c.r.d.	2.7	3.0	3.1	3.4	3.9	4.2	4.9	3.5	0.6	0.3	1.2	2360 1795
	85-15-14	sand (f.a. 4) t.c.b.	1.8	1.9	2.0	2.1	2.4	2.6	3.4	2.2	0.4	0.6	1.3	2360 1795
	85-15-15	sand (f.a. 4) r.c.l.	2.7	2.9	3.0	3.3	3.7	4.0	4.8	3.4	0.6	0.3	1.2	2360 1795
	85-17-2	silt (facies A, M.N.)	4.5	4.8	5.0	5.5	6.3	6.9	9.7	5.7	1.3	0.5	1.6	0801 2275
	85-17-3	sand (facies A, M.N.)	3.1	3.3	3.4	3.8	4.4	4.7	6.0	3.9	0.8	0.4	1.2	0801 2275
	85-17-4	silt (facies A, M.N.)	3.9	4.4	4.6	5.1	5.7	6.2	7.7	5.2	1.0	0.3	1.4	0801 2275
	85-17-5	clay (facies A, M.N.)	5.7	7.7	8.7	-	-	-	-	-	-	-	-	0801 2275
	85-17-6	silt (facies A, M.N.) r.c.l.	3.3	3.5	3.7	4.3	4.8	5.2	6.7	4.3	0.9	0.3	1.3	0801 2275
	85-17-7	clay (facies A, M.N.)	-	6.4	7.0	8.0	-	-	-	-	-	-	-	0801 2275
	85-17-8	silt (facies A, M.N.)	4.0	4.4	4.6	5.0	5.5	5.9	7.1	5.1	0.8	0.3	1.4	0801 2275
	85-17-9	sand (facies A, M.N.) r.c.l.	3.1	3.3	3.5	3.8	4.3	4.6	5.4	3.9	0.7	0.3	1.2	0801 2275
	85-17-10	sand (facies A, M.N.) r.c.l.	2.9	3.2	3.3	3.6	4.1	4.4	5.2	3.7	0.7	0.4	1.2	0801 2275
	85-17-11	silt (facies A, M.N.) c.r.d.	3.5	3.9	4.0	4.5	5.0	5.4	6.7	4.6	0.9	0.2	1.3	0801 2275
	85-17-12	sand (facies A, M.N.) r.c.l.	2.9	3.1	3.2	3.5	4.1	4.4	5.1	3.7	0.6	0.4	1.1	0801 2275
	85-17-13	silt (facies A, M.N.)	4.5	5.1	5.4	6.2	7.1	7.8	-	6.4	-	-	-	0801 2275

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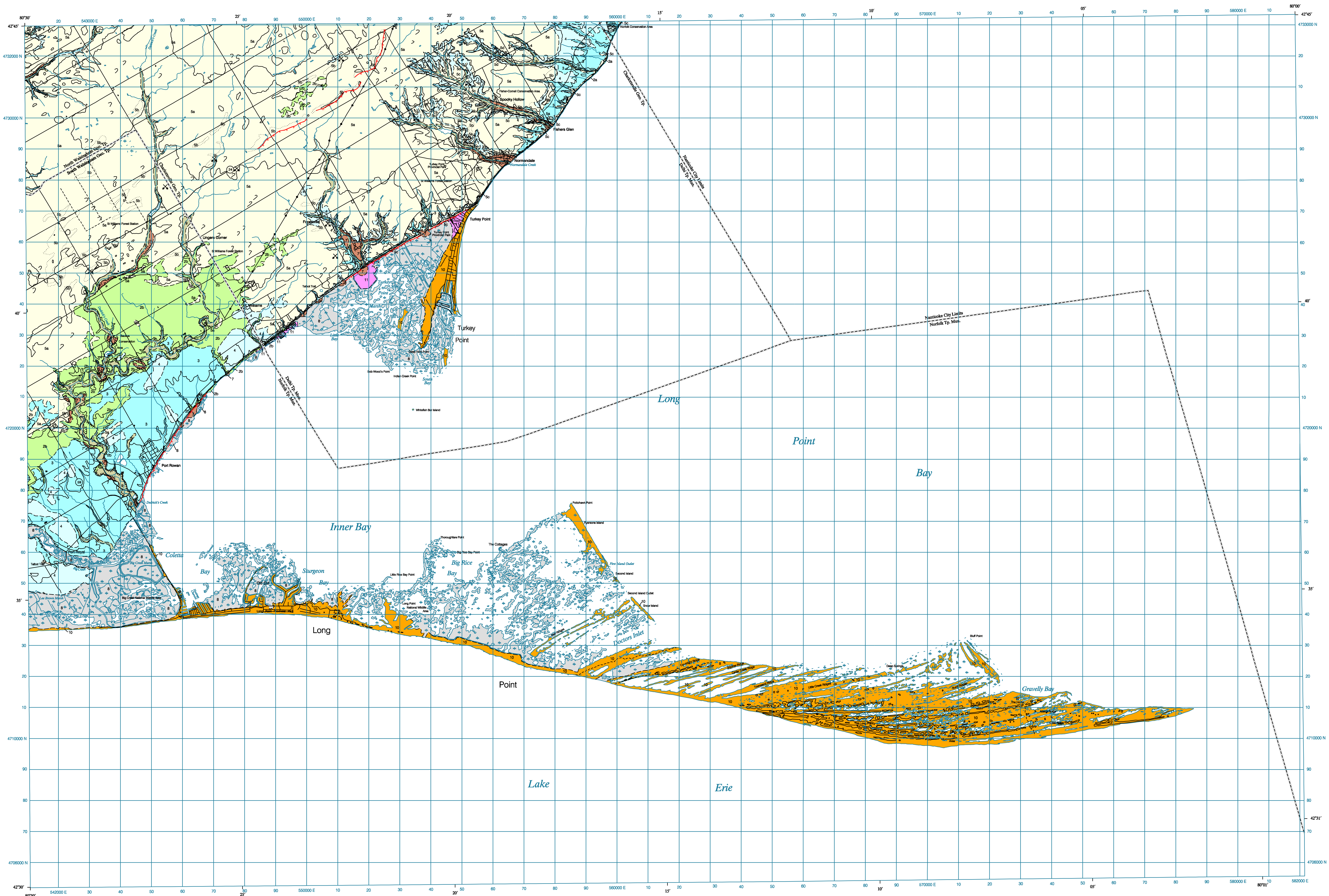
Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
<i>SI Unit</i>	<i>Multiplied by</i>	<i>Gives</i>	<i>Imperial Unit</i>	<i>Multiplied by</i>	<i>Gives</i>
LENGTH					
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
AREA					
1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm ³	0.061 023	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m ³
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 90	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	<i>Multiplied by</i>	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.



Ontario Geological Survey

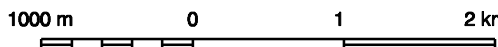
MAP 2600

QUATERNARY GEOLOGY

LONG POINT AREA

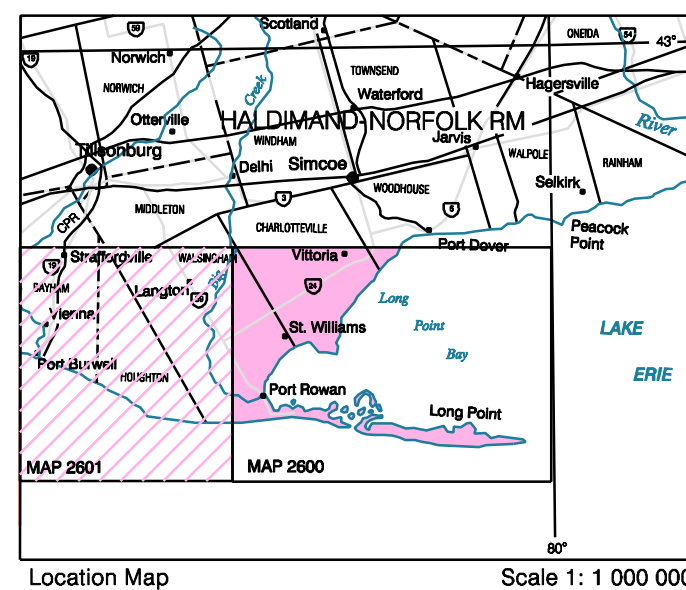
SOUTHERN ONTARIO

Scale 1:50 000



NTS 40 I/9

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LEGEND

PHANEROZOIC CENOZOIC QUATERNARY RECENT

- 11 Fill
- 10 Modern Lake Erie Beach Deposits: sand and minor gravel
- 9 Modern Alluvium: undifferentiated sand, silt, clay, muck
- 8 Bog and Swamp Deposits: muck, peat

PLEISTOCENE

- Late Wisconsinan
 - 7 Older Alluvium: medium- to coarse-grained sand, occasional gravel
- 6* Glaciolacustrine Beach or Neeshore Deposits: gravel, gravely sand
- 5 Glaciolacustrine Sand Deposits: fine- to medium-grained sand
 - 5a Modified slightly by wind
 - 5b Large dunes
 - 5c Older, rhythmically bedded, very fine to fine-grained sand
 - 5d Older, medium- to very coarse-grained sand, minor gravel
- 4 Glaciolacustrine Silt Deposits: clayey silt to very fine sandy silt
- 3 Glaciolacustrine Clay Deposits: clay to silt and clay
- 2 Wentworth Till: silty clay to silt
 - 2a Silt till
 - 2b Silty clay to clayey silt till
- 1* Port Stanley Till: clayey silt to silty clay

* These deposits do not occur within the Long Point area, but are found in the Port Burwell area to the west.

SYMBOLS

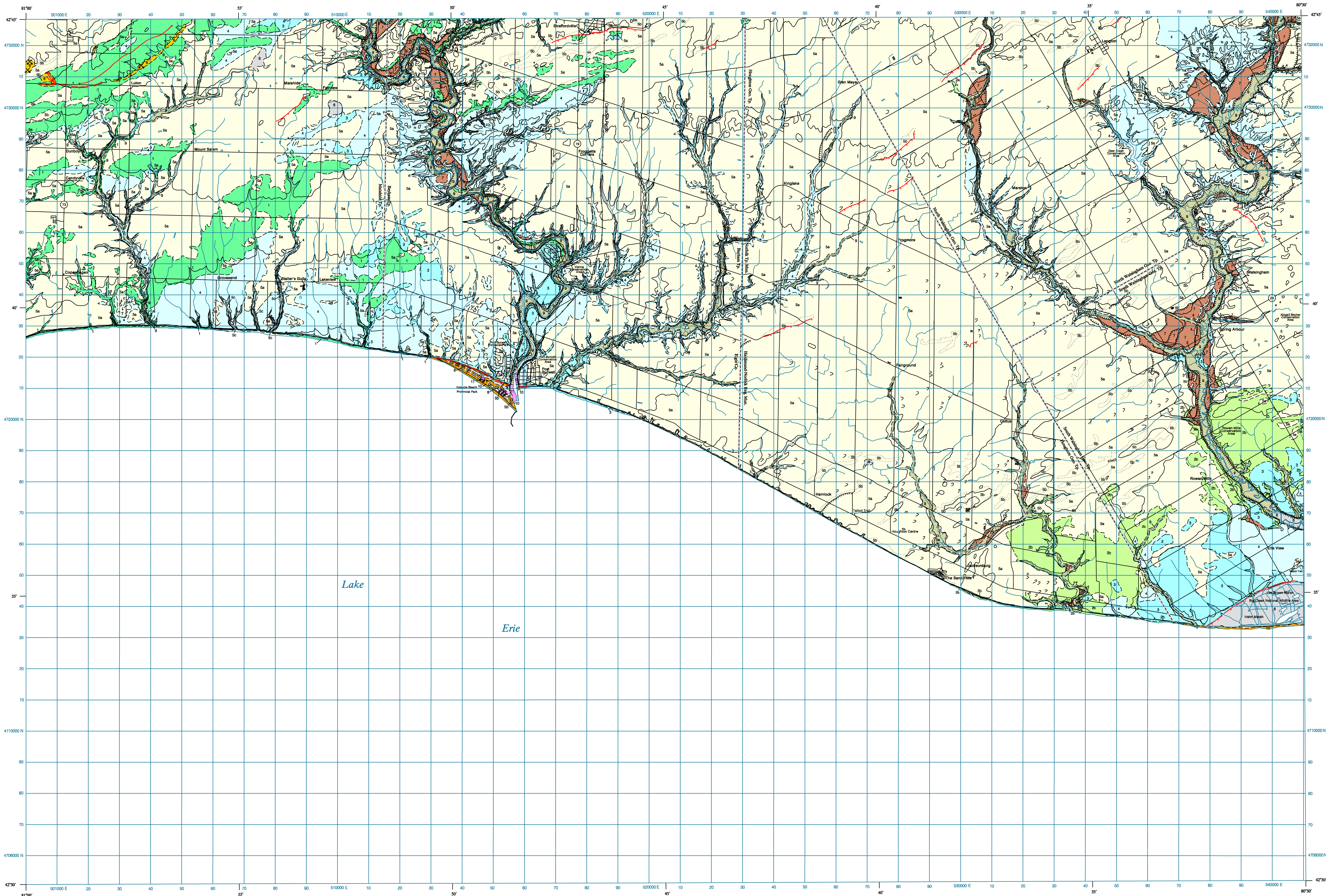
- Geological boundary (approximate, gradational)
- Fluvial terrace
- Abandoned shore bluff
- Beach bar or spit
- Area of small dunes
- Sand and/or gravel pit
- Mappable edge of sand and/or gravel pit
- Wetland
- Flooded area
- Powerline

SOURCES OF INFORMATION

Base map derived from map 40 I/9 of the National Topographic System, scale 1:50 000.
ODM-GSC Aeromagnetic Map 4577G.
OGS Geological Compilation Map: 2418.
Air photographs: Ontario Ministry of Natural Resources.
Contour interval: 25 feet.
Magnetic declination: approximately 3° 1' in 1977.
Metric conversion factor: 1 foot = 0.3048 m.

CREDITS

Geology by P.J. Barnett and A. Zilans, 1982, 1983.
Cartographic production by L.A. Henderson.
Editing by M.A. Rutka.
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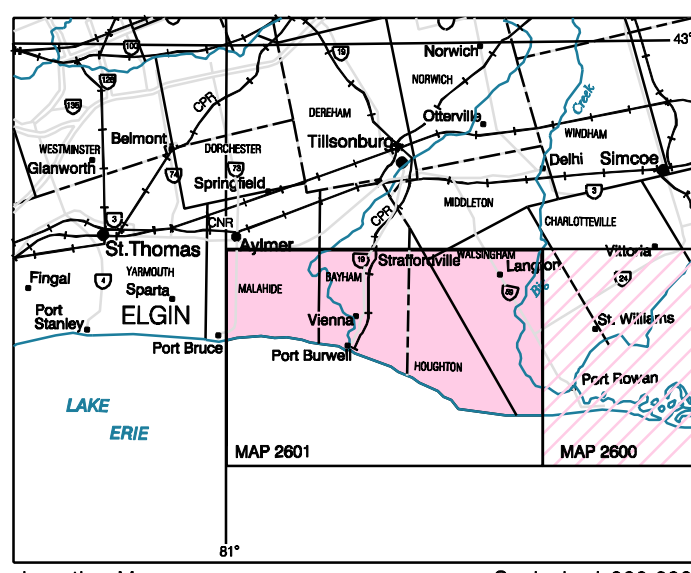


Ontario Geological Survey
MAP 2601
QUATERNARY GEOLOGY
PORT BURWELL
SOUTHERN ONTARIO

Scale 1:50 000
1000 m 0 1 2 km
NTS 40 I/10

Queen's Printer for Ontario, 1998.

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LEGEND

PHANEROZOIC
CENOZOIC
QUATERNARY
RECENT

- 11 Fill
- 10 Modern Lake Erie Beach Deposits: sand and minor gravel
- 9 Modern Alluvium: undifferentiated sand, silt, clay, muck
- 8 Bog and Swamp Deposits: muck, peat
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- Late Wisconsinian
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 - 5b Large dunes
 - 5c Older, rhythmically bedded, very fine to fine-grained sand
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- 4 Glaciolacustrine Silt Deposits: clayey silt to very fine sandy silt
- 3 Glaciolacustrine Clay Deposits: clay to silt and clay
- 2 Wernworth Till: silty clay to silt
 - 2a Silt till
 - 2b Silty clay to clayey silt till
- 1 Port Stanley Till: clayey silt to silty clay

* These deposits do not occur within the Port Burwell area but are found in the Long Point area to the west.

SYMBOLS

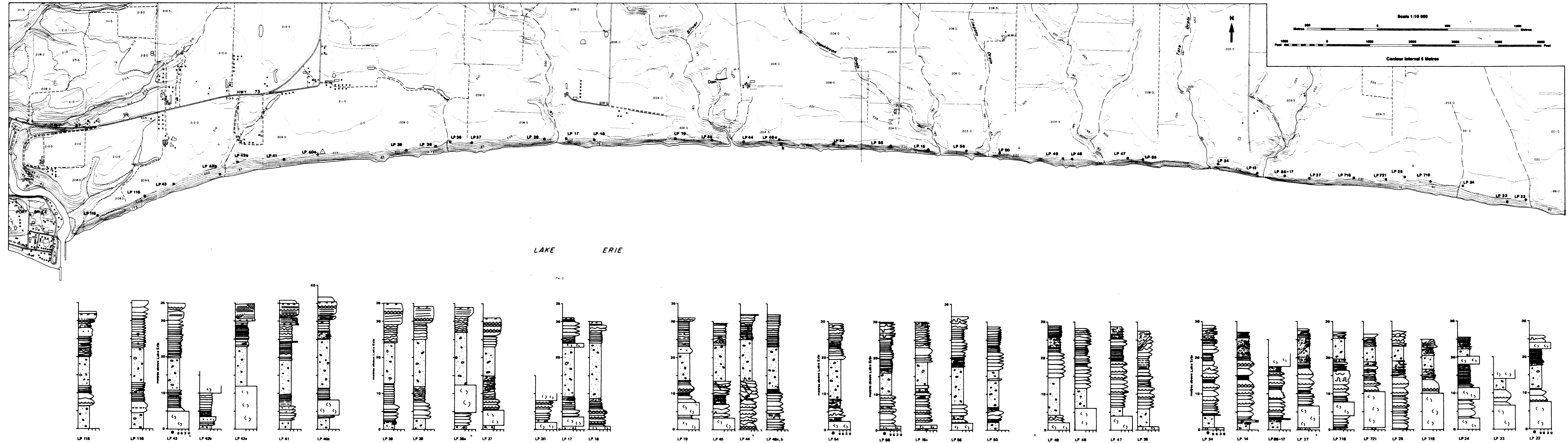
- Geological boundary; approximate, gradational
- Area of small dunes
- Fluvial terrace
- Sand and/or gravel pit
- Abandoned shore bluff
- Beach bar or spit

SOURCES OF INFORMATION

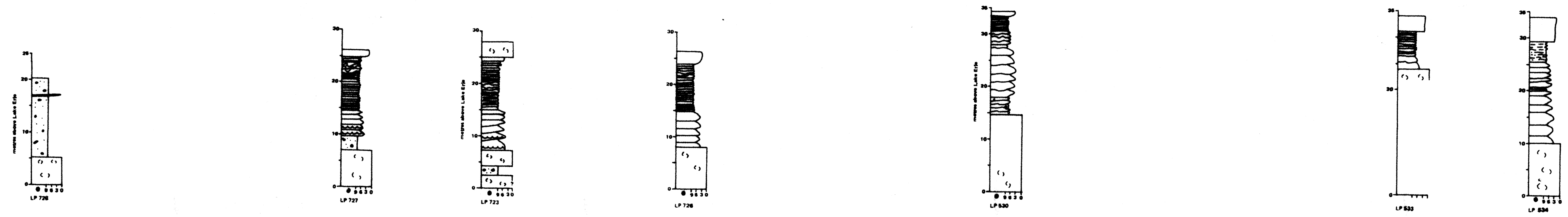
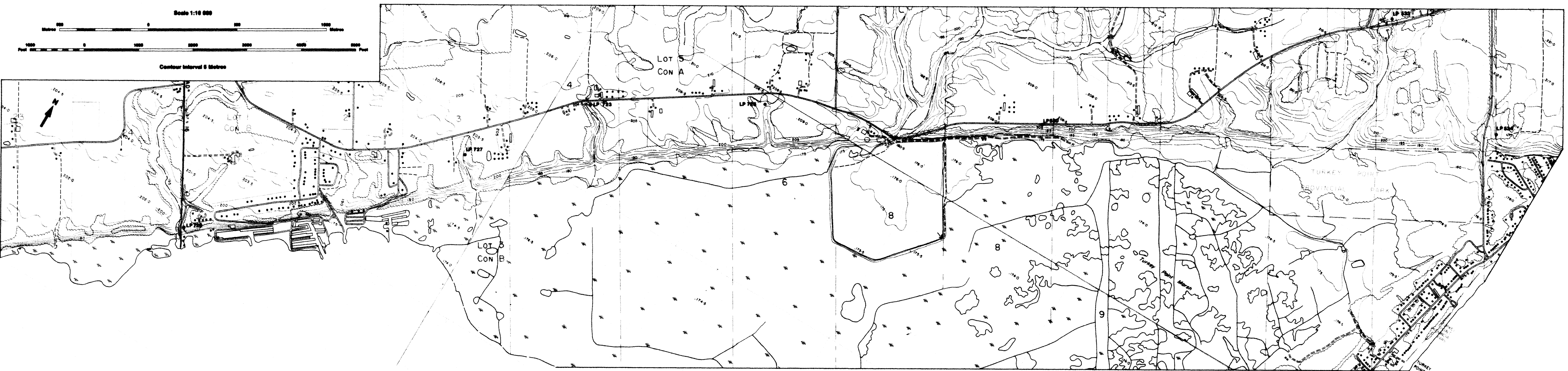
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ODM-GSC Aeromagnetic Map 4576G.
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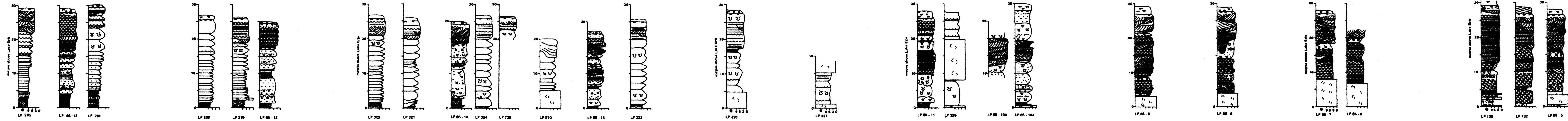
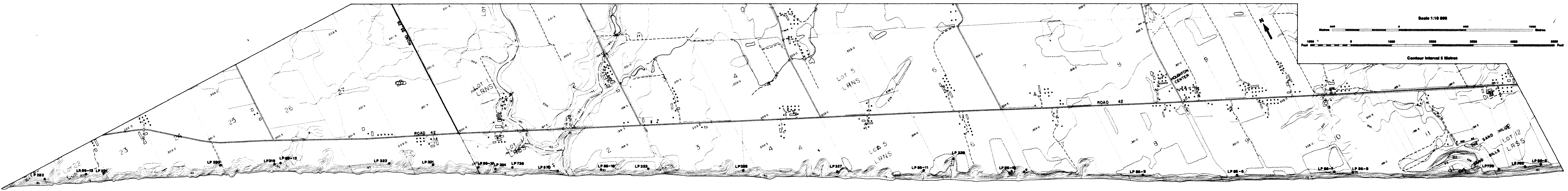


SHORE BLUFF SEGMENT : A



SHORE BLUFF SEGMENT : E

Figure 7e.



SHORE BLUFF SEGMENT : C



SHORE BLUFF SEGMENT : B

Figure 7b.

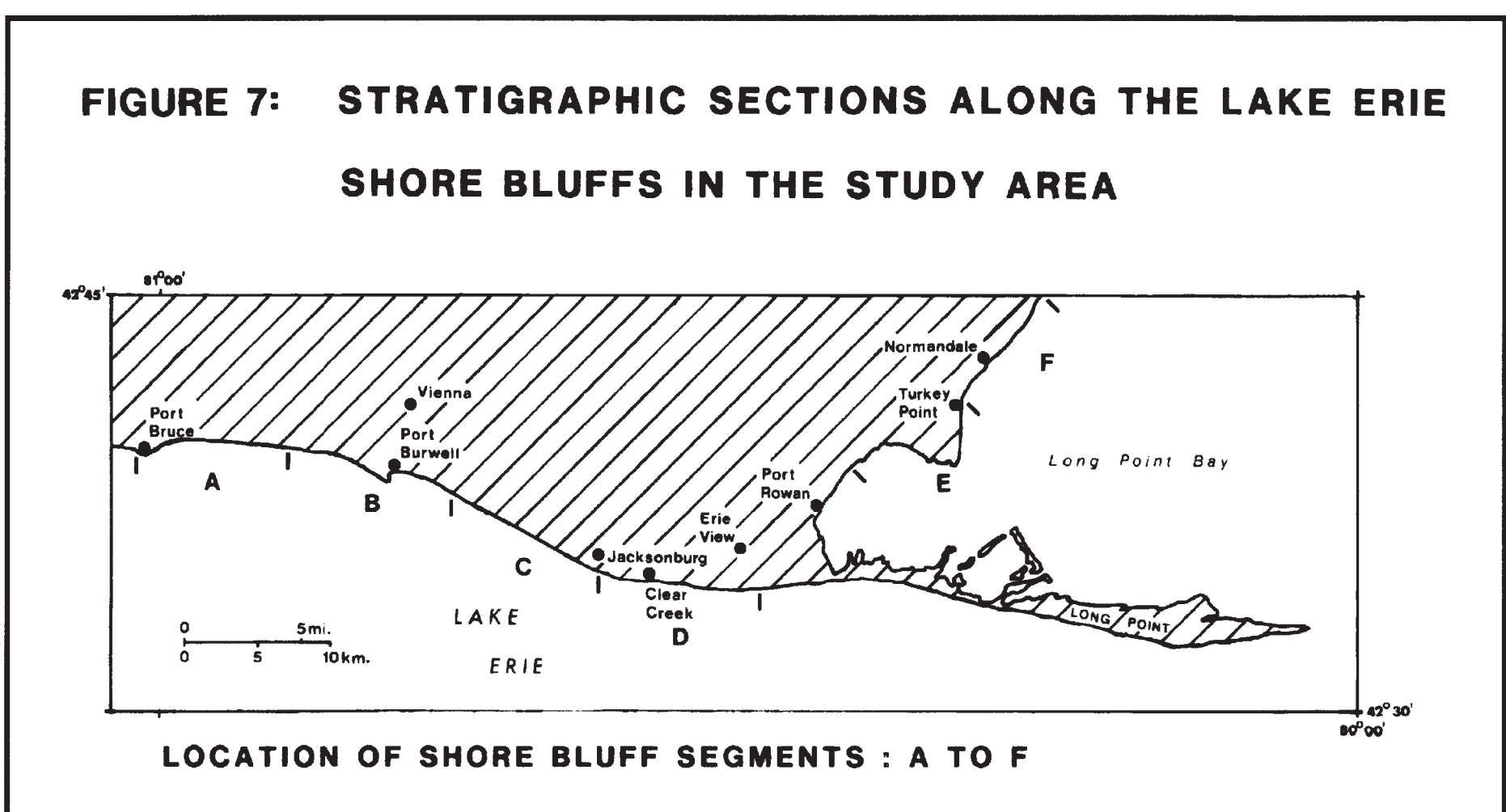
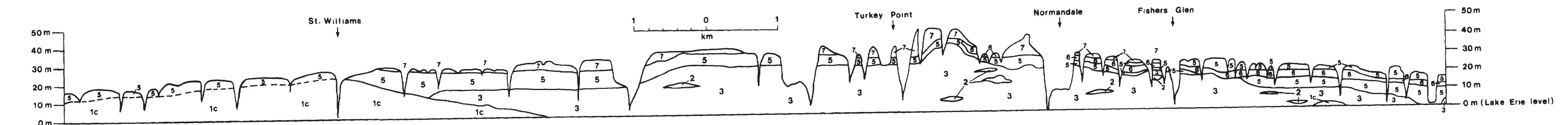
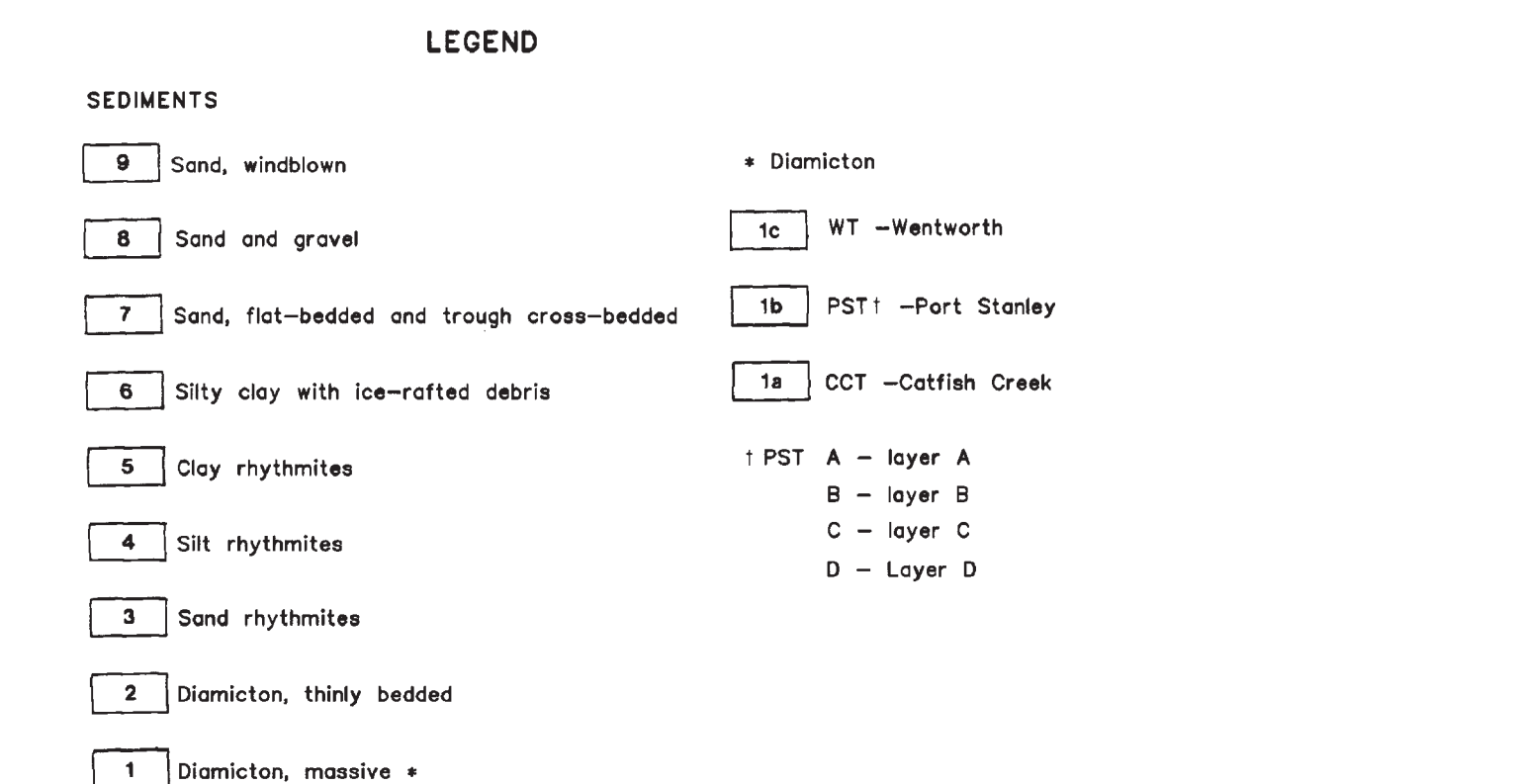
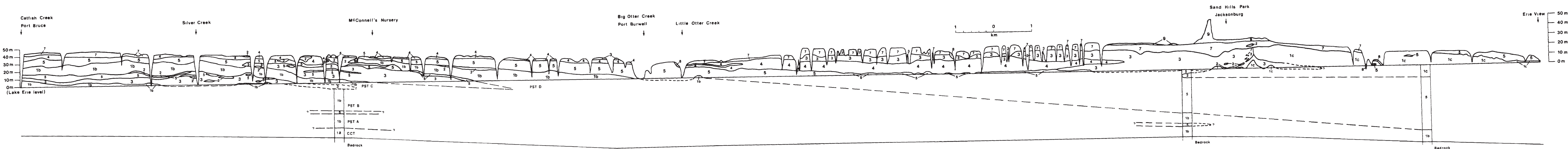


Figure 7g. CORRELATION OF LAKE BLUFF SEDIMENTS