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ONTARIO GEOLOGICAL SURVEY
Open File Report 5361

Quaternary Geology and Industrial Minerals of the Niagara-Welland Area, Southern Ontario.

by

B.H. Feenstra

1981

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FOREWORD

NIAGARA-WELLAND REPORT

The Niagara-Welland region contains valuable agricultural soils. This is one of the few places in Canada capable of producing tender fruit. Conflict regarding the "use of land" here has resulted from rapid urbanization, reflecting the regions increasing importance as an industrial, commercial and tourist centre. A geological inventory of this area is necessary to ensure the wise and effective management of mineral resources that are present.

This report contains a description of the unconsolidated glacial sediments exposed at the surface and outlines the geological processes that have been active in shaping this area over the last 60,000 years. Such information provides the first step in understanding the nature and distribution of soils, the location and extent of construction aggregate, the nature and variation of foundation conditions, and the location and potential yield of aquifers.

E.V. Sado, Geologist,
Engineering and Terrain
Geology Section.

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CHARTS
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The Quaternary deposits of the Niagara-Welland area range in thickness up to about 120 m. Deposits dating back to the Middle and perhaps the Early Wisconsinan Substage occur in the buried St. Davids Gorge. The Late Wisconsinan Substage is represented in ascending stratigraphic order by lower till (Nissouri and Port Bruce Stadials),

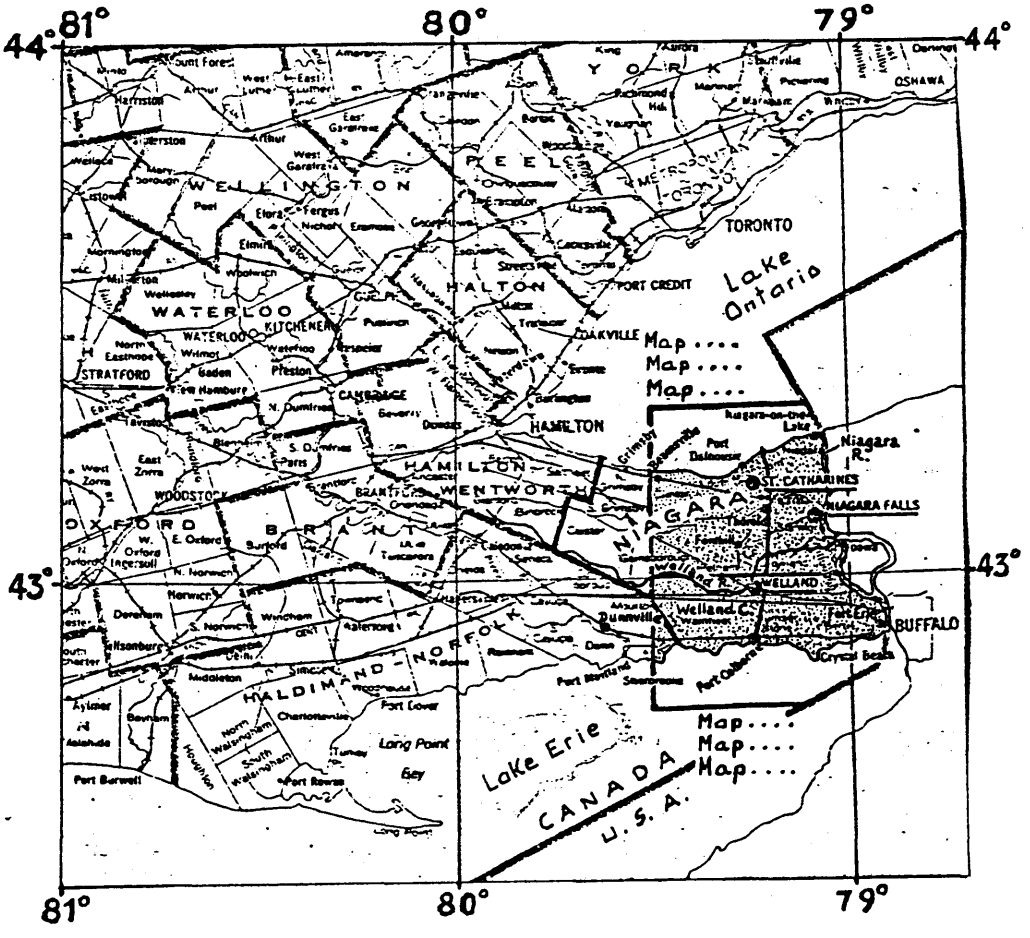

Figure 1 - Key map showing location of the Niagara-Welland Area. Scale 1:3,168,000.

lower glaciolacustrine deposits, Halton Till (Port Huron Stadial), and upper glaciolacustrine deposits. This sequence was exposed at excavations for the relocated Welland Canal.

Halton Till records the Port Huron advance of the Ontario-Erie glacier lobe across the area. The mode of glacier retreat is indicated by the Mohawk Bay, Wainfleet, Crystal Beach, Fort Erie. Niagara Falls, and Vinemount Moraines and correlative positions.

The near-ubiquitous upper glaciolacustrine deposits, of lake-bottom (areally predominant), ice-contact, nearshore, beach, and deltaic origin, record the inundation of the area by the Warren to Iroquois sequence of Erie and Ontario basin lake stages during glacier retreat. The Fonthill Kame is an ice-contact deltaic complex formed when the glacier fronted Lake Warren at the Fort Erie and Niagara Falls Moraine positions. An ancestral Grand River formed a delta in the much lower Lake Dana and Dunnville stages west of Wainfleet. A field of small inland dunes occurs on this delta plain. The Lake Iroquois bluff is the most prominent abandoned shoreline feature in the area. It is interrupted by a baymouth bar in St. Catharines. The Welland Bog may form a vestige of remnant ponded waters in front of the Onondaga Escarpment.

The Lake Ontario shore is characterized by eroding bluffs and the Lake Erie shore by flat headlands where bedrock is exposed, beach deposits along intervening bays, and backshore dunes.

Sand and gravel aggregate potential on a commercial scale is essentially limited in the area to the Fonthill Kame. The Welland Bog forms a commercial source of peat. The large clay-resource has not been commercially worked for the manufacture of drain tile and brick since the 1920's.

Quaternary Geology and Industrial Minerals of the Niagara-Welland Area

by

B.H. Feenstra[1]

INTRODUCTION

LOCATION AND ACCESS

The Niagara-Welland map-area forms the eastern part of the Niagara Peninsula in southern Ontario Ontario between Lake Ontario to the north and Lake Erie to the south (Figure 1). It extends from the Niagara River, the international boundary between Canada and the United States of America, westward to 79°30'W. The total land-area is about 1,500 km^2 and includes almost the entire Regional Municipality of Niagara (former counties of Lincoln and Welland) and a very small part of the Town of Dunnville (Regional Municipality of Haldimand-Norfolk) in the southwest. The cities of St. Catharines, Niagara Falls, Welland, and Port Colborne are the major urban centres.

Access to the area from Hamilton and Toronto is provided by the Queen Elizabeth Way. This principal highway traverses the report-area in an arc extending west-east across the northern part and north-south at the eastern

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end. Other major east-west roads serving to link the study-area with points beyond its boundaries are Highway 20 (Niagara Falls - Hamilton) in the central part, and Highway 3 (Fort Erie-Simcoe) in the southern part. The entire area is served by a network of intra-regional roads which are generally aligned in east-west and north-south directions and from 0.8 km to 1.6 km apart.

The Welland Canal, under the jurisdiction of the St. Lawrence Seaway Authority, is the key link in the movement of ships using the Great Lakes. The canal is 43 km long and crosses the map-area in a northerly direction between Port Colborne on Lake Erie and Port Weller on Lake Ontario. A new section of canal (Welland By-Pass), two tunnels for road and rail traffic, and a syphon for diversion of the Welland River were recently constructed between Port Colborne and Port Robinson.

PREVIOUS INVESTIGATIONS

The bedrock geology of the map-area formed part of a comprehensive report by Caley (1940) on the Paleozoic geology of the Toronto-Hamilton area including formation descriptions, structural and economic geology, and a summary of previous work since 1843. Later, stratigraphic studies by Best (1953) and Bolton (1957) included respectively the Devonian rocks of the Onondaga cuesta and the Silurian rocks

of the Niagara Escarpment in the Niagara-Welland map-area. The physiography and geology of the Niagara Escarpment were summarized by D.F. Hewitt in 1971. Slightly differing interpretations of the bedrock geology of the report-area were presented by Sandford (1969) and Hewitt (1972) as part of larger, regional compilations of the Paleozoic geology of southwestern Ontario. Most recent maps of the Paleozoic geology of the Welland and Niagara areas at a scale of 1:50,000 were compiled by Telford and Tarrant (1975) and Telford et al (1976) respectively. There exists an abundance of subsurface data for the Welland map-area because of the many exploratory drillings for oil and natural gas (Sanford 1964).

The topography of the bedrock surface in the Welland map-area was outlined by Sanford (1954, 1956) as part of a larger compilation based on data from the exploratory drillings for oil and natural gas. A more detailed interpretation of the bedrock surface topography in the eastern half of the Niagara-Welland area, and based largely on seismic data, was recently presented by Hobson and Gagne (1975). The Port Colborne part of this survey was published earlier (Owen 1972). In another seismic survey supplemented by stratigraphic drilling (Hobson and Terasmae 1969), the course of the buried St. Davids channel was outlined between The Whirlpool and Niagara-on-the-Lake confirming an earlier study by Spencer (1907).

Recent descriptions of commercial sources of raw material for the limestone products industry in the study-area can be found in Hewitt (1960, 1964), and Hewitt and Vos (1972). An excellent former account of limestone quarries in the map-area was given by Goudge (1938), while a comprehensive study of building stones, including descriptions of inactive sandstone quarries along the Niagara Escarpment, was presented by Parks (1912). Vos (1969) made a survey of stone resources with a view to outlining potential areas of quarry development between the Niagara Escarpment and the Welland River.

The only quarry in the map-area where shale is extracted for the manufacture of brick is located northwest of St. Davids. This quarry is described in the study of the clay products industry in Ontario by Guillet (1967).

Geological and production data for the Welland gas field is summarized in Koepke and Sanford (1966). The gas field is mainly in Silurian sandstones underlying the Welland map area and continuing offshore under Lake Erie.

The work of Spencer (1907) and of Kindle and Taylor (1913) capped early studies of the Niagara River and the drift-filled buried gorge between The Whirlpool and St. Davids. The mapping of the Quaternary geology of the Niagara quadrangle in New York State by F.B. Taylor included a narrow strip along the Niagara River on the Canadian side (Kindle and Taylor 1913). The stratigraphy of the Quaternary deposits in the buried St. Davids channel was

recently investigated by Hobson, Terasmae, and Karrow (Hobson and Terasmae 1969; Karrow and Terasmae 1970). Calkin and Brett (1978) recently conducted a study of the stratigraphic and paleontologic setting of the ancestral Niagara River drainage. Modern river bottom soundings, engineering studies of the Falls, and additional subsurface data formed the basis of several papers by Philbrick (1970,1974) on past and future recession of the Falls.

In a study of the moraine systems of southwestern Ontario, Taylor (1913) described and named Wisconsinan-age end moraines formed during the retreat of the glacier ice front in the Niagara-Welland area. Taylor correlated these end moraines into adjacent New York State. The end moraines were regared as having been deposited by glacier ice floating or grounded in glacial lake waters.

The map-area was also included in regional studies or summaries of the history of the Whittlesey and Warren to Erie and Ontario sequences of Great Lakes stages by Leverett and Taylor (1915), Coleman (1937a and b), Leverett (1939), Hough (1958, 1963), Chapman and Putnam (1966), and Sly and Lewis (1972). Stratigraphic studies by Dreimanis, Goldthwait, and Karrow resulted in a revised classification of Wisconsinan-age deposits and events in the Great Lakes Region (Dreimanis and Karrow 1972; Dreimanis and Goldthwait 1973).

The surface features of the map-area are described in the regional study of the physiography of southern Ontario

by Chapman and Putnam (1966). This study discusses the cuesta structure of the bedrock and the landforms created by the recession of the last ice sheet, the ancestral and modern lakes in the Ontario and Erie basins, and drainage in the area. The map of Chapman and Putnam (1966) and other maps by the Ontario Soil Survey (Report No.5 1935; Wicklund and Matthews 1963) show in a general way the surficial geology of the map-area.

E.B. Owen (1972) recently mapped the surficial geology of the Welland-Port Colborne area at a scale of 1:25,000. Owen (1969,1972) also prepared geological cross-sections based on excavations and test borings along or near the 14 km long relocated Welland Canal segment between Port Colborne and Port Robinson.

Maps of the drift thickness in the Welland area and in the Niagara area south of the Niagara Escarpment were prepared by Sanford (1954, 1956) and Vos (1969).

The few commercial sources of sand and gravel in the Niagara-Welland area are described in Hewitt and Karrow (1963), the descriptions being updated later in Hewitt and Cowan (1969).

The Welland Bog forms the only commercial source of peat in the map-area. This bog, its resources and producers have been described by Haanel (1924), Awer (1930), Leverin (1946), and Swinnerton (1958).

Natural resources and socio-economic developments in the Niagara Peninsula Conservation Area, including the

Niagara-Welland area, are discussed in a comprehensive survey report by the Ontario Ministry of the Environment (1972).

PRESENT GEOLOGICAL SURVEY

Mapping of the surficial geology of the Niagara-Welland area at a scale of 1:50,000 was initiated in 1969 and terminated in 1972 after 13 months of field work. The Quaternary deposits of this area were investigated by driving a sampling tube to depths ranging between 1 m and 2 m below the surface at points predominantly located along the grid of roads. They were also examined at many natural and man-made exposures and from borehole samples. The Quaternary map-units were primarily selected on the basis of lithlogy, origin, and age. However, only those deposits 1 m or more in thickness are delineated on the Quaternary geology maps (in back pocket). Sites where orientations of striae and larger grooves of glacial origin were measured, and those where samples of the Quaternary deposits were taken are also indicated on the geologic maps. The descriptions of the samples obtained from exposures and borings are given in Appendices A-D.

Laboratory work for which results are reported consist of grain size analysis by sieve and hydrometer, carbonate analysis of the smaller than 0.074 mm fraction (mainly silt- and clay-size material) (Dreimanis 1962), trace element

analysis (May 1971, 1973) of the smaller than 0.037 mm fraction (silt- and clay-size material) by atomic absorption and emmission spectroscopy, heavy mineral separation of the 0.105 mm to 0.250 mm fraction (mainly fine sand-size material) using tetrabromethane (S.G. 2.95), and sand lithology analysis of the 0.354 mm to 0.707 mm fraction (medium to coarse sand-size material) by microscopy. These analyses were carried out by the Geoscience Laboratories of the Ontario Geological Survey. Lithologic analysis of the pebble-size rock fragments in the 8 mm to 32 mm fraction (Vagners 1966) of Quaternary deposits was carried out in the field. Results of all the above analyses are tabulated in Appendices E-H for till, in Appendix I for some till-like clay deposits, and in Appendices J-L for sand and gravel deposits.

The upper boundaries of sand-, silt-, and clay-size fractions were taken at 2 mm, 0.063 mm,. and 0.002 mm respectively, as these sizes are commonly used in North America. The upper boundary of till matrix is taken at 2 mm and is considered as a natural one between matrix material and clasts since the "terminal grades" (Dreimanis and Vagners 1971) of the most common minerals occur in the smaller than 2 mm fraction (Vagners 1966, 1969).

ACKNOWLEDGMENTS

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The work could not have been completed without the co-operation of the residents of the area in providing access to private land.

Special appreciation is expressed to Peto Associates Limited, (now Peto MacCallum Ltd.), the Geological Survey of Canada, the St. Lawrence Seaway Authority, Ontario Hydro, the Ontario Ministry of the Environment, and the Ontario Ministry of Transportation and Communications for their co-operation in providing boring records and samples, and to Professor J. Terasmae of Brock University who contributed an unpublished pollen diagram of the Welland Bog and radiocarbon date BGS-58.

PHYSIOGRAPHY

Two escarpments have formed in the underlying Paleozoic bedrock of the Niagara-Welland area. Quaternary geomorphic features include end moraines, lake plains, shorelines and deltas, stream valleys and terraces, and bogs and swamps.

ESCARPMENTS

The map-area is underlain by an east-west trending cuestaform bedrock structure forming two north-facing erosional scarpslopes called the Niagara and Onondaga Escarpment.

Niagara Escarpment

The Niagara Escarpment forms a physiographic region in southern Ontario (Chapman and Putnam 1966). The Escarpment is also the major ridge in the map-area extending across its northern part west of Queenston. It separates the lowland to the north bordering Lake Ontario with a water level at about elevation 75 m(246 feet) from the upland on the cuesta dipslopes to the osuth bordering Lake Erie with a water level at about elevation 175 m (573 feet).

The upper part of the Niagara Escarpment is marked by a low but steep cliff of resistant caprock forming the

principal or Lockport scarp (Hewitt 1971). The elevation of the crest of the Escarpment varies between 162 and 195 m (530-640 feet). The remainder of the face below the resistant caprock consists of about 60 m of more erodable rocks which are generally mantled by glacial drift and talus (mantled scarp; Hewitt 1971). Two subsidiary scarps, the Whirlpool and Irondequoit scarps, are formed by relatively harder formations and protrude through this mantle at lower levels in several places. The base of the Escarpment is buried but occurs roughly parallel to the top at distances varying up to 2 km northward.

The Escarpment is breached by the Niagara River Gorge at Queenston and by an ancestral Niagara River gorge at St. Davids. The St. Davids Gorge is buried below thick drift. A large V-shaped re-entrant in the Escarpment occupies the north-central part of the map-area. The mouth of this re-entrant valley is approximately 20 km wide at the Escarpment edge southeast of Homer and west of Vineland. The mantled Lockport scarp at the head of the valley occurs approximately 8 km southward and extends east-west for about 2 km between Effingham and St. Johns West. Thick glacial drift which buries this bedrock valley is partially dissected by the Twelve Mile Creek. Smaller re-entrants are mainly found in the upper part of the Escarpment south of Beamsville, Vineland and Jordan, and between Thorold and St. Davids.

Onondaga Escarpment

The Onondaga Escarpment across the southern part of the map-area is, except for the upper part of its resistant caprock, mainly buried below a thick mantle of glacial drift. The low rise formed by this upper part varies in height to a maximum of 15 m above the plain to the north. Its configuration, indented like that of the Niagara Escarpment, is indicated on the topographic maps by the 600 foot contour (183 m) between Fort Erie on the Niagara River and Burnaby near Lake Erie to the west. The resistant caprock is exposed along the Onondaga Escarpment between Ridgemount and Ridgeway, between Bethel and Port Colborne, along the Welland Bog, and in the vicinity of Burnaby and Long Beach. It forms the headland on Lake Erie north of Rock Island and at Mohawk Point.

LAKE PLAINS

Three lake plains are superposed on the cuestaform structure of the Niagara-Welland area. The two major lake plains are portions of the Haldimand Clay Plain and Iroquois Plain physiographic regions of southern Ontario (Chapman and Putnam 1966). The Haldimand Clay Plain is the oldest and the Iroquois terrace the youngest lake plain in the map-area. The third lake plain is small and occurs in the lowland north of the Niagara Escarpment south of and

topographically above the Iroquois Plain; it is intermediate in age.

Haldimand Clay Plain

The Haldimand Clay Plain is a very gently south-sloping plain on the upland formed by the Niagara and Onondaga cuestas. It extends from the top of the Niagara Escarpment 30 km southward to Lake Erie and it is extensively underlain by proglacial lake clays. These clays were deposited on the Halton Till in Lakes Warren and several younger lake stages accompanying glacier retreat to the Niagara Escarpment and vicinity.

The lake plain can be topographically divided into northern, central, and southern segments. Elevations on the northern segment bordering the Niagara Escarpment are above 183 m (600 feet) except in areas marginal to the Twelve Mile Creek re-entrant valley and the Niagara River. Elevations on the central segment decline southward to about 176 m (570 feet). The southern segment includes the low rise of the upper part of the Onondaga Escarpment and the area on the cuesta dipslope south to the Lake Erie shore. Elevations on this segment rise again above 183 (600 feet).

The lake plain has very low relief in general. Large portions of the central and northern segments are characterized by a washboard-type surface with very low relief. This wash board-type surface and its origins are

discussed in the "Small Moraines" section of this chapter. Highest relief on the lake bottom plain is locally formed by various end moraine ridges scattered across the northern, central, and southern segments. These ridges also form sites of shore and nearshore features associated with wave action during the Warren and lower lake stages on the plain. The undulating bedrock surface of the Onondaga cuesta protrudes frequently through the veneer of drift in the southern segment of the lake plain. Bedrock is also exposed in the northern segment at a few knolls west to southwest of Campden near the Niagara Escarpment.

Iroquois Terrace

The gently north-sloping plain or terrace in the lowland north of the Niagara Escarpment was formed by proglacial Lake Iroquois following deglaciation of the northeastern part of its basin. This terrace is bordered in the south by the shoreline of Lake Iroquois at approximate elevation 110 m (360 feet). It is truncated in the north at the shoreline of Lake Ontario. The Iroquois terrace is about 11 km wide along the lower Niagara River, but it narrows considerably westward to approximately 2 1/2 km near Beamsville.

The terrace is extensively cut in Halton Till and veneered by the most prominent sheet of nearshore sands in the map-area. A sequence of clay and silt deposited in

deeper Lake Iroquois waters is exposed in a small portion of the plain at Niagara-on-the-Lake. An older sequence of lake bottom clay and silt is exposed to the south in a slightly larger portion of the plain between the Niagara River and St. Catharines. Shale bedrock is exposed in several smaller areas northwest of St. Davids, between Jordan and Beamsville, and at Beamsville and vicinity.

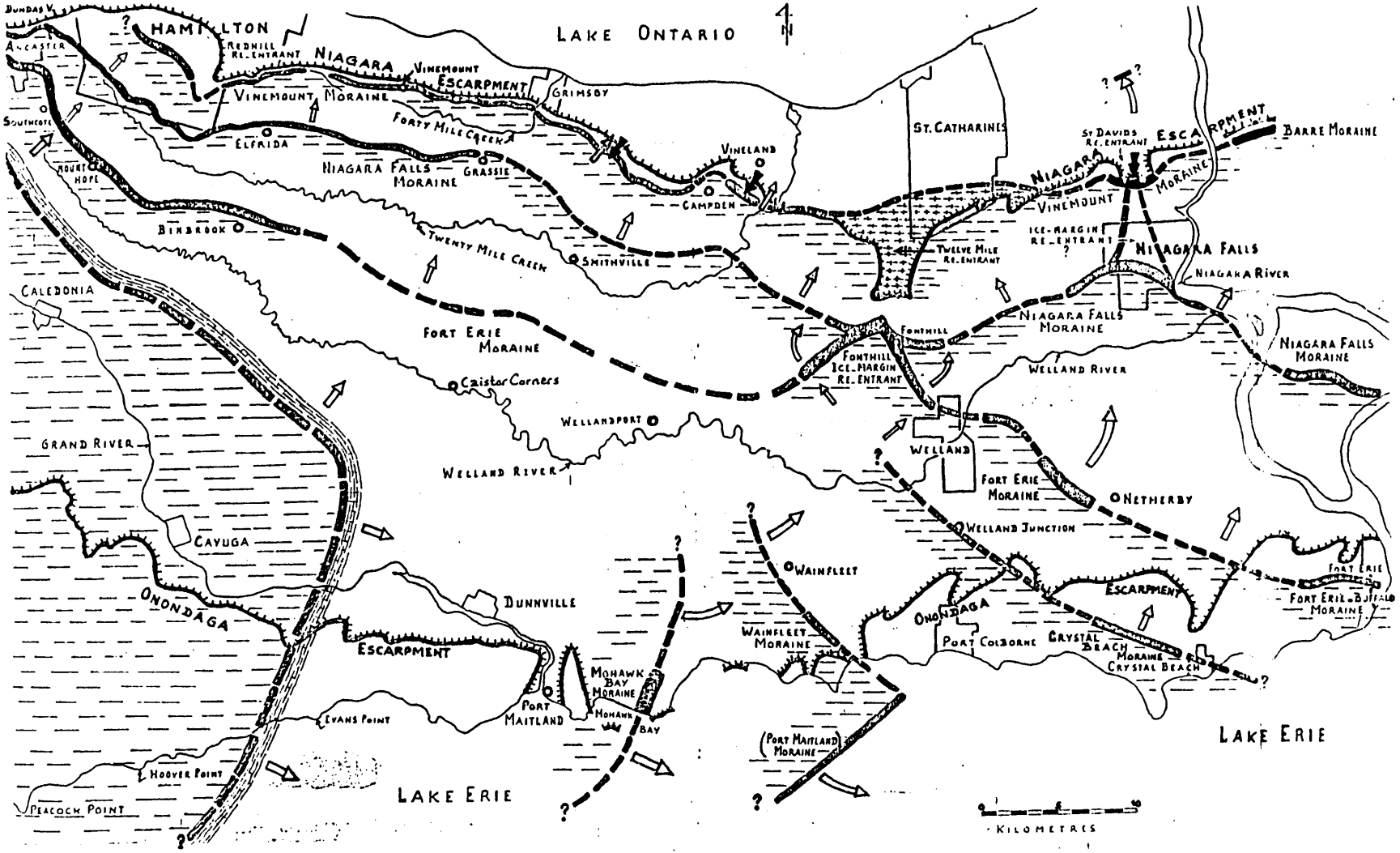
Third Plain

The smaller, third lake plain in the map-area was formed during comparatively brief stands of pre-Iroquois waters ponded in the lowland between the Niagara Escarpment to the south and the retreating glacier front at some distance to the north. This lake plain is best defined in the Twelve Mile Creek re-entrant valley in the Niagara Escarpment near St. Catharines. It is underlain there by a thin, stratified sequence of clay, silt and very fine grained sand overlying Halton Till at elevations of less than 137 m (450 feet). This sequence is truncated approximately 7 km to the north at the top of the Iroquois shorebluff at about elevation 113 m (370 feet). Similar fine grained lake bottom sediments are found in the area between the Iroquois shoreline and the Niagara Escarpment east of the Welland Canal. They occur probably also at similar elevations underneath the Bell Terrace (Spencer 1907) in the Four Mile Creek re-entrant valley in the

Escarpment south of St. Davids. They are however, indistinguishable from underlying older lake bottom sediments encountered in this area.

END MORAINES

The Mohawk Bay, Wainfleet, Crystal Beach, Fort Erie, Niagara Falls, and Vinemount Moraines form a group of successively younger end moraines in the Niagara-Welland area (Figure 2). The Fort Erie and Niagara Falls Moraines converge at the large Fonthill kame. These moraines were formed by the Ontario-Erie glacial lobe during its eastward, then northeastward, and later northward retreat from the eastern Erie basin area. The glacier fronted proglacial lake waters during its retreat. These recessional end moraines appear in the map-area as short ridges protruding through the glaciolacustrine clay cover on the Haldimand Plain. These ridges have been externally modified by wave action and are wholly or in part internally composed of Halton Till or glaciolacustrine deposits. The Vinemount, Niagara Falls, Fort Erie, and Crystal Beach Moraines were named and briefly described by Taylor (1913). The Wainfleet and Mohawk Bay Moraines are newly named and described in this report.



LEGEND

- Terminal position of glacier ice front(inferred).
- Recessional position of glacier ice front(mappable).
- Recessional position of glacier ice front(inferred).
- Local direction of glacier ice front recession.
- Local direction of glacier ice front advance.
- Floating glacier ice-shelf.
- Proglacial lake waters.

Figure 2. Terminal and recessional positions of the Ontario-Erie glacial lobe which deposited Halton Till in the Niagara Peninsula.

Mohawk Bay Moraine

The name Mohawk Bay Moraine is proposed here for several ridges forming a 4 km wide belt truncated at the Lake Erie shore between Mohawk Point in the Welland map-area and Rockhouse Point to the west in the adjacent Dunnville map-area. This moraine was referred to by Feenstra (1974) as the Port Maitland Moraine after its occurrence east of Port Maitland in the Dunnville area. This name, however, was already given by Lewis (1966) to another ridge submerged in Lake Erie at distances varying from 4 to 8 km offshore between Port Colborne and Port Maitland (see also Rukavina and St. Jacques 1971, and Figure 12 in Sly and Lewis 1972).

The Mohawk Bay Moraine ridges trend with a slight convex-westward curvature for approximately 3 km in north-northeast direction inland from Lake Erie. These ridges have an even outer surface and rise 8 to 15 m above the surrounding lake plain. Halton Till is exposed along the smaller ridge at Mohawk Point. The till and its buried, uneven surface can be traced along the shorebluff to a larger ridge about 3 km to the west in the Dunnville area. The hummocky surface of the till in this main ridge is concealed by a cover of contorted stratified sand, till, clay, and silt of subaqueous ice-contact origin. Beach and nearshore deposits are found on both ridges.

Wainfleet Moraine

The name Wainfleet Moraine is proposed here for a small northwest-trending ridge located approximately 12 km east-northeastward from the Mohawk Bay Moraine and midway between Morgans point on Lake Erie and the village of Wainfleet inland in the Welland area. This ridge is 2 1/2 km long, up to about 1/2 km wide, and its smooth crest rises to 8 m above the surrounding lake plain. Halton Till is exposed along the proximal northeast side of the ridge while its crest and distal southwest side are covered by beach and nearshore deposits of gravel, sand, and silt. This ridge was correlated by Taylor (1913) with the Crystal Beach Moraine located approximately 20 km to the east in the Welland area.

Crystal Beach Moraine

The Crystal Beach Moraine was named by Taylor (1913) after its occurrence at Crystal Beach on Lake Erie. It forms a 6 1/2 km long and less than 1 km wide ridge trending west-northwest inland to Sherkston. Its even crest rises to 8 m above the local bedrock of the Onondaga cuesta dipslope. Halton Till is mainly exposed along the crest and distal southern flank of the moraine ridge while its proximal northern flank is largely covered by glacio-lacustrine clay and silt. The till has been wave-worked and

is sporadically covered by thin beach and nearshore deposits.

The Mohawk Bay, Wainfleet, and Crystal Beach Moraines represent three distinct positions of the glacier front during the east- to northeastward retreat of the ice front from the eastern Lake Erie area. These moraines cannot be surficially traced beyond the ridges described in the previous paragraphs. The submerged Port Maitland Moraine may form a correlative of the Wainfleet Moraine.

Fort Erie Moraine

The Fort Erie Moraine was traced by Taylor (1913) from Fort Erie in the southeast of the Welland map-area, intermittently across the Niagara Peninsula to Ancaster in the northwest of the Grimsby map-area. The moraine was named after its occurrence at Fort Erie where it forms a west-trending ridge on the Onondaga cuesta dipslope. A few ridges at Welland and vicinity and the Fonthill kame to the northwest form the only surface expressions of the moraine between Fort Erie and Binbrook in the Grimsby area.

The ridge at Fort Erie is 6 1/2 km long, up to 1 1/2 km wide, and possesses an even outer surface. The crest of this ridge rises to 7 m above the surrounding lake plain. Halton Till is exposed along most of this segment of the moraine. Lake bottom clay and silt cover the lower portions of the proximal northern flank. The gentle slopes along the

distal south side were produced by wave action and several beach ridges occur along the crest.

The two parallel northwest-trending ridges between the hamlets of Brookfield and Cooks Mills at Welland and vicinity are composed of Halton Till and reflect rises in the till surface of about 8 m. These ridges are extensively covered by beach and nearshore deposits of gravel, sand, and silt and very little Halton Till is exposed. Other exposures of the till in the lake plain are found near Netherby to the southeast and to the northwest along Lyons Creek at Cooks Mills and also at a small rise marked by a beach ridge on top near the relocated Welland Canal west of Cooks Mils. These till exposures form additional surface expressions of the two Fort Erie Moraine ridges in an area measuring approximately 10 km in length and 3 km in width at Welland and vicinity. The buried northwestward extensions of these two ridges were encountered along the relocated Welland Canal between Main Street in Welland and 2 to 3 km south of Port Robinson in the Niagara map-area area to the north (see Figure 2 in Owen 1969 and Section A-b on Map 8-1971 in Owen 1972). These two Fort Erie Moraine ridges likely continue farther northwestward in the subsurface to the Fonthill kame. This kame complex was formed at the Fort Erie and Niagara Falls Moraine positions of the glacier front and will be discussed after the Niagara Falls Moraine.

Niagara Falls Moraine

The Niagara Falls Moraine was traced by Taylor (1913) from Niagara Falls westward across the Niagara Peninsula to Ancaster in the Grimsby map-area. This moraine was named after its occurrence in the City of Niagara Falls where it forms an 8 km long, up to 2 km wide, west-trending and concave-southward ridge. It is smooth-crested and rises along Lundy's Lane about 30 m at a maximum above the lake plain to the south. Test borings indicate that this segment of the moraine is composed of till and stratified deposits of sand and silt. Taylor (Kindle and Taylor 1913) reported finding gravelly kame deposits along Lundy's Lane and former Highway 8 to the north. Taylor suggested the existence of an ice-marginal re-entrant based on the curvature of this end moraine segment and the northward continuation of the kame deposits. The moraine ridge and the area to the north in Niagara Falls are extensively covered by beach and nearshore deposits and Halton Till is not exposed.

The Niagara Falls Moraine is surficially indistinguishable in the lake plain between the City of Niagara Falls and the hamlet of Turners Corners to the west-southwest. The crest of the moraine reappears as a gentle, 2 km long, and generally west-trending rise in the lake plain south of Highway 20 between Turners Corners and Fonthill. Near Fonthill, the crest of the moraine is marked by a sand and gravel bar forming part of a recurved spit.

At Fonthill, the moraine joins the Fonthill kame on its northeast side and Halton Till was encountered in excavations below a surficial veneer of nearshore sediments.

The Niagara Falls Moraine is again imperceptible in the lake plain between the hamlets of North Pelham on the west side of the Fonthill kame and Grassie to the west in the Grimsby area.

Fonthill Kame

The Fonthill kame is a large ice-contact deltaic complex deposited at the Fort Erie and Niagara Falls Moraine positions of the glacier margin fronting Lake Warren waters. This complex consists of three large ridges merging in the upland area at Fonthill and vicinity near the head of the Twelve Mile Creek re-entrant valley in the Niagara Escarpment. It stands 40 to 76 m above the surrounding lake plain. One ridge extends 3 km southeast towards Welland, another 5 km southwest to Fenwick, and the third 3 km west-northwest to North Pelham. The two southeast and southwest trending ridges are highest, and form and inverted V, and also possess 1 km wide flat tops which rise very gradually northward to elevation 247 m (810 feet) at the area of their coalescence. This 1 1/2 km^2 area is marked by a scarp and platform above it at approximate elevation 253 m (830 feet). Several small, parallel, southwest trending ridges occur on top of this platform and some of their

crests reach elevations of about 260 m (850 feet), the highest in the entire Niagara Peninsula. The west-northwest trending ridge has narrow and irregular tops at lower elevations ranging from 222 to 235 m (730-770 feet).

Slopes of the deltaic complex are steepest along the northern ice-contact sides at elevations of greater than 198 m (650 feet). Slopes are much more gradual along all sides of the complex at lesser elevations.

The two southeast and southwest trending ridges were formed along a re-entrant in the glacier front at the Fort Erie Moraine position. The ice-contact deltaic sequence at the southwest trending ridge is approximately 100 m thick at a maximum. This sequence consists of a thick lower sub-unit of fine grained sands and a generally thinner upper sub-unit of coarser grained sands and gravel which thickens northeastward. Remnants of a middle sub-unit consisting of sand and Halton Till occur very sporadically. The ice-marginal re-entrant disappeared largely during retreat of the glacier front from the Fort Erie to the Niagara Falls Moraine position and the west-northwest trending ridge was added to the complex.

The whole kame complex from its highest point downwards has been reworked by the waters of the various Erie basin proglacial lake stands, with generally lowering levels, occupying the map-area. This reworking resulted in the formation of scarps, terraces, an extensive cover of beach and nearshore deposits, and more gradual slopes along the lower reaches of the complex.

Vinemount Moraine

The Vinemount Moraine is the youngest and northernmost of the group of recessional end moraines in the map-area formed by the Ontario-Erie glacial lobe that deposited the Halton Till. This moraine was traced by Taylor (1913) and was later also shown by Chapman and Putnam (1966) as a near-continuous ridge along the top of the Niagara Escarpment from Queenston westward to Hamilton in the adjacent Grimsby map-area. It was named after its occurrence at Vinemount in the Grimsby area.

The moraine ridge enters the Niagara map-area southwest of Beamsville and continues eastward for about 4 km. Another 3 km long segment occurs south of Vineland. These segments are less than 1 km wide and possess even to somewhat hummocky crests rising 15 m at a maximum above the surrounding plain. Halton Till is exposed along both segments. The moraine segment south of Vineland consists of two parallel ridges and the northernmost of the two ridges is composed of Halton Till and contorted beds of clay, silt, and sand. A wave-cut bench occurs along the distal side of the moraine segment south of Beamsville and the underlying till is locally covered by a very thin veneer of nearshore sand and silt.

A kame deposit was formed at the Vinemount Moraine position of the glacier front at the head of the Four Mile Creek re-entrant valley in the Niagara Escarpment south of St. Davids (Kindle and Taylor 1913). Halton Till occurs in

this deposit of ice-contact deltaic origin. The southern slopes of the deposit are covered by nearshore sand and silt and rise gradually to about 15 m above the lake plain. A small beach deposit is found at the top. Steeper slopes exist along the ice-contact side to the north.

ANCIENT SHORELINES AND DELTAS

Ancient shorelines mapped in the Niagara-Welland area were formed initially by Erie and later also by Ontario basin lake stands accompanying glacier retreat some 12,000 to 13,000 years ago. Relic shoreline forms in the map-area include sand and gravel bars, bluffs, and terraces. The most extensive shoreline in the area was built by ancestral Ontario basin Lake Iroquois in an east-west direction across the lowland north of the Niagara Escarpment. Mainly small, insular shorelines were formed by various ancestral Erie basin lake stands on the Haldimand Plain in the area. Deltas were built in several of the ancestral Erie and Ontario basin lake stands by the Grand River and by streams draining the Niagara Escarpment area. These shoreline and associated features in the map-area have since been abandoned because of lake-level lowering and isostatic rebound.

Erie Basin

Raised shoreline and associated features on the Haldimand Plain have been correlated by earlier workers with ancestral Erie basin lake stages. Leverett (1939) and Chapman and Putnam (1966) identified a series of parallel ridges, reaching elevations of about 259 m (850 feet) on top of the Fonthill kame complex, as beach ridges of Lake Warren. Taylor (Kindle and Taylor 1913) identified beaches mapped in the City of Niagara Falls at elevations varying between 198 and 213 m (650-700 feet) as shoreline features of Lake Lundy. These features included the beach on the Niagara Falls Moraine along Lundy's Lane after which Lake Lundy was named earlier by Spencer. The Lundy beaches in the Niagara region of Ontario and New York were correlated by Taylor (Kindle and Taylor 1913, Leverett and Taylor 1915) with the Dana beaches traced by Fairchild (1907) farther east in New York and the Elkton beaches in Michigan. This correlation was disputed by Leverett (1939), Hough (1958), and Calkin (1970). Chapman and Putnam (1966) also stated that one cannot be sure that the original Lundy beach at Lundy's Lane represents the same water plane as do the Lundy (Elkton) beaches in Michigan. Chapman and Putnam (1966) and Calkin (1970) accepted Hough's (1963) argument for the existence of the Early Lake Algonquin stage in the Erie basin. The ancestral Grand River delta at Dunnville and vicinity and beach ridges in the Welland map-area were

correlated with this lake stand by Chapman and Putnam (1966). Calkin (1970), however, considered the elevation of about 189 m (620 feet) used for the tilted level of the Early Lake Algonquin water plane in the Welland map-area much too low and assigned the beaches to Lake Dana. Shoreline features occur in the Welland area at elevations below 200 m (660 feet) and show too much local variation in altitude to belong solely to Early Lake Algonquin or Lake Dana. Some of the lower beaches identified at elevations below 189 m (620 feet) were formed by Early Lake Erie according to Chapman and Putnam (1966).

Raised shoreline features found on the Haldimand Plain in the Peninsula (Figure 3) are correlated in this report with the post-Warren I sequence of lake stages in the Erie basin based on studies by Calkin (1970) and Barnett (1978). Calkin (1970) correlated raised beaches and other abandoned shoreline features present in northwestern New York with nine known major proglacial lake stands in the Erie basin. These in general successive lower stands are from oldest to youngest as follows (with elevations of their untilted levels between brackets): Lake Whittlesey (225 m or 738 feet), Lake Warren I (210 m or 690 feet), Lake Warren II (207 m or 680 feet), Lake Wayne (201 m or 660 feet), Lake Warren III (206 m or 675 feet), Lake Grassmere (195 m or 640 feet), Lake Lundy (189 m or 620 feet), Early Lake Algonquin (185 m or 605 feet), and Lake Dana (159 m or 570 feet?). Barnett (1978, Figure 10) reconstructed the tilted profiles

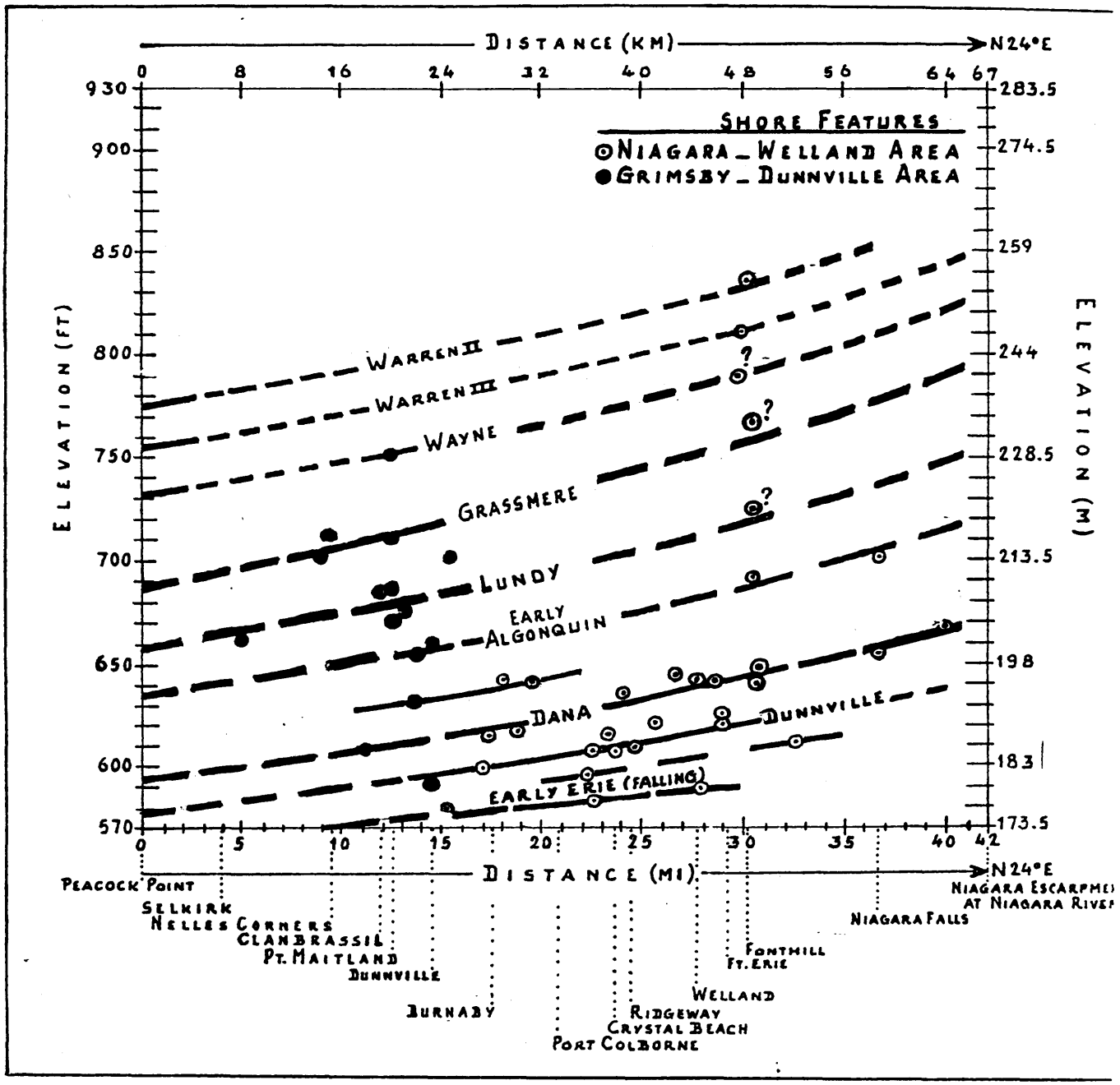


Figure 3. Tilted shorelines of former lake stages of the Erie Basin in the Niagara Peninsula. Elevations of the shore features have been projected at right angles to the N24°E direction of maximum tilt used by Calkin(1970).

of the Whittlesey, Warren I, and Warren II water planes in the Simcoe and adjacent map-areas of southwestern Ontario.

Lake Dunnville (newly named) and Early Lake Erie (lowering levels) are the lowest ancestral Erie basin stands represented by shoreline and associated features in the Niagara Peninsula.

Lake Whittlesey

Lake Whittlesey shoreline features are absent from the Peninsula. The Ontario-Erie glacial lobe that deposited Halton Till covered the Niagara-Welland area and, according to Barnett (1979), fronted Lake Whittlesey at the terminal margin in the western portion of the adjacent Grimsby-Dunnville area. The water plane stood well above any point in that part of the Peninsula and would have been at least 10 m above the highest point on the Fonthill kame complex.

Lakes Warren, Wayne, Grassmere, Lundy

The Fonthill kame complex forms the only portion of the Niagara-Welland map-area high enough to be intersected by the Warren, Wayne, Grassmere, and Lundy water planes.

Shoreline features presumed to be formed by Lakes Warren II and III are the only features which have been recognized and identified. The crests of the most prominent

of the beach ridges on top of the highest terrace at the area of coalescence of the large southeast and southwest trending ice-contact ridges stand at about the tilted level of the Warren I water plane (elevation 259 m or 850 feet). This terrace and the beach ridges on top correspond better with the tilted level of the Warren II water plane (elevation 255 m or 835 feet). Lake Warren III formed a lower terrace and a wave-cut bluff backing it on the southeast and southwest trending ice-contact ridges of the kame complex. The base of the bluff is at elevation 247 m (810 feet).

The lower Wayne stand existed immediately before the Warren III stand (Hough 1963). Any Wayne shoreline feature formed near elevation 240 m (785 feet) at Fonthill was most likely destroyed by wave action during submergence in the shallow waters of Lake Warren III.

Tilted levels of the Grassmere and Lundy water planes reach elevations 232 m (760 feet) and 220 m (720 feet) at Fonthill. Shoreline features, however, have not been found locally at or near these levels during the field mapping. Grassmere beaches are identified near elevation 216 m (708 feet) and Lundy beaches near elevation 207 m (680 feet) in the northwestern portion of the Dunnville area (Feenstra 1974).

Early Lake Algonquin

The Fonthill kame complex and the Niagara Falls Moraine ridge along Lundy's Lane form the only portions of the Niagara-Welland area high enough to be intersected by the Early Lake Algonquin water plane. Beach deposits formed by Early Lake Algonquin occur at elevation 210 m (690 feet) along the northeast facing ice-contact slope at Fonthill and near elevation 213 m (700 feet) at the summit of the moraine ridge along Lundy's Lane. In addition, slopes along the Fonthill kame complex northeast of Fenwick appear to be terraced by this lake stand near elevation 210 m (690 feet).

One finds another beach ridge corresponding to the tilted level of the Early Lake Algonquin water plane at elevation 200 m (655 feet) on the crest of the Mohawk Bay Moraine ridge in the Dunnville area (Feenstra 1974).

Lake Dana

The Lake Dana stand in the Erie basin is represented by relatively numerous shoreline forms scattered predominantly across the Haldimand Plain in the Niagara-Welland area. These features occur at several bedrock rises on the Onondaga cuesta but they are mainly developed at the various end moraine ridges composed of till and ice-contact stratified drift. The end moraine localities include the Wainfleet Moraine (elevation 188 m or 615 feet), the Fort

Erie Moraine at Fort Erie and Welland (elevation 195 m or 640 feet), the Niagara Falls Moraine at Niagara Falls and the Fonthill kame complex (elevation 198 m or 650 feet), and the Vinemount Moraine south of Beamsville and at the head of the re-entrant valley in the Niagara Escarpment south of St. Davids (elevation 204 m or 670 feet). The shoreline forms include wave-cut terraces but consist predominantly of sand and gravel bars including a recurved spit along the Niagara Falls Moraine at Fonthill. The vertical positions of these features fit a tilted shoreline between elevations 185 m (605 feet) near Port Maitland in the Dunnville area (Feenstra 1974) and 204 m (670 feet) near the Niagara Escapment at the Niagara River approximately 45 km to the north-northeast.

Lake Dunnville

Lake levels in the Erie basin dropped about 4 m from the Dana to the next lower stand named here Lake Dunnville after the town of Dunnville where the Grand River formed a delta. Somewhat higher ground on the northern portion of the Onondaga cuesta in the Welland map-area formed a slight barrier in Lake Dunnville. This barrier separated open waters in the Lake Erie area from more protected and shallow waters on the Haldimand Plain to the north. Almost all shoreline features of Lake Dunnville in the Niagara Peninsula are found along the open-lake side of this

barrier. The shoreline forms consist predominantly of small sand and gravel bars. Their vertical positions fit a tilted level between elevations 181 m (595 feet) near Long Beach and 189 m (620 feet) near Fonthill about 23 km to the north-northeast.

The ancestral Grand River delta extends for about 24 km from Dunnville and vicinity eastward to near Winger in the Welland map-area, and it is as much as 10 km wide. The proximal deltaic sediments found in and around Dunnville consist of gravelly sands and silty fine to medium grained sands. The finer distal deltaic sediments consist of silty very fine to fine grained sands and some interbedded silt and clay. The distal portion of the delta in the Welland map-area is found west of Wainfleet and Chambers Corners and between the abandoned Welland Canal feeder in the south and Perry and Montague in the north. Elevations of the delta plain surface rise from 177 m (580 feet) at the distal portion to 180 m (590 feet) and 183 m (600 feet) at the proximal portion in and around Dunnville. The delta was formed during the Lake Dana and Lake Dunnville stands when the mouth of the Grand River migrated downstream from Cayuga to Dunnville. Small dunes were later formed on the delta plain by prevailing western winds.

Early Lake Erie

Further lake-level lowering following deglaciation of

the Niagara-Welland area resulted in separation of the waters in the Lake Erie area (Early Lake Erie: falling levels) from those impounded on the Niagara cuesta (central segment Haldimand Plain) and in the Ontario basin between the Niagara Escarpment and the glacier margin (Lake Iroquois, pre- and post-Iroquois levels). Possible Early Lake Erie shoreline features are formed by a very small sand and gravel bar found at elevation 181 m (595 feet) at Shisler Point and by two low scarps in clay and silt found at elevations varying between 177 m and 180 m (580-590 feet) near Lake Erie at Crystal Beach and Fort Erie.

Lake Tonawanda

Taylor (Kindle and Taylor 1913) identified a faint bluff in clay near elevation 177 m(580 feet) at Chippewa in the Niagara map-area as a western shoreline feature of Lake Tonawanda. This lake was formed by shallow waters impounded on the lowland between the Niagara and Onondaga Escarpments in northwestern New York State. Raised shoreline features of Lake Tonawanda in New York vary in elevations from about 177 m (580 feet) near Tonawanda to 198 m (650 feet) eastward at the Holley spillway (Kindle and Taylor 1913).

No definite shoreline forms of ponded waters on the central segment of the Haldimand Plain in the map-area were identified during the present survey.

Ontario Basin

Early observations concerning the Iroquois beach, the Bell Terrace, and other ancient shoreline features documenting changes in Ontario basin water levels are discussed by Spencer (1907). The prominent ancient shoreline of Lake Iroquois is also described in a later comprehensive study by Coleman (1937a).

Lake Iroquois

Proglacial Lake Iroquois formed the most prominent ancient shoreline in the Niagara-Welland area. The Iroquois shoreline is followed in the Niagara area for the most part by Regional Road 81 (former Highways 8 and 8A) across the lowland between Beamsville and Queenston. The shoreline consists predominantly of a low, north-facing erosional bluff backing the Iroquois terrace. This shorebluff is interrupted by a large baymouth bar at St. Catharines (Homer bar, Coleman 1937a). Several, much smaller deposits of beach sand and gravel occur along the base of the bluff west of St. Catharines. The base of the shorebluff rises eastward from about elevation 107 m (350 feet) at Beamsville to about elevation 113 m (370 feet) at Queenston. The crest of the baymouth bar reaches about elevation 114 m (373 feet).

This prominent shoreline marks the farthest

encroachment of rising Lake Iroquois waters on its western shore due to the more rapid isostatic rebound following deglaciation of the northeastern portion of the lake basin.

Pre-Iroquois

A higher, pre-Iroquois proglacial lake level in the Ontario basin is suggested by several small deposits of deltaic sand found below elevation 143 m (470 feet) on the smaller third lake plain in the Twelve Mile Creek re-entrant valley near St. Catharines and the Four Mile Creek re-entrant valley south of St. Davids (Bell Terrace, Spencer 1907). These small deltas were formed by runoff from the higher areas of ice-contact stratified drift at or near the head of the re-entrant valleys in the Niagara Escarpment.

Two very small sand and gravel bars mapped at elevations varying between 183 and 186 m (600-610 feet) near Campden may have been deposited locally along the western shore of the highest stand of these proglacial lake waters in the Twelve Mile sub-basin.

Post-Iroquois

Evidence in the Niagara area for lake-level lowering in the Ontario basin following the main Lake Iroquois stand

consists possibly of small sand and gravel bars found on the Iroquois terrace at elevations varying between 91 and 101 m (300-330 feet) near Beamsville, St. Catharines, and Niagara-on-the-Lake (see also Coleman 1937a). These ridges are more or less parallel to the main shoreline of Lake Iroquois.

Another, poorly preserved sand and gravel deposit occurs on the Iroquois terrace along Twenty Mile Creek north of Jordan at elevations varying between 98 and 104 m (320-340 feet). It is more or less perpendicular to the main shoreline, and may represent a remnant of an ancestral Twenty Mile Creek delta in Lake Iroquois or alluvial material deposited during post-Iroquois lake-level lowering.

MODERN SHORELINES

Lake Erie

Since low-level Early Lake Erie came into existence, postglacial waters in the Erie basin have risen to the present level because fo more rapid isostatic rebound of the Fort Erie-Buffalo outlet and return of Huron basin drainage (Lewis et al. 1966, Lewis 1969).

The modern Lake Erie shoreline in the Welland area is characterized by low, flat headlands or points where bedrock is exposed, by beach deposits along intervening bays, and by

backshore dunes. The dunes reach heights of about 30 m at the Sugar Loaf west of the Welland Canal at Port Colborne and eastward also in the area between Shisler Point and Point Abino.

Lake Ontario

Since low-level Early Lake Ontario became established, postglacial waters in the Ontario basin have also risen to the present level because of more rapid isostatic rebound of the eastern outlet (Karrow et al. 1961, Sly and Lewis 1972).

The modern Lake Ontario shoreline in the Niagara area was previously investigated by Coleman (1937b). It is characterized by low bluffs in Halton Till and overlying Lake Iroquois sediments. The bluffs are interrupted by baymouth bars at the mouths of drowned stream valleys.

"SMALL MORAINES"

A large portion of the Haldimand Plain in the Niagara-Welland area underlain by glaciolacustrine clay and silt is characterized by a washboard-type surface. Difference in relief between rises and depressions is a matter of only about 1 m, which is barely discernable in the

field. The resulting micro-relief pattern trends in a very general way northwest-southeast. It is masked near Fenwick by a cover of nearshore sand spread out by wave-action from the Fonthill ice-contact deltaic complex, suggesting a pre-Dana age in this area. The lake-bottom sediments were observed to be folded in donw-glacier direction or pressed-up near-vertically and roughly transverse to glacial movement at the few exposures available at the low rises. Many of the shallow depressions contain bog deposits and the underlying glaciolacustrine clay is strongly weathered. One depression was found to be filled with silt and gravelly silt-sand which may have been left after a block of stagnant ice had melted away.

Loken and Leahy (1964) proposed on the basis of air photo interpretation that the micro-relief pattern was formed by "small moraines", i.e. features formed by the squeezing of unfrozen substrate into crevasses at the base of a glacier advancing into deeper proglacial lake waters. The distribution of these "small moraines" does coincide approximately with the deeper portions of the former proglacial lake basin in this area during for example the Warren stages (Loken and Leahy 1964, Figure 7). The glacial lobe receded, however, during this time in the Peninsula to the Niagara Escarpment and vicinity where apparently the only, minor, oscillations took place in this area.

Henderson (1967) suggested that the oriented ridge topography, roughly transverse to the last direction of ice

movement, in glaciolacustrine clays near Kingston, Ontario, was formed when a crevassed floating ice-shelf lowered onto clays during shallowing of the water. The washboard-type surface of the upper glaciolacustrine bottom sediments underlying the Haldimand Plain in the Niagara-Welland area may have originated in a similar way during glacial recession accompanied by lowering of the proglacial lake level. The micro-relief pattern, however, trends roughly parallel to only one of the two crossing sets of crevasses suggested by the orientation of the southern ice-contact deltaic (eskerine) ridges at Fonthill. Little evidence for the squeezing-up of the clay and silt into crevasses has been found to date. Possible areas of waterlain till on the Haldimand Plain associated with a floating ice-shelf should also be investigated. A similar surface pattern is developed on the small, third lake plain of the pre-Iroquois ponded waters below the Niagara Escarpment near the mouth of the Twelve Mile re-entrant valley. It is possibly associated with the waterlain upper layer of Halton Till.

Other origins for the micro-relief pattern on the Haldimand Clay Plain were recently suggested by Mollard (1975). They are as follows:-

1. it resembles the surface expression of wooded permafrost regions underlain by fine-grained lacustrine soils after removal of the vegetation and melting of

the ground ice (periglacial origin);

2. it resembles the forms seen on gently shelving nearshore zones (longshore-current origin);

3 it could also be connected with differential solution and removal of soluble constituents in the underlying glacial drift or bedrock (chemical origin).

STREAMS, VALLEYS, AND TERRACES

The present surface drainage of the Niagare-Welland area is almost entirely into Lake Ontario to the north; only a few small streams drain southward on the narrow Onondaga cuesta backslope into Lake Erie.

The Ontario basin drainage system includes: the Niagara River, the Welland River, Twelve, Fifteen, Sixteen, and Twenty Mile Creeks, and numerous smaller streams that arise in or near the Niagara Escapment. Early stages of these streams, with the exception of the younger Welland River, developed soon after deglaciation of the map-area and during lowering of the accompanying lake stands.

Niagara River

The Niagara River is a 50 km long channel along the eastern border of the map-area connecting Lakes Erie, and Ontario. Almost the entire discharge of Lakes Erie, Huron, Michigan, and Superior passes through this channel. Its waters flow in an updip direction across the Onondaga and Niagara cuestas and through the lowland to the north. The Niagara River drops 22 m along its 29 km long upper section between Lake Erie and the crest of the Canadian or Horseshoe Falls. The river drops an additional 55 m at the Falls and another 23 m along its 22 km long lower section to Niagara-on-the-lake. The River has cut an 11 km long canyon (Niagara Gorge) from the Niagara Escarpment at Queenston-Lewiston upstream to the present position of the Falls. The flow over the Falls is reduced by the diversion of water for production of hydroelectric power.

The present Niagara River began as the Lewiston outlet of Lake Tonawanda to Lake Iroquois some 12,000 years ago. Cutting of the several sections of the Niagara Gorge since that time has been correlated in Kindle and Taylor (1913) with alternate bypassing and return of Huron basin drainage. This was dependent upon the opening or closing of other outlets of the ancestral upper Great Lakes. The correlations made by Kindle and Taylor (1913) are somewhat speculative according to recent radiocarbon dating of mollusk shells from Niagara River gravels (Calkin and Miller

1977, Calkin and Brett 1978).

The Lewiston outlet consisted of two channels which are outlined in Kindle and Taylor (1913). Remnants of one of the abandoned channels follow the Niagara River closely at the top of the Niagara Gorge on the Canadian side; the other channel is in Niagara Falls, New York.

The few Niagara River terraces in the map-area are found primarily at levels below the Lewiston outlet and were identified in Kindle and Taylor (1913) as "older abandoned" or "recent abandoned". The most prominent of these terraces is at the Falls and vicinity. Two sets of smaller terraces are found 10 to 20 m above the lower Niagara River level between Queenston and Fort George. All these terraces probably correlate with stages of post-Iroquois lake-level lowering in the Ontario basin.

Welland River

The Welland River flows generally parallel to strike on the central portion of the Niagara cuesta backslope in the Peninsula. It takes a shallow, meandering course across the Haldimand Clay Plain from Southcote near Hamilton east to the Chippewa-Queenston Power Canal about 7 km west of the original confluence with the Niagara River at Chippewa. Because of its very shallow gradient the water level of the Welland River is controlled by the Sir Adam Beck

hydroelectric power generating station near Queenston. The River is siphoned underneath the Welland Canal at Welland and Port Robinson. Valley and flood plain of the Welland are narrow with no trace of a terrace.

Twelve-Twenty Mile Creeks

Most of the streams in the map-area discharging into Lake Ontario have been named according to their approximate distance west from the mouth of the Niagara River. The larger of these streams are the Twelve, Fifteen, Sixteen, and Twenty Mile Creeks. These streams drain the northern segment of the Haldimand Clay Plain, the Niagara Escarpment, and the Iroquois Plain west of the Welland Canal. Major downcutting by these streams may have been accomplished during the time of lowering lake levels in the Ontario basin, and alluviation during the time of rising base levels. The mouth-areas of these streams have been drowned by rising Lake Ontario waters.

Twelve Mile Creek

The headwaters of Twelve Mile Creek originate on the northern slopes of the Fonthill kame complex. Twelve Mile has a relatively steep average gradient along its northward

course between Fonthill and the Martindale Pond at Port Dalhousie. It descends over bedrock at St. Johns West at the head of the re-entrant in the Niagara Escarpment. During periods of high runoff many small waterfalls also originate where the numerous tributaries flow over resistant bedrock ledges along the re-entrant walls. Twelve Mile Creek leans against the Escarpment at the DeCew hydroelectric power station in St. Catharines. Most of the water downstream in the Twelve Mile Creek comes from the Welland Canal via Lake Gibson, the forebay of the power station.

Twelve Mile Creek has dissected the glacial drift to depths of about 30 m. Its valley and flood plain are generally narrow although significant widening occurs along the Escarpment at the mouth of a tributary gorge at DeCew Falls. The bottom of Twelve Mile valley at its mouth-area is 10 to 14 m below the level of Lake Ontario. Small, slightly elevated terraces occur along the valley south of St. Johns West.

Early stages of Twelve Mile Creek discharged into ponded pre-Iroquois Ontario basin waters at the head of the re-entrant, into Lake Iroquois at St. Catharines where the construction of the Homer baymouth bar blocked and diverted flow westward, and into a lower post-Iroquois stand farther northward on the Iroquois terrace.

Twenty Mile Creek

Twenty Mile Creek, follows a shallow,meandering course from Hamilton, eastward across the Haldimand Clay Plain to the Niagara Escarpment at Ball's Falls south of Jordan. The stream has a low average gradient along this course. It enters the map-area near St. Anns and turns northeastward to the Escarpment west of Pelham Union. The Twenty Mile Creek valley is intermittently based on bedrock between St. Anns and Tintern downstream, and has been cut into bedrock downstream from Tintern to the Escarpment. The gradient steepens somewhat upstream from Ball's Falls where the stream bends around the east end of a Vinemount Moraine ridge segment. The drop at Ball's Falls and in the nearly 1 1/2 km long gorge cut into the Escarpment is about 80 m. Twenty Mile issues from the narrow gorge at Jordan.

The valley and flood plain of Twenty Mile Creek upstream from Jordan are generally narrow, but wider than the Welland River or any other stream in the map-area draining into Lake Ontario west of the Niagara River. Where constricting bedrock is present, the valley is straight and the flood plain narrow or absent. A small, but distinct terrace occurs at the mouth of the gorge at Jordan approximately 15 m above the present rocky stream bed. Downstream from Jordan, Twenty Mile Creek levels considerably in a wide valley and flood plain cut through the Iroquois terrace northward to Jordan Harbour. The base

of the valley increases in depth from 4 to 5 m below the flood plain near Jordan to 14 m below the level of Lake Ontario at the baymouth bar at Jordan Harbour.

Early stages of Twenty Mile Creek also discharged into ponded, pre-Iroquois Ontario basin waters in the Ball's Falls-Jordan area, and into Lake Iroquois at Jordan or a lower, post-Iroquois stand north of Jordan.

Fifteen and Sixteen Mile Creeks

The headwaters of Fifteen Mile Creek rise on the westflank of the Fonthill kame complex and also on the surrounding lake plain to the west. Fifteen Mile Creek takes a northeastern course across the Haldimand Clay Plain to Rockway at the Niagara Escarpment where it carved a small gorge, and continues northward across the Iroquois Plain to Lake Ontario.

Sixteen Mile Creek heads also in the Haldimand Clay Plain but south of St. Anns near the western boundary of the map-area. Sixteen Mile Creek takes an eastern to northeastern course across the lake plain to the Niagara Escarpment where it follows a large, hairpin-shaped glacial groove in the Escarpment's brow and also carved a small gorge. Sixteen Mile Creek also continues northward across the Iroquois Plain to Lake Ontario.

Fifteen and Sixteen Mile Creeks are alike in length and gradient. Their valley and flood plain characteristics are

similar to those of Twenty Mile Creek on the Haldimand Clay Plain and at the Niagara Escarpment, and similar to those of Twelve Mile Creek below the Escarpment.

BOGS AND SWAMPS

Organic materials such as peat and muck tend to accumulate in the form of bogs and swamps in areas of poor drainage. In the Niagara-Welland area, poorly drained areas are found on the Haldimand Clay Plain near Port Colborne in low areas in front of the Onondaga Escarpment (Welland Bog) or at re-entrants in the Escarpment where southward drainage was impeded (Humberstone Marsh). Numerous small, poorly drained depressions also characterize the extensive washboard-type surface of this lake plain farther northward from the Escarpment. Other shallow and poorly drained depressions, probably representing former lagoons, are found on the undulating surface of the Onondaga cuesta backslope behind the Lake Erie shore between Port Colborne and Crystal Beach. Small, shallow, poorly drained depressions also occur on the narrow, third lake plain at St. Catharines, and some of these depressions are former channel bogs. Poor drainage conditions also exist in the map-area at the drowned mouth-areas of streams flowing to Lake Ontario. Their passage to the lake is almost entirely blocked by baymouth bars.

Welland Bog

The Welland Bog (or Wainfleet Marsh) near Port Colborne is the most extensive bog (1200 hectares) in the map-area; it is a shallow peat bog with a slightly domed surface. This bog originated at least 8,000 years ago and is possibly a vestige of remnant ponded waters on the Haldimand Clay Plain north of the Onondaga Escarpment. A detailed discussion of the peat and lake deposits in the Welland Bog follows in a latter section of this report.

PALEOZOIC GEOLOGY

BEDROCK GEOLOGY

Paleozoic rocks of Ordovician, Silurian, and Devonian age underlie the Quaternary deposits in the Niagara-Welland area. In general, the Paleozoic strata strike east-west and dip gently (about 5 1/2 m/km) to the south. Table 1 lists the Paleozoic formations of the map-area. All known outcrops of bedrock in the area are indicated on the Quaternary geology maps (in back pocket).

The Niagara and Onondaga Escarpments divide the area into three distinct belts of differing bedrock lithology and width (Figure 4). They are as follows:-

1. A belt between about 4 and 14 km wide north of the crest of the Niagara Escarpment and consisting mainly of shale, siltstone, and sandstone. Red shales of the Queenstone Formation (Figure 4, unit O) underlie the lowland in front of the Escarpment and the several re-entrants (Whirlpool-St. Davids Gorge, Twelve Mile Creek re-entrant). Grey, green, and red shales, silt and sandstones with interbedded grey limestones and dolostones form the overlying Cataract and Clinton Groups (Figure 4, Unit Sl) which terminate updip in the face of the Niagara Escarpment.

TABLE 1 CLASSIFICATION OF THE PALEOZOIC ROCKS IN THE NIAGARA-WELLAND AREA (after Telford and Tarrant 1975, and Telford et al. 1976).

Standard Time	Reference	Group	Formation	Member	Lithology	Map-Legend
Devonian	Middle		Onondaga	Moorehouse Clarence Edgecliff	Limestone,moderately cherty Limestone,very cherty Limestone,irregularly cherty	6
	Lower		Bois Blanc	Springvale	Limestone, argillaceous,cherty Sandstone,glauconitic	
Silurian	Upper		Bertie		Dolostone,argillaceous,mottled	5
			Salina		Dolostone,shale,evaporites	4
	Middle	Clinton	Guelph		Dolostone	*
			Lockport	Eramosa Goat Island Gasport	Dolostone,bituminous Dolostone,cherty at base Limestone,dolostone,crinoidal	3
			DeCew Rochester Irondequoit Reynales Neahga Thorold		Dolostone,argillaceous Shale,limestone interbeds Limestone,crinoidal Dolostone,limestone,argillaceous Shale Sandstone,siltstone	2
	Lower	Cataract	Grimsby Cabot Head Whirlpool		Sandstone,siltstone,shale Shale, limestone interbeds Sandstone	
Ordovician	Upper		Queenston		Shale,siltstone	1

* Not exposed in map-area.

D — DEVONIAN
Onondaga and Bois Blanc Formations

S_2 — SILURIAN
Bertie, Salina, Guelph and Lockport Formations

S_1 — SILURIAN
Clinton and Cataract Groups

O — ORDOVICIAN
Queenston Formation

20 — Glacial striae on bedrock; direction of ice movement from N 20° E to S 20° W.

• Location of glacial striae measurements.

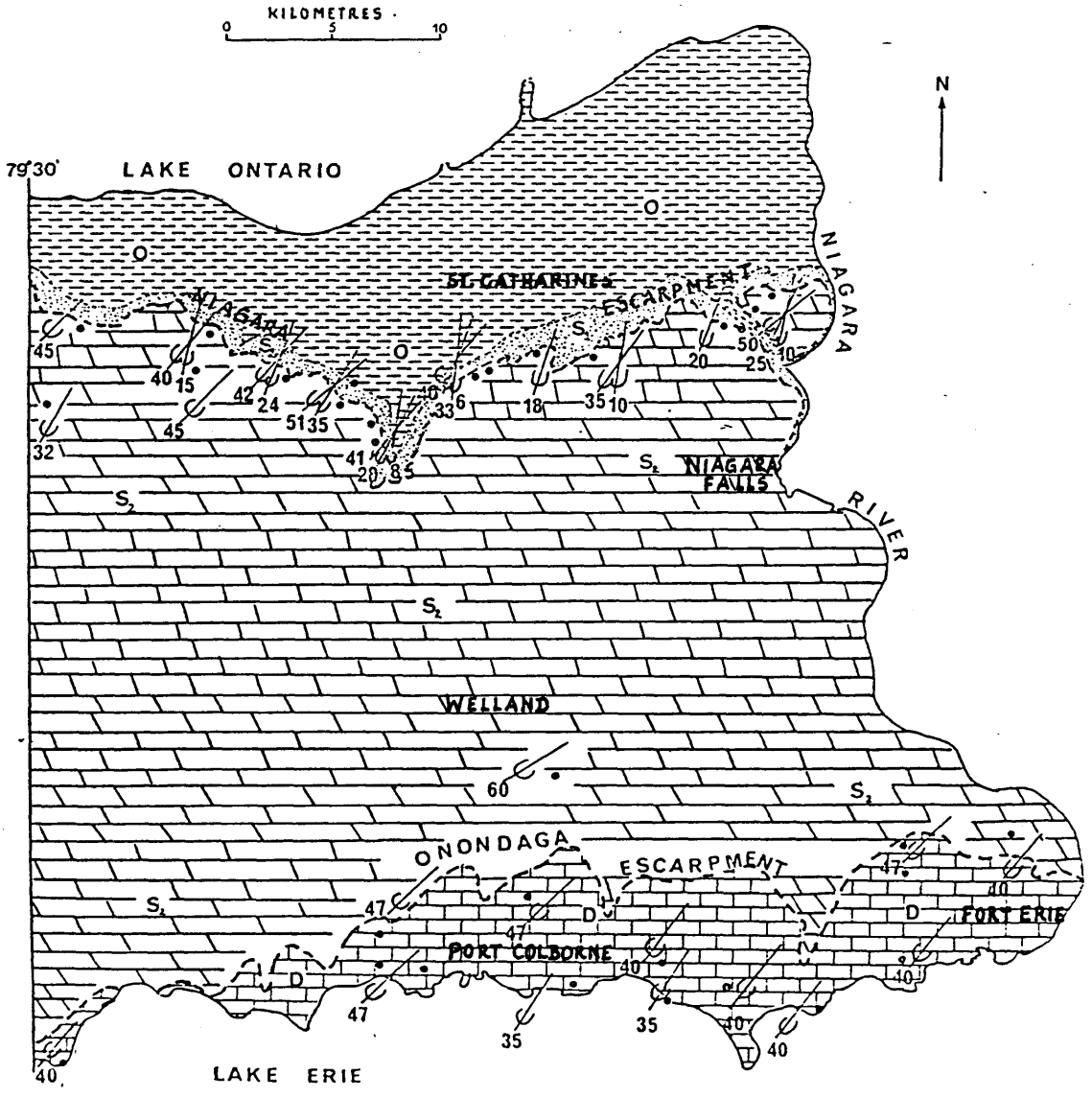


Figure 4 - Generalized Areal Bedrock Surface Geology and Direction Of Local Glacial Movement in the Niagara - Welland Area

2. A belt between 21 and 36 km wide which is bounded by the crest of the Niagara and Onondaga Escarpments and which consists mainy of dolostones (Figure 4, unit S_2). From north to south the following formations are present. The brown and grey dolostones of the Lockport Formation cap the Niagara Escarpment and together with the next younger brown or tan dolostones of the Guelph Formation underlie the northern part of the backslope of the Niagara cuesta. Alternating shaley dolostones with evaporites and grey, green, red shales of the Salina Formation underlie the southern part of this backslope, and the brown, cream, grey dolostones and shaley dolostones of the Bertie Formation overlie the Salina and terminate in the face of the Onondaga Escarpment.
3. An area between the crest of the Onondaga Escarpment and Lake Erie is up to 8 km wide to the east of Port Colborne but pinches out to the west. The area is underlain by the brown and grey cherty limestones of the Bois Blanc and the Onondaga Formations (Telford 1974, Figure 4, Unit D). The Bois Blanc forms the cap rock of the Escarpment and the Onondaga underlies the backslope of the cuesta.

BEDROCK SURFACE TOPOGRAPHY

The topography of the bedrock surface underlying the Niagara-Welland area is shown on Maps 2400 and 2403 (Feenstra 1981a and b; back pocket). These maps are based on data from rock outcrops, exploratory drillings for water, oil and gas, and other borings for geotechnical and stratigraphic purposes. A generalized bedrock surface topography map is shown in Figure 5.

The major topographic features of the bedrock surface, viz the northern lowland and the Niagara and Onondage cuestas, are also reflected in the configuration of the ground surface. There are, however, other features such as the Erigan and St. Davids valley systems and many smaller irregularities in the bedrock surface which are obscured by the cover of the Quaternary deposits.

Lowland

The lowland north of the Niagara Escarpment is underlain by shale of the Queenstone Formation, and its surface is dissected by several channels (Figure 5). Three channels with bottom elevations ranging between 45 and 60 m (145-200 feet) above sea-level form a set of distributary courses from the Twelve Mile re-entrant in the Escarpment to points on Lake Ontario at Jordan Harbour, Port Dalhousie, and Palatine Hill. The section of the Palatine Hill

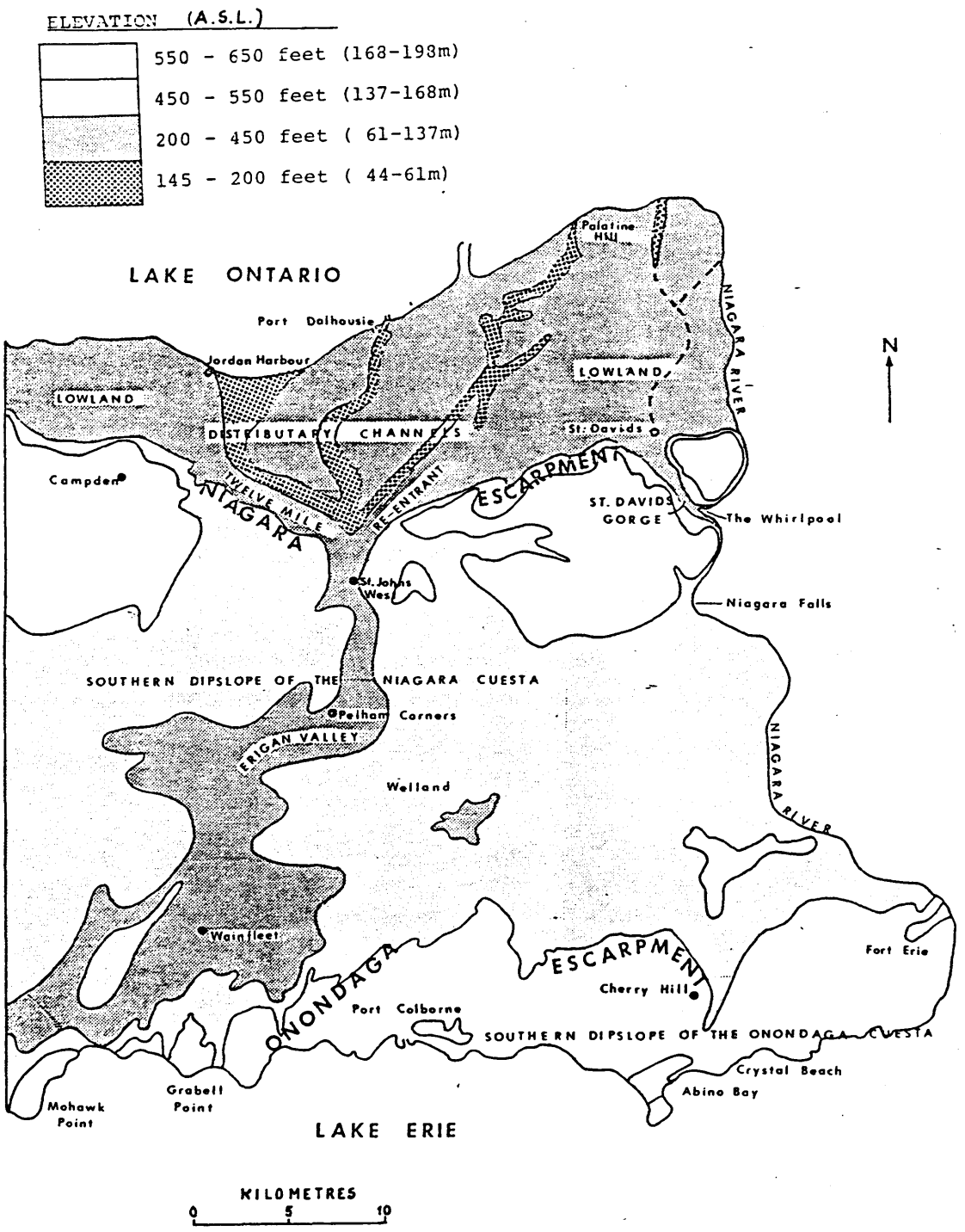


Figure 5 -Generalized Bedrock Surface Topography of the Niagara-Welland Area

distributary channel downstream from St. Catharines was set out by Hobson and Gagne (1975, Figure 37.5) and is based largely on seismic refraction data. The path of its upstream section still has to be confirmed. The course of the downstream portion of the Port Dalhousie distributary channel is also somewhat speculative.

The path of the St. Davids channel, northward from St.Davids to Niagara-on-the-Lake and paralleling the present course of the Niagara River (Figure 5) is inferred from seismic refraction and borehole data (Hobson and Terasmae 1969). Bottom elevations of this channel range between about 60 m (190 feet) at Niagara-on-the-Lake and 75 m (250 feet) at St. Davids.

Niagara Escarpment

The Niagara Escarpment rises between 60 and 110 m from its base in the shale of the Queenston Formation to its top in the dolostone of the Lockport Formation. Greatest relief in the order of 90 to 110 m occurs along the Escarpment between Jordan and Rockway, at St. Catharines, and at St. Davids, where the Queenston surface has been dissected to greater depths.

The Niagara Escarpment has a very much indented outline and it is breached west of the Niagara Gorge by the Whirlpool-St. Davids Gorge and possibly also at the head of

the Twelve Mile Creek en-entrant at St. Johns West (Figure 5). The course of the buried gorge between the Whirlpool and St. Davids has been confirmed by seismic surveying and drilling (Spencer 1907, Plate XVIII; Hobson and Terasmae 1969, Figure 12). The bottom of the gorge is probably mainly underlain by the Queenston Formation. The bottom profile may be quite irregular like that of the Upper Great Gorge section of the Niagara Gorge (Philbrick 1970, Figure 2). In general, the bottom of the Whirlpool-St. Davids Gorge slopes down from an elevation of 75 m (250 feet) at St. Davids to an elevation of about 60 m (208 feet) at The Whirlpool.

The bottom of the large Twelve Mile Creek re-entrant is probably also mainly underlain by the Queenston Formation. A bottom elevation of about 80 m (253 feet) was encountered by exploratory drilling for oil and gas in the valley approximately 2 km northwest of St. Johns West.

Niagara Cuesta Dipslope

The bedrock surface of the southern dipslope of the Niagara cuesta is underlain in its northern half by relatively harder dolostones of the Lockport and Guelph Formations, and in its southern half by relatively softer shaley dolostones and shales of the Salina Formaton. This backslope is dissected by a broad valley (Figures 5, Erigan

Valley) which enters the map-area from the west in Salina shales at the base of the Onondaga Escarpment north of Mohawk Point and which continues in an easterly direction in the same shales along the Escarpment to Wainfleet. It turns in a northerly direction in alternating shaley dolostones and shales of the Salina Formation to a point about 3 km south of Fenwick from where it takes again an easterly course along the Guelph-Salina contact to Pelham Corners between Welland and Fonthill. This main valley follows again a northern course in Guelph-Lockport dolostones to the head of the Twelve Mile Creek re-entrant in the Niagara Escarpment at St. Johns West. Possible bottom elevations of about 115 m (384 feet) and between about 120 and 130 m (400-420 feet) were encountered in the main valley by exploratory drillings for oil, gas, and water at a point near Pelham Corners and at points along the base of the Onondaga Escarpment respectively.

A buried valley along the Guelph-Salina contact underlies the Welland River area between Chippewa and Port Robinson. Its junction with the main valley occurs between Port Robinson and Fonthill, but it may connect with other buried channels to the south and east of Chippewa (Philbrick 1974, Figure 1).

The surface topography of the Salina Formation in the southeastern part of the dipslope between the Welland River and the Onondaga Escarpment varies from undulating to very much dissected (Hobson and Gagne 1975, Figure 37.4 and

37.5). This surface rises from the area about Welland in southeast direction to the Onondaga Escarpment. It is dissected by channels aligned in perpendicular northeast-southwest and northwest-southeast directions, and centripetally arranged around a few deeper basins particularly in the area east and south of Welland. The longest of these channels connects with the main valley probably southwest of Welland and with the tributary valley along the Guelph-Salina contact northeast of this city. Relief caused by the channels and basins varies between about 10 and 30 m, being greatest at the basins. Further to the southeast of Welland, slight rises of about 8 m in the bedrock surface are also aligned in northeast-southwest direction.

Onondaga Cuesta

The Onondaga Escarpment is formed in Bois Blanc limestones and Bertie dolostones overlying softer Salina shales. The Escarpment rises generally between 10 and 25 m in the area to the east of Port Colborne but considerably more (up to 55 m) west of this city where the Salina shales have been dissected to greater depths along the main valley. The Onondaga Escarpment, like the Niagara, is also highly indented and re-entrants in it from the Welland Bog eastward are aligned in southeast-northwest direction.

Breaching in the vicinity of Crystal Beach, however, is not indicated by the seismic survey of Hobson and Gagne (1975, Figure 37.4).

Relative major relief of about 10 to 20 m on the backslope underlain by Onondaga limestones is provided by a prominent biohermal mound at Cherry Hill northwest of Ridgeway (Telford and Tarrant 1975), and also by two basins located at Port Colborne and in the Abino Hills-Crystal Beach area (Hobson and Gagne 1975, Figure 37.4). Like the prominent mound at Cherry Hill, minor undulations in the bedock surface are also aligned in northeast-southwest direction.

Interpretation

The Niagara and Onondaga cuestas were formed by differential erosion of a gently dipping series of harder and softer rocks. The Ontario and Erie basins are glacially modified river valleys.

Spencer (1907) concluded from studies of the preglacial drainage in the Great Lakes Region that the Erie Basin was drained by the Erigan River. It supposedly crossed the cuestas and lowland in the map-area in a generally northern obsequent course from a point on Lake Erie between Port Colborne and Port Maitland to a point on Lake Ontario north of St. Catharines (White and Karrow 1971, Figure 1; Karrow

1973, Figure 3). This drainageway starts in the Pensinsula at Port Maitland, about 6 km west of the map-area, where the Onondaga cuesta is breached by a gorge cut to depths of about 30 m through the more resistant carbonate rocks down into the softer shales of the upper Salina Formation (Sanford 1969). It continues eastward in front of and parallel to the Onondaga Escarpment to Wainfleet, generally northward across the southern dipslope of the Niagara cuesta to St. Johns West, via the Twelve Mile Creek re-entrant in the Niagara Escarpment and the distributary channels in the lowland to several points on Lake Ontario northwest, north, and northeast of St. Catharines (Figure 5, Erigan Valley). The course of this main valley through the Niagara Peninsula and of a possible tributary north to northeast of Welland seems to be controlled by bedrock lithology and structure, i.e. it is parallel to the strike near the contact between softer shales and more resistant carbonates but cuts across the strike of the latter rocks. This buried course of the Erigan Valley still has to be confirmed by geophysical means and further drilling. Although the drainageway, if real, probably evolved in its entirety before the St. Davids Gorge segment originated, the term "preglacial" still implies only pre-Wisconsinan.

Opposing views on the origin of Twelve Mile Creek re-entrant were expressed by Straw (1968, p.909) and Liberty (1969, p. 6-7). Straw argued that its size and shape were largely controlled by glacial erosion during Wisconsinan

times, while Liberty considered it a result of pre-Wisconsinan stream erosion in a synclinal area. Straw, however, referred only to the narrower, southern part of the re-entrant which is definitely aligned parallel local glacial ice movements as determined during the present survey (Figure 4; Photos 1 and 2). He also found no evidence to suggest that it was ever used by "Erie waters". The present study suggests a glacially-modified-stream-valley-origin for the entire re-entrant. Glacial erosion obviously helped sculpture the bedrock surface in the map-area. This is, at first glance, suggested by alignment of the various re-entrants in the Escarpments (Figure 4) and of the undulations in the southern dipslopes mentioned above (Hobson and Gagne 1975, Figure 37.4), parallel local ice movements and substantiated by field- observations of large glacial grooves (Photo 1), ice-moulded ridges, and abundance of local rock fragments in till. Glacial erosion is most noticeable in the upper part of Escarpment sequences in the map-area. Calkin et al (1974), however, could not draw any general conclusions about the degree of glacial shaping of a partly buried river valley in western New York State for a lack of reference data.

The buried St. Davids Gorge (Figure 5) is an obvious stream-eroded drainage segment for it trends across local ice movement directions (Figure 4). It formed part of another former drainageway joining the Erie and Ontario basins, and appears to have originated during the Sangamon

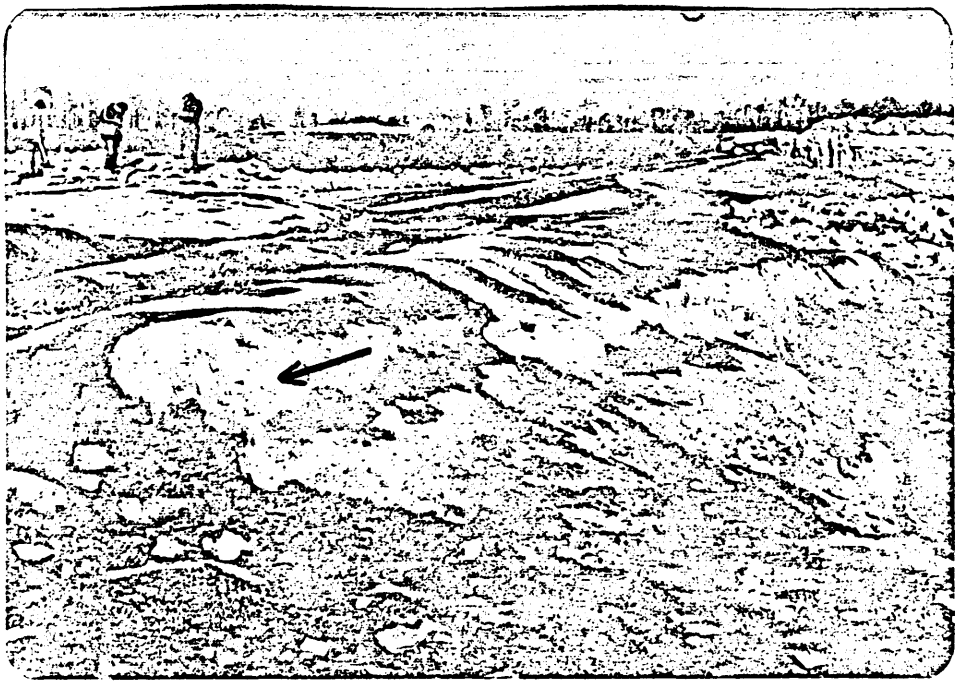


Photo 1. Glacially gouged bedrock surface at Vineland Quarries and Crushed Stone Limited. Arrow indicates direction of local ice movement.

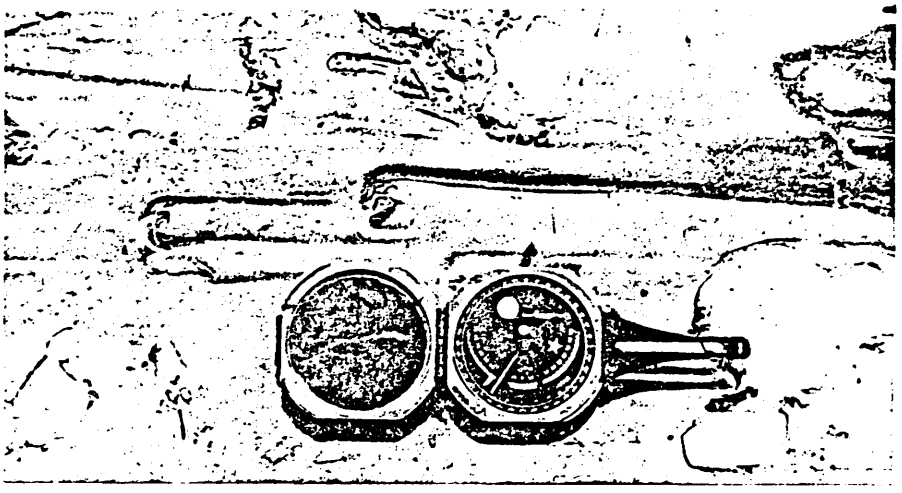


Photo 2. Hairpin striae in cherty bedrock surface at Ridgemount Quarries Limited. Compass points in direction of local glacial ice movement.

Interglacial (more than 100,000 year ago) or at least Middle Wisconsinan times (23,000-70,000 year ago; Hobson and Terasmae 1969; Karrow and Terasmae 1970).

The above-mentioned perpendicular oriented channels and deeper basins with centripetally arranged valleys in the southeastern part of the map-area (Hobson and Gagne 1975, Figure 37.4) may occur because of the presence of karstic features in the Salina surface.

QUATERNARY GEOLOGY: STRATIGRAPHY

The Niagara-Welland area was covered at various times during the Wisconsinan Stage of the Quaternary Period by the Ontario-Erie lobe of the continental ice sheet and during its oscillations also by proglacial lakes. The glacial materials deposited during these Wisconsinan Stage events in the map-area are collectively referred to as "drift" and they are altogether also the most prominent in thickness and extent when compared with the non-glacial deposits of Recent age in the area.

Drift-thickness values in the map-area range beteeen 0 and about 120 m. This variation is shown in detail on Maps ... and .... (in back pocket) and is presented in a reduced and generalized form in Figure 6. In general, the drift is thin over the bedrock topographic high areas but it thickens considerably over the bedrock topographic low areas. Exceptions to this generalization are formed by the Fonthill kame complex, the Vinemount Moraine west of Campden, and the Fort Erie Moraine at Fort Erie.

Glacial and non-glacial deposits and events of Wisconsian and Recent age in the map-area are listed in Table 2. Correlation of the layers of till, clay and silt, sand and gravel, and those with organic remains forming the depositional sequences as encountered in exposures and

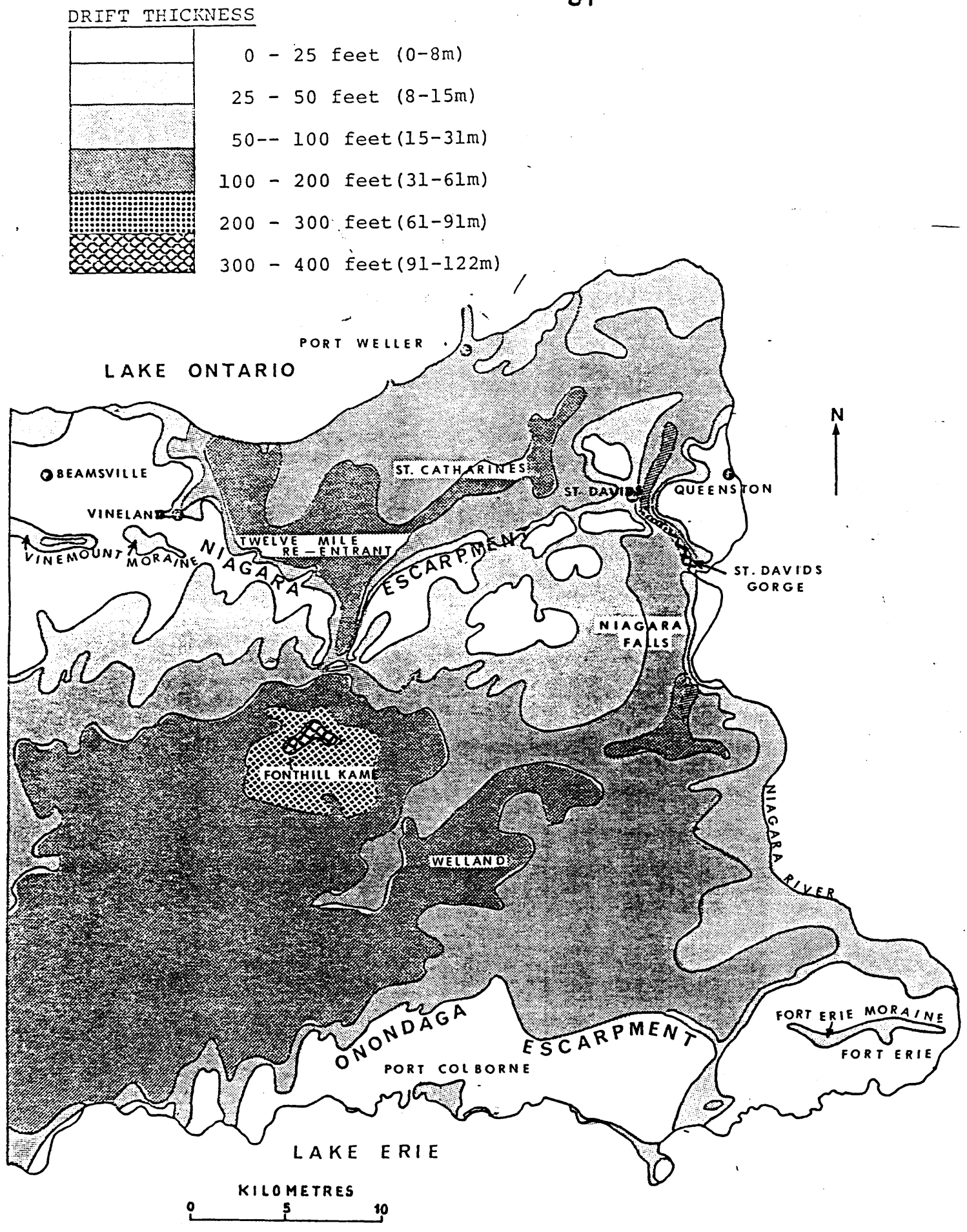


Figure 6. Generalized drift-thickness map of the Niagara-Welland area.

TABLE 2. CLASSIFICATION OF QUATERNARY FORMATIONS AND EVENTS IN THE NIAGARA-WELLAND AREA, SOUTHERN ONTARIO

Age/Stage	- Substage	Stadial	-Interstadial	Formation/Event	Lithology	Morphology
Recent				Eolian	Sand	Coastal dunes
				Lake Erie, Ontario	Sand, gravel	Beach ridges
				Bog and swamp	Muck, peat, less organic-rich clay, silt and sand	Filled depressions
				Alluvium	Gravel, sand, silt, clay organic matter	Modern flood plains, former flood plain remnants
				Eolian	Sand	Inland dunes
				Upper glaciolacustrine (Lakes Warren-Iroquois)	Sand, gravel Sand Sand Clay, silt Sand, gravel (clay, silt, till)	Beach ridges Delta plains Nearshore plains Offshore plains Ice-contact deltaic ridges with wave-worked surfaces (three lake plains)
Wisconsinan	Late	Port Huron		Halton Till	Silt-clay matrix	Ground-and end moraine wave-worked surfaces; extensively buried
			Mackinaw	Lower glaciolacustrine	Clay, silt, sand, (gravel)	Buried lake plain
		Port Bruce Nissouri		Lower till	Gravelly; silt-sandy loam matrix	Buried ground moraine
	Middle		Plum Point	Fluviatile-lacustrine	Fossiliferous sand (silt, clay)	Buried (St. Davids Gorge fill)
	Early?			Glacial?	Gravel, sand (till?)	Buried (St. Davids Gorge fill)

borings between Niagara-on-the-Lake and The Whirlpool, Port Weller and Port Colborne, Port Dalhousie and the Fonthill kame complex, and along the Lake Ontario shore is shown respectively in Figures 7, 8, 9, and 10 (Charts A-D, in back pocket). The stratigraphic units are described and discussed in the following sections of the report.

PRE-LATE WISCONSINAN DEPOSITS

The oldest Quaternary deposits in the area, dating back to the Middle and possibly Early Wisconsinan Substages, are found in the materials forming the fill of the buried St. Davids Gorge. They are exposed in the wall of the Niagara Gorge at The Whirlpool forming the "older drift" portion of Map-Unit 7. Their extent has been further revealed in several boreholes which have penetrated these materials at some depth below the surface. They have been previously reported on by Spencer (1907), Hobson and Terasmae (1969), and Karrow and Terasmae (1970).

These oldest Quaternary deposits consist of gravel (Figure 7, Unit 1), possibly with interbedded till, and overlying pollen and wood-bearing, silty and clayey sands of fluviatile-lacustrine origin (Figure 7, Unit 2). The fossiliferous sands are overlain by a sequence of Late Wisconsinan glacial deposits (Figure 7, Units 3-7).

The fluviatile-lacustrine unit consists primarily of fine grained sands with thinly interbedded clay and silt.

This unit also contains pollen grains, wood fragments, and pre-Quaternary spores (Spencer 1907; Hobson and Terasmae 1969; Karrow and Terasmae 1970; Koopmans 1974). A radiocarbon age of about 23 000 years BP was obtained on a sample of wood (Hobson and Terasmae 1969: ^{14}C-date GSC-816).

Karrow and Terasmae (1970) propose that filling of the gorge with these fluviatile-lacustrine sediments occurred during a high water stage in the Ontario basin associated with local ponding between an advancing Ontario glacial lobe and the Niagara Escarpment. The spores are probably Devonian in age and their bedrock sources occur in upstream direction to the south. The pollen assemblages obtained are considered by Karrow and Terasmae (1970) to be indicative of a cooler northern boreal climate about 23 000 years BP. The pollen-bearing beds were assigned to a late Middle Wisconsinan interstadial age (Plum Point Interstadial of Dreimanis 1975). Morner (1971), however, assigned them an early Late Wisconsinan stadial age (Nissouri Stadial of Dreimanis and Karrow 1972). He subdivided the Plum Point Interstadial into:

1. Early - or Plum Point I, the most temperate period from 32 000 to 28 000 years BP;
2. Middle- or Plum Point II, a cold period from 28 000 to 27 000 year BP; and,
3. Late- or Plum Point III, a period less temperate than Plum Point I from 27 000 to 23 000 years BP.

The radiocarbon date (GSC-816) marks the transition from

Middle to Late Wisconsinan in this area (Dreimanis and Goldthwait 1973), and the pollen assemblages indicate, according to Morner, even cooler climatic conditions than existed during his Plum Point III.

Karrow (Karrow and Terasmae 1970) found mollusc shell fragments only in the lower beds at The Whirlpool (Figure 7, Karrow's measured section No.3). Koopmans (1974), however, considers these lower, pollen-bearing and shelly beds to have been deposited during a postglacial period when higher water levels prevailed in the Niagara River.

LATE WISCONSINAN DEPOSITS

The Late Wisconsinan Substage in the Niagara-Welland area is in ascending stratigraphic order represented by lower till, lower glaciolacustrine deposits, Halton Till, and upper glaciolacustrine deposits. This sequence was exposed at excavations for the relocated Welland Canal between Port Colborne and Port Robinson where it is predominantly underlain by bedrock of the Salina Formation (Figure 8). Similar sequences were encountered in boreholes penetrating the upper part of the fill in the buried St. Davids Gorge and the materials overlying shale of the Queenston Formation in the eastern portion of the northern lowland (Figures 7, 8, and 9). The lower units may pinch out at the Niagara and Onondaga Escarpments.

Lower Till

Reddish, relatively coarse textured till was encountered at some depth below the surface in borings in the fill at the buried St. Davids Gorge (Figure 7, Unit 4). The till overlies gravel and the Middle to Late Wisconsinan fluviatile-lacustrine sands and similar till overlies bedrock of the Lockport Formation in a sand and gravel pit on the eastside of former Highway 8 near Mountain Road, Niagara Falls (Figure 7; Appendix A: N2446). The upper contact of the till occurs at these sites at depths ranging between 24 and 35 m. The till is up to 5 m thick, and is overlain by deposits of glaciolacustrine and ice-contact origin (Figure 7, Unit 5).

Relatively coarse textured, reddish (predominant) and grey lower till was also encountered in borings in the eastern portion of the lowland at depths varying between 5 and 36 m (Figures 7-9). The till overlies Queenston Formation red shale, is as much as 10 m thick, and is overlain by glaciolacustrine deposits or fine-textured upper or Halton Till. "Hard and ancient boulder clay of a red colour" (Coleman 1937a, p.5) encountered in the subsurface during excavations for the locks of the Welland Canal at the foot of the Niagara Escarpment near Thorold (Figure 8, location map), and coarse textured red and grey till exposed in the Lake Ontario shorebluff between Port Weller and Niagara-on-the-Lake (Figure 10; Appendix A; N466) may also

be this lower till.

The upper contact of relatively coarse textured, grey and red lower till encountered in borings and excavations for the newly constructed Welland By-Pass segment of the Welland Canal (Figure 8) occurs at depth ranging between 9 and 37 m. At this location, the till overlies predominantly Salina Formation bedrock, is generally thicker (up to 16 m) in the northern than in the southern part (up to 6 m), and is overlain mainly by glaciolacustrine deposits (Figure 8; Photo 3). It corresponds to Unit 8A of Owen (1969, Figure 2) or Unit 2 of Owen (1972, Map 8-1971, Sections A-B and C-D). Sporadically, lower till overlies so-called glaciofluvial deposits (Owen, 1972, Section A-B, Unit 1) of uncertain correlaton, or is overlain by them (Owen 1972, Sections A-B and C-D, Unit 3), or finer textured upper till (Owen, 1969, Unit 8; Owen 1972, Section C-D, Units 10 to 12). The greater thicknesses (16 m) of lower till shown in the cross-sections of Owen (1972) occur in the vicinity of the Fort Erie Moraine in the east-central part of the City of Welland (Figure 8, location map), and are suggestive of end morainic tract or drumlinization.

Coarse-textured grey or red till exposed at a depth of about 2 m in a railway cut in the Onondaga Escarpment at Fort Erie (Appendix B: W616), and in a quarry at the top of this escarpment west of Port Colborne (Appendix B: W1006), may also be this lower till. It overlies Bertie dolostone and Bois Blanc cherty limestone respectively at these sites.

Photo 3. Gravelly lower till overlain by lower glaciolacustrine clay at the Townline Tunnel excavation, Welland. Note: top of pick at contact.

Lower and possible-lower till in the map-area is generally compact and gravelly. It has a reddish and (or) grey silt to sandy loam matrix (Figure 11) composed of much sand- and silt-, but little clay-sized material (Table 3). The mechanical composition of 34 samples of the till along the Welland By-Pass segment of the Canal is as follows: 42 to 92 percent gravel and sand, 6 to 48 percent silt, and 2 and 23 percent gravel, 6 to 48 percent silt, and 2 and 23 percent clay (Owen 1972, Figure 1). Lower till along this segment of the Welland Canal also includes scattered, thin lenses of silt and fine sand.

All of the above evidence suggests that a buried sheet of relatively coarse-textured till, up to about 9 m thick (thicker where possibly forming drumlins or an end moraine) was deposited by the Ontario-Erie glacial lobe chiefly on bedrock-substrate in the Niagara-Welland area. The glacial lobe moved in southwesterly directions out of the Ontario- and into the Erie basin crossing the strike of the various bedrock formations underlying the map-area (Figure 4). Thus Upper Ordovician red shales form areally the predominant bedrock type in up-glacier direction from the Niagara Escarpment, Silurian dolostones up to 45 km in down-glacier direction from it and Devonian cherty limestones up to 16 km from the Onondaga Escarpment. Further up-glacier from the red Queenston shale, grey shales with harder carbonate and siltstone interbeds of the Upper Ordovician Whitby and Georgian Bay Formations (Liberty 1969) also underlie the

Figure 11. Textural classification of lower, possible-lower, and local till samples.

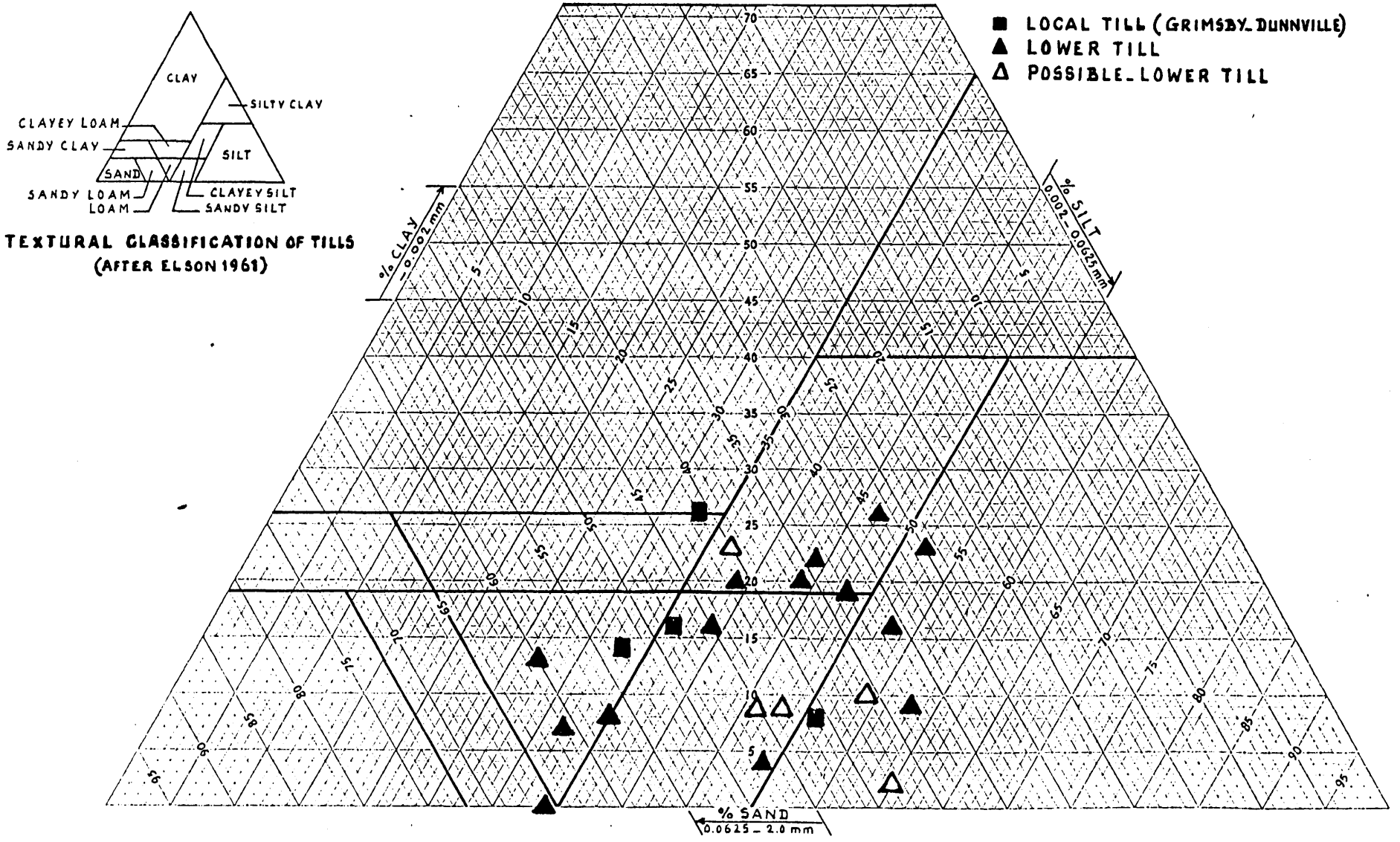


TABLE 3. SUMMARY OF LOWER, POSSIBLE-LOWER, AND LOCAL TILL ANALYSES

SAMPLE AREA / TILL UNIT	STATISTIC	GRAIN SIZE ANALYSIS % Sand	% Silt	% Clay	CARBONATE ANALYSIS % Calcite	% Dolomite	% Total	Ratio Calc/Dol.	TRACE ELEMENT ANALYSIS ppm Copper	ppm Lead	ppm Zinc	ppm Nickel	ppm Chromium	ppm Cobalt	HEAVY MINERAL ANALYSIS % Total	% Garnets	Ratio Purple/Red Garnets	PEBBLE LITHOLOGY ANALYSIS % Limestone	% Chert	% Dolostone	% Sand- & Siltstone	% Shale	% Igneous & Metamorphic
L.ONTARIO-NIAGARA ESC. Possible-lower till	M	37	57	6	7	9	16	0.8	43	-	71	32	55	10	4	13*	1.6*	15	0	——82——		2	1
	R	36-38	54-60	2-10	7-7	6-12	13-19	0.6-1.2															
	N		2			2					1					1				1			
Lower till	M	47	44	9	8	11	19	0.7	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
	R	31-66	32-58	0-19	7-10	10-13	17-23	0.6-0.8							4-5								
	N		7			4									4								
Queenston Formation derived local till	M	50	35	15	8	5	13	1.8	16	22	90	46	81	18	<0.1	-	-	0	0	0	19	81	0
	R	48-53	33-36	14-16	7-9	4-6	12-13	1.2-2.3	15-16	21-22	88-91	42-49	79-82	15-20	0-0.1								
	N		2			2					2				2					1			
NIAGARA-ONONDAGA FSC. Lower till	M	38	42	20	6	29	35	0.2	33	45	113	30	38	6	4	14	1.7	1	0	93	4	0	2
	R	25-60	27-52	13-26	4-8	26-34	32-41	0.2-0.3	21-68	44-46	85-177	23-40	30-45	5-7	2-6	11-17	1.4-2.0	1-2	0-0	90-95	0-7	0-1	1-3
	N		7*			8			10*	3	10*	10*	10*	4	14*	6*	6*			2			
Lockport Formation derived local till	M	41	51	8	9	50	59	0.2	60	127	940	16	30	<5	2	-	-	5	0	94	0	1	0
	R																						
	N		1			1					1				1					1			
ONONDAGA ESC.-L. ERIE Possible-lower till	M	43	44	13	6	30	36	0.2	40	-	107	17	36	6	3	15*	2.1*	6	2	81	7	0	4
	R	40-45	37-47	9-23	4-9	27-32	33-40	0.1-0.3	32-49		97-126	16-18	32-41	6-6	2-4			2-9	0-3	68-89	1-17	0-0	1-6
	N		3			3					3				4*		1			3			
Devonian bedrock derived local till	M	41	33	26	40	16	56	2.5	23	25	56	8	22	<5	4	-	-	78	16	6	0	0	0
	R																						
	N		1			1					1				1					1			

M= Mean, R= Range, N= Sample size

*Includes analytical results from the samples listed by Barnett (1975).

Lake Ontario Basin.

Colour and lithologic composition (Table 3) of lower and possible-lower till in the area between Lake Ontario and the Niagara Escarpment suggest derivation mainly from the Upper Ordovician bedrock locally and in up-glacier direction. Basal till overlying red Queenston shale in this area is red in its lower but grey and red in its upper part. The red coloration is caused by incorporation of material derived from the red Queenston shale, and the grey coloration by incorporation of material derived from the predominantly grey Upper Ordovician bedrock further up-glacier. Karrow (1963, p.44-45) already noticed the conversion of grey into red till in down-glalcier direction from the contact between the Georgian Bay (Meaford) and Queenston Formations. Lower till reportedly becomes richer in red shale fragments towards its base, and till sampled just above the Queenston Formation in the adjacent Grimsby area (Feenstra 1975) consists almost entirely (99 1/2%) of such bedrock fragments in the pebble grade (Table 3, Queenston Formation derived local till). Pebble-lithology of possible-lower till (Table 3) higher up in the sequence does not reflect the predominant shale lithology of the Upper Ordovician bedrock. The low content of soft shale fragments in this till is in sharp contrast to the large subcrop area traversed by the glacial lobe and most likely cause by rapid communition, while its high concentration of brittle, resistant siltstone debris contrasts sharply with

the small subcrop area traversed and is most likely due to slower communition (Holmes 1952). The low content of calcite and dolomite and the concentrations of trace elements (Table 3) reflect the abundance of shale in the fine fractions of the red and grey basal till including local till (Dreimanis 1961, Guillet 1967, Czurda et al. 1973, Candy 1963, and May 1971, 1973).

The changes in lithology taking place in the till across the map-area south of the Niagara Escarpment (Table 3) are related to those in the underlying Silurian and Devonian bedrock. They are clearly demonstrated by the local tills derived from the Lockport Formation and Devonian bedrock (Table 3) and sampled in the adjacent Grimsby and Dunnville map-areas (Feenstra 1974, 1975). The Lockport Formation can be relatively rich in lead and zinc (Warren and Delavault 1961) and grey basal till sampled just above it consists almost entirely of dolostone fragments in the pebble grade and has also higher concentrations of dolomite, lead, and zinc in its finer size fractions than till derived mainly from Upper Ordovician shales. Devonian cherty limestone bedrock, however, has low concentrations of copper, lead, and zinc (Warren and Delavault 1961) and grey basal till sampled also just above it consists almost entirely of limestone and chert fragments, has a higer concentration of calcite but lower concentrations of dolomite, copper, lead, and zinc than the local till derived from the Lockport Formation. Till immediately overlying

Silurian and Devonian bedrock of the area generally also has lower concentrations of nickel, chromium, and cobalt than till on the Upper Ordovician shale (Table 3).

Gywn (1971, p.24-30) showed that the local Paleozoic bedrock contributed to the heavy minerals in the tills of southwestern Ontario only to a minor extent in contrast to the major contribution of the Precambrian Shield rocks. Thus samples of local till derived from the Queenston and Lockport Formations and collected just above this Paleozoic bedrock contain typically lower amounts of heavy minerals than samples from higher up in the till (Table 3). The garnet composition determined by Barnett (1975) in the heavy mineral assemblage of lower or possible-lower till (Table 3) suggests principal distant provenance to the northeast in the eastern Grenville source of Gwyn and Dreimanis (1979).

The lower till of the Niagara-Welland map-area has been previously correlated (Feenstra 1972a and b; Barnett 1975) with the Late Wisconsinan (Port Huron Stadial) Wentworth Till of Karrow (1963, 1974). The Wentworth Till sheet was deposited by the Ontario glacial lobe fanning out into the area around the west end of Lake Ontario and southwestward into the Erie basin (Karrow 1963, 1968, 1974; Cowan 1972, 1976; White 1975; Feenstra 1974, 1975; Barnett 1978). This lobe formed the Paris Moraine at its outer margin which has been correlated with the Port Huron Morainic System in the Great Lakes Region. Recent fieldwork by the Ontario Geological Survey suggests, however, that this correlation

may be erroneous and that the Paris Moraine is slightly older and perhaps equivalent to the Late Wisconsinan Port Bruce Stadial of Dreimanis and Karrow (1972).

Wentworth Till in the Brantford area (Cowan 1972) is underlain by the Late Wisconsinan Port Stanley and Catfish Creek Tills of De Vries and Dreimanis (1960). Port Stanley Till was also deposited by the Ontario-Erie Lobe fanning out farther westward from the Ontario basin and into the Erie basin earlier during the Port Bruce Stadial. Catfish Creek Till is probably represented in the exposures by its main sub-unit of Dreimanis and Reavely (1953). It is deposited by the maximum glacial advance across southwestern Ontario during the still earlier Nissouri Stadial of Dreimanis and Karrow (1972). Coarse-textured till directly underlying the Late Wisconsinan (Port Bruce Stadial) Halton Till of Karrow (1963, 1974) or separated from it by stratified drift has been recognized as Wentworth Till by Karrow (1963) in the Cedar Springs re-entrant area, by Barnett (1975) in an excavation at Burlington, and tentatively by White (1975) in the Woodbridge Cut and in the York University Campus excavation, and also as the former Lower Leaside Till in and about Toronto (Karrow 1967, 1970, 1974; Dreimanis 1969).

The Lower Leaside Till was correlated with "middle till" of Dreimanis and Terasmae (1958) in the Toronto area. Dreimanis and Terasmae concluded that local ice movements recorded by "middle till" were definitely first from the southeast and south out of the Lake Ontario basin and later

from the north-northeast and northeast (Middle-to Late Wisconsinan maximum glacial advance), and still later perhaps again out of the Lake Ontario basin. Karrow (1974, p.766), however, regards the Lower Leaside Till of uncertain provenance (to the north-northeast or east-southeast), correlation and age: representing glacial deposition ranging perhaps through much of Late Wisconsinan time, and therefore suggests dropping the name from formal nomenclature.

Lower till of the Niagara-Welland map-area, rather than being just a correlative of the Wentworth Till as was previously suggested,may also represent glacial deposition through much of Late Wisconsinan time (Table 2: Nissouri - Port Bruce Stadial), i.e. a correlative of Catfish Creek, Port Stanley, and Wentworth Till or former Lower Leaside Till in and about Toronto.

Lower Glaciolacustrine Deposits

Borings in the Pleistocene fill of the buried St. Davids Gorge (Figure 7) encountered stratified deposits of clay, silt, and sand (Unit 5) between upper and lower Late Wisconsinan tills. These proglacial lake-bottom deposits are here mainly reddish brown and up to 12 m thick. Their upper contact occurs about 12 to 15 m below the surface. They consist chiefly of sand and silt in the upper part and of clay and silt in the lower part. Thin gravel at the base of this sequence (boring WH3) probably represents washed

lower till.

Borings in the Iroquois Plain in the eastern part of the area (Figures 7-10) also encountered as much as 12 m of stratified proglacial lake-bottom deposits in a similar stratigraphic position. They consist mainly of grey clay, silt, and sand. The upper contact of this sequence occurs at depths ranging between 10 and 20 m.

Stratified drift between upper and lower Late Wisconsinan tills was also encountered in borings and excavations along the relocated Welland Canal (Welland By-Pass) on the Haldimand Clay Plain (Figure 8; Photos 4 and 5). The material consists of so-called glaciofluvial gravel, sand, and silt (Owen 1972, Map 8-1971, Sections A-B and C-D, Unit 3), sporadically veneering the lower till, but chiefly consisting of overlying proglacial lake-bottom clay, silt, and sand (Owen 1969, Figure 2, Unit 11; Owen 1972, Map 8-1971, Sections A-B and C-D, Units 4-9). The glaciolacustrine deposits are relatively thin (about 3 m) northward near Port Robinson and southward at the Onondaga Escarpment but thicken up to 30 m when infilling bedrock surface depressions between these two locations. The glaciolacustrine sequence is predominantly reddish brown, and can be divided into a basal sub-unit of silt and fine grained sand (Owen 1972, Unit 4), a lower sub-unit of clay and silt (Owen 1972, Unit 5), a middle sub-unit of massive, till-like, clayey silt-silty clay (Owen 1972, Units 6 and 7), and an upper sub-unit of stratified clay and silt (Owen

Photo 4: Lower glaciolacustrine clay and silt sequence at Welland By-Pass excavation near Port Colborne.

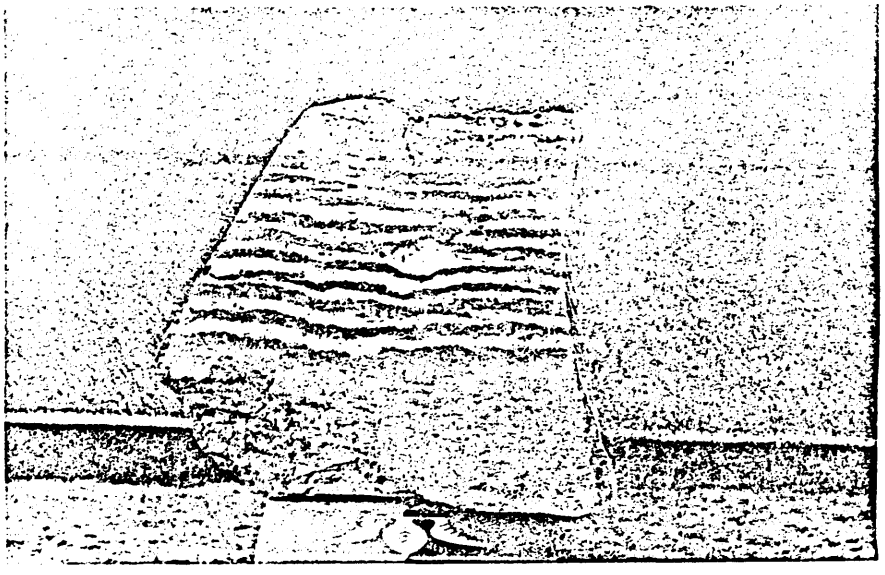


Photo 5. Sample of stratified clay-silt of the lower glaciolacustrine sequence (upper sub-unit) at the Townline Tunnel excavation, Welland.

1972, Unit 8) overlain northward by silts (Owen 1969, Unit 11; Owen 1972, Unit 9). The contact of these proglacial lake-bottom sediments with the overlying upper or Halton Till (Owen 1969, Unit 8; Owen 1972, Unit 12) occurs generally between 12 and 18 m below the surface. The upper contact is, however, quite irregular where overriding glacier ice pressed up and contorted the upper part of this lower glaciolacustrine sequence (Owen 1972, Map 8-1971, Section A-B). Results of analyses carried out on a few samples from the middle, till-like, sub-unit (Appendix I) suggest a mixed Ordovician shale-Silurian dolomite composition.

A buried sand and gravel deposit, on top of the Niagara Escarpment at the head of the St. Davids re-entrant valley and exposed in the lower part of the pits operated by St. Davids Sand and Gravel Limited along former Highway 8 near Mountain Road in the City of Niagara Falls (Figure 7, lower ice-contact deposit), overlies lower till and is overlain by glacially deformed glaciolacustrine clay and sand. This deposit is about 20 m thick and consists chiefly of parallel and cross-stratified fine to medium grained sand in its upper part and coarser grained sand and gravel in its lower part. Coarse gravel showing large-scale crossbedding and encountered by Coleman (1937a) below till (Halton Till?) and glaciolacustrine clay in another pit in the same area, may belong to the same deposit.

This buried sand and gravel deposit at the head of the

St. Davids re-entrant valley in the Niagara Escarpment is possibly ice-contact deltaic in origin; meltwater flowed to the west and southwest judging from the crossbed directions.

The above sequences were deposited in high-level proglacial lake waters associated with retreat and possibly subsequent re-advance of the Ontario-Erie glacial lobe during Mackinaw Interstadial-Port Huron Stadial times (Table 2). They may be correlatives of:-

1. - glaciolacustrine clay between the Halton-and supposed Wentworth Till at Burlington (Barnett 1975);
2. - gravels of possible ice-contact origin containing lenses of supposed Wentworth Till and which are capped by Halton Till in the Cedar Springs re-entrant area (Karrow, 1963);
3. - the sequence of clay, interbedded sand and gravel, and interbedded clay, silt, and sand between former Upper (now Halton Till)-and Lower Leaside Tills in the Humber River area between Bolton and Claireville, and considered by Dreimanis (1969) as Mackinaw Interstadial deposits;
4. - sand and some gravel of varying origin between former Upper (now Halton Till)-and Lower Leaside Tills away from the Lake Ontario shore in the Scarborough and Thornhill map-areas (Karrow 1967, 1970); and possibly,

5. - the Maple Formation of White (1975), consisting of sand, silt, clay, and gravel of glaciofluvial and - lacustrine origin and capped by Halton Till in the Bolton map-area.

Halton Till

The Ontario-Erie glacial lobe overrode and incorporated chiefly fine grained proglacial lake-bottom sediments and then deposited a sheet of silty and clayey upper till across the Niagara-Welland map-area (Map-Unit 8). This till sheet appears to be part of the larger sheet of Halton Till (Karrow 1963, 1974) which marks the last advance of the glacial lobe into the area around the west end of Lake Ontario and across the Niagara Peninsula into the area of Lake Erie during the Port Huron Stadial (Table 2; see also upper till of Dreimanis and Terasmae (1958), former Upper Leaside Till of Karrow (1967, 1970), Halton Till of White (1975), and upper till of Feenstra (1974, 1975). The terminal position of the Ontario-Erie glacial lobe which deposited the Halton Till in the Niagara Peninsula, and possibly formed the Port Huron ice margin in this area, together with the next younger recessional positions are outlined in Figure 2.

The grey or brown upper sub-unit of Halton Till in the Lake Ontario - Niagara Escarpment part of the map-area has a variable silt to clayey silt or silty clay to clay matrix

related to the incorporation of proglacial lake-bottom silt and clay (Figure 12, Table 4). Incorporated reddish lower sub-unit has a silt matrix. The upper sub-unit of the till becomes quite clayey further southward in the area to the east of Twenty Mile Creek, including the two layers in the Twelve Mile re-entrant valley. The lower layer in this re-entrant valley is more sandy and silty at the head of the valley due to the incorporaiton of underlying fine grained silty sands (Figure 9). Colour and lithologic composition of Halton Till in the Lake Ontario - Niagara Escarpment portion of the area (Table 4) suggest incorporation of material mainly derived from the Upper Ordovician bedrock locally and in up-glacier direction.

Halton Till has a silt to clayey silt matrix in the northern part of the Niagara cuesta dipslope (Figure 12; Table 4; Photo 6). Its carbonate- and trace element compostion is essentially similar to that of the till north of the Niagara Escarpment. Slight changes in the lithologic composition of its pebble-size fraction occur across the Escarpment, i.e. the till contains more dolostone and limestone and less sandstone, siltstone, and shale.

Halton Till has a fine grained silt to silty clay matrix along and in the vicinity of the relocated Welland Canal segment on the southern part of the Niagara cuesta dipslope and at the Lake Erie shorebluff along Mohawk Bay in the vicinity of the buried Onondaga Escarpment (Figure 12; Table 4; Photo 7). The fine grained matrix of the till is

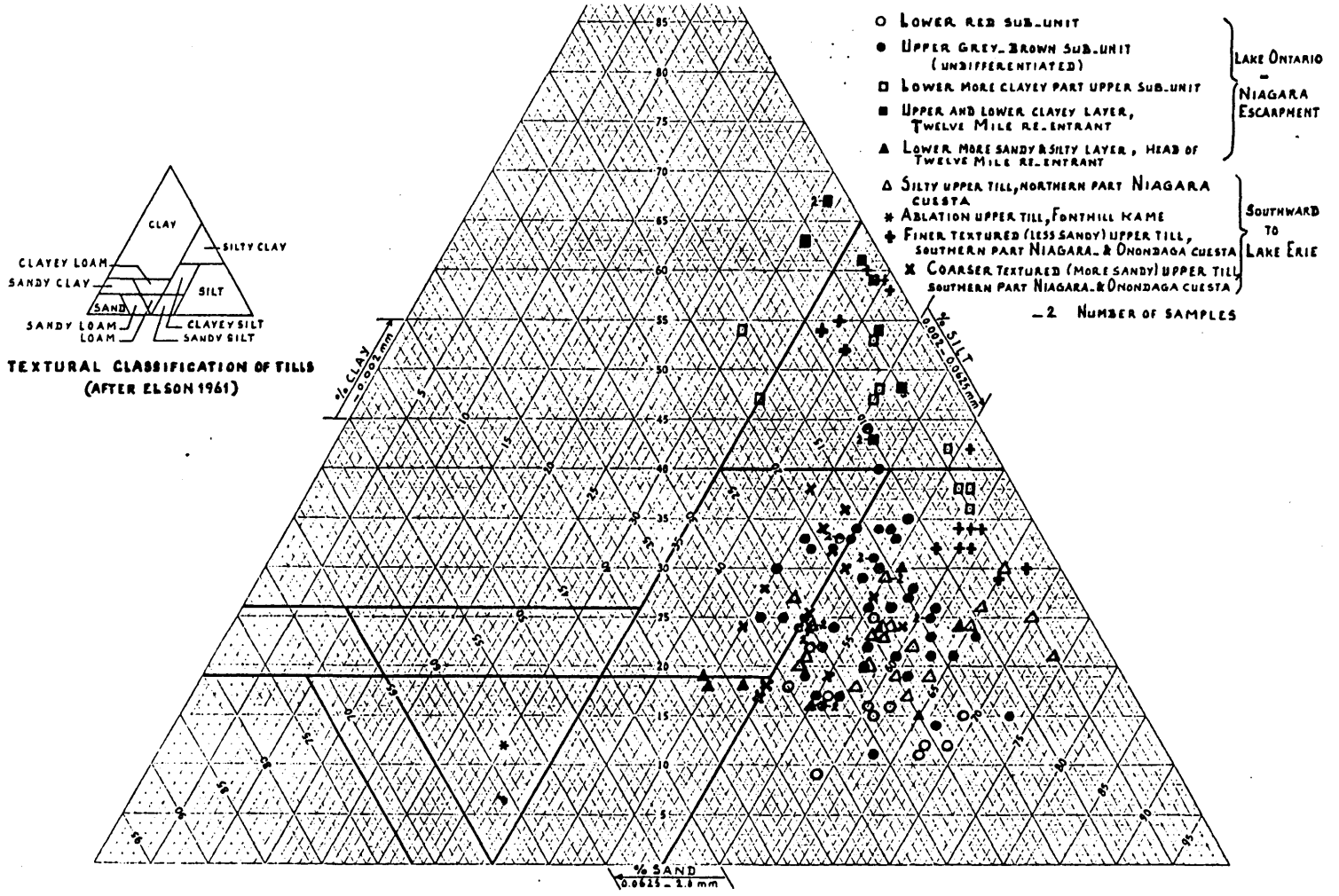


Figure 12. Textural classification of Halton Till samples.

TABLE 4. SUMMARY OF UPPER OR HALTON TILL ANALYSES

SAMPLING AREA / TILL SUB-UNIT	STATISTIC	GRAIN SIZE ANALYSIS % Sand	% Silt	% Clay	CARBONATE ANALYSIS % Calcite	% Dolomite	% Total	Ratio Calc/Dol.	TRACE ELEMENT ANALYSIS ppm Copper	ppm Lead	ppm Zinc	ppm Nickel	ppm Chromium	ppm Cobalt	HEAVY MINERAL ANSLYSIS % Total	% Garnets	Ratio Purple/Red Garnets	PEBBLE LITHOLOGY ANALYSIS % Limestone	% Chert	% Dolostone	% Sand- & Siltstone	% Shale	% Igneous & Metamorphic
L.ONTARIO-NIAGARA ESC.																							
Lower Red Sub-Unit	M	24	61	15	9.0	8.6	17.6	1.0	43	28	79	40	52	12	4.3	15.5	1.7	10	0	64		23	3
	R	16-32	52-69	9-25	6.3-15.4	6.3-9.7	15.2-24.8	0.7-1.6	29-66	27-29	74-86	34-45	40-67	11-13	2.8-6.0	11.0-20.0	1.5-1.9	3-14	0-0	44-75		12-38	2-5
	N		12			10			7*	2		7*		3	15*		5*			4			
Upper Grey-Brown Sub-Unit(Coarser)	M	19	56	25	8.3	8.6	16.9	1.0	46	31	88	42	65	13	4.2	13.3	1.7	16	0	58		20	6
	R	11-29	45-73	11-35	6.4-11.2	3.9-13.3	12.7-22-2	0.5-2.3	33-75	21-38	74-127	36-46	50-81	9-16	3.0-5.7	12.0-16.0	1.4-2.1	0.41	0-0	30-91		2-56	3-7.5
	N		45*			18			17*	7		17*		12	31*		5*			11			
Upper Grey-Brown Sub-Unit (Finer)	M	7	50	43	9.1	9.1	18.2	1.0	41		92	47	71		4.3			-	-	-		-	-
	R	4-11	45-59	36-53	7.6-12.2	5.8-11.1	14.5-20.5	0.5-1.6	40-42	-	84-100	44-50	65-76	13	3.6-5.4	11.0	2.0						
	N		9			9			2*			2*		1	9*		1*						
Upper & Lower Layer (Finer), Twelve Mile Re-entrant	M	7	38	55	13.5	7.4	20.9	1.8	-	-	-	-	-		4.6	-	-	-	-	-		-	-
	P	2-18	30-47	43-63	9.2-18.0	4.8-10.9	17.9-24.5	1.0-3.0							2.8-6.1								
	N		11			9									7								
Lower Layer(Coarser) Head Twelve Mile Re-entrant	M	23	54	23	11.3	8.5	19.8	1.3							4.3			-	-	-	-	-	-
	R	12-37	43-65	15-30	9.2-13.8	5.3-10.8	18.8-20-7	0.9-2.6	42	-	95	50	60	-	3.5-6.2	9.5	1.5	-	-	-	-	-	-
	N		8			8			1*			1*			8*		1*						
NIAGARA ESC.- L. ERIE																							
Upper Till- Northern Part Niagara Cuesta	M	18	59	23	8.8	8.8	17.6	1.0	41	33	10	43	61	12	4.6	12.4	1.6	25	0	51	8	13	3
	R	5-28	48-74	17-30	6.5-13.0	4.0-16.9	13.0-25.9	0.5-2.3	29-50	29-50	74-860	35-50	50-73	9-15	2.8-7.2	10.5-14.0	1.2-2.0	9-44	0.0	40-73	2-16.5	3-27	0-6
	N		22			21			15*	4		15*		7	19*		8*			8			
Upper Till- Southern Part Niagara Cuesta	M	9	52	39	9.4	13.6	23.0	0.7	42	33	115	34	62	12	4.6	13.5	1.9	5	0	86	5	0	4
	P	1-26	37-76	19-60	7.0-12.4	7.9-21.3	17.9-30.9	0.4-1.6	28-96	25-54	92-235	27-45	49-79	8-16	2.8-7.3	11.5-15.5	1.6-2.2	1-11	0-0	73.5-93	3.5-6	0-1	1.11
	N		19			21			19*	8		19*		14	23*		5*			4			
Upper Till- Norther Part Onondaga Cuesta	M	25	49	26	9.8	23.9	33.7	0.4	37	28	102	22	49	8	3.8	-	-	18	3	64	4	0	11
	R	18-33	44-45	17-38	7.9-15.4	12.7-33.7	28.1-41.9	0.2-1.2	28-58	25-34	84-122	16-27	38-64	5-10	2.6-5.1	-	-	7.5-35	0-8	41-80	1-6 1/2	0-1	5-17
	N		11			11			10	5		10			11					3			

*Includes analytical results listed by Barnett (1975) from generally the same samples. N=SAMPLE SIZE, R=RANGE, M=MEAN

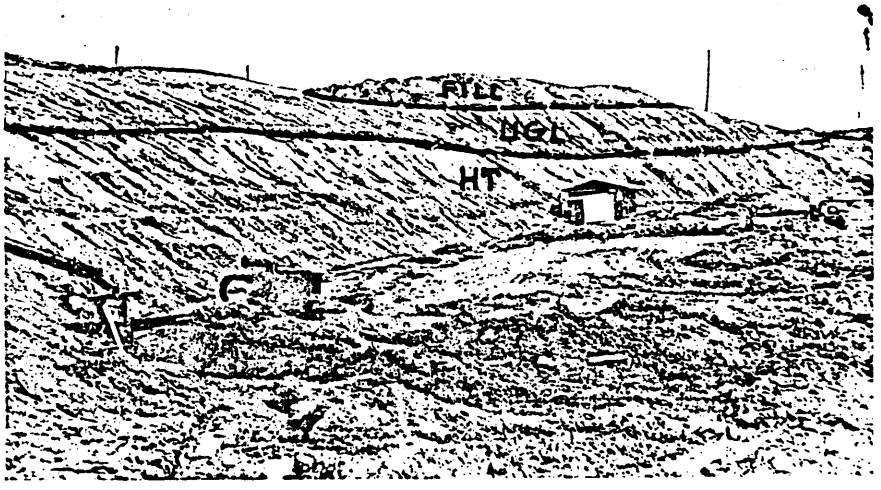


Photo 6. Halton Till buried below upper glaciolacustrine bottom sediments at the Welland River syphon culvert excavation near Port Robinson. Note: HT= Halton Till; UGL=upper glaciolacustrine.

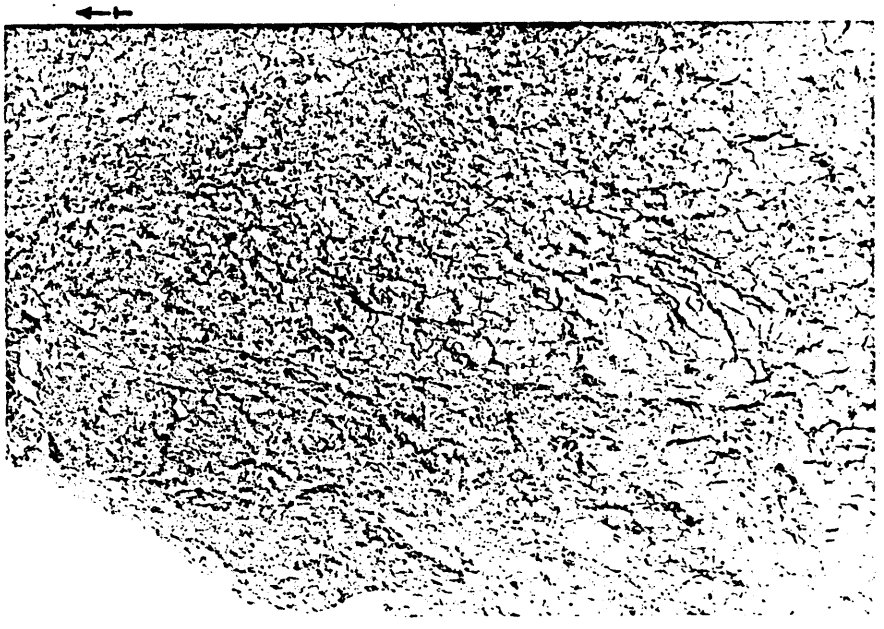


Photo 7. Silty clay Halton Till of the Mohawk Bay Moraine, Lake Erie shorebluff west of Mohawk Point.

also related to incorporation of proglacial lake-bottom sediments. The mechanical composition of 34 samples of the till along the relocated Welland Canal ranges as follows: 1-21 percent sand and gravel, 40-70 percent silt, and 25-50 percent clay (Owen 1972, Figure 1, Unit 12). The lower part of the till at the Fort Erie Moraine in the City of Welland is more gravelly and sandy due to the incorporation of lower till and lower glaciolacustrine sand and silt (Owen 1972, Figure 1, Unit 10). Abundance of dolostone fragments in the pebble grade and higher concentrations of dolomite and zinc in the finer matrix sizes of Halton Till at the above locations are related to the dolostone bedrock underlying the Niagara cuesta dipslope.

Halton Till has a silt to sandy and clayey silt matrix on the Onondaga cuesta dipslope to the east of Port Colborne (Figure 12, Table 4). Abundance of dolostone fragments in its pebble grade and of dolomite in its finer matrix sizes indicates predominance of material derived from the Silurian dolostone bedrock of the Niagara cuesta in up-glacier direction. The increase in limestone and chert fragments in the pebble grade is derived from the underlying Devonian bedrock. The nickel content in the finer matrix sizes is relatively low.

Principal distant provenance in the Precambrian Shield to the northeast (eastern Grenville source of Gwyn and Dreimanis 1979) is suggested by the garnet composition in

the fine sand size fraction of Halton Till (Table 4), measured by Barnett (1975).

Ground Moraine

Halton Till is extensively covered by upper proglacial lake deposits in the Niagara-Welland map-area. As ground moraine (till plain) it is chiefly exposed in the Iroquois Plain and along the debris-mantled face of the Niagara Escarpment. As much as 7 m of the Halton Till is exposed along the lower part of the Lake Ontario shorebluff (Figure 10). Thickest sections of the till occur between Port Weller and Jordan Harbour. The till is buried below Lake Iroquois sediments which are 11 m thick at the most and reach up to the top of the bluff. A thin layer of gravel separates brown Halton Till with inclusions of sand from red and grey, coarser textured, possible-lower till at the shorebluff midway between the Niagara River and the Welland Canal (Figure 10, measured section N466).

The above silt to clayey silt till along the Lake Ontario shorebluff in the Niagara area represents a brown, oxidized, and grey, unoxidized, upper sub-unit of the Halton Till; its reddish lower sub-unit, resting on red shale of the Queenston Formation, is exposed along the Lake Ontario shorebluff in the adjacent Grimsby area (Feenstra 1975). The upper sub-unit of the Halton Till in the Niagara area

contains inclusions of proglacial lake-bottom sediments (lower glaciolacustrine?) and intercalated fine textured reddish till of the lower sub-unit.

In general, borings on the Iroquois Plain in the eastern part of the Niagara area encountered between about 5 and 20 m of Halton Till, but as much as 30 m locally (Figures 7-9). The till is partially covered by surficial glaciolacustrine sediments,and overlies coarser textured lower till near Lake Ontario and fine grained proglacial lake-bottom sediments of the lower glaciolacustrine sequence inland.

The predominantly grey upper sub-unit of Halton Till becomes separated into two layers by upper glaciolacustrine sediments further southward in the Iroquois Plain. It also contains inclusions of fine-grained lake-bottom sediments and of reddish till. The gradational contact between the till and underlying clay was observed at a few exposures east of St. Catharines.

Two layers of more clayey Halton Till and intercalated upper glaciolacustrine clay, silt, and sand were measured in exposures and borings in the Twelve Mile re-entrant valley (Figure 9). This sequence is as much as 43 m thick near the mouth of the re-entrant but thins southward to about 15 m at its head between Effingham and St. Johns West. The sequence is overlain by surficial upper glaciolacustrine bottom and deltaic sediments, and overlies chiefly sands possibly

forming a continuation of the lower sands of the upper glaciolacustrine ice-contact deltaic sequence at Fonthill to the south. In the re-entrant valley to the north, the lower layer consists of up to 18 m of brown or grey silty clay to clayey silt till, and southward of up to 6 m of brown or grey to reddish silt till. It contains inclusions of the underlying stratified drift. The upper layer consists northward in the re-entrant valley of up to 21 m of grey or brown, massive or thin-stratified, silty clay with contorted inclusions of silt and stratified clay-silt-sand. It thins to the south to about 6 m of reddish or greyish brown, massive appearing, but thin-stratified fine-gravelly silty clay. This upper layer of the Halton Till in the Twelve Mile re-entrant valley may represent waterlain till deposited by a floating ice-shelf. The upper layer probably pinches out in the area just south of and beyond the head of the re-entrant valley and only the lower silt till layer, as much as 6 m thick, is exposed.

A thin (about 2 m), brown, silty Halton Till layer was also encountered by boreholes in the sedimentary fill of the buried St. Davids Gorge (Figure 7, Unit 6). It occurs at a depth of about 14 m below the surface and also between lower and upper glaciolacustrine deposits.

On the top of the Niagara Escarpment and away from the Vinemount Moraine, Halton Till is generally thin and extensively covered by surficial upper glaciolacustrine bottom sediments. At the Thorold quarry of Walker Brothers

Limited along the brow of the Niagara Escarpment, 2 m of Halton Till of which the lower part is reddish (lower sub-unit of lowland) rests on the Lockport Formaton and is overlain by 4 m of upper glaciolacustrine clay and silt (Figure 8).

Borings and excavations along the relocated segment of the Welland Canal (Figure 8) show that Halton Till thickens from the top of the Niagara Escarpment southward to about 12 m near the Fort Erie Moraine at Welland, and thins again south of this moraine to about 3 m at the Onondaga Escarpment (Owen 1969, Figure 2, Unit 8; Owen 1972, Map 8-1971, Section A-B, Unit 12). Halton Till on the Niagara cuesta dipslope is generally a fine-textured silty and clayey till, reddish, grey or brown northward and chiefly reddish brown southward. It overlies mainly fine grained sediments of the lower glaciolacustrine sequence, but sporadically also the coarser textured lower till. Halton Till contains also inclusions of these underlying deposits (see also Owen 1969). It is extensively covered by thick, surficial upper glaciolacustrine bottom sediments.

Grey, reddish, or brown silt to silty clay Halton Till on the Onondaga cuesta away from the end moraines is generally thin, as much as 3 m, and also covered by surficial upper glaciolacustrine sediments.

End Moraines

Halton Till is exposed at the Mohawk Bay, Wainfleet, Crystal Beach, Fort Erie, and Vinemount Moraines. The till probably increases in thickness at all these moraines. Halton Till is also exposed at the Fonthill kame complex which represents a very large increase in the thickness of ice-contact sand and gravel. The till is not exposed along the Niagara Falls Moraine.

The Lake Erie shorebluff section through the Mohawk Bay Moraine (Figure 13) is nearly perpendicular to the trend of the moraine ridges. The hummocky surface of the till in the main ridge rises locally more than 20 m above the bedrock surface which is submerged below the level of the lake (well-log data). The till has a reddish brown or grey colour and a silty clay to clayey silt matrix. Similar till is exposed along the shorebluff sections and on top of the moraine ridge at Mokawk Point to the east. At the main ridge, Halton Till is overlain by and also interbedded with contorted-stratified silty, fine sand, silt, and clay forming an unit of subaqueous ice-contact origin. Halton Till was found interbedded with glaciolacustrine clay and silt only to the east of the ridge (proximal side).

It is unknown to this author if the Wainfleet Moraine consists entirely of Halton Till. The Crystal Beach Moraine is probably a till ridge deposited on bedrock of the Onondage cuesta backslope. The buried extension of this

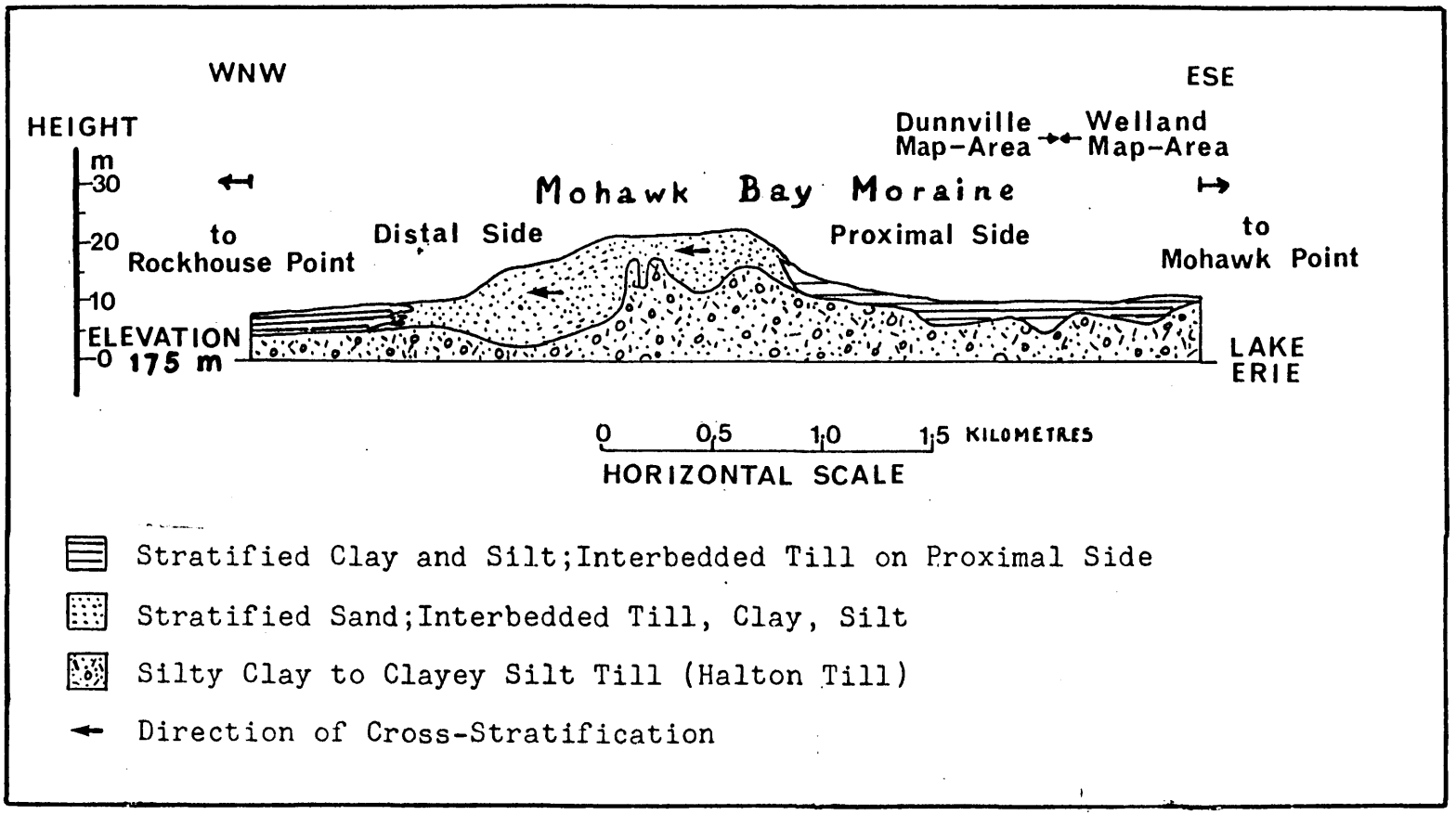


Figure 13-Lake Erie shorebluff section through the Mohawk Bay Moraine east of Port Maitland.

moraine north of the cuesta may be indicated by a slightly uneven surface of the Halton Till at the relocated Welland Canal about 10 km west-northwest of Sherkston (Owen 1972, Map 8-1971, Section A-B).

The Fort Erie Moraine ridge at For Erie consists of reddish brown or grey Halton Till with a clayey silt matrix. The till probably overlies bedrock (testborings) and varies in thickness between 8 and 12 m.

The exposure of Halton Till in the vicinity of Netherby reflects a buried rise of about 6 m (testborings). The northernmost of the two ridges between Brookfield and Cooks Mills also constitutes a rise of about 8 m (Owen 1972, Map 1971, Secion C-D, Units 10 and 12). The lower part of the Halton Till is slightly coarser textured than its upper part (Owen 1972, Figure 1, Units 10 and 12 respectively). This is due to the incorporation of lower till and lower glacio-lacustrine sand and silt. The exposure of Halton Till along Lyons Creek at Cooks Mills, and another rise in the till surface at the relocated Welland Canal segment about 3 km south of Port Robinson (Owen 1969, Figure 2), form probably part of the buried extension of the northernmost of the two Fort Erie Moraine ridges at Welland.

The exposure of Halton Till at the very small ridge near the relocated canal west of Cooks Mills, and another rise in the till surface further west at the canal between Main Street and the northern margin of the Welland area (Owen 1972, Map 8-1971, Section A-B), probably form part of

the buried extension of the southernmost of the two Fort Erie Moraine ridge at Welland.

Halton Till with interbedded sand and silt was encountered just below the surface in borings and excavations at the Niagara Falls Moraine at Fonthill. A testboring at the western boundary of the City of Niagara Falls, and possibly into the buried distal slope of the moraine, penetrated 5 m of upper glaciolacustrine clay and silt and 9 m of Halton Till before reaching bedrock. The moraine ridge at Niagara Falls seems to consist of till, sand, and silt. A few testborings near the Queen Elizabeth Way encountered about 20 m of silt and fine sand overlying as much as 5 m of till based on bedrock. Other testborings near the Niagara River, however, penetrated about 10 m of till overlying 10 m of sand and silt.

Halton Till is also associated with the Fonthill kame complex. A layer of the till can be traced southward in the Twelve Mile re-entrant to the northern ice-contact slopes of the kame complex (Figure 9). In addition, a few remnants of a middle unit consisting of ablation Halton Till and sand occur at the same stratigraphic position but higher up in the southwestern ice-contact ridge of the kame complex. Fragments of basal and ablation Halton Till are also included in the sands and gravels of the upper unit at this southwestern ridge. The Fonthill kame is a large ice-contact deltaic complex and it is discussed in the following Upper Glaciolacustrine Deposits section in the

report.

The Vinemount Moraine segment south of Vineland consists of two parallel ridges oriented perpendicularly to local glacial movement. The northern ridge consists at Vineland Quarries of a cap of silty Halton Till which truncates contorted-stratified silt and sand. They in turn overlie contorted beds of silty and clayey Halton Till, silt, and clay which dip in up-glacier direction to the northeast. The whole sequence is about 10 m thick and overlies a glacially eroded bedrock surface. A similar, 14 m thick sequence of interbedded Halton Till (10 m in total) and upper glaciolacustrine clay, silt, and sand, and also based on bedrock, was penetrated by a borehole into the Vinemount Moraine 20 km to the west in the adjacent Grimsby area (Feenstra 1975).

Contrary to Taylor (1913) and Chapman and Putnam (1966), the present survey did not find any other Vinemount Moraine segment, which is mainly composed of Halton Till, along the top of the Niagara Escarpment east of Twenty Mile Creek. However, an ice-contact deltaic sand deposit was formed at the Vinemount Moraine position of the glacier front at the head of the re-entrant in the Escarpment south of St. Davids (Figure 7, U.I.C.). This deposit also contains layers and inclusions of Halton Till at the pits operated by St. Davids Sand and Gravel Limited along former Highway 8 near Mountain Road in Niagara Falls. A thin (about 1 m) layer of dense, greyish brown clayey silt till

was found interbedded with the sands near the top of the pit on the east side. Inclusions of brown silt till were also found in the sands overlying a thin, contorted-stratified unit of glaciolacustrine clay and sand in the pit on the west side. Coleman (1937a, p.4) also reported till overlying coarse gravel and overlain by a thin layer of varved clay from a pit at the head of the re-entrant.

Interpretation and correlation of the sequences encountered in the Vinemount Moraine west of Twenty Mile Creek, in the Twelve Mile re-entrant, and at the head of the re-entrant south of St. Davids suggest that the glacier front oscillated between the Niagara Escarpment and a position in the lowland to the north. It suggests also that a floating ice-shelf extended at the time in proglacial lake waters over a distance of about 5 to 10 km from the main mass of the glacial lobe into the Twelve Mile re-entrant valley.

Upper Glaciolacustrine Deposits

The upper glaciolacustrine formation (Table 2) documents the inundation of the Niagara-Welland area first and foremost by Erie basin and later in the north also by Ontario basin proglacial lake stands accompanying the retreat of the Ontario-Erie glacial lobe which deposited the Halton Till ("Halton" ice). This formation consists of

ice-contact deltaic, beach, nearshore and deltaic, and lake bottom deposits (Map-Units 9-13). The deposits are described in the following sections of the report.

Ice-Contact Deltaic Deposits

Deltaic deposits formed at different positions of the "Halton" ice front in the map-area are found at Fonthill and vicinity (Fonthill kame complex) and at the northern boundary of the City of Niagara Falls. These two sites occur at or near the heads of re-entrants in the Niagara Escarpment, viz. the Fonthill kame complex near the head of the Twelve Mile re-entrant and the other at the head of the Four Mile re-entrant south of St. Davids. Both deposits are extensively veneered by nearshore and beach deposits. Sand and gravel has been for a long time and still is extracted from these deposits. Consequently, portions of their internal structure and composition can be seen in sand and gravel pits.

A correlation of the materials encountered at sand and gravel pits and penetrated by boreholes in the southwestern ice-contact ridge of the Fonthill kame complex is shown in Figure 9 (in back pocket). The ice-contact deltaic sequence of materials is as much as 100 m thick and consists mainly of fine grained sands which are overlain by a thinner sheet of gravel and coarser grained sands. It is covered by a veneer of upper glaciolacustrine beach and nearshore

sediments. It is underlain by a sequence consisting in descending stratigraphic order probably of Halton Till, lower glaciolacustrine clay, silt, and sand, and lower till, and which varies in thickness between 15 and 45 m.

Only the upper 3 to 11 m of the finer grained lower sands of the ice-contact deltaic sequence are exposed in pits of Moyer Sand (Division of Steed and Evans Limited) and T.C.G. Materials Limited. This upper part consists mainly of cross-stratifed, fine and medium grained sands. Current flow varied in directions between south and west. The lower sands continue northward underneath Halton Till in the Twelve Mile re-entrant.

The upper beds of gravelly, coarser grained sands and gravel of the ice-contact deltaic sequence range in thickness from less than 3 m in the Moyer Sand pit, on the southside of Highway 20 at the southwest end, to possibly about 46 m at the area of coalescence of the two southern ridges to the northeast. They vary in thickness between 3 and 12 m in the Moyer Sand and T.C.G. Materials Limited pits on the northside of Highway 20 in the south-central part of the ridge (Photo 8). As much as 9 m of upper beds is intermittently exposed along the steep faces at the northeast end of the area of coalescence (measured section N68). The upper beds are frequently cemented. They show large- and small-scale crossbedding in northerly (Photo 8) and southerly directions, and sporadic collapsed- bedding.

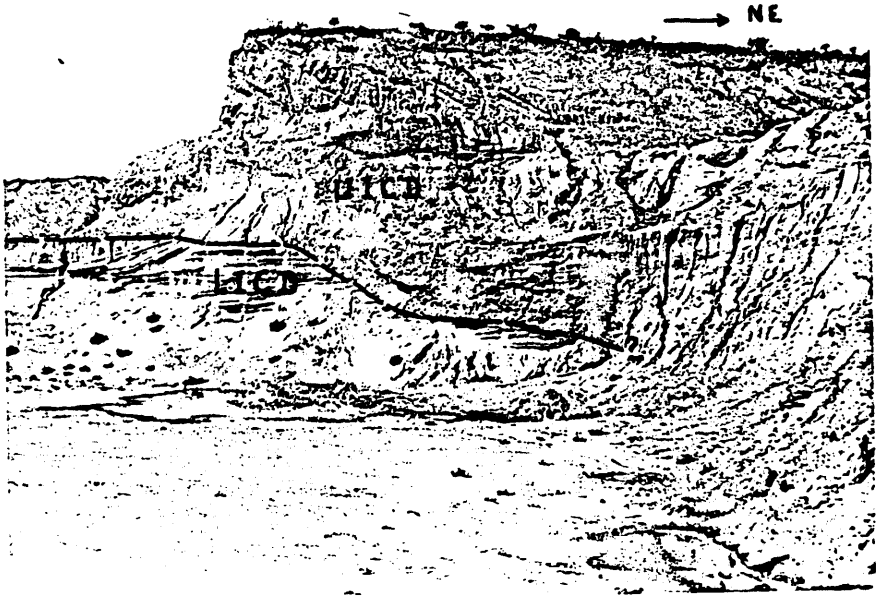


Photo 8. Bedding features in upper and lower units of the ice-contact glaciolacustrine delta at Fonthill (T.C.G. Materials Ltd. pit). Note: UICD and LICD= upper and lower ice-contact deltaic units respectively.

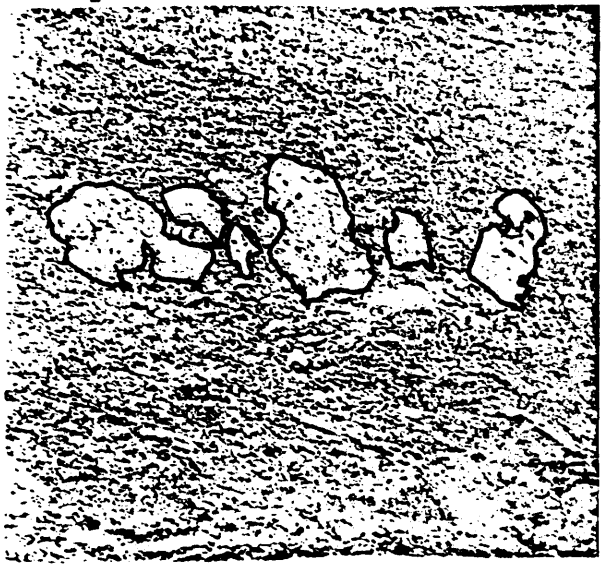


Photo 9. Clasts of ablation Halton Till in gravelly sand (upper unit) of ice-contact glaciolacustrine delta at Fonthill (Moyer Sand pit, north side of Highway 20). Note: till clasts are outlined.

The lower contact of the sequence of upper beds is erosional (Photo 8).

Possible remnants of a unit consisting of interstratified coarser grained sands and coarse-textured ablation Halton Till (sample N1767-6) were sporadically found intercalated between the two major units in the pits on the northside of Highway 20 at depths ranging between 3 to 10 m below the surface. Clasts of this till (Photo 9) and large fragments of the lower sands occur in the lower part of the sequence of coarser grained upper beds in the pits, while clasts of basal Halton Till (sample N68-C) were also found in the same sequence along the steep face at the northeast end of the area of coalescence.

The following features of the Fonthill ice-contact deltaic complex suggest deposition of the sediments at the receding "Halton" ice front:-

1. it is in line with the Fort Erie and Niagara Falls Moraines;
2. the steep slopes along the northern sides definitely represent ice-contact faces;
3. Halton Till is associated; and,
4. melting away of blocks of stagnant ice is indicated by collapsed upper beds and a depression in the top surface of the western ridge.

Deposition of this upper glaciolacustrine ice-contact deltaic sequence in initially deep (about 75 m) water of

Lake Warren I or II and which subsequently shallowed locally is suggested by:

1. occurrence of beach deposits on top of the highest platform at approximate elevation 255 m (835 ft);
2. interfingering of the finer grained lower sands with clays underlying the lake bottom at elevations between 174 and 183 m (570-600 ft) at the foot of the ridges; and,
3. growth and coarsening upwards of the sequence.

The following are important considerations in the localization of this ice-contact deltaic sequence in the area between Fonthill, North Pelham, and Fenwick:

1. differential retreat of the glacial lobe as indicated by the moraine pattern in the Niagara Peninsula and resulting in the formation of an ice-marginal re-entrant, i.e. the shape of the ice front was regionally controlled by relative more rapid retreat from its terminal position to that of the recessional Fort Erie Moraine in the eastern Lake Erie basin area than in the western part of the Peninsula;
2. intersecting crevasses locally controlling the shape of the ice-frontal re-entrant as indicated by the straightness, steepness, and inverted-V pattern of the sides of the southern ridges;
3. upshearing of the drift within the glacial lobe

caused by the rise in the substrate (bedrock) surface at the head of the Twelve Mile re-entrant valley in the Niagara Escarpment and perhaps resulting in relatively more rapid subaqueous melting of the marginal shear zone in proglacial lake waters; and,

4. the ice front was essentially stationary, although its sides receded locally over a very short distance from the Fort Erie- to the Niagara Falls Moraine position during which the ice-marginal re-entrant largely disappeared.

The Fonthill kame is essentially a trilobate, ice-contact, upper glaciolacustrine deltaic feature. Both southern ridges originated at the Fort Erie Moraine position of the receding ice margin, while the western ridge at its Niagara Falls Moraine position. The thick sequence of fine grained lower sands of the southwestern ridge represents most of the rapid accumulation of sediment as foreset beds (Figure 14). It is correlated with beds of similar sand below the lower, basal Halton Till layer in the Twelve Mile re-entrant. Paleocurrent flow was generally in directions between south and west although locally in opposite directions in the re-entrant valley (backset beds?). The thinner, but coarser grained upper sheet of sand and gravel of the southwestern ridge may represent topset beds (Figure 14). They were deposited under shallowing lake- and/or relatively stronger current conditions. Paleocurrent flow

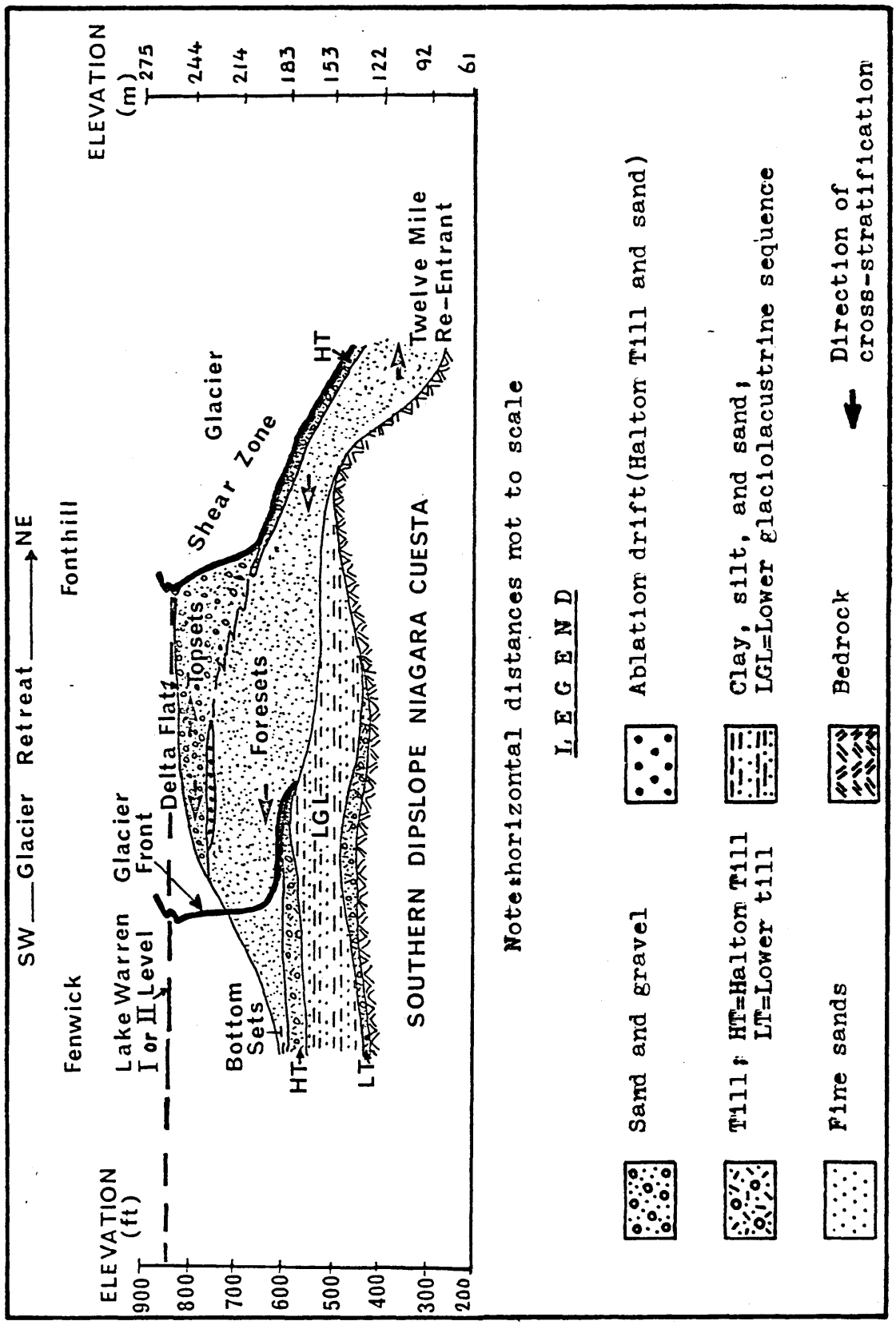


Figure 14-Origin of the ice-contact glaciolacustrine delta at Fonthill (southwest ridge).

was also in the same directions between south and west or in opposite directions (backset beds?, washover beds?).

The two southern ice-contact ridges may also be eskerine in origin. Sediments were transported by meltwater through ice-walled tunnels located along northeast-southwest and northwest-southeast intersecting sets of crevasses, and the paleoflow was essentially parallel to the long axes of the ridges to the southwest and southeast respectively. The sediments were rapidly deposited by decelerating currents discharging into the low-energy environment of the proglacial lake. The depositional sites at the mouth of the tunnels moved respectively to the northeast and northwest during recession of the ice front from the Fort Erie- to the Niagara Falls Moraine position and they merged ultimately. Such environmental conditions have been discussed in more detail by Banerjee and McDonald and by Rust and Romanelli (in Jopling and McDonald 1975, p.132-154 and p.177-192 respectively). The large-scale crossbeds in the upper sheet of coarser grained sand and gravel, which dip apparently upstream in the T.C.G. Materials Limited pit (Photo 8), may have originated as backset beds associated with open-channel flow (Banerjee and McDonald in Jopling and McDonald 1975, p.136). Bank-collapse and/or bottom-scour resulted probably in the erosion of fragments of the lower finer grained sands, of the unit of ablation Halton Till and sand, and of basal Halton Till which were redeposited with the upper beds (Photo 9).

The ice-contact deltaic deposit at the head of the Four Mile re-entrant in the Niagara Escarpment south of St. Davids was formed at the Vinemount Moraine position of the "Halton" ice front. This deposit consists mainly of stratified sands and silts; some gravel, clay, and Halton Till is also interbedded. The materials are exposed in pits operated by Calaguiro Brothers Limited, Half-Way Sand Pit Limited, and St. Davids Sand and Gravel Limited.

The pit operated by St. Davids Sand and Gravel Limited along the west side of former Highway 8 at Mountain Road in Niagara Falls shows about 10 m of alternating sub-units of stratified very fine to coarse grained sands and silts with some interbedded clay and gravel (Figure 7, UIC). This sequence overlies a thin unit of contorted-stratified glaciolacustrine clay and sand. Another pit worked by St. Davids Sand and Gravel Limited is to the east of a pit operated by the same company on the eastside of former Highway 8, and it also exposed about 10 m of stratified fine to medium grained sands. The sands are finer grained (predominantly silty fine) in the adjacent pit worked by Half-Way Sand Pit Limited.

The surface of this ice-contact deltaic deposit has been extensively reworked by proglacial lake waters. It is veneered with nearshore sand and silt, and beach deposits occur locally at elevations corresponding to the tilted level of the Lake Dana stand. The ice-contact deltaic deposit may have been formed when the glacier fronted Lake

Dana, or perhaps during the earlier stand of Early Lake Algonquin.

A third site of ice-contact deltaic deposition may be formed by the Niagara Falls Moraine ridge in Niagara Falls and possibly also by the area in the city northward to Stamford Centre. This site is at the ice-marginal re-entrant proposed by Taylor (Kindle and Taylor 1913). However, the whole area has been extensively modified by wave action and it is also extensively built over at present.

Beach Deposits

Ancestral Erie Basin Lake Stands

The map-area contains beaches and other raised shoreline features of the following ancestral lake stands in the Erie basin: Lake Warren II, Lake Warren III, Early Lake Algonquin, Lake Dana, Lake Dunnville, and possibly Early Lake Erie.

The Warren II beach ridges are found on the highest terrace at the Fonthill ice-contact deltaic complex. The surface of the possibly wave-built terrace is at approximate elevation 255 m (835 ft) above sea-level. The beach ridges consist mainly of gravelly sand, are oriented parallel in northeast-southwest direction, occur within a vertical interval of 6 m, and show as much as 3 m of

relief. The material in the beaches and in the upper part of the terrace is derived from the ice-contact sand and gravel deposit.

The Warren III shore is also at Fonthill and it consists of a wave-cut bluff and associated terrace. The bluff is formed in the highest terrace at the deltaic complex. The bluff is about 6 m high and its base is at elevation 247 m (810 ft). It backs a terrace formed on the large, southeast and southwest trending ice-contact ridges. This terrace is underlain by as much as 2 m of gravelly sand derived from the underlying ice-contact sand and gravel deposit.

The Early Lake Algonquin shore is marked by small beach deposits at two localities. The first locality is at elevation 210 m (690 ft) along the northeast-facing slope of the ice-contact deltaic complex at Fonthill. The beach deposit consists of 3 m of coarse, well-rounded gravel. The second locality is at approximate elevation 213 m (700 ft) above sea-level on the summit of the Niagara Falls Moraine along Lundy's Lane in Niagara Falls. This beach deposit consists of about 2 m of gravelly sand.

The more numerous shoreline features (mainly beach deposits) of Lake Dana are as follows:-

1. a very low bluff with its base at about elevation 185 m (605 ft) backing a small terrace locally veneered by wave-washed Halton Till inland from Splatt Bay, west of

Port Maitland in the Dunnville map-area (Feenstra 1974);

2. a small ridge of sand and gravel (Appendix B: sample W1002), about 2 m thick, at approximate elevation 188 m (615 ft) and overlying silt and bedrock on the Onondaga cuesta in the vicinity of Morgans Point and Burnaby in the Welland map-area;
3. a low ridge of sand and gravel also at about elevation 188 m (615 ft) on Halton Till along the crest of the Wainfleet Moraine, Burnaby-Wainfleet, Welland map-area;
4. two small ridges of sand and gravel, as much as 2 m thick, at approximate elevation 194 m (635 ft) on Halton Till and bedrock on top of the Onondaga Escarpment near Bethel, Welland map-area;
5. a sandy ridge also at about elevation 194 m (635 ft) in the vicinity of Crystal Beach and Ridgeway, Welland map-area;
6. a relatively large ridge containing more than 3 m of sand and gravel (Appendix B: samples W185-A and -B) at approximate elevation 197 m (645 ft) on Halton Till and bedrock of the Onondaga cuesta along the eastside of the re-entrant valley in the escarpment north of Ridgeway, Welland map-area;
7. three small ridges of sand and gravel at elevation 195 m (640 ft) on Halton Till along the crest of the Fort Erie Moraine, Fort Erie, Welland map-area;

8. two relatively large ridges of sand and gravel (Appendix B: samples W47-A, W69-B and -C, W74, and W77-C) at about elevation 198 m (645 ft) on Halton Till along the crests of the double-ridged Fort Erie Moraine mainly within the southeastern limits of the City of Welland, Welland map-area (Photo 10); the southern of the two beach ridges contains locally more than 5 m of gravelly sand and backs a small terrace underlain by gravelly sand at approximate elevation 194 m (635 ft);
9. a recurved spit of sand and gravel (Appendix A: samples N1877 and N1881), locally more that 2 m thick, with its top at elevations varying between 190 and 195 m (625-640 ft) at the eastside of the ice-contact glaciolacustrine delta at Fonthill, Niagara map-area (Photo 11);
10. a small deposit of beach gravel, about 1 m thick, at about elevation 198 m (650 ft) at the apex of the northern ice-contact slopes of the delta at Fonthill, Niagara map-area;
11. small terraces in Halton Till at elevations varying between 195 and 203 m (640-650 ft) along the distal side of the Vinemount Moraine east and west of Vinemount in the Grimsby map-area (Feenstra 1975) and west of Campden in the Niagara map-area; thin deposits of reworked till locally veneer the distal slope of the moraine;

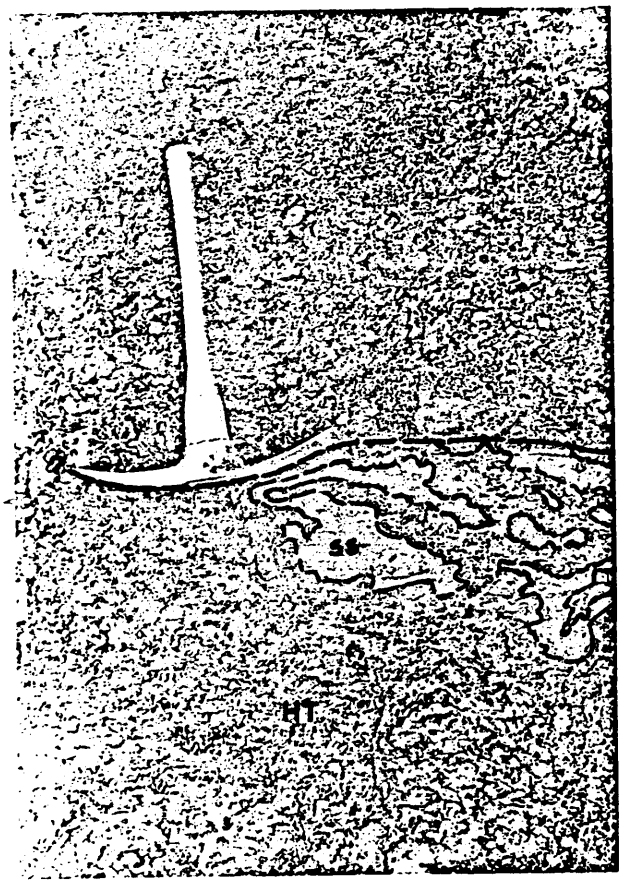


Photo 10. Lake Dana beach gravel and sand overlying Halton Till (HT) with silt-sand inclusions (ss), Fort Erie Moraine at Welland.

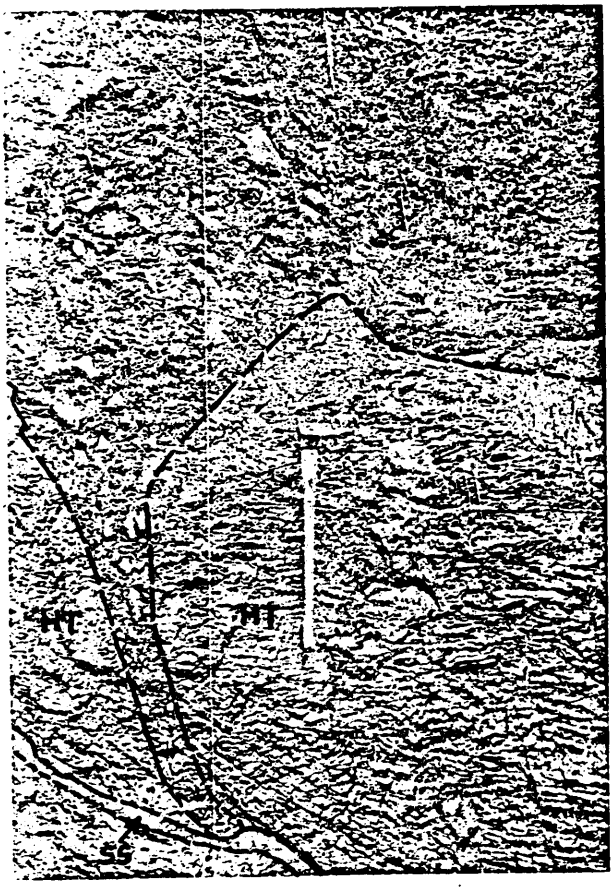


Photo 11. Lake Dana gravel and sand infilling fossil ice-wedge in fissile Halton Till (HT) with silt-sand band (ss), Niagara Falls Moraine at Fonthill.

12. small ridges of gravelly sand, more than 1 m thick and at about elevation 200 m (655 ft), diverging from the crest of the Niagara Falls Moraine near Horseshoe Falls eastward along its flanks to the Queenston- Chippewa power canal, City of Niagara Falls, Niagara map-area;
13. sand and gravel (Appendix A: sample N2526), more than 2 m thick, possibly representing wave-reworked ice-contact deposits at approximate elevation 198 m (650 ft) in the Stamford Centre area of the City of Niagara Falls, Niagara map-area; and,
14. a small deposit of beach gravel, about 2 m thick, at about elevation 204 m (670 ft) on top of the ice-contact deltaic deposits in the pit operated by St. Davids Sand and Gravel Limited along the west side of former Highway 8 near Mountain Road at the head of the St. Davids re-entrant valley in the Niagara Escarpment.

The six samples of Lake Dana beach granule-pebble gravel and medium-gravelly, very coarse grained sand are predominantly poorly sorted or well graded (Appendix J: samples W69-B and -C, W77-C, W185-A and -B, and W1002).

Lithologic composition of the pebble grade of the beach material on the Haldimand Plain mainly reflects that of the underlying Halton Till and associated ice-contact, stratified drift. Dolostone or dolostone and sand-siltstone together predominate in all seven samples from across the southern dipslopes of the Niagara and Onondaga cuesta

(Appendix K: samples N1877, N1881, N2526, W47-A, W74, W185-A, and W1002), while limestone (sample W47-A and W74) replaces shale (samples N1877, N1881, and N2526) as the next important component further southward across the Niagara cuesta, and small amounts of chert are added over the Onondaga cuesta (samples W185-A and W1002).

Limestone and dolostone together also predominate among the rock fragments in the medium to coarse sand fraction of two samples (Appendix L: W69-C and W77-C), whereas shale and siltstone occurring together as a group is common.

Two small deposits of lacustrine sand and gravel occur in the map-area at elevations intermediate between the tilted levels of the Early Lake Algonquin and Lake Dana water planes. One of the deposits is found at approximate elevation 192 m (630 ft) on the Mohawk Bay Moraine inland from Mohawk Point, and the other at about elevation 195 m (640 ft) on bedrock at the Onondaga Escarpment at Burnaby to the east.

Shoreline features (mainly beach deposits) identified as belonging to the Lake Dunnville stand in the map-area are the following:-

1. a very small ridge of gravelly sand, about 2 m thick, at approximate elevation 182 m (597 ft) and overlying silt and bedrock on the Onondaga Escarpment in the vicinity of Long Beach inland from Grabell Point,

Welland map-area;

2. four small ridges of sand and gravel (Appendix B: sample W358), also about 2 m thick, at elevation 185 m (607 ft) and overlying clay and silt or bedrock on the Onondaga cuesta in the vicinity of Shisler Point, Sherkston, and northeast of Gasline, Welland area;
3. another small ridge of sand and gravel (Appendix B: samples W334-A to -D), more than 2 m thick, at elevation 187-188 m (615 ft) and overlying clay on the Onondaga cuesta in the same area along the westside of the re-entrant valley in the escarpment north of Gasline, Welland map-area;
4. a small wave-cut terrace in Halton Till veneered by 1 m of gravelly sand along the distal slope of the Crystal Beach Moraine at elevation 184-185 (605 ft) on the Onondaga cuesta northwest of Crystal Beach, Welland map-area;
5. sporadic, thin veneer of sand and gravel (Appendix B: sample W156) at about elevation 189 m (620 ft) overlying clay or Halton Till at small, probably bedrock-controlled, rises on the Onondaga cuesta near Mulgrave, Welland map-area;
6. two small ridges of gravelly sand, 1 m thick, also at elevation 189 m (620 ft) on Halton Till or bedrock at the Onondaga Escarpment at Ridgemount, Welland map-area; and,

7. another small ridge of sand and gravel (Appendix B: sample W2418), as much as about 2 m thick, also at about elevation 189 m (620 ft) on Halton Till along the crest of probably the southern ridge of the mainly buried, double-ridged Fort Erie Moraine near the Welland By-Pass segment of the Welland Canal in the City of Welland.

Samples of the pebbly-cobbly beach gravel are poorly sorted or well graded (Appendix J: samples W334-A, W358, and W2418), while samples of the medium-gravelly, very coarse grained beach sand are moderately to well sorted (Appendix J: samples W334-B to -D).

The lithologic composition of the pebble grade of the beach material was determined only in two samples: one (W2418) on the southern part of the Niagara cuesta and the other (W156) on the very northern part of the Onondaga cuesta. The results (Appendix K) reflect the lithologic composition of the underlying Halton Till source in turn related to the Paleozoic bedrock underlying the map-area, i.e. predominance (flood) of dolostone in both samples, marked increase in limestone (abundant) in the sample on the Onondaga cuesta, scarce-common sand-siltstone, and rare-very rare shale and chert.

The lithologic composition of the medium-coarse sand grade of the beach material was determined in three samples: one (W2418) from the same locality on the southern part of the Niagara cuesta, and two (W334-A and -C) from another

locality on the northern part of the Onondaga cuesta. The results (Appendix L) show fragments of limestone and dolostone to be abundant at the locality on the Onondaga cuesta, and those of shale and siltstone to be common at the same locality but more abundant at the locality on the Niagara cuesta.

Lowering Early Lake Erie levels are possibly represented in the map-area by a small beach deposit on bedrock midway between the Crystal Beach Moraine and Shisler Point on Lake Erie, by a low, wave-cut bluff in clay and silt near Lake Erie at Crystal Beach, and by another low bluff also in the clay and silt near Lake Erie at Fort Erie. The beach deposit consists of about 1 m of gravelly sand and occurs at elevation 181 m (595 ft). The wave-cut bluffs are found at lower elevations which vary between 177m and 180 m (580-590 ft).

Ancestral Ontario Basin Lake Stands

The map-area also contains beach deposits and other raised shoreline features of Lake Iroquois and of pre- and post-Iroquois stands in the Ontario basin. They are discussed in the following paragraphs.

The highest stand of pre-Iroquois proglacial lake waters in the map-area is possibly marked by two very small ridges of sand and gravel which occur at about elevation 184-185 m (605 ft) near Campden.

Two small bodies of deltaic sand, one in the Twelve Mile re-entrant and the other in the re-entrant south of St. Davids, record a lower (about 35 m) stand. The deltaic deposits are discussed in the "Nearshore and Deltaic Deposits" section.

The prominent Iroquois shoreline in the map-area consists mainly of a wave-cut bluff interrupted by a baymouth bar (Homer bar) in St. Catharines. The bluff varies in height to as much as 12 m.

The Homer bar extends for about 6 km along the former Highway 8 constructed on top of it between Homer at the Welland Canal and where the Twelve Mile Creek breaches the shoreline in St. Catharines. The crest of this baymouth bar reaches about 3 m above the former lake level. The bar consists of about 8 m of gravel and gravelly sand deposited on clayey Halton till as indicated by former gravel pits (Coleman 1937a) and recent borings (Peto Associates Limited) near its east- and west end respectively. Borehole samples P66-51-11-4 and -15-2 consist of about 64 percent medium-pebble gravel, 33 percent finer gravel and sand, and 3 percent silt. Both samples and other borehole samples P66-51-15-5, taken from gravelly, coarse to very coarse grained sand interbedded with the gravel, and P66-51-9-3, taken from overlying gravelly, fine to medium grained sand, are poorly sorted or well graded (Appendix J). The sand fraction of borehole sample P66-51-9-3, however, is well sorted.

Much smaller deposits of beach sand and gravel are found scattered along the base of the shorebluff between St. Catharines and Beamsville. These beach deposits are sporadically as much as 3 m thick.

More rapid isostatic rebound following deglaciation of the northeastern part of the Lake Iroquois basin caused its waters to encroach on the western shores. The shorebluff of Lake Iroquois in the Niagara area marks the farthest encroachment of these rising waters and the Homer bar was constructed by westward-effective longshore currents across the City of St. Catharines. Bar migration is also recorded by the Hamilton baymouth bar to the west (Karrow et al. 1961) and by the Lewiston spit in New York State to the east (Kindle and Taylor 1913). The Lewiston spit extends across the mouth of the early Niagara River (Lewiston spillway) where it entered Lake Iroquois beyond the falls over the Niagara Escarpment and the Cataract Basin (Kindle and Taylor 1913). The crest of the Lewiston spit rises to about elevation 114-115 m (375 ft) and this spit apparently truncates another paralleling the Niagara River on the east side (Kindle and Taylor 1913).

The rising waters at the west end of the lake basin caused flooding of features associates with lower levels of Lake Iroquois (pre-Main Iroquois). The Newfane beach and the truncated spit at Lewiston in New York State may form such features (Kindle and Taylor 1913; Calkin and Miller 1977). In the Niagara area, sand and gravel (up to

cobble-size) was found buried at approximate elevation 85-86 m (280 ft) below a cover of nearshore sediments along the Lake Ontario shorebluff near Sixteen and Eighteen Mile Creeks. Another feature is formed by gravel and gravelly sand buried below fine grained nearshore sand north of Queenston and possibly represents the western portion of an early Niagara River delta. Its eastern portion north of Lewiston in adjacent New York State was previously mapped (Kindle and Taylor 1913).

Further retreat of the ice sheet in the St. Lawrence Lowlands resulted in abandonment of the Rome N.Y. outlet of Main Lake Iroquois for outlets at lower elevations (Frontenac stage). Evidence in the Niagara area for this post-Main Iroquois lowering is possibly formed by ridges of sand and up to cobble-size gravel found scattered across the Iroquois terrace in the vicinity of Beamsville, St. Catharines, and Niagara-on-the-Lake (see also Coleman 1937a, p.3). These ridges are aligned more or less parallel to the main shoreline, rise generally less than 3 m above the surrounding terrace, and suggest several levels below the main stand at elevations between about 90 and 100 m (300-330 ft). Most of the ridges are underlain by Halton Till which formed the main source of their material (Appendix A and K: sample N1090). These small beach ridges should be examined for possible evidence of reworking similar to that occurred at the Newfane beach (Kindle and Taylor 1913).

Nearshore and Deltaic Deposits

In this section on the nearshore and deltaic deposits in the map-area, the material deposited in the ancestral Erie basin lake stands is described first and the material deposited in the ancestral Ontario basin lake stands later.

Ancestral Erie Basin Lake Stands

A surficial veneer of nearshore sediments consisting mainly of silty, fine to very fine grained sand is found on:-

1. ice-contact glaciolacustrine drift at Fonthill and in the City of Niagara Falls (Lundy's Lane-St. Davids re-entrant);
2. end moraine ridge segments composed of Halton Till south of Beamsville (Vinemount Moraine), between Turners Corners and Fonthill (Niagara Falls Moraine) where also a recurved spit is developed, between Welland and Fonthill (Fort Erie Moraine), Crystal Beach and Sherkston (Crystal Beach Moraine), west of Port Colbourne (Wainfleet Moraine), and inland from Mohawk Point on Lake Erie (Mohawk Bay Moraine);
3. ground moraine of Halton Till, or bedrock, in the vicinity of Ridgeway and Crystal Beach along the east side of a re-entrant valley in the Onondaga cuesta and

to the south of the Vinemount Moraine south of Beamsville; and,

4. a small rise in the lake-bottom plain to the north of Lyons Creek northeast of the hamlet of Cooks Mills.

These nearshore sediments occur at elevations varying between 178 and 247 m (285-810 ft) and were derived by wave-reworking of principally ice-contact glaciolacustrine sands and Halton Till during the Warren III to Dunnville lake stages.

Wave-working of sand, gravel, and Halton Till associated with the trilobate ice-contact glaciolacustrine delta at Fonthill during the Warren III to Dana lake stages resulted in deposition of a relatively large surficial veneer or apron of nearshore sands blanketing this delta complex from the lower platform on its two southern ridges down along its flanks to about elevation 183 m (600 ft) on the surrounding clay plain (Figure 9, in back pocket). The coarsest grained nearshore deposits, consisting of gravelly sand and fine to medium sand and sporadic gravel which are as much as 2 m thick, are found at the top of the ice-contact ridges and along their flanks at elevations above 198 m (650 ft). They represent principally reworked coarser grained sands of the upper and lower units of the ice-contact delta. The finest grained nearshore deposits consisting predominantly of silty, fine to very fine sands, are found along the basal part of the flanks of the ice-contact ridges and on the surrounding clay plain. They

are as much as 3 m thick at elevations above 189 m (620 ft) and represent reworked finer grained sands of the lower deltaic unit and Halton Till.

Another relatively large apron of nearshore sands covers the area at elevations varying between 178 and 210 m (585-690 ft) of the ice-contact glaciolacustrine sand, silt, minor gravel and Halton Till associated with the ice-marginal re-entrant in the City of Niagara Falls. This apron is generally more than 1 m thick east of the Queen Elizabeth Way and was deposited during the Early Algonquin - Dana lake stages. Predominantly silty, fine to very fine grained sand veneers the crest and flanks of the Niagara Falls Moraine ridge-segment along Lundy's Lane. Clean, fine to medium grained sand occurs sporadically along the relatively highest portion of this morainic ridge-segment. Silty, fine to very fine grained nearshore sand also blankets the area along both sides of former Highway 8 northward to Stamford. Similar textured nearshore sand and silt west of the Queen Elizabeth Way is generally less than 1 m thick. The apron of nearshore sediments continues northward to the head of the St. Davids re-entrant valley in the Niagara Escarpment where reworking of the upper ice-contact glaciolacustrine sequence resulted in deposition of a veneer of silty, fine sand and silt (Figure 7, in back pocket).

A very thin veneer of massive or stratified gravelly, sandy silt and silty, very fine grained sand, generally less

than 1 m thick, covers Halton Till locally at elevation varying between 192 and 204 m (630-670 ft) along the distal slope of the Vinemount Moraine south of Beamsville.

The crest of the Niagara Falls Moraine in the lake-bottom plain near Turners Corners is also thinly veneered by less than 1 m of gravelly, fine sand at approximate elevation 185 m (605-610 ft). The crest of this moraine forms near Fonthill the location of the longer of the two east-west aligned portions of a rather narrow recurved spit. This spit consists of gravel, gravelly sand and silty fine to coarse grained sands generally more than 1 m thick, while interstratified silty, very fine grained sand, silt,and minor clay is found at lower elevations.

Wave-reworking of Halton Till along the crest of the double-ridged Fort Erie Moraine segment in the Cities of Welland and adjacent Niagara Falls north of Townline Road resulted in the deposition, particularly on the south sides, of a nearshore sequence consisting of pebbly or silty fine sand and interstratified silty, fine to very fine sand, silt and minor clay (Appendix B and J: sample W69-A). This sequence forms a small, and as much as 2 m thick veneer at elevations varying between 186 and 194 m (610-635 ft). A thin veneer of reworked till is also found at the same elevations along the northwestern portion of the northernmost of the two morainic ridges southeast of Cooks Mills. Generally less than 1 m of silty fine grained nearshore sand and silt occurs at similar elevations on top

of lake-bottom clay and silt covering this moraine in the northwestern part of the City of Welland.

Gravel, gravelly sand, and interstratified very fine sand and silt of beach - nearshore origin form a thin veneer, generally less than 1 m thick, on Halton Till at the Crystal Beach Moraine at elevations varying between 184 and 190 m (605-620+ ft).

Wave-reworking of Halton Till at the small Wainfleet Moraine ridge segment west of the City of Port Colborne also resulted in deposition of a one metre (maximum) cover of nearshore silty, fine sand and silt at similar elevations.

A very small veneer of about 1 m of silty, fine to very fine grained sand covers Halton Till or lake-bottom clay also at the same elevations on the north side of a small ridge segment of the Mohawk Bay Moraine in the vicinity of Mohawk Point.

The nearshore sediments on the above morainic ridge segments in the Niagara-Welland map-area originated during the Early Algonquin to Dana lake stages, most of them probably during the Dana stage. The recurved spit near Fonthill is a beach - nearshore feature of Lake Dana.

Ground moraine composed of Halton Till was reworked by wave-action during the the Early Algonquin to Dunnville lake stages into a more than one metre thick veneer of mainly silty, fine grained nearshore sand along the east side of the re-entrant valley in the Onondaga cuesta in the vicinity of Ridgeway and Crystal Beach.

A few bedrock knolls composed of the Eramosa Member of the Lockport Formation to the south of the Vinemount Moraine south of Beamsville are also thinly veneered with gravelly and silty fine grained sand and silt. This very thin cover of nearshore sediment probably originated also by reworking of ground moraine composed of Halton Till during the Lake Dana stand.

A very small rise in the lake-bottom plain to the north of Lyons Creek northeast of the hamlet of Cooks Mills is also covered with a thin veneer of silty fine grained Lake Dana-nearshore sand.

Only the distal, eastern portion of the ancestral Grand River delta is found in the Welland map-area west of the hamlets of Wainfleet and Chambers Corners and between the abandoned Welland Canal feeder in the south and the hamlets of Perry and Montague in the north. The distal sequence consists here of about 1 m of stratified, moderately well sorted, silty, fine to very fine grained sand (Appendix B and J: sample W763-A) with some silt and little clay thinly intercalated. The sequence is current-stratified in its lower part. Individual sets of cross-strata indicate that the paleocurrent flow was consistently from westerly directions (Photo 12).

Although most of the sand ridges on the delta plain are of eolian origin there are some knolls of low relief (about one metre) which may have a different, perhaps subaqueous nearshore sand bar, origin. A cross-section through one

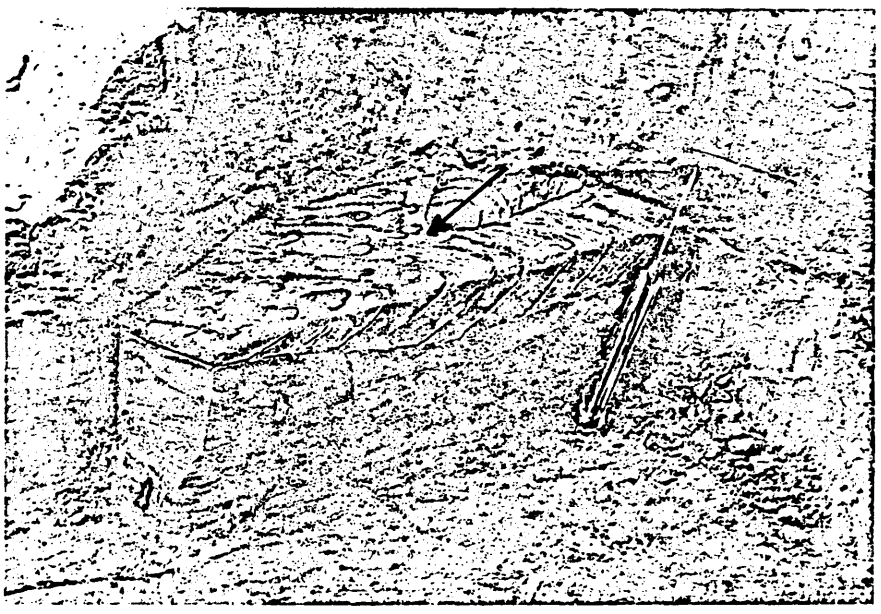


Photo 12 Current cross-stratified sand of the ancestral Grand River delta west of Wainfleet. Note: arrow indicates paleocurrent direction.

such knoll shows near-horizontally and contorted (slumping along the sides) stratified fine to very fine grained sand with minor medium sand thinly intercalated.

Ancestral Ontario Basin Lake Stands

Three small aprons of deltaic sand were formed in the Twelve Mile and St. Davids re-entrant valleys by runoff from the Niagara Escarpment and higher areas of ice-contact glaciolacustrine drift near the head of these valleys into proglacial, pre-Iroquois waters ponded between this Escarpment and the ice margin in the Ontario basin to the north.

Two of the aprons are found in the Twelve Mile re-entrant valley: one north of a line through Effingham and St. Johns West near the head of the valley at elevations varying between about 128 and 142 m (420-465 ft), and the other further northward paralleling the Niagara Escarpment in the City of St. Catharines west of the DeCew Falls generating station at elevations varying between about 115 and 125 m (380-410 ft). The sheet near the head of the valley is thin and fragmentary (dissected), the fragments being generally about 1 m and as much as 2 m thick, and consists mainly of silty, fine to very fine grained sand and sporadically of coarser textured material (gravel, gravelly - medium sand). The sheet further northward in the valley west of the DeCew Falls generating station is even thinner,

generally less than one metre thick, and consists of slightly gravelly, fine grained sand near the escarpment but of finer textured sand (silty, very fine) farther away. The deltaic sand at these two small areas in the Twelve Mile re-entrant valley is underlain by lake bottom deposits of clay, silt, and very fine sand.

The third apron of deltaic sand is found on the Bell Terrace (Spencer 1907) in the St. Davids re-entrant valley at elevations varying between about 120 m (390 ft) to the north in the vicinity of St. Davids at the top of the Iroquois shorebluff, which truncates it, and about 140 m (450 ft) at the foot of a drift-mantled subsidiary scarp of the Niagara Escarpment to the south. This apron is generally also thin, i.e. less than 2 m thick, although a waterwell drilling near the southeastern margin towards its head penetrated a thickness of 4 m. It consists of slightly gravelly, fine-and silty, very fine grained sand and is also underlain by lake-bottom sediments.

The extensive sheet of nearshore sediments deposited by Lake Iroquois on its terrace consists mainly of silty, fine to very fine grained sand with some interbedded clay, silt, and fine to medium sand. The sand is slightly coarser grained west of Beamsville. The thickness of the sheet may increase to about 5 m, but it is usually less than about 3 m. Further northward from the shore where the depth of Lake Iroquois was probably greater than 20 m, the nearshore sands grade into the underlying lake-bottom sequence

consisting of interbedded clay, silt, and fine to very fine grained sand which is well-exposed along the Lake Ontario shorebluff (Figure 10, in back pocket). A borehole sample taken by Peto Associates Limited from near the base of the nearshore sand at Port Dalhousie consists of about 50 percent sand (fine to very fine mainly) and about 50 percent silt (Appendix J: sample P64-164-1-2).

Thin deposits of reddish brown clay and silt are found on top of nearshore sand in a few, small depressions on the Iroquois terrace near the shoreline in the vicinity of Beamsville. This quiet-water clay and silt was probably derived locally from the Queenston shale and may also have been carried by runoff from the Halton Till-mantled Niagara Escarpment.

Although the construction of the Homer bar across St. Catharines enclosed probably a small lagoonal area, no such deposits have been found either underneath the bar or behind it; they may have been eroded by the Twelve Mile Creek.

Lake Bottom Deposits

Ancestral Erie Basin Lake Stands

The upper glaciolacustrine sequence of lake-bottom clay and silt (Map-unit 10) is most extensively exposed on the Haldimand Clay Plain. This sequence was deposited during the Warren to Early Algonquin lake stages when "Halton ice"

retreated to the Niagara Escarpment and vicinity. Water depths in the deeper portions of these lake stands in the Niagara-Welland area varied between 15 and 75 m; they were greatest (45-75 m) during the Warren to Grassmere stages. The lake-bottom clay and silt mainly covers Halton Till. Facies changes to deep water and nearshore sand-sequences occur at the Mohawk Bay Moraine (Figure 13), at Fonthill (Photo 13; Figure 9, in back pocket), and probably also at the Niagara Falls ice-marginal re-entrant and at the head of the St. Davids re-entrant valley (Figure 7, in back pocket).

The undulating Halton Till surface at the Mohawk Bay Moraine (Figure 13) is covered by as much as 6 m of massive or stratified, buff and reddish silt (lower part) and brown and grey clay (minor red; upper part); deposition of this glaciolacustrine sequence at the recessional ice-margin position is suggested by intercalated Halton Till.

An excavation on the Onondaga cuesta at Waverly Beach in the Town of Fort Erie exposed about 4 m of stratified, greyish and reddish brown clay and silt on top of Halton Till; the glaciolacustrine sequence becomes relatively clast-rich near the contact with the till.

Excavations along the newly relocated seqment of the Welland Canal between Port Colborne and Port Robinson provided about 14 km of continuous exposure of the upper glaciolacustrine sequence (Owen 1969, Figure 2, Units 9 and 11; Owen 1972, Map 8-1971, Section A-B, Unit 16). The present survey only examined the sections at Ramey's

Photo 13 Upper glaciolacustrine bottom clay over sand sequence at the Thorold sanitary landfill site near Fonthill.

Junction, the Townline- and Main Street East Tunnels, and near Port Robinson (Figure 8, in back pocket). The sequence consists mainly of massive and thinly stratified, brown, reddish, and grey clay and silt. The lower part of the sequence near Port Robinson consists of silt, with a few interbeds of clay, which grades laterally southward into sandy silt and sand at the buried flanks of the Fort Erie Moraine (Owen 1969). The entire upper glaciolacustrine sequence is as much as about 10 m thick at the Townline Tunnel and near Port Robinson but thins considerably near the Onondaga Escarpment and the Fort Erie Moraine.

The upper glaciolacustrine sequence along the relocated segment of the Welland Canal has been described for engineering purposes by Conlon et al.(1971), Kwan (1971), and Owen (1969, 1972). It is a weathered, fractured, desiccated, stiff, heavily overconsolidated, massive or stratified (varved in places) silty clay of medium to high plasticity and with generally more than 50 percent clay and less than 5 percent sand. Weathering of the silty clay extends along vertical fractures down to depths of 3 to 6 m, whereas a one metre fluctuation of the water table is suggested by masses of gypsum crystals contained over the same vertical distance within these fractures.

The upper glaciolacustrine bottom seugence on the Haldimand Plain thins northward to less than 10 m; a thickness of only 2 to 4 m was measured on top of Halton

Till at the Thorold quarry of Walker Brothers Limited on top of the Niagara Escarpment (Figure 8, in back pocket). Borings at the buried St. Davids Gorge (Figure 7, in back pocket), however, encountered about 14 m of stratified, brown, grey, and reddish clay, silt, and silty very fine grained sand (alternating more clayey and silty to sandy sub-units) of the upper glaciolacustrine sequence.

Clay and silt found below sand of the ancestral Grand River delta probably represents the fine sediment discharged by this glacial meltwater stream into Early Lake Algonquin.

Other stratified, deeper water or lake-bottom sediments of the upper glaciolacustrine sequence are associated with the oscillating "Halton ice" margin at the Niagara Escarpment and vicinity. These sediments consist predominantly of brown and grey clay, silt, and very fine grained sand. They are found:-

1. intercalated with Halton Till at the Vinemount Moraine west of the Twelve Mile re-entrant valley (as much as 3 m thick);
2. between upper and lower Halton Till layers in the Twelve Mile re-entrant valley (3 to 8 m) thick; Figure 9, in back pocket);
3. in the pit operated by St. Davids Sand and Gravel Limited along the west side of former Highway 8 at the head of the St. Davids re-entrant valley where they are overridden by "Halton ice" associated with the upper

ice-contact deltaic deposit (about 1 m thick; Figure 7, in back pocket); and,

4. underlying part of the Iroquois Plain and the area between it and the Niagara Escarpment (including the St. Davids re-entrant valley) to the east of St. Catharines where a stratigraphic boring by the Geological Survey of Canada penetrated about 14 m in the vicinity of St. Davids (Figure 7, boring WH1).

Ancestral Ontario Basin Lake Stands

A thin veneer of interstratified clay, silt, and very fine grained sand, generally less than 2 m thick, rests on the upper layer of Halton Till in the Twelve Mile re-entrant valley (Figure 9, in back pocket). These lake-bottom sediments were probably deposited in pre-Iroquois waters ponded between Niagara Escarpment and the northward retreating ice front in the Ontario basin. They underlie part of the narrow remnant of the third lake plain. Similar bottom sediments cover Halton Till sporadically in this lake plain remnant south and southeast of Homer. They continue probably further eastward and into the St. Davids re-entrant valley underneath the Bell Terrace deltaic sand, but are indistinguishable from similar, older upper glaciolacustrine sediments.

Near the Lake Ontario shore, nearshore sands of Lake Iroquois grade downward into its bottom sequence of grey or

brown, interstratified clay, silt, and fine to very fine grained sand (Photo 14). These sediments underlie a small portion of the Iroquois terrace at Niagara-on-the-Lake at the mouth of the Niagara River. They are best exposed on top of Halton Till along the Lake Ontario shorebluff where greatest thicknesses of about 10 m were measured between Port Dalhousie and Jordan Harbour (Figure 10, in back pocket). The lower part of the sequence along this shorebluff east of Jordan Harbour often consists of a much more pebbly, massive or contorted-stratified, grey silty clay. It may have been deposited in the pre-Iroquois waters ponded in the Ontario basin when the ice front was nearer.

Non-Glacial Deposits

Non-glacial deposits in the map-area include alluvial and bog deposits, remains of mastodons, beach deposits of Lakes Erie and Ontario, and eolian deposits (Map-Units 14-19).

Alluvial Deposits

Only the deposits of the major streams in the map-area are described and discussed in this section. The streams are the following: the Niagara River, the Welland River, and the Twelve, Fifteen, Sixteen and Twenty Mile Creeks.

According to Kindle and Taylor (1913), shell-bearing

Photo 14 Interbedded sand, silt, and clay of Lake Iroquois, Lake Ontario shorebluff at Charles Daley Park.

older Niagara River gravels occur on the terrace at Queen Victoria Park in Niagara Falls. Unionid clams from older Niagara River gravels on Goat Island recently yielded two radiocarbon dates of about 9,000 years B.P. (Calkin and Miller 1977; Calkin and Brett 1978).

According to Kindle and Taylor (1913), older Niagara River gravel was also deposited on a terrace at Queenston; the terrace is cut in shale at elevation 94-95 m (310 ft). Two terraces farther downstream at about elevation 90 m (300 ft) are possibly also underlain by older alluvium consisting of gravelly, silty sand. Recent alluvium underlies the flood plain at Niagara-on-the-Lake.

Several small deposits of fine sand over interstratified sand, silt, and clay and resting on Halton Till occur at the top of the Twenty Mile Creek gorge at about elevations 149-150 m (490 ft) and 125 m (410 ft) between Ball's Falls and Jordan. They may form older alluvial deposits of the Twenty Mile Creek possibly discharging initially already into the pre-Iroquois proglacial waters ponded between the front of the receding Ontario glacial lobe and the Niagara Escarpment.

The thin, level, and poorly preserved deposit of gravel and sand found on the Iroquois terrace north of Jordan at elevations varying between about 98 and 104 m (320-340 ft) is also associated with an ancestral Twenty Mile Creek. This deposit is less than 2 m thick and overlies Halton Till. It is oriented more or less perpendicular to the

Iroquois shoreline, and it may represent a remnant of a delta in Lake Iroquois or alluvial material deposited during post-Iroquois lowering of the lake level in the Ontario basin.

Another older and gravelly alluvial deposit occurs on a very small terrace at about elevation 107 m (350 ft), i.e. about 15 m above the present rocky streambed, on the west side of Twenty Mile Creek at the mouth of its gorge near Jordan.

Recent alluvium of Twenty Mile Creek at the mouth of the gorge is quite gravelly. Further northward, however, the present flood plain in the much wider stream valley cut in the Iroquois Plain is underlain by as much as 3 m of clayey sand and silt with organic material and minor gravel overlying as much as 1 m of coarser textured silty sand and gravel (in borings). At the baymouth bar at Jordan Harbour, the bottom of the Twenty Mile Creek valley is about 14 m below the present level of Lake Ontario (borings). The valley has been cut here through the Lake Iroquois sediments into the underlying Halton Till and its alluvial fill consists also of silty sand with minor gravel overlain by organic-rich silt with some intercalated sand and gravel. This valley is here also located at the west side of an older, deeper, and much wider Twelve Mile re-entrant distributary valley (Figure 5).

The organic-rich silt and overlying baymouth bar deposits of sand and gravel at Jordan Harbour are correlated

with a rising Lake Ontario related to differential, postglacial uplift of its outlet area (Karrow et al 1961; Clark and Persoage 1970). The rising lake level caused flooding at the mouth area of the stream, and ponding resulting in marshy conditions, and also southward migration of the baymouth bar across the organic-rich deposit. The rising lake level is probably also reflected in the fining upward alluvial fill sequence encountered upstream in the valley near Jordan.

The present flood plain of Twenty Mile Creek on the Haldimand Plain is mainly underlain by silty clay alluvium which is primarily derived from the upper glaciolacustrine clay and silt. The alluvium includes some interbedded sand and gravel derived from bedrock and/or overlying Halton Till.

Recent alluvial deposits underlying the modern flood plain of Twelve Mile Creek south of St. Johns West consist of interbedded sand and gravel at the ice-contact slope near Fonthill, but of interbedded sand, silt, and clay (fining upward) with organic matter, in places more than 2 m thick and overlain by muck, further downstream. Small, slightly elevated, stream terraces along this segment of Twelve Mile Creek are underlain by interbedded sand and gravel, in place also more than 2 m thick. The coarser grained alluvial deposits were probably derived mainly from the upper ice-contact sand and gravel, and the finer grained alluvial deposits from the lower ice-contact deltaic sands and

glaciolacustrine sand, silt, and clay (Figure 9, in back pocket).

Bedrock of the Reynales-Lockport sequence of formations is exposed in the narrow Twelve Mile Creek valley at the head of the re-entrant in the Niagara Escarpment at St. Johns West. Coarse, angular, gravelly alluvium changes in this area over a short distance downstream to finer, more rounded material.

Further downstream in the Twelve Mile re-entrant valley, the present flood plain is underlain by alluvial deposits consisting of clay and silt with organic material in the upper part and clayey or pebbly sand with organic material in the lower part, and which are as much as 5 m thick in borings near DeCew Falls. Coarse gravelly mud occurs on the wide flood plain at the foot of the Niagara Escarpment at DeCew Falls. The alluvial fill sequence encountered in borings at the Glendale Avenue bridge in St. Catharines is as much as 6 m thick, and also consists of upper clay and silt with organic material over lower, coarser textured, silt, sand, and gravel with organic material. Further downstream, at Welland Vale Road near the Lake Iroquois shore in St. Catharines, the alluvial fill below the present flood plain consists only of the upper clay and silt with some intercalated sand and including in places muck at the top. This alluvial fill is as much as 4 m thick in borings.

The coarser grained alluvial deposits of Twelve Mile

Creek in the lare re-entrant valley were probably derived primarily from ice-contact deltaic sands, till, and the various bedrock formations of the adjacent Niagara Escarpment, and the finer grained alluvial deposits from the more clayey Halton Till and intercalated glaciolacustrine clay and silt (Figure 9, in back pocket).

The bottom of the Twelve Mile Creek valley at its present mouth area (Martindale Pond-Port Dalhousie harbour) is, like that of the Twenty Mile Creek, also 10 to 14 m below the present Lake Ontario level (borings).

The valley bottom is underlain by lower till, or shale bedrock downstream at Lake Ontario, and the lower part of the valley occupies an older, possibly glacially gouged channel. The alluvial fill consists from top to bottom of organic deposits composed of muck (organic clayey silt) and peat with pieces of wood and shells, and dark to reddish silt and sand with organic matter. The silt and sand at the base of the sequence were probably derived from the Lake Iroquois nearshore sediments and underlying tills. The organic deposits underlying Martindale Pond are also correlated with ponding as a result of flooding by rising Lake Ontario waters.

Recent alluvial deposits underlying the present flood plain of Fifteen- and Sixteen Mile Creek vary in textural composition from predominantly silty clay on the Haldimand Plain, including some interbedded sand and gravel derived from underlying and constricting bedrock and/or till, to

gravel, sand and silt at the gorges cut into the bare and till-mantled Niagara Escarpment face. It includes some interbedded clay (reddish where Queenston shale is exposed) downstream toward the Iroquois bluff, and it changes to predominantly silt and sand at the Lake Iroquois terrace. The flooded mouth areas are also underlain by relatively thick accumulations, as much as 12 m in borings, of organic clayey silt or muck.

Recent alluvial deposits underlying the present flood plain of the Welland River along its meandering course across the Haldimand Plain in the map-area between Wellandport in the west and Chippewa in the east consist predominantly of massive or stratified, soft, silty clay with organic matter. This alluvial silty clay is primarily derived from ubiquitous upper glaciolacustrine clay and silt. The alluvial deposits are as much as 6 m thick in borings at Welland.

Bog Deposits

This section of the report incudes a description and discussion of the peat and lake deposits at the Welland Bog, and also of deposits of muck, peat, and less organic-rich clay, silt, and sand at the Humberstone Marsh, at low areas along the Lake Erie shore, in the numerous small depressions on the Haldimand Plain, and in small depressions near St. Catharines on the narrow, third lake plain in the map-area.

Sites in the Welland area where mastodons have been found, their habitat, extinction, and geologic age are discussed in a separate subsection of this report.

The sequence of peat and lake or pond deposits at the Welland Bog was investigated by Auer (1930) more than half a century ago as part of a general study on the peat bogs in southeastern Canada. The location of the line of section through the bog, along which Auer constructed the idealized profile (Figure 15) is unfortunately not indicated in the published, abridged version of his manuscript. The profile shows the following sequence of sediments from bottom to top:-

1. pond or lake deposts - thin but as much as 4 m thick where filling a depression, and consisting of blue grey clay overlain by detrital organic ooze (minute plant remains);
2. grass-herb-forest peat (decayed brushy growth material) - very thin accumulation (less than one metre) in a very shallow, local depression on higher ground, and thicker (about one metre), more extensive accumulations on lower ground along the margin of the bog;
3. pond deposits (mud and detrital ooze) - very thin layer (less than 1 m), partially covering the grass-herb-forest peat in the local depression on higher ground;

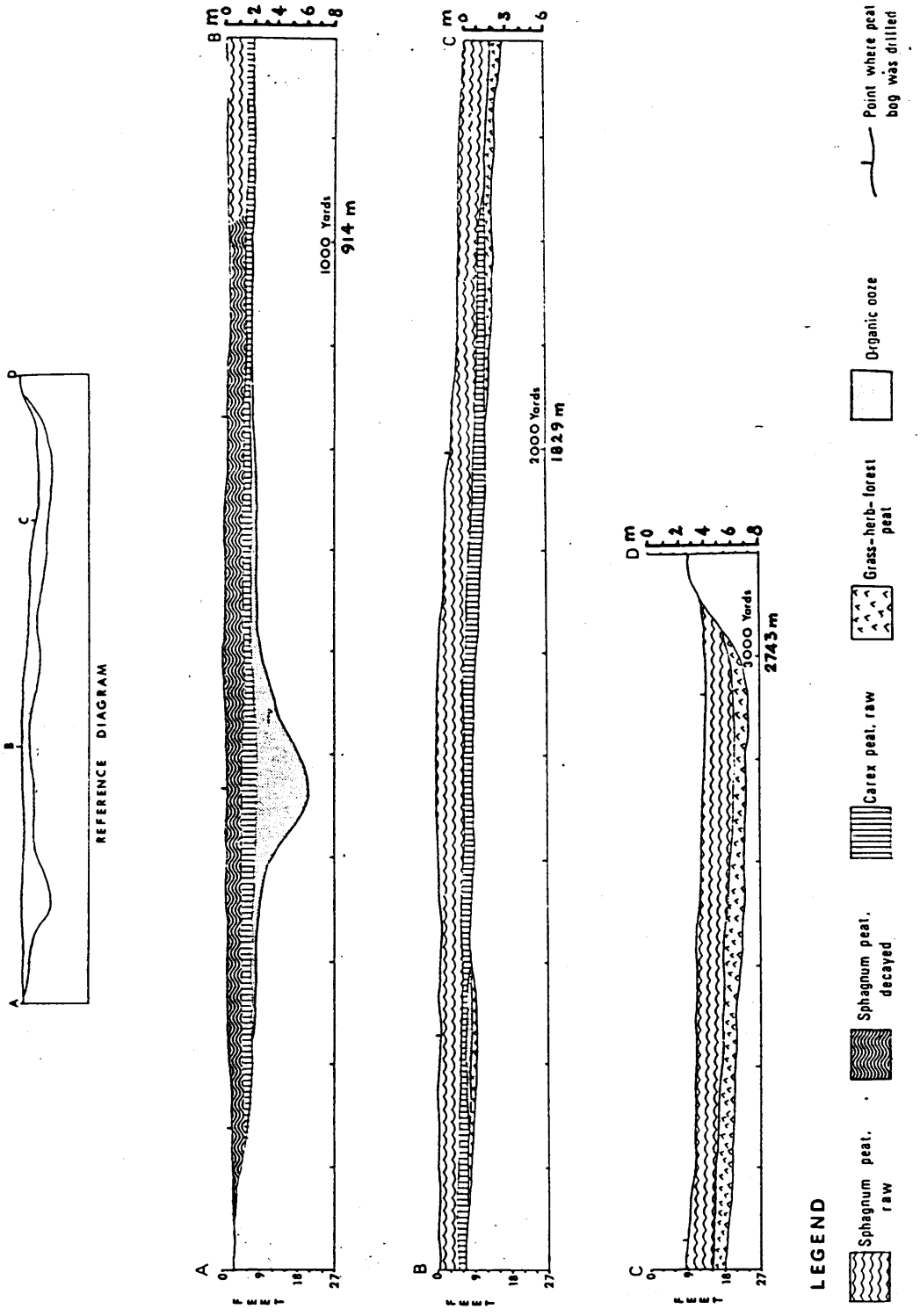


Figure 15-Profile of the Welland Bog(Auer 1930).

4. Carex (sedge) peat - layer less than 2 m thick and extending almost entirely across the peat bog covering the pond or lake deposit (1 and 3) completely but the grass-herb-forest peat layer (2) on lower ground near the margin of the bog only partially; and,
5. Sphagnum (moss) peat - layer as much as 2 m thick, blanketing the entire peat bog which has a slightly domed surface.

The total thickness of peat and lake or pond deposits varies generally between 2 and 4 m, but can be locally as much as 6 m in deeper depressions in the underlying upper glacio-lacustrine clay and silt (Figure 15).

Auer (1930), in discussion the origin of peat bogs in southeastern Canada in general, states that the limnetic deposits at the bottom occupy a comparatively small part of the total area of the peat bogs investigated. Auer suggests that the peat bogs largely developed by paludification of dry land, i.e. due to upward growing peat accumulations in a relatively smaller pond, bog water on then higher ground overflowed to dryer, lower ground resulting in bog transgression (Figure 15, from left to right).

A pollen and spore diagram of the peat and lake or pond deposits (Figure 16) from a site near the western margin of the Welland Bog to the west of the peat operations of Atkins and Durbrow Limited was obtained by Dr. J. Terasmae, Professor of Geology, Brock University, St. Catharines,

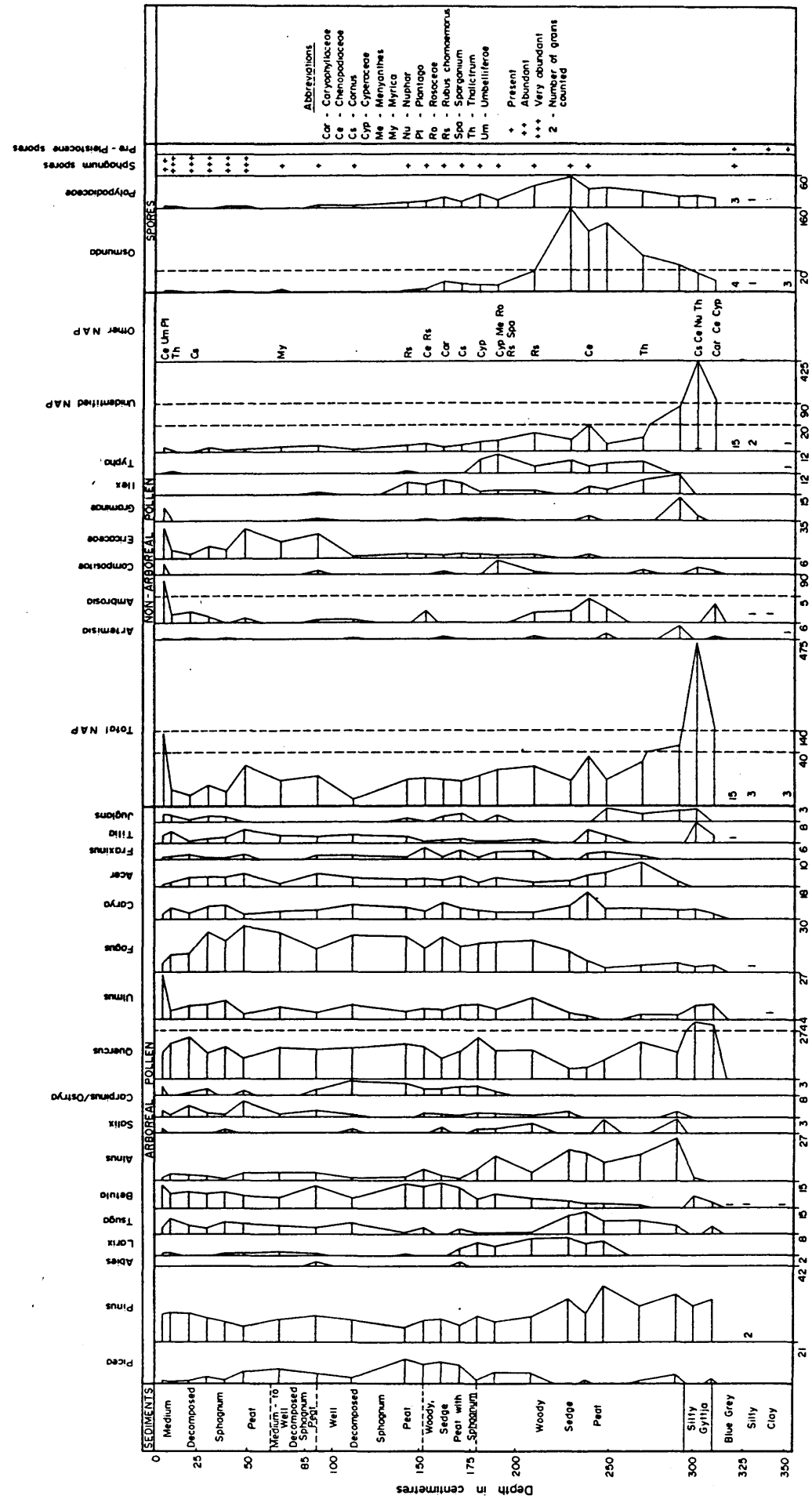


Figure 16-Pollen diagram of peat and lake deposits, Welland Bog, Ontario (Terasmae, personal communication 1973).

Ontario (personal communication 1973). The sequence of deposits at this site correlates with the succession shown along the section A-B of Auer's (1930) profile section (Figure 15). The pollen and spore diagram (Figure 16) illustrates the local vegetational changes at the Welland Bog site accompanying overgrowth of an open pond (hydrarch succession) since the establishment, concomitant with a warming climate, of a deciduous forest in the area some 8,000 years or more ago and until land-clearing in historical time. The blue grey silty clay at the bottom may represent rapid accumulation of fines under reducing conditions in an open pond. The fines are derived from the surrounding slopes mantled by glaciolacustrine clay and silt possibly containing pre-Pleistocene (Devonian?) spores.

Other, shallower accumulations of about one metre of muck and peat are found at the Humberstone Marsh and at several areas behind the Lake Erie shore between Port Colborne and Crystal Beach. Their origin in the area north of Point Abino and between Shisler Point and Crystal Beach is probably related to the filling in of a lagoon formed by enclosing tombolo bars connecting Port Abino to the headland. Dune sand is presently migrating into these areas behind the Lake Erie shore.

As much as 2 m of muck, less organic-rich clay, and blue grey silty clay fills the small depressions associated with the washboard-type surface of the Haldimand Clay Plain north of the Onondaga Escarpment.

Small depressions filled with bog sediments also occur in the surface of the clayey Halton Till and overlying glaciolacustrine clay and silt in the St. Catharines area to the south of the Iroquois shore. The bog sediments are in places as much as 3 m thick and consist mainly of muck and silty clay which is also shell-bearing.

A basement excavation for a house at Power Glen on the west side of the Twelve Mile Creek valley exposed the upper 1 to 2 m of a channel bog sequence consisting of grey to dark, more or less organic-rich silty clay layers, a lens of fine sand, and a thin layer of very fine gravel. A piece of wood from one of the silty clay layers was radiocarbon dated at 5 214 $^{+}$60 years B.P. at Brock University, St. Catharines, Ontario (BGS-58).

Mastodons

Several Late Wisconsinan mastodon sites in the Niagara Peninsula have been reported at Dunnville, Smithville, St. Catharines, and to the west of Welland by Hay (1923), Sternberg (1930), and Russell (1965). None have been radiocarbon dated.

Most of a mastodon skeleton was found in 1912 in a small bog somewhere along Forks Road west of Welland and later mounted at the Royal Ontario Museum in Toronto (Sternberg 1930). According to the description accompanying this mounted specimen at the museum: "pollen analysis of a

mud sample from the skull shows that the animal died between 10,500 and 14,000 years ago". Also to the west of Welland but near the Welland River to the northwest of Chambers Corners, a scattered mastodon skeleton was uncovered and partly destroyed during excavation of a small bog in 1963 (Russell 1965). The remains are also at the Royal Ontario Museum.

Radiocarbon dates of mastodon sites in southwestern Ontario indicate that the age of the oldest Late Wisconsinan sites is about 12 000 years B.P., and the youngest sites appear to date approximately 10 000 years B.P. (Winn 1977). Sometime around 10 000 years B.P. the mastodon became extinct in southwestern Ontario. Dreimanis (1967, 1968) developed an "Environmental-Climatic" theory explaining mastodon extinction in southwestern Ontario, and this has been summarized with some modifications by Winn (1977) as follows:-

I. the type of habitat preferred by mastodons in southwestern Ontario was open spruce parkland with areas of open water (shallow lakes, ponds, wet lands in general);

2. the significant regional change towards a warmer and drier climate some 10 000 to 11 000 years ago resulted in the establishment of a closed boreal forest by at least 10 000 years B.P. and was also responsible for the disappearance of shallow lakes, ponds, and wet

lands, i.e. a considerable reduction in the preferred habitat of mastodons;

3. when their preferred habitat became considerably reduced, the mastodons could not find their way to the northern boreal spruce forests, being separated from them by a wide belt of pine and hardwood forests which meanwhile had developed over the better drained morainic area of southern Ontario; and,
4. although spruce parkland refugiums probably persisted in marshy or wet areas for at least another 500 years or so, by 9 000 year B.P. the mastodon had reached that critically low level of population at which time any adverse factors might have led to their extinction.

The preferred habitat of mastodons described above, including the spruce parkland refugiums, could have prevailed, in the present writer's opinion, in the Niagara Peninsula from about Lake Dana time to until approximately 9 000 years ago. Open spruce border refugiums may have persisted at the many small ponds in the map area, including the Welland Bog site, during the establishment of the closed boreal forest (predominant pine, notable oak) in the Peninsula.

Lake Erie Beach Deposits

The Lake Erie shoreline in the map-area consists of low, flat bedrock headlands or points separating shallow

bays (Photo 15). The rocky points form in many instances the lakeward continuation of bedrock topographic highs mapped inland on the backslope of the Onondaga cuesta. Point Abino became attached to the mainland due to the construction of a double tombolo.

Shore material consists predominantly of beach sand and gravel (Photo 16). Six samples from the beach deposits at Pleasant Beach, Empire Beach, and on the westside of the point north of Rock Island are well- to moderately well sorted and near- symmetrically skewed or moderately to poorly sorted and strongly fine or coarse skewed (Appendix A and J: samples W597-A, W600-B, -C, -D, W706-E, and W732-B). Pebble lithologic composition varies from mainly dolostone along Moulton Bay, derived from Halton Till offshore (Rukavina and St. Jacques 1971), to mainly local limestone and chert at Grabell Point, derived from Devonian bedrock offshore. At Empire Beach a mixed assemblage of Silurian dolostone and local Devonian limestone and chert is found. This has apparently been derived from the glacial drift and bedrock offshore to the southwest (Appendix B and K: samples W600-A, W731-B, W732-A, W765-C, and W768-C). Quartz (44-62%) predominates in the medium- to coarse grained sand fraction of three samples (Appendix L: W597-A, W600-D, and W706-E).

Measurements of Lake Erie shoreline accession or recession in the map-area indicate a net weighted average annual recession of approximately 14 cm during the period

Photo 15-Lake Erie shore at Shisler Point looking east across bay to dunes at Abino Hills and Point Abino.

Photo 16-Lake Erie beach west of Mohawk Point.

from 1952 to 1973, but a net weighted average annual accession of about 6 cm over the period since 1900 (Haras and Tsui 1976).

Lake Ontario Beach Deposits

Much of the Lake Ontario shoreline in the map-area is characterised by eroding bluffs (Photo 17). The bluffs are interrupted by baymouth bars, the largest of which is found at Jordan Harbour. The baymouth bars and a narrow strip along the base of the bluffs west of the Port Weller-Port Dalhousie area and also east of Four Mile Point form the only areas of beach sand and gravel accumulation. Layers relatively rich in slumped bluff material were found interbedded with the gently lakeward dipping sand and gravel.

Measurements of Lake Ontario shoreline erosion in the map-area indicate a net weighted average annual recession of approximately one metre since 1900, or about 74 cm annually during the period from 1952 to 1973 (Haras and Tsui 1976).

Eolian Deposits

Windblown or eolian deposits in the map-area are found on the ancestral Grand River delta plain and also along the Lake Erie shore.

The field of stable inland dunes on the ancestral Grand

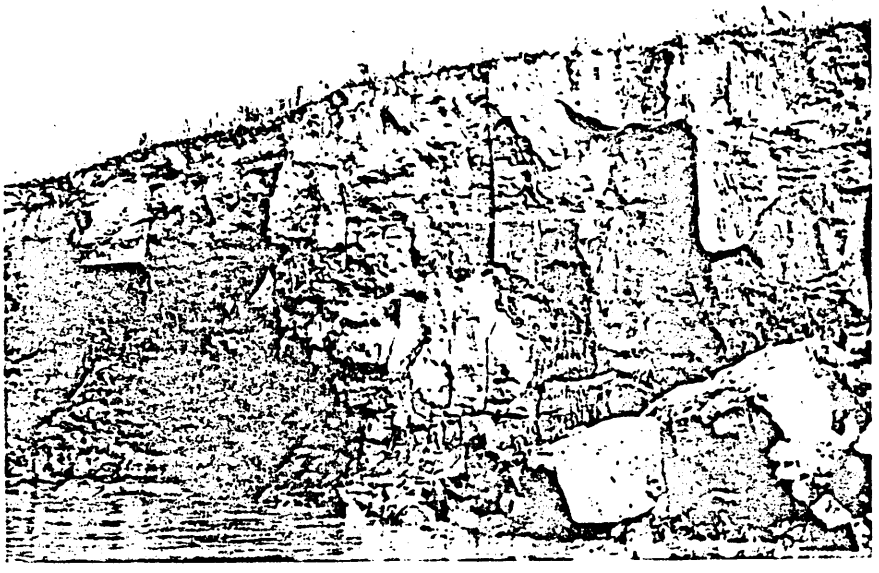


Photo 17. Lake Ontario shorebluff erosion east of Port Weller.

River delta flat west of Wainfleet (Photo 18) consists of uniform, fine to very fine grained sand (Appendix B and J: samples W762 and W764). They represent the finer textured sands of this delta windblown from prevailing westerly directions, perhaps as soon as the lowering of the water table accompanying lowering of the lake level from the Dunnville stand had taken place. Their shapes are predominantly parabolic in comb-like complexes which may represent modified, originally transverse ridges. The largest of the dunes reaches a height of about 6 m and occurs at the hamlet of Forks Road.

The Lake Erie shoreline is also characterized for the most part by more recent backshore or coastal dunes which reach heights of about 30 m at the Sugar Loaf to the west of the Welland Canal at Port Colborne and also in the area to the east between Shisler Point and Point Abino. They consist of uniform fine to medium sand derived from the Lake Erie beach (Photo 19; Appendix B and J: samples W2-A, W3-A, W3-B, W5-A, W265, W556, W706-A to -D). Quartz (48-65%) predominates in the medium to coarse grained sand fraction of five samples (Appendix L: W556, and W706-A to -D).

Photo 18-Low inland dune ridge on the ancestral Grand River delta plain west of Wainfleet.

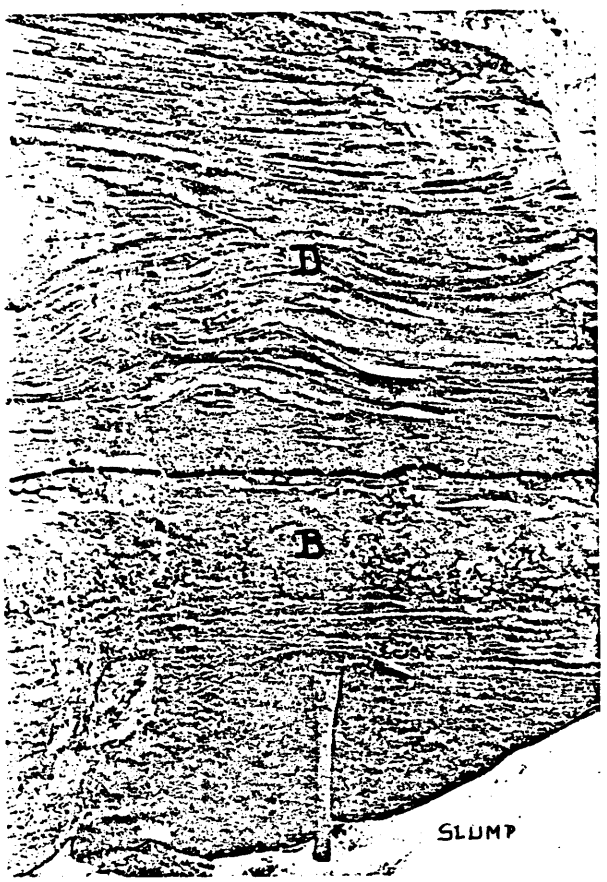


Photo 19. Bedding features in Lake Erie coastal dune sand (D) overlying beach sand and gravel (B) at an abandoned pit of Sherkston Beach Limited.

QUATERNARY GEOLOGY: HISTORY

PRE-LATE WISCONSINAN

The known record of Quaternary events in the Niagara-Welland map-area begins with the buried St. Davids Gorge. It formed part of a former drainageway joining the Erie and Ontario basins during the Sangamon Interglacial more than 100 000 years ago, or during Middle Wisconsinan times lasting from about 70 000 to 23 000 years ago.

Part of the sedimentary fill in the buried St. Davids Gorge consists of fossiliferous fluviatile-lacustrine sediments of Middle to Late Wisconsinan age. These sediments were possibly associated with impounded waters in the Ontario basin between the advancing Ontario glacial lobe and the Niagara Escarpment. A radiocarbon age of about 23 000 years ago was obtained on a sample of wood, and pollen assemblages suggest a cooler northern boreal climate existed at the time. The age and origin of underlying beds of gravel and sand in the buried gorge remain unknown.

LATE WISCONSINAN

The advancing ice out of the Ontario basin moved chiefly over bedrock substrate in southwesterly direction across the Niagara-Welland area and into the Erie basin. The glacial lobe covered the map-area during the next 9 000

years of Late Wisconsinan time (Nissouri Stadial - Port Bruce Stadial) and deposited the lower till.

The lower glacioloacustrine sequence in the Niagara-Welland area documents inundation of the area by proglacial lake waters accompanying retreat of the Ontario-Erie glacial lobe back into the Ontario basin during the Mackinaw Interstadial about 13,000 to 14,000 years ago.

Younger Late Wisconsinan events are documented widely by the surficial Quaternary geology of the Niagara-Welland map-area. Halton Till records the readvance of the Ontario-Erie glacial lobe during the Port Huron Stadial about 13,000 years ago. The glacial lobe moved out of the Ontario basin in southwestern directions across the map-area and into the eastern Lake Erie basin area. Glacier margin recession from the Erie basin back into the Ontario basin was first in a more easterly and later in more northerly directions across the map-area as indicated by the pattern of the Mohawk Bay, Wainfleet, Crystal Beach, Fort Erie, Niagara Falls and Vinemount Moraines.

The upper glaciolacustrine sequence documents the inundation of the Niagara-Welland map-area first and foremost by Erie basin and later in the north also by Ontario basin proglacial lake waters. The Port Huron or "Halton" readvance of the Ontario-Erie glacial lobe had raised proglacial waters in the Erie basin to the level of Lake Whittlesey. As new outlets opened up elsewhere in the Great Lakes Region, lake levels in the Erie basin fell

generally from Lake Whittlesey to Early Lake Erie through various stages namely: Lakes Warren I and II, Wayne, Warren III, Grassmere, Lundy, Early Algonquin, Dana, and Dunnville. Lake levels in the Ontario basin also dropped through several stages to Lake Iroquois and below it. This sequence of lake stages in the Erie and Ontario basins is bracketed by radiocarbon dates between about 13 000 and 12 000 years ago.

The sequence of events and correlation of the former lake stages and ice margins in the Niagara Peninsula are summarized in Table 5 and illustrated by a series of interpretative sketch maps in Figure 17a to -h.

The glacial lobe fronted the Warren I to Dana succession of lake stages during its retreat to the Ontario Lowland-Niagara Escarpment portion of the map-area. Formation of the ice-contact deltaic complex at the Fort Erie Moraine position at Fonthill began possibly in Lake Warren I or II but it was completed in Lake Warren II when the ice front had receded locally over a very short distance to the Niagara Falls Moraine position. The ice front oscillated between positions in the Ontario Lowland and the Vinemount Moraine on top of the Niagara Escarpment during the Lakes Warren III to Dana stages. A floating ice-shelf extended from the main mass of the glacial lobe into the Twelve Mile Creek valley.

The Lake Warren II and III, Early Lake Algonquin, and Lake Dana stages are recorded in the map-area by shoreline

TABLE 5. CORRELATION OF FORMER LAKE STAGES AND "HALTON" ICE MARGINS IN THE NIAGARA PENINSULA.

YEARS BP	LAKE STAGES ERIE BASIN	LAKE STAGES ONTARIO BASIN	ICE MARGINS NIAGARA PENINSULA
12 100*	Early Lake Erie → Lake Tonawanda → Lake Iroquois		Ice margin in Ontario basin retreating further east- and northward away from the Niagara Peninsula
	Early Lake Erie	Proglacial waters ponded between ice margin and Niagara Escarpment	
	Lake Dunnville Lake Dana	Possibly extending for short distances into Ontario basin.	
	Early Lake Algonquin		Ice margin oscillated over short distances between Vinemount Moraine and Lowland north of Niagara Escarpment
	Lake Lundy		
	Lake Grassmere		
	Lake Warren III		
	Lake Wayne		
	Lake Warren II		Niagara Falls Moraine Fort Erie Moraine Crystal Beach Moraine Wainfleet Moraine Mohawk Bay Moraine
	Lake Warren I		
13 000†	Lake Whittlesey		Inferred terminal position Port Huron re-advance

* Calkin (1970)
† Calkin (1970); Dreimanis (1966); Lowdon et al.(1976,GSC-2213).

Figure 17- Sketch-Maps showing Retreat of 'Halton' Ice, Associated Lake Stages, and Enlargement of Land-Area in the Niagara Peninsula.

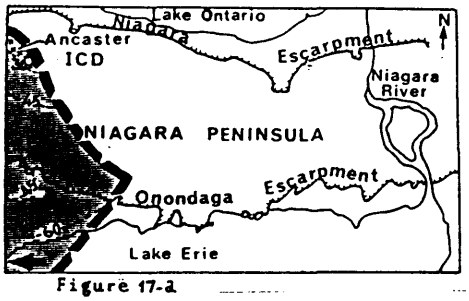


Figure 17-a

Terminal position Ontario-Erie glacial lobe fronting Lake Whittlesey (Port Huron readvance, Halton Till).

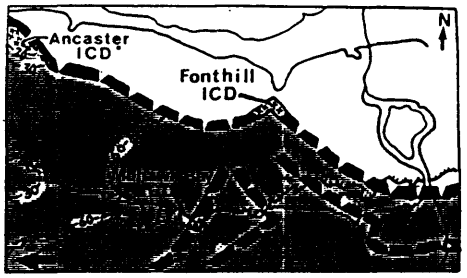


Figure 17-b

Fort Erie Moraine recessional position fronting Lake Warren I-II.

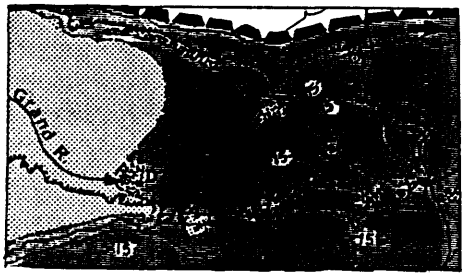


Figure 17-e

Eastward enlarging Niagara Peninsula at a Ontario lowland recessional position fronting Lake Dana.

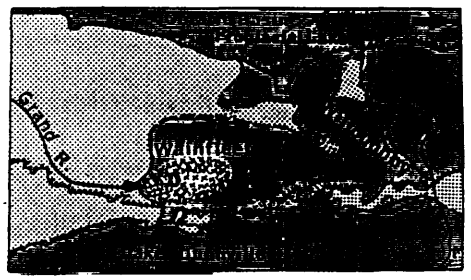


Figure 17-f

Eastward enlarging Niagara Peninsula at the Lake Dunnville stage.

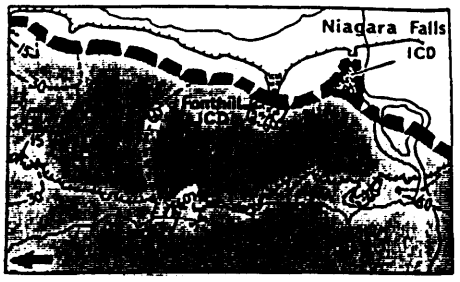


Figure 17-C

Niagara Falls Moraine recessional position fronting Lake Warren II.

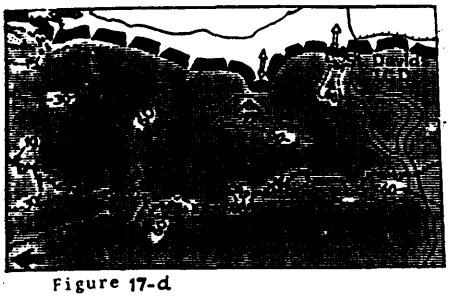


Figure 17-d

Vincmount Moraine recessional position fronting Lake Warren III; lake level dropped to Early Algonquin stage during ice-marginal fluctuations.

Figure 17-g

Eastward enlarging Niagara Peninsula at the Early Lake Erie pre-Iroquois Ontario basin pro-glacial lake stage.

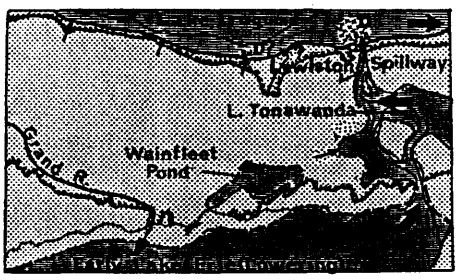


Figure 17-h

Niagara Peninsula at the Early Lake Erie - Lake Iroquois stage.

Legend

- Glacier Ice
- Water
- Land
- Ice Margin
- ICD Ice-Contact Stratified Drift
- D Deltaic sedimentation
- Fluctuating Ice Margin
- Streamflow Direction
- Outlet Direction
- --60-- Depth of Water (in meters)

20 0 20 km.

features at scattered localities on the Haldimand Plain. Lowering of lake levels in the Erie basin resulted in eastward enlargement of land-area on the Haldimand Plain in the Niagara Peninsula and drainage development on its southeastward sloping surface. The early Grand River entered the Lake Dana and the next lower Lake Dunnville stand in the vicinity of Dunnville and formed a wide delta extending eastward almost as far as Wainfleet. Most shoreline features of Lake Dunnville are found along a barrier formed by the very northern part of the Onondaga cuesta in the Niagara-Welland map-area. This barrier separated deeper, open water in the Erie basin to the south from shallow, more protected water on the Haldimand Plain to the north.

Further lake-level lowering following deglaciation of the map-area resulted in a more distinct separation of the waters in the Erie basin (Early Lake Erie: falling levels) from those impounded on the southern dipslope of the Niagara cuesta and in the Ontario basin between the Niagara Escarpment and the retreating glacial lobe (Lake Iroquois, pre- and post-Iroquois levels).

A field of inland dunes was developed on the ancestral Grand River delta by prevailing westerly winds reworking the finer grained deltaic sands. This reworking began perhaps as soon as water levels in the Erie basin dropped from the Lake Dunnville to the low-level Early Lake Erie stand.

Small deltas were formed in the Twelve Mile and St. Davids valleys by inwash from the Niagara Escarpment and higher areas of adjacent ice-contact deposits into the Ontario basin proglacial lake waters standing at a higher pre-Iroquois level. Possible alluvial deposits along the top of the Twenty Mile Creek gorge south of Jordan may also be associated with ancestral Niagara Escarpment drainage into these ponded waters. Lowering of these waters to levels below the main Lake Iroquois stand may be documented by the buried gravel and sand deposits found along the Lake Ontario shore and the Niagara River. More rapid isostatic rebound of the eastern end of the Ontario basin following deglaciation caused proglacial lake waters to encroach on the western shores. The shorebluff of Lake Iroquois in the map-area marks the farthest encroachment (i.e. main stand) of these rising waters. The Homer bar was constructed across St. Catharines by longshore currents moving in westerly directions. Further retreat of the ice sheet in the St. Lawrence Lowlands resulted in abandonment of the Rome N.Y. outlet of Lake Iroquois for outlets at lower elevations and lowering of the lake level in the Ontario basin (12 000-11 000 years ago). Strandline features on the Lake Iroquois terrace, older terraces along the lower Niagara River, and a possible alluvial fan remnant along Twenty Mile Creek north of Jordan may document this lake level lowering in the map-area.

ECONOMIC GEOLOGY

The industrial mineral resources utilized in the Niagara-Welland area include Paleozoic shale, limestone and dolostone bedrock formations and Quaternary deposits of sand, gravel, and peat. The construction industry is supported by the extraction in the area of shale as a raw material for the manufacture of bricks and by the extraction of limestone, dolostone, sand, and gravel as raw materials for the production of aggregates. Sand deposits in the area are also worked for special industrial uses such as metal casting and filtration. Peat moss is used primarily as a soil conditioner. Around the turn of the century, Quaternary clay material was also worked at several pits in the area for the manufacture of bricks and drain tiles.

Resource planning requires an inventory of the resources. Typically, resource areas are mapped and classified according to resource potential. Mineral resource potential includes evaluation of geologic, economic, land use, and environmental factors. The general locations of the industrial mineral resource areas and operating extractive industries in the Niagara-Welland area are shown in Figure 18. The general geologic evaluation of the resource is presented in the following sections of the report. The Geological Survey published recently as part of its Aggregate Reosurces Inventory Program the results of a detailed inventory and evaluation of the aggregate resources

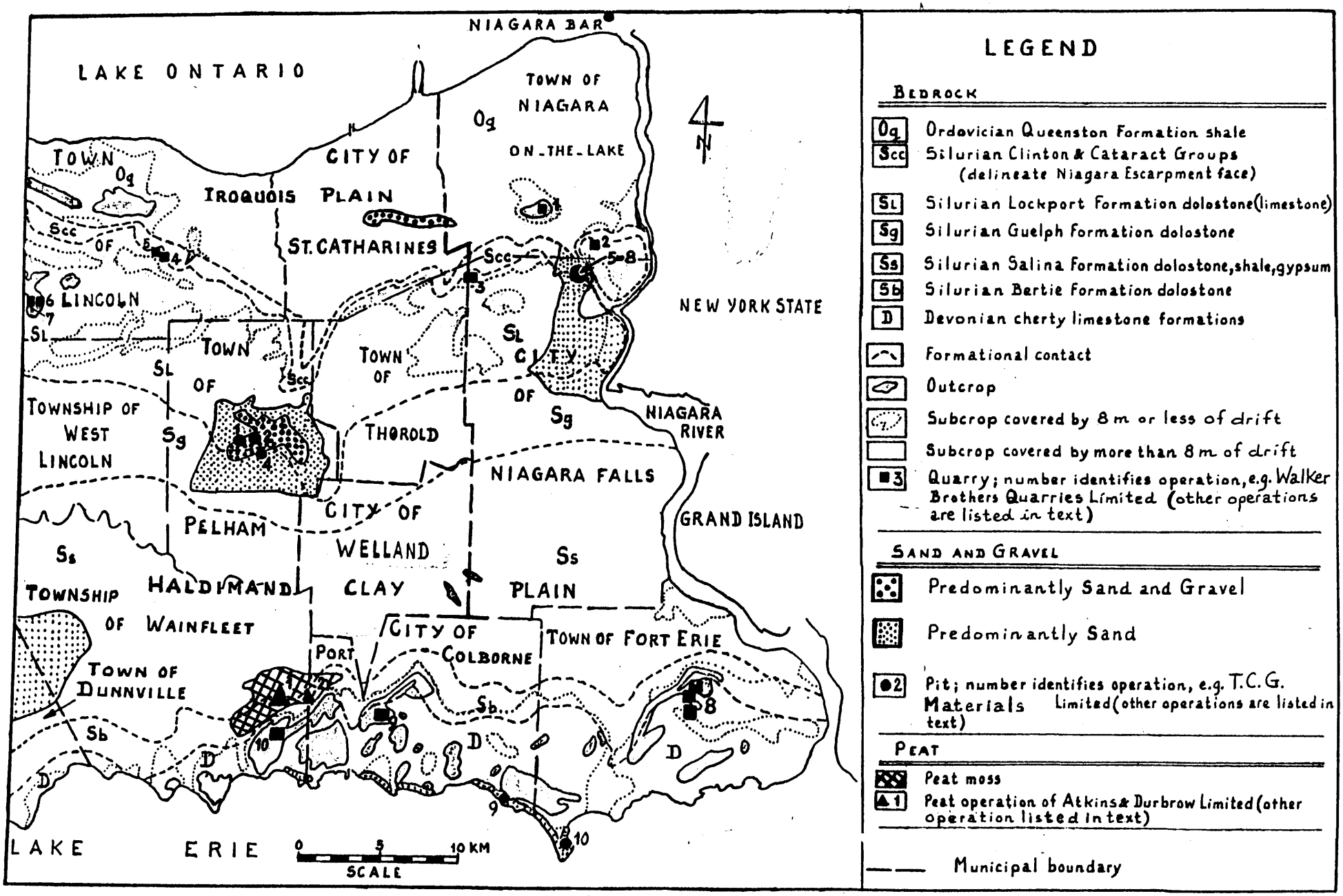


Figure 18-Industrial mineral resources of the Niagara-Welland area.

in the Town of Pelham (Ontario Geological Survey 1980). Inventory statistics such as production and reserve data of the licenced pits and quarries in the Niagara-Welland area are also compiled at the Niagara District Office of the Ministry of Natural Resources. A study of the supply and demand for sand and gravel in the Niagara Region has also been initiated by the Regional Municipality of Niagara (C.T.Cambray, Regional Muncipality of Niagara, personal communication, 1980).

BEDROCK

Queenston Formation

Red shale of the Queenston Formation is used in Ontario for the manufacture of brick and tile (Guillet 1967,1977). This shale occurs in the map-area underlying part of the Town of Niagara-on-the-Lake, the Town of Lincoln and the City of St. Catharines (Figure 18). The resource is delineated by the areas of outcrop of Queenston red shale and by the larger areas of less than 8 m of overburden.

The Queenston Formation red shale is quarried for the manufacture of brick by the Canada Brick Company Limited about 3 km northwest of St. Davids in the Town of Niagara-on-the-Lake (Figure 18, quarry #1). This quarry was formerly operated by Burnstein Brick Limited of St. Catharines. The quarry section near St. Davids and the

results of chemical, mineral, and ceramic tests on a channel sample from the shale have been described by Guillet (1967, p.99-100). Baker (1906, p.78) refers to earlier brick-manufacture using weathered red Medina (Queenston) shale in the adjacent Grimsby map-area by the Beamsville Brick and Terra Cotta Company (later known as Grimsby Brick and Tile Limited).

Lockport Formation

Dolostone and limestone of the Lockport Formation capping the Niagara Escarpment and underlying the Haldimand Plain at the top of the Niagara cuesta dipslope has been used for a long time in the Peninsula primarily as a resource for building- and crushed stone (Parks 1912; Goudge 1938; Hewitt 1960, 1964; Hewitt and Vos 1972). Areas of outcrop and with less than 8 m of overburden form an approximately 8 km wide resource belt across the map-area through the Towns of Lincoln, Pelham, Thorold and Niagara-on-the-Lake and the Cities of St. Catharines and Niagara Falls (Figure 18; see also Vos 1969, Preliminary Map P.537). The potential areas of future quarry development are discussed in more detail by Vos (1969, p.25-29).

Hewitt (1960,1964) and Hewitt and Vos (1972) described the geology, operations, and products of the limestone

industry utilizing the Lockport Formation in the map-area. These include the quarries operated by the Queenston Quarries Limited in the Town of Niagara-on-the-Lake (Figure 18, quarry #2), Walker Brothers Quarries Limited at Thorold (Figure 18, quarry #3), Vineland Quarries and Crushed Stone Limited in the Town of Lincoln (Figure 18, quarry #4 and quarry #6) and Clinton Quarries Limited also in the Town of Lincoln (Figure 18, quarry #5). In addition, King Paving and Materials Limited also operates a quarry in the Town of Lincoln (Lincoln Quarries; Figure 18, quarry #7).

The massive basal beds of the Gasport Member are worked by Queenston Quarries Limited for the production of building stone ("Queenston Limestone"). The upper beds of the Gasport Member, the Goat Island Member and the Eramosa Member of the Lockport Formation are mainly worked at all the above quarries as a source for crushed stone in the production of construction aggregates (granular base and subbase material, concrete).

Guelph Formation

Dolostone of the Guelph Formation is quarried in southern Ontario for the manufacture of lime, blast furnace flux, and crushed stone although it is too soft for many construction aggregate needs (Hewitt 1960, 1964, Hewitt and Vos 1972). Almost the entire belt of this dolostone formation across the map-area is heavily drift-covered,and

as a result is unfavourable for potential quarry development (Figure 18).

Salina Formation

The Salina Formation in southern Ontario contains, in the vicinity of its outcrop belt, lenticular beds of gypsum interbedded with dolostone and shale. Beds of gypsum, 1 to 3 m thick, are mined underground in the Niagara Peninsula at Caledonia and near Hagersville for the production of plaster, lath, and wallboard (Guillet 1964).

In the map area, the Salina Formation is heavily drift covered except for two areas along the Niagara River in the Town of Fort Erie (Figure 18). Beds of gypsum up to 1/2 m thick were encountered at the excavation for the Townline Tunnel at Welland (Conlon, Tanner, and Coldwell 1971, Figure 9).

Onondaga Cuesta

Dolostone of the Bertie Formation and Devonian cherty limestone underlie the Haldimand Plain at the Onondaga Escarpment and cuesta dipslope along the Lake Erie shore in the Township of Wainfleet, City of Port Colborne and the Town of Fort Erie (Figure 18). Areas of outcrop and with less than 8 m of drift-cover predominate. These areas narrow considerably from about 7 km in the Town of Fort Erie

and the City of Port Colborne to less than 1 km in the Township of Wainfleet (Figure 18).

These formations have been quarried for a long time in this area for the production of construction aggregates, lime and flux (Goudge 1938). More recent descriptions of the existing quarry operations are found in Hewitt (1960, 1964) and Hewitt and Vos (1972). These operations are the following:-

1. Port Colborne Quarries Limited in the City of Port Colborne (Figure 18, quarry operation #9);
2. R.E. Law Crush Stone Limited in the Township of Wainfleet (Figure 18, quarry operation #10); and,
3. Ridgemount Quarries Limited, including the former Campbell Quarries Limited, in the Town of Fort Erie (Figure 18, quarry operations #8).

These industries mainly work the Bertie and Bois Blanc Formations as a source for crushed stone in the production of construction aggregates.

SAND AND GRAVEL

Deposits of sand and gravel in the Niagara-Welland area and surrounding waters, and of importance to the construction industry, were already being worked during the first quarter of this century (Ledoux 1918).

Much sand and gravel for construction works on the Welland Canal came from dredging along the north shore of

Lake Erie and at the Niagara Bar in Lake Ontario at the mouth of the Niagara River. Today, sand from the Niagara Bar (Figure 18) is dredged by Erie-Ontario Limited for use as fine aggregate in construction and for such special uses as filter sand, foundry sand, sand high in silica for pH control, and winter sand. The tonnage production, however, is much lower compared to the early 1970's.

The most important sand and gravel pits were worked at deposits in the northern part of the City of Niagara Falls and near Fonthill in the central part of the Town of Pelham (Figure 18). These deposits were thought to be associated with ancient, buried bedrock channels between Lake Erie and Lake Ontario (Ledoux 1918). The greater number of pit operations were active in the Stamford-head of St. Davids re-entrant valley area in the City of Niagara Falls. Today, the gravel reserves in this part of Niagara Falls are virtually depleted. The Fonthill dpeosit in the Town of Pelham, however, still form the largest commercial source of construction aggregates from natural sand and gravel in the entire Niagara Peninsula.

Much smaller deposits of sand and gravel are formed by the glaciolacustrine beach ridges scattered throughout the Niagara-Welland area. The Homer bar on the Iroquois Plain in St. Catharines (Figure 18), the largest such deposit, provided in the past aggregate needed for road construction in that city (Keele 1924, p.91); it is now entirely built over.

Deposits of dune sand were also worked at pits along the Lake Erie shore in the City of Port Colborne (Ledoux 1918). These deposits are still being worked at two localities in the City of Port Colborne and the Town of Fort Erie (Figure 18).

During the 1970's, about 20 percent of the average annual total production of mineral aggregates in the map-area came from sand and gravel deposits.

The following sections of the report discuss the general geology of the sand and gravel deposits including descriptions of the major pits, analytical results, uses, and reserves.

Fonthill Kame

The "Fonthill kame" on the Haldimand Clay Plain at Fonthill in the Town of Pelham in the central portion of the Niagara-Welland map-area (Figure 18) is essentially a trilobate ice-contact deltaic complex, probably eskerine at the two southern inverted V-shaped ridges. The deltaic sequence consists of an upper unit of coarser grained sands and gravel wave-reworked at the top, and a much more extensive and thicker lower unit of finer grained sands (Figure 9 in back pocket, Figure 14). The distribution of the lower sands coincides, in the North Pelham-Fenwick-Pelham Corners area, approximately with the mappable extent of the surficial veneer of mainly nearshore sand. The lower

deltaic unit extends also northward into the Twelve Mile re-entrant valley, however, it is buried underneath Halton Till and intercalated glaciolacustrine clay and silt.

This ice-contact deltaic complex and in particular its upper unit of coarser grained sands and gravel provides about 90 percent of the total sand and gravel production in the area. The average annual production during the 1970's is approximately 1 million tonnes from the licenced pit operations of Moyer Sand Division of Steed and Evans Limited (Figure 18, pit operations #1), TCG Materials Limited (former Fonthill Sand and Gravel Limited; Figure 18, pit operations #2), and Graystep Incorporated (former Bishop pit; Figure 18, pit operation #4). These pit operations have been previously described by Hewitt and Karrow (1963) and Hewitt and Cowan (1969). The products from these pit operations include granular base and subbase materials, asphalt sand, concrete sand, cushion sand, mortar sand, sand fill, and winter sand. The inventory and evaluation of the aggregate resources at the Fonthill kame recently published by the Ontario Geological Survey (1980) estimates licenced reserves of sand and gravel at about 6 to 7 million tonnes and unlicenced reserves in the selected resource areas of primary significance at 86 million tonnes.

The quality of this sand and gravel deposit is adversely affected by the variability in thickness and extent of the gravel beds restricting the supply of crushable material, the selective cementation of the sand

and gravel by calcium carbonate making extraction and further processing of the material more difficult, and the presence of appreciable amounts of very fine grained material and deleterious lithologies (shale, siltstone) requiring beneficiation (washing, jigging, and blending with quarry screenings).

The south-pit of Moyer Sand Divison of Steed and Evans Limited is located south of Highway 20 near Cream Street, i.e. along the western margin of the southwestern ice-contact deltaic ridge. Pit-faces showed averages of 1 to 2 m of weathered, wave-reworked fine to medium grained sand (overburden) and about 2 m of upper deltaic unit sand and gravel which are underlain by more than 3 m of lower deltaic unit fine to medium grained sand. The upper deltaic unit is here as much as 3 m thick, poorly bedded, commonly cemented, and consists mainly of medium to very coarse grained, gravelly sands with some interbedded gravel. It contains large inclusions of finer grained, lower unit sand. The stone content of the upper unit varies between 5 and 10 percent, and the stones are predominantly smaller than 100 mm (4 inches, pebbles and small cobbles) while those greater than 256 mm (10 inches, boulders) occur sporadically.

The north- or main pit of Moyer Sand is located north of Highway 20 between Cream and Centre Street, i.e. along the northern margin of the western part of the southwestern ice-contact deltaic ridge. Pit-faces also showed here

averages of 1 to 2 m of weathered, wave-reworked fine to coarse grained gravelly sand (overburden) and 8 m of upper unit sand and gravel underlain by as much as 8 m of fine to medium grained, lower unit sand. The upper unit is here at a maximum 10 m thick, commonly cemented, and consists of interbedded fine to very coarse grained, gravelly sand, averaging 70 percent of the unit, and gravel. It includes sporadically interbedded medium to coarse grained, gravelly sand and lenticular, coarse-textured till at the base. The stone content of this upper unit averages 30 percent of which only up to 5 percent is of boulder-size and as much as 90 percent is of pebble- to small cobble size. A pebble count of the gravel shows rare shale (2%) but abundant siltstone (30%), while the medium-coarse sand fraction also contains in 3 samples abundant shale and siltstone (33-39%; Hewitt and Karrow 1963; Hewitt and Cowan 1969). Two grainsize distributions of upper unit sand from the Moyer Sand north-pit are shown in Figure 19 (curve no. 4 and 5).

The Fonthill pit of T.C.G. Materials Limited is also located north of Highway 20 but east of Centre Street, i.e. in the north-central portion of the southwestern ice-contact deltaic ridge.

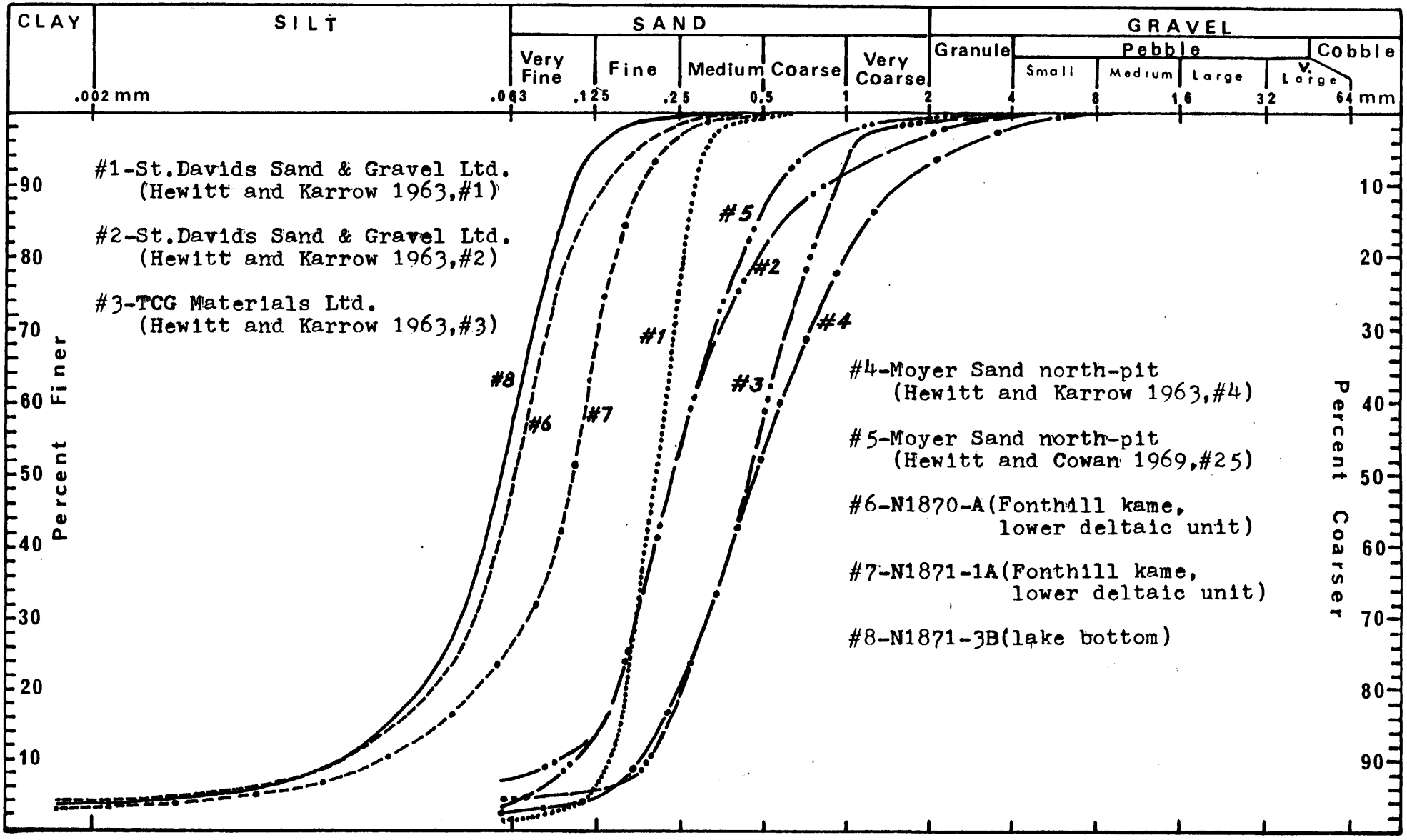


Figure 19-Grain size distribution curves of ice-contact deltaic and lake bottom sands.

Pit-faces showed averages of 1 to 2 m of weathered, wave-reworked fine to coarse grained, gravelly sand and some gravel (overburden), and about 8 m of upper unit sand and gravel underlain by as much as 10 m of fine to medium grained sand of the lower unit. The upper unit varies here in thickness from 3 to 12 m, is commonly cemented, and consists of interbeded gravel and mainly gravelly, medium to coarse grained sands. It contains at its base also sporadically the till-bearing unit and large inclusions of finer grained sand of the lower unit. The stone content of this upper unit averages here about 50 percent, and the stones are predominantly (70-95%) smaller than 100 mm (4 inches). A pebble count of the gravel shows also rare shale (2%) but common siltstone (21%) and cemented aggregate (14%), while the medium to coarse grained sand fraction contains in one sample abundant shale and siltstone (38%; Hewitt and Karrow 1963). A grainsize distribution of upper unit sand is shown in Figure 19 (curve no. 3).

The small pit of Graystep Incorporated (the former Bishop pit) is located south of Highway 20 at the contact between the upper and lower ice-contact deltaic units along the wave-reworked southern flank of the central part of the southwestern ridge. Pit-faces up to about 18 m high exhibit fine to gravelly, coarse grained sands which are commonly cemented in the upper part.

The reserves of finer grained sands included in the nearshore, lake-bottom, and lower ice-contact deltaic units

at the Fonthill Kame complex are very large and classified as an aggregate resource of secondary significance (Ontario Geological Survey 1980). Several small and abandoned pits in these sands are found along the gently sloping south side of the kame complex south of Canboro Road and also to the north along the valleys of Twelve Mile Creek and its tributaries as far as St. Johns West. The sands are chiefly very fine to medium grained and very silty (Appendix A and J; samples N1870-A, N1871-1A and 3B). Some examples of the grainsize distribution of several samples of these sands are shown in Figure 19 (curve no. 6,7, and 8).

St. Davids Re-Entrant

Mainly sand and some gravel of ice-contact glaciolacustrine origin is being worked at several pits in the City of Niagara Falls (Figure 18, pits #5-8). These pits are specifically located at the head of the St. Davids re-entrant valley in the Niagara Escarpment between the Hydro-Electric Power Commission's reservoir and rock waste sites (Figure 20). The ice-contact glaciolacustrine deposit is here approximately 30 m thick on top of the Escarpment rock sequence on the southwest side of the buried St. Davids Gorge. The deposit consists in its upper part mainly of stratified silty very fine to coarse grained sand and silt and some interbedded gravel, clay, and till, and in its lower part chiefly of stratified very fine to coarse grained

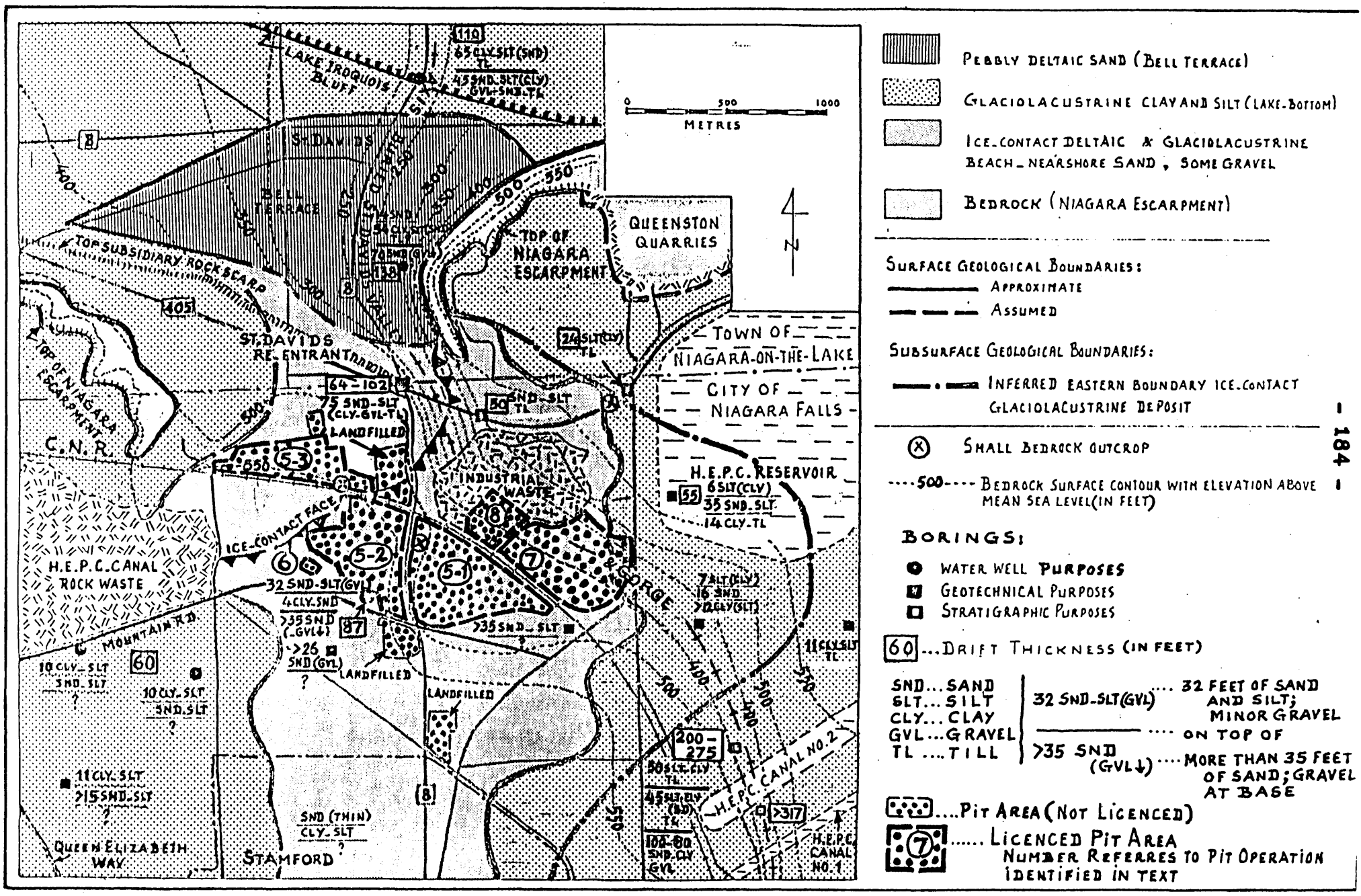


Figure 20-Map of the ice-contact deltaic deposit and surroundings at the St.Davids re-entrant valley in the Niagara Escarpment, Niagara Falls - Niagara-on-the-Lake.

sand and gravel and some interbedded fines (Figure 7, in back pocket). The upper and lower part are separated in the large pit on the west side of the former Highway 8 (Figure 20, pit #5-2) by a thin unit of contorted glaciolacustrine clay and sand. Till is found at the base of the deposit where it rests on a bedrock outcrop of the DeCew and Lockport Formations in the large pit adjacent on the east side of the former highway (Figure 20, pit #6-1).

Only the approximately eastern subsurface boundary of the ice-contact glaciolacustrine deposit near the head of the St. Davids re-entrant valley can be outlined from borings (Figure 20). The ice-contact stratified drift probably interfingers in the subsurface with proglacial lake-bottom clay and silt (Figure 7, in back pocket). Older beds of sand and gravel occur deeply buried in the St. Davids Gorge (Figure 7).

The ice-contact glaciolacustrine deposit possibly continues in the subsurface within the ice-marginal re-entrant postulated by Taylor (Kindle and Taylor 1913) southward underneath the built-over part of the City of Niagara Falls to the Niagara Falls Moraine at Lundy's Lane. This southward continuation of the deposit may consist chiefly of fine sand and silt, and little gravel. The surface of the ice-contact glaciolacustrine deposit has been wave-reworked resulting in the accumulation of some beach sand and gravel but mainly of an extensive cover of nearshore sand and silt (Figure 18).

More than half a century of extractive activity at the ice-contact glaciolacustrine deposit has virtually depleted this source of gravel. Coleman (1937a, p.3-4) mentions a gravel pit showing about 15 m of large-scale cross-bedded coarse gravel and which was opened to obtain material for the diversion of former Highway 8. The gravel supposedly extended for hundreds of metres toward the southwest where it was opened by large pits on both sides of the former highway at Mountain Road. More recent descriptions of the pit operations in the area are found in Hewitt and Karrow (1963, p.48-50). The products from these pit operations included granular base and subbase materials, asphalt sand, mortar sand, and backfill sand. Today, the sands are primarily utilized for backfill purposes.

St. Davids Sand and Gravel Limited operates Pit 1 Area 1 on the east side of former Highway 8 at Mountain Road and Pit 1 Area 2 on the west side (Figure 20, pit #5-1 and 5-2). The pit on the west side was worked on two levels. The upper level consists of about 10 m of alternating sub-units of stratified very fine to coarse grained sand and silt with some interbedded clay and gravel. A thin unit consisting of glaciolacustrine clay and sand separates the upper from the lower level. The lower level consists of about 8 m of cross-stratified fine to coarse grained sand, also with some interbedded fines, overlying more than 3 m of interbedded sand and gravel dipping to the southwest. The stone content of this lower level is about 30 percent and

the stones are predominantly less than 76 mm (3 inches) in diameter, i.e. of pebble-size. A pebble count of the gravel (Hewitt and Karrow 1963) showed scarce (6%) shale but abundant (42%) siltstone. The medium to coarse grained fraction of a sample of sand from interbedded sand and gravel in the extensively worked pit on the east side of former Highway 8 also contains abundant (29%) shale and siltstone (Hewitt and Karrow 1963). A grainsize distribution of the sand is shown in Figure 19 (curve no.1). The very large "erratic" (Photo 20) left after excavation of the sand and gravel about it near the entrance to the pit on the east side was derived locally from the Gasport Member of the Lockport Formation.

Further to the east, St. Davids Sand and Gravel Limited operates Pit 2, the former Braas Brothers pit, on the east side of the C.N.R. tracks (Figure 20, pit #7). This pit exposed about 10 m of stratified fine to medium grained sands of the upper level of the ice-contact glaciolacustrine deposit. A grainsize distribution of the sand is shown in Figure 19 (curve no.2). The medium to coarse grained sand fraction contains in one sample also abundant (27%) shale and siltstone (Hewitt and Karrow 1963).

Other, small sand pit oprations in this area are the following:

1. St Davids Sand and Gravel Limited Pit 1 Area 3 (Figure 20, pit # 5-3);
2. Half-Way Sand Pit Limited (Figure 20, pit # 8);

Photo 20. Glacial erratic at the St. Davids Sand and Gravel Limited Pit 1 Area 1.

and,

3. Calaguiro Brothers Limited (Figure 20, pit # 6).

The remaining aggregate resources in the unlicenced area of the ice-contact glaciolacustrine deposit consist mainly of sands. The portion of this deposit south of Mountain Road has largely urban development on it.

Glaciolacustrine Beach Sand and Gravel

The shorebluff of Lake Iroquois is interrupted in the City of St. Catharines by the 6 km-long Homer baymouth bar extending in an east-west direction along former Highway 8 between Homer and the Twelve Mile Creek. This baymouth bar consists of as much as 8 m of interbedded gravel and sand (Appendix J: samples P 66-51-9-3, -11-4, -15-2, and -15-5). Grainsize distribution of samples P 66-51-9-3, -11-4, and -15-5 are shown in Figure 21 (curve nos. 10-12). This commercial-size beach deposit is now built over but it provided in the past, from its eastern part near Homer, the aggregate needed for road construction in St. Catharines (Keele 1924, p.91; Coleman 1937a, p.4).

The remaining deposits of sand and gravel on the Iroquois Plain are quite small and scattered across this plain. These deposits contain weathered material and are probably also rich in deleterious fragments of shale and siltstone derived from the underlying Halton Till (Appendix K: sample N1090). One such beach deposit was worked in the

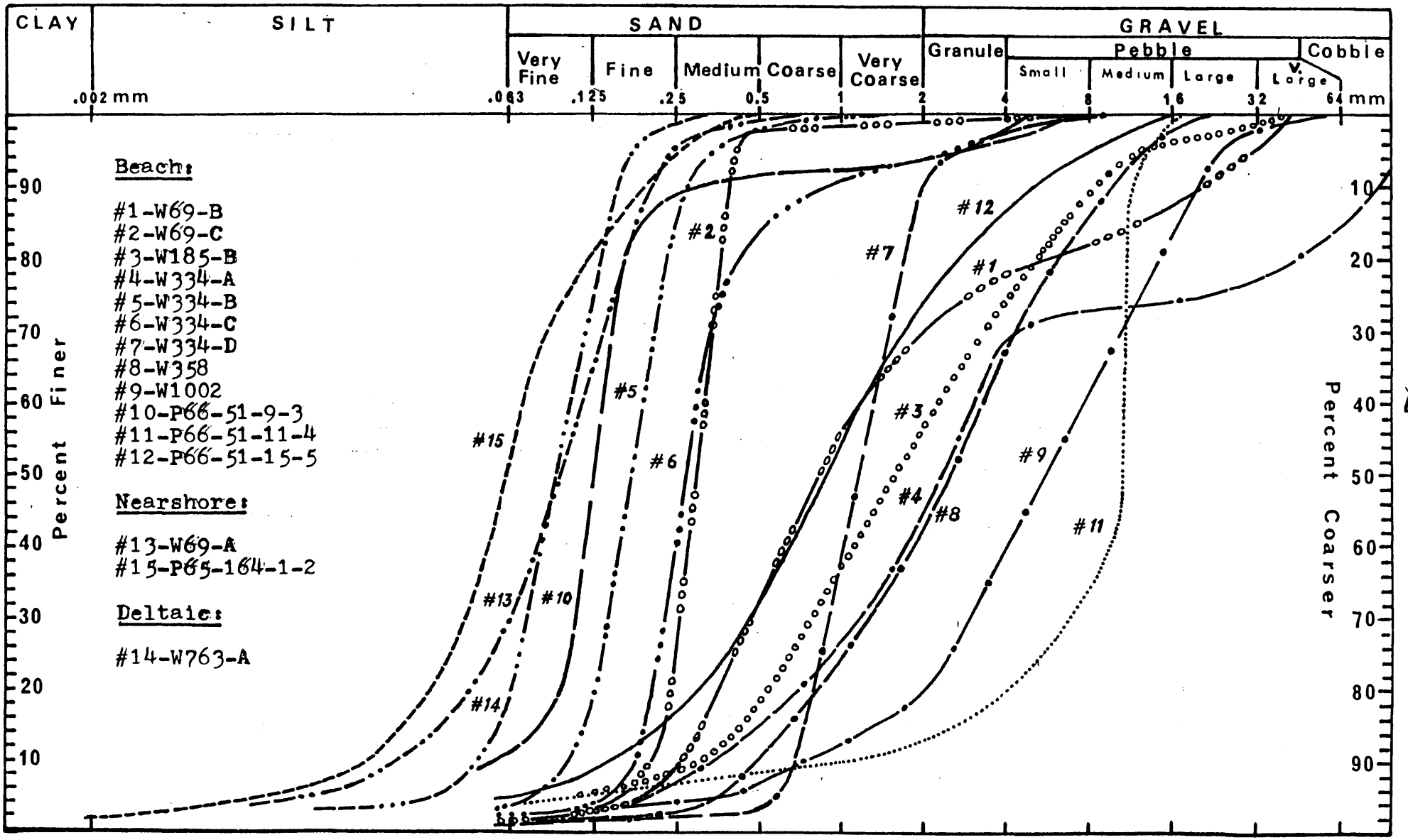


Figure 21-Grain size distribution curves of glaciolacustrine beach, nearshore, and deltaic sand and gravel.

past at Niagara-on-the-Lake (Coleman 1937a, p.3).

The Lake Warren beach deposits encountered on top of the Fonthill kame on the Haldimand Plain in the Town of Pelham have been included with the reserves of sand and gravel contained in this ice-contact deltaic complex, and discussed previously.

The remaining post-Warren beach sand and gravel deposits on the Haldimand Plain are found scattered across this plain at lower elevations. These deposits are very small and frequently contain weathered material. Deleterious shale and siltstone is abundant (more than 40%) in the pebble grade of these deposits in the northern part (Appendix K: samples N1877, N1881, and N2526) but scarce (about 10%) in the central part of the Haldimand Plain (Appendix K: samples W47-A, W47, and W2418). Deleterious shale and/or chert is rare (0-3%) in the pebble grade of the glaciolacustrine beach deposits on the Onondaga cuesta near the Escarpment (Appendix K: samples W156, W185-A, and W1002). Shale and siltstone is common or abundant (12-30%) however in the medium to coarse sand fraction of several samples from these deposits in the central part (Appendix L: samples W69-C, W77-C, and W2418) and on the Onondaga cuesta in the south (Appendix L: samples W334-A and -C).

The largest number (7) of small, abandoned wayside pits was encountered in the two Lake Dana beach ridges on top of the Fort Erie Moraine at the City of Welland-City of Niagara Falls boundary (Figure 18; Appendix J,K, and L: samples

W47-A, W69-B and -C, W74, and W77-C). Representative grainsize distributions of the sand and gravel in these ridges (samples W69-B and -C) and others to the south on the Onondaga cuesta (samples W185-B, W334-A to -D, W358, and W1002) are shown in Figure 21 (curve nos. 1-9).

Glaciolacustrine Nearshore and Deltaic Sand

The sands of glaciolacustrine nearshore and deltaic origin in the Niagara-Welland map-area are generally fine to very fine grained and very silty (Appendix J: samples W69-A, W763-A, and P65-164-1-2). Representative grainsize distributions are shown in Figure 21 (curve nos. 13-15).

These sands are generally too fine grained to be considered as source material for construction aggregates or for special industrial uses.

Dune Sand

The narrow, discontinuous strip of Lake Erie shore dunes (Figure 18) reach a maximum height of about 30 m at the Sugar Loaf at the boundary between the City of Port Colborne and the Township of Wainfleet, and in the Abino Hills in the Town of Fort Erie. These eolian (windblown) landforms consist of uniform fine to medium, predominantly fine, grained sand (Appendix J: samples W2-A, W3-A, and -B, W5-A, W265, W556, and W706-A to -D). Representative

grainsize distributions are shown in Figure 22 (curve nos. 1-6). Petrographic analysis of 5 unweathered samples (Appendix L: samples W556 and W706-A to -D) show that this dune sand consists mainly of grains of quartz (mean=56%, range=48-65%), feldspar (23%, 21-27%), and of limestone and dolostone (13%, 8-18%), and rare grains of chert and sandstone. The dune sand can be almost totally leached of calcium carbonate to a depth of 3 m, while weathering-profiles may also occur buried at greater depths.

Lake Erie shore dune sand is worked as a source of blending sand in asphalt productions, metal casting sand, filtration sand, and backfill sand by Eberly and Hard Rock Paving Company Limited at the two small pit operations at Sherkston Beaches and near Point Abino respectively (Figure 18, pit #9 and pit #10).

This uniform fine to medium grained sand of the Lake Erie shore dunes is also, like other dune sands (Carter et al. 1964), in the size range required for special industrial sands, i.e. for example glass, abrasive, or moulding sand, although it is slightly finer textured than a sample of the glass-making sand derived from the Oriskany Formation sandstone near Nelles Corners in the Dunnville map-area (Ledoux 1918; Figure 22). A very high silica content of 95 percent or more is usually required of sands for such purposes. The Lake Erie shore dune sand in the map-area may yield only about 70 percent silica, probably more after beneficiation (Carter et al. 1964), although chemical

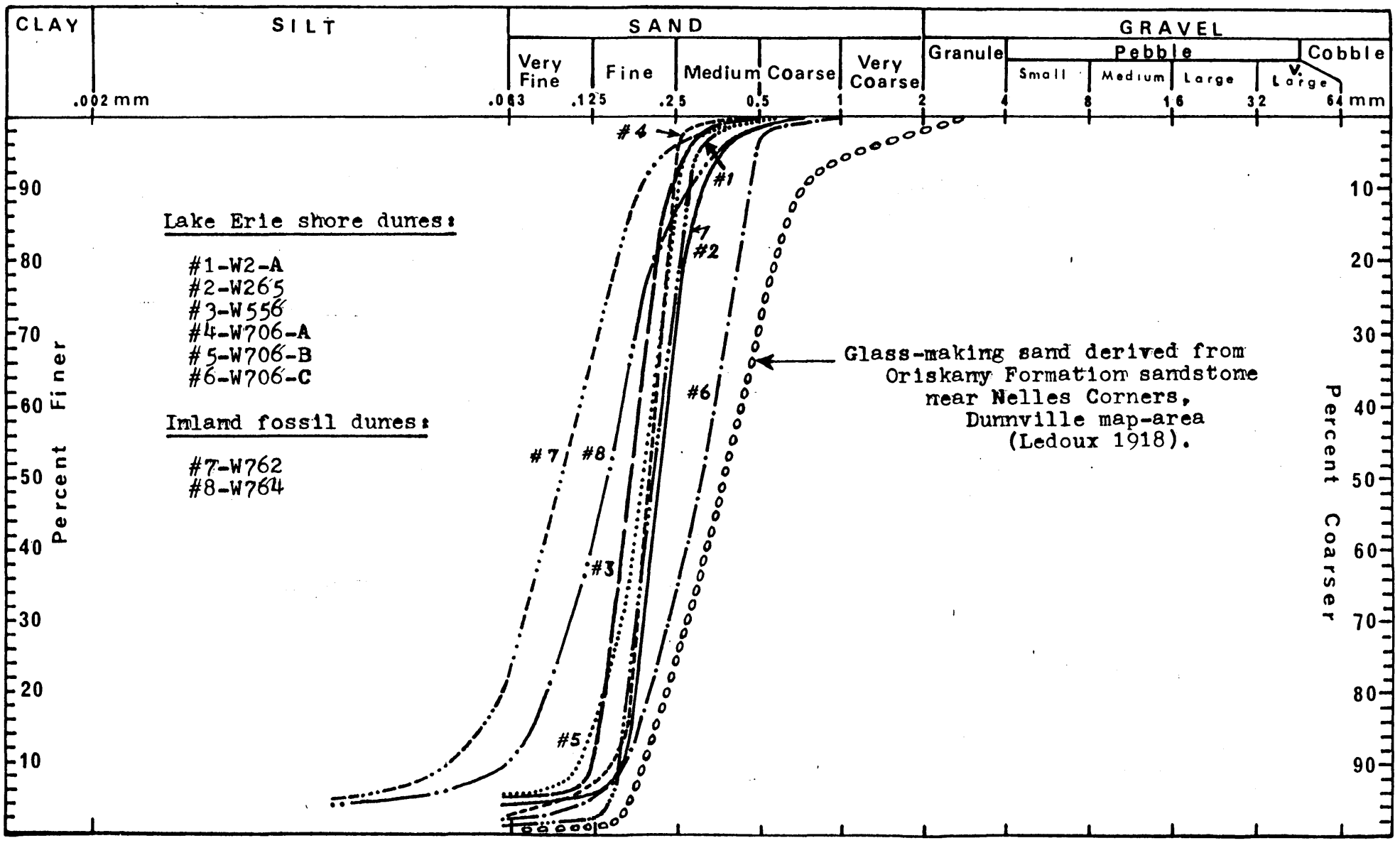


Figure 22-Grain size distribution curves of dune sands.

analysis has not been carried out.

Another source of eolian or windblown sand is formed inland by the generally much smaller, stable fossil dunes scattered across the plain of the ancestral Grand River delta west of Wainfleet (Figure 18, Township of Wainfleet, and Town of Dunnville). This sand is even finer grained and more silty than the sand in the Lake Erie shore dunes, but slightly coarser grained than the sand of glaciolacustrine and deltaic origin (Appendix J: samples W762 and W764; Figure 22: curve no. 7 and 8).

CLAY

Clay is mainly utilized in the manufacture of brick and drain tile in Ontario (Baker 1906; Keele 1924; Montgomery 1930; Guillet 1967, 1977). Only clay with less than 18 percent lime (CaO) is used as raw material. Clay deposits should also be free of stones, particularly limestone fragments and calcareous concretions, and sufficiently plastic. Baker (1906) refers to the use of the upper one metre of weathered clay (red-burning or "Red-top clay"), generally stonefree and leached of lime to about 3 percent, in red brick and tile, Portland cement, and pottery. A higher lime content of more than about 8 percent in the raw material (cream to buff-burning) resulted in "white brick and tile" which did not retain its colour.

Several clay pits were being worked during the turn of the century in the map-area at St. Catharines, Niagara Falls, and Welland, however, except for the Paxton and Bray pit in St. Catharines, all of them were inactive during the 1920's (Baker 1906; Keele 1924; Montgomery 1930). The one metre of "Red-top clay" was utilized in the manufacuture of brick and the underlying "Erie blue clay" mainly for drain tile. Some of this surface clay, however, tended to be too stony. Paxton and Bray's pit in St. Catharines worked red-burning, massive, stiff but plastic, calcareous clay comparatively free of stones (thick silty clay Halton Till?), and the raw material was used for making good-quality building-brick (Keele 1924; Montgomery 1930).

The glacial lake clay-resource is very large in the Niagara-Welland map-area. The excavations along the relocated Welland By-Pass segment of the Welland Canal between Port Robinson and Ramey's Bend exposed at the top a clay-dominated glaciolacustrine sequence. This sequence overlies the Halton Till and is generally between 5 and 10 m thick to the north of the Onondaga Escarpment. This Welland By-Pass cut through the Haldimand Clay Plain is probably characteristic for the entire heavily drift-covered part of the Niagara cuesta dipslope. The massive or stratified, clay-dominated, upper glaciolacustrine sequence is of medium to high plasticity and contains predominantly between 50 and 90 percent clay and less than 5 percent sand (Owen 1972, Figures 2 and 4, Unit 16). The Lake Iroquois terrace near

St. Davids is also underlain by about 15 m of glacio-lacustrine deposits consisting mainly of relatively stonefree clay.

Utilization of clays in the manufacture of brick and drain tile has generally been in decline in Ontario since the 1920's (Guillet 1977). Agricultural use of heavy clay soils such as those on the Haldimand Plain needs drainage tile presently consisting mainly of plastic pipe. This pipe, however, is a petroleum product increasing in cost today, and clay-tile may therefore become more competitive. Unleached glaciolacustrine silty clay in the Niagara-Welland map-area contains between 7 and 19 percent calcite in the silt-clay size-fraction. Similar Late Wisconsinan clays of the Erie basin in the Brantford area and along Lake Erie at Port Dover and Port Rowan contain between 14 and 29 percent calcite yielding most of the lime content (13-20%) in the clay-size fraction (Guillet 1967, 1977). These cream to buff-burning clays possess fair to excellent firing characteristics.

PEAT

The only commercial source of peat in the Niagara-Welland area is formed by the approximately 1200 hectares of Welland Bog in the Township of Wainfleet and City of Port Colborne (Figure 18). Peat-thicknesses vary generally between 2 and 4 m (Figure 15).

Peat can be used commercially for the manufacture of

peat moss and peat fuel (Haanel 1924; Leverin 1964; Swinnerton 1958). The lower, dark, well-decomposed (humified) peat in the Welland Bog was cut and air-dried around the turn of the century for possible use as peat fuel by the Ontario Peat Fuel Company of Toronto and by Peat Industries Limited of Brantford. The manufacture of peat fuel, however, was unsuccessful due to problems with the drying of sufficient quantities for briquetting. Dried peat from the bog contains 5 percent ash and has a calorific value of about 8700 B.Th.U (Haanel 1924).

Least-decomposed Sphagnum peat forms the best raw material for commercial peat moss used as soil conditioner (mulch), packing material (mull) for the preservation of perishable fruits, vegetables, and cut flowers, poultry litter and stable bedding, filler in fertilizer, and as heat-insulation material. Today peat moss is used mainly as a soil conditioner (Graham and Tibbets 1961).

Sphagnum peat from the Welland Bog was also cut and tunnel-dried around the turn of the century for the manufacture of moss-litter. Today, peat moss from the Welland Bog is processed for use as soil conditioner and mainly exported to the United States by Atkins and Durbrow (Erie) Limited of Port Colborne (Figure 18, peat operation #1; Leverin 1946; Swinnerton 1958). The peat is air-dried and vacuumed (Photo 21) rather than wet-cut.

Fay Farms Incorporated of Port Colborne is another producer of peat moss from the Welland Bog (Figure 18, peat operation #2).

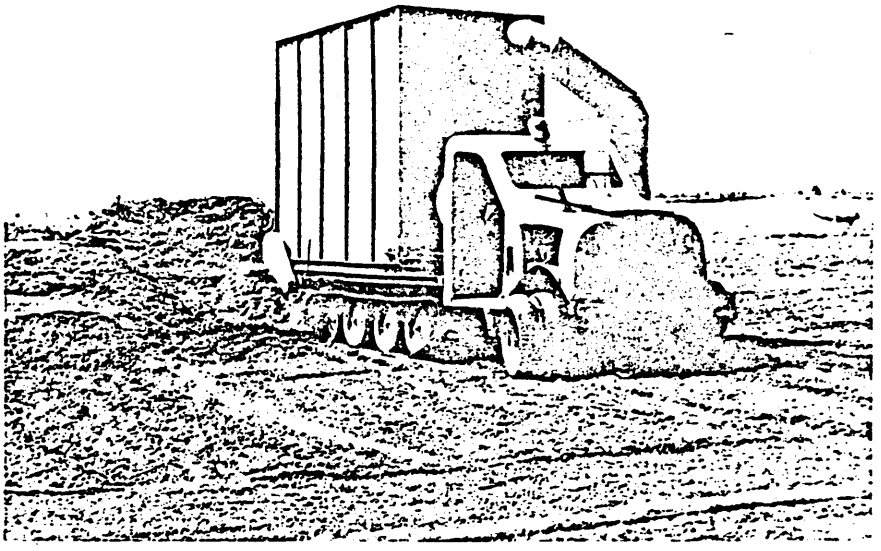


Photo 21-Vacuuming at the Welland Bog peat operation of Atkins and Durbrow(Erie) Limited.

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APPENDIX A : LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH † m
N32	Lake-bottom plain near Niagara Esc. at Rockway 357735	Upper till: buff silt matrix; overlain by 1 metre of upper lacustrine gravelly, silty sand with a few interbeds of clay (reworked till).	1.2	-0.6
N35	Niagara Esc., Rockway - DeCew Falls 386739	Upper till: buff silt matrix; with bands of silt; overlies Irondequoit Formation limestone and is overlain by upper lacustrine deposits.	1.8	-1.2
N36-B,-C	Twelve Mile re-entrant in Niagara Esc. 391716	Upper silty clay: brown, reddish- and grey brown, massive and contorted-stratified, numerous small, soft-sediment clasts; overlies contorted- and parallel- stratified clay and silt; overlain by fine sand over massive-laminated clay.	9.1	-2.4
N36-F	ibid	Lower silty clay: brown, reddish brown and grey, massive and contorted-stratified, numerous small soft-sediment clasts; overlies contorted-stratified clay and silt over fine sand, contortions truncated at top by silty clay unit.	3	-1½
N41-A	Twelve Mile re-entrant in Niagara Esc. 384712	Upper silty clay: brown, contorted-stratified silty clay with numerous soft-sediment clasts and fine gravelly, sandy silt; sample from thin silty clay layer; overlies contorted- and parallel-stratified clay and silt.	6.7	+4.9
N41-C	ibid	Upper silty clay: grey, contorted-stratified, silt streaks, numerous small soft-sediment clasts.		+0.9

† — indicates measurement from top of unit
\+ indicates measurement from bottom of unit

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N42-A	Twelve Mile re-entrant Niagara Esc. 383710	Upper till: reddish grey silt matrix; sample from till layer 0.3 m thick with near-parallel silt streaks near top of 2.1 m thick interbedded sand and silt sequence.	2.1	-½
N42-B	ibid	Upper till: brown and reddish brown sandy silt matrix; from silt till with north-dipping inclusion of contorted-stratified sand, silt, and clay; overlies interbedded sand and silt; overlain by stratified silts and upper silty clay.	5½	+0.6
N42-C	ibid	Upper till: greyish- and yellow brown silt matrix; streaks of incorporated sand and silt.		+1½
N42-D	ibid	Upper till: brown and reddish grey sandy silt matrix; some streaks of incorporated sand and silt.		+2.7
N48	Proximal side "Fonthill kame" 387687	Upper till: yellow brown silt matrix; overlies interbedded silt and silty, fine to medium sand; overlain by about 1.2m of upper lacustrine nearshore fine sand with pebbles.	2.1	-0.9
N63-A	Proximal side "Fonthill kame" 396680	Upper till: yellow brown silt matrix; interbanded sand and silt at base; overlies 1½ m of contorted-stratified fine- and very fine, silty sand; overlain by 4.3 m of upper lacustrine silty, fine sand-silt with contorted inclusions of clayey silt.	1½	-0.3

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N67	Proximal side "Fonthill kame" 396686	Upper till: brown silt matrix; overlies 2 m of fine- to very fine grained sand with inclusions of clay and fine sand; overlain by 1.8 m of upper lacustrine nearshore fine sand with pebbles.	3.7	-1½
N68-C	Ice-contact slope "Fonthill kame" 388676	Upper till: brown silt matrix; sample from rounded till-cobbles in 2.4 m of northeast-inclined (22°) medium-coarse grained sand strata; overlain by 7m of gravel: rounded pebbles and cobbles, cemented, strata northeast-, southeast-, and southwest inclined (12°-30°), clasts of upper till and clay in basal layers; and 1.2m of upper lacustrine fine gravel and pebbly, fine sand (nearshore).	2.4	-1.2
N71-A	Twelve Mile re-entrant in Niagara Esc. 391729	Upper till: grey, clayey silt-silty clay matrix; large inclusion of contorted-stratified grey very fine grained sand and silt with some reddish gritty silt (till?) pebbles; overlain by contorted- and parallel-stratified clay, silt and sand, and upper silty clay unit.	3.4	-0.6
N73-A	Lake-bottom plain, syphon culvert near Port Robinson for diversion of Welland River 456654	Upper till: brown silt matrix; from brown to reddish brown silt till with inclusions of silt and clay; overlain by 8½m of upper lacustrine, interbedded- laminated clay and silt weathered massive in upper part.	5.8	-5½

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N73-B	ibid	Upper till: brown to reddish brown silt matrix.		-4.3
N73-C	ibid	Upper till: brown to reddish brown silt matrix.		-2.7
N73-D	ibid	Upper till: brown silt matrix.		-0.6
N73-E	ibid	Upper till: brown silt matrix.		-1.8
N73-F	ibid	Upper till: brown silt matrix.		-2.7
N115-A	Twelve Mile re-entrant in Niagara Esc., St.Catharines 424769	Silty clay: greyish brown, massive appearing thin-bedded to laminated; from massive to stratified, brown-reddish brown, grey-greyish brown silty clay with few stones, inclusions of contorted stratified silt and clay (boudinaged interbeds?) along several horizons dipping 15°-42° southeast, and sporadic interbeds of red and greenish grey clay.	21.4	-4.6
N115-B	ibid	Silty clay: greyish brown, massive appearing.		-17.4
N165	Lake Iroquois shore east of Fifteen Mile Ck. 385774	Upper till: brown silty clay matrix; overlain by 0.9m of Lake Iroquois beach sand and gravel.	3.4	-3.4
N210	Lake Ontario shorebluff north of Beamsville 251836	Upper till: grey silt matrix; overlain by 1.8 m of Lake Iroquois nearshore silty sand and sandy silt.	1.8	-1.2

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N211-A	Lake Ontario shorebluff at Geneva St., St.Catharines 428858	Upper till: grey silt matrix;from grey silt till with sheared-in silt and few northeast inclined interbeds of reddish silt till, capped by relatively more gravelly and sandy till layer with reddish silt matrix and thin interbeds of fine sand; overlain in ascending stratigraphic order by 1 m of grey,silty,glaciolacustrine clay with numerous small clasts and contorted layers of silt, and 2.7 m of stratified sand, silt, and clay deposited in Lake Iroquois.	5	- 4.3
N211-B	ibid	Upper till: reddish silt matrix;from interbed.		-3.7
N211-C	ibid	Upper till: grey silt matrix,		-3
N211-D	ibid	Upper till: grey silt matrix.		-2.4
N211-E	ibid	Upper till: grey silt matrix.		-2
N211-F	ibid	Upper till: grey silt matrix.		-1½
N211-G	ibid	Upper till: reddish silt matrix; from relatively more gravelly and sandy till cap.		-½
N216-A	Lake Ontario shorebluff at Charles Daley Park 369825	Upper till: grey silt-clayey silt matrix;from similar till with incorporated silt and clay; overlain in ascending stratigraphic order by 6½ m of near-horizontally interbedded clay,silt,and fine-very fine sand, and 1 m of very fine nearshore sand deposited in Lake Iroquois.	6	-5.2

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N216-B	ibid.	Upper till: grey more clayey silt matrix.	6.1	-3
N216-C	ibid.	Upper till: grey silt matrix		-1.8
N216-D	ibid.	Upper till: grey silt matrix		-0.6
N216-E	ibid.	Upper till: reddish silt matrix; from inter-banded reddish, relatively more sandy silt till and silt		-1.8
N230-A	Lake Ontario shore bluff east of Jordan Harbour 336820	Upper till: grey clayey silt matrix; from similar till overlain in ascending stratigraphic order by 0.6m of pebbly, glaciolacustrine clay with contorted laminae of sand, and 6.7m of Lake Iroquois deposits consisting of 4.9m of interbedded clay, silt and very fine sand and 1.8m of interbedded sand and silt at top.	5.8	-5.2
N291-A	Vinemount Moraine at Vineland quarry, Niagara Esc. south of Vineland 299770	Upper till: buff silt matrix; from similar till with numerous fragments of Queenston Formation shale, thin interbeds of sand and silt at very base; truncates 2.4m of contorted-stratified silt and sand sequence consisting of thin, stratified gravelly sand at top over stratified buff and grey silt with some inter-laminated fine sand and interspersed wavy till bands at base; silt and sand sequence overlies contorted-interbedded till, silt and clay.	2.1	-1.8

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N291-B	ibid.	Upper till: Grey, relatively finer grained silt matrix; from 0.6-1.2m thick wavy till layer at top of contorted-interbedded sequence of till, silt, and clay dipping to the northeast and resting on glacially eroded bedrock surface (Lockport Formation, Gasport Member) with N40°E-S40°W mode of orientations of striae and larger grooves.	4	-0.6
N291-C	ibid.	Upper till: grey, relatively coarser grained silt matrix; from 0.3m thick till layer near top of contorted-interbedded sequence of till, silt, and clay.		-0.9
N407	Top Niagara Esc. south of Jordan 328754	Upper till: buff silt matrix; inclusion in contorted-interbedded upper lacustrine clay and silt.		-1.8
N419	Near L.Iroquois shorebluff east of Jordan 336773	Upper till: grey silty clay matrix.	3	base section (Creekbed)
N437	Vinemount Moraine South of Vineland 309759	Upper till: brown silt matrix; from similar till with inclusions of silt.	2.7	-2.6
N461	Niagara Esc. South of Vineland 307777	Upper till: buff silt matrix; till rests on glacially eroded bedrock surface (Irondequoit Formation) with striae in N15°E-S15°W direction.	3.7	-3

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N466-A	Lake Ontario shorebluff near Palatine Hill 501899	Lower? till: gravelly, with reddish and grey sandy to silty matrix; overlain in ascending stratigraphic order by about 0.2m of gravel with rounded clasts and 1.7m of upper till with buff silt matrix and contorted stringers of fine sand.	2.1	-1.8
N467	Lake Ontario shorebluff east of Port Weller 465876	Upper till: reddish silt matrix; till overlain in ascending stratigraphic order by 1.2m of massive-faintly stratified, pebbly, silty glaciolacustrine clay and 4.9m of Lake Iroquois deposits (near-horizontally and contorted stratified clay, silt, sand).	0.6	-0.3
N483	Niagara Esc. south of Beamsville 239785	Upper till: grey-greyish brown clayey silt matrix.	5.2	-4.3
N491	Lake Iroquois shorebluff east of Beamsville 252796	Upper till: grey-greyish brown clayey silt matrix.	5.2	-3.7
N501	Lake Iroquois shorebluff east of Jordan 338774	Upper till: brown silt - clayey silt matrix.	4	-3.4

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N839-A	Pits at St.Johns West near head of Twelve Mile re-entrant 402705	Upper till: buff silt matrix; till exposed below 12.2m of covered interval; over 13.7m of silt and cross-laminated sand with some interbedded clay, till, and cobbly sand and gravel (including cobbles of till; interbedded till, sand and gravel are associated with a collapse-structure).	3.4	+0.6
N839-B	ibid.	Upper till: reddish brown sandy silt matrix; from up to 0.3m thick contorted interbed of till.		
N839-C,-D	ibid.	Upper till: greyish-reddish brown silt matrix from till-cobbles in sand and gravel.		
N855-A	Lake Iroquois terrace between Virgil and Port Weller 494880	Upper till: brown silt matrix; from brown to greyish buff silt till with north-dipping sand inclusions; overlain by 0.8m of laminated Lake Iroquois clay and silt.	1.8	-1
N855-B	ibid.	Upper till: greyish buff silt matrix.		-1½
N855-C	ibid.	Lower? till: relatively more gravelly till with purplish grey silt-sandy silt matrix at base of section.	0.6	-0.3
N863	Lake Iroquois terrace between Virgil and Port Weller 494873	Upper till: reddish brown silt matrix.	1½	-1

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N1032	Niagara Esc. east of Thorold 504776	Upper till: reddish brown silt matrix; till rests on Lockport Formation bedrock.	1.8	-1½
N1067-A	Quarry of Walker Brothers Quarries on top of Niagara Esc. east of Thorold 490766	Upper till: reddish silt matrix; from basal part of brown, buff, and reddish silt till with north-dipping inclusions of contorted stratified clay and silt; till rests on glacially eroded Lockport Formation bedrock surface with striae in N10E-S10W and N35E-S35W directions; overlain by 4m of upper lacustrine clay and silt.	2.1	+0.2
N1067-B	ibid.	Upper till: buff silt matrix.		+0.6
N1067-C	ibid.	Upper till: reddish silt matrix.		+0.6
N1067-D	ibid.	Upper till: reddish silt matrix.		+0.3
N1090	Lake Iroquois terrace north of Homer 469821	Lake Iroquois gravel: cobbly gravel; from small beach ridge on more clayey upper till.	2.4	-1½
N1092	Lake Iroquois terrace north of Homer 467831	Upper till: brown clayey silt matrix; from similar till with abundant small fragments of Queenston Formation shale and sporadic boulder-size inclusion of silt; overlain by about 0.3m of gravelly, silty, Lake Iroquois nearshore fine sand.	1.2	-1.2

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N1767-6	Moyer's main pit "Fonthill kame" 358669	Upper till: gravelly, with buff-reddish buff sand - sandy silt matrix; from lens of till and interlayered sand at about 8-10m depth in ice margin delta - proglacial lake deposits at southeast corner of pit, and possibly representing erosional remnant of till layer separating fine-medium grained sand below from coarser grained sand and gravel above.	1½	-0.9
N1814-A	Lake Iroquois terrace south of Virgil 525841	Upper till: greyish brown silty clay matrix; from brown-grey silty clay till with inclusions of sand, silt, and reddish silt till rich in fragments of Queenston Formation shale; transitional lower contact with grey and red stratified clay.	3.4	-1½
N1814-B	ibid.	Upper till: reddish silt matrix; from inclusion of reddish silt till rich in fragments of Queenston Formation shale.		-2.1
N1814-C	ibid.	Upper till: grey silty clay matrix.		-3.4
N1870-A	Dissected Lake plain Fonthill-St. Johns West 400690	Ice margin deltaic? sand: extremely loamy fine sand; overlain in ascending stratigraphic order by 1½m of upper silt till and 7.3m of upper lacustrine deposits consisting of 4.3m of silty very fine sand with some interbedded clay, 1½m of clay with contorted layers of silt, and 1½m of nearshore fine-very fine sand (with sporadic pebbles) at top.	6.4	0 to -6.4

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N1871-1A	Pit in dissected Lake plain Fonthill-St.Johns West 402692	Ice margin deltaic? sand: very loamy fine sand; from current (to east-southeast) cross-laminated silty fine-very fine sand with few interbeds of clay and silt and inclusions of clay, silt, sand; overlain in ascending stratigraphic order by 0.9m of reddish brown upper silt till and 10.7m of upper lacustrine deposits.	7.6	-3.7
N1871-3A	ibid.	Upper lacustrine sand: very silty, very fine sand; from sandy silt-silty, very fine grained sand sequence, current (to east) cross-laminated along various horizons and with a few interbeds of silt and clay at base; overlain by 3.4m of laminated upper lacustrine clay with interbedded-laminated sand and silt in lower part, and 0.9m of upper lacustrine nearshore sand (with sporadic pebbles) at top.	6.4	-5.2
N1871-3B	ibid.	Upper lacustrine sand: sandy silt-silty, very fine sand.		0 to -5.5
N1877	"Fonthill kame" -lake plain east of Fonthill 410677	Upper lacustrine spit gravel: pebbly gravel; from 1.1m of gravel with interbedded medium-coarse sand overlying 0.8m of pebbly fine-medium sand; spit attached to eastside of ice margin delta possibly at junction with buried Niagara Falls Moraine east of Fonthill.	1.9	-0.9

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N1879-14	Dissected lake plain Fonthill-Turners Corners 409682	Upper lacustrine sand-silt: slightly sandy silt; from parallel-and contorted stratified buff and reddish brown silty, very fine sand and sandy silt with some layers and inclusions of clay and clayey silt; overlain by 3.4m of upper lacustrine clay with interlayered very fine sand at base, being contorted laminated reddish brown and grey clay and reddish brown and buff silt (clay>silt) in lower part, and weathered greyish brown massive clay in upper part of unit.	3.4	-0.6
N1881	"Fonthill kame" -lake plain east of Fonthill 409674	Upper lacustrine spit gravel: cobbly gravel; overlies 1.2m of interlaminated very fine sand and silt; possibly on buried Niagara Falls Moraine.	0.9	-0.8
N1887	Proximal side "Fonthill kame" at Fonthill 401676	Upper till: brown silt matrix; till is overlain by 1.8m of upper lacustrine silty very fine, laminated, sand with silt at base, and ½m of upper lacustrine nearshore weathered gravelly sand at top.	0.3	-0.3

LIST OF SAMPLES FROM MEASURED SECTIONS IN NIAGARA MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
N1896	Proximal side "Fonthill kame" at Fonthill 399673	Upper till: brown silt matrix; from till with bands of sand and silt exposed in sewer excavation possibly in buried Niagara Falls Moraine	3	-3
N1972-A	Lake Ontario shorebluff north of Beamsville 245834	Upper till: grey silt matrix; from grey silt till with bands of stratified, gravelly, medium-coarse sand; overlain by 0.9m of Lake Iroquois fine sand.	2.7	-2.1
N1972-B	ibid.	Upper till: grey silt matrix.		-2.7
N2346-A,-B	Proximal side "Fonthill kame" at Fonthill 400673	Upper till: greyish brown-grey silt matrix; from fissile till with bands of reddish fine sand and silt exposed in sewer excavation possibly in buried Niagara Falls Moraine; upper till with intercalated sand and silt is more than 5½m thick (boring); overlain by 1.2m of upper lacustrine sand and gravel (thin, at base) and laminated silt and very fine sand.	2.1	-1.7
N2446	St. Davids Sand & Gravel Limited Pit 1 Area 1 at City of Niagara Falls 545779	Lower till: gravelly, with reddish silt-sandy silt matrix; rests on glacially eroded Lockport Formation (Gasport Member) bedrock surface with striae in N10E-S10W to N25E-S25W directions; overlain by gravelly sand.	0.6	-0.3
N2526	Cemetery Stanley Ave. at Bridge St., Niagara Falls 555743	Upper lacustrine beach gravel: faintly stratified, loamy; upper 0.6m of sequence consists of gravelly, fine-medium sand.	1.8	-1.2

APPENDIX B: LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W1-A	Townline Tunnel E City of Welland 459577	Lower till: gravelly, grey sandy silt matrix; overlies dolostone and interbedded gypsum (Salina Formation) with glacially polished and N50-70E striated surface.	1.2	+0.6
W1-B	ibid	Lower lacustrine: massive, reddish brown silty clay with few gravel-size fragments; overlies laminated, reddish brown clay and interbedded sand, silt at contact with the lower till.	1.2	+0.6
W2-A	Pleasant Beach 541467	Recent eolian fine sand (Lake Erie shore dune): buff and grey, leached (only 3½% CaO soluble in HCl), horizontally stratified.	3.7	-2.4
W3-A,-B	ibid	Recent eolian fine sand (Lake Erie shore dune): buff and grey, leached (only 1½% CaO soluble HCl), horizontally stratified.	13½	
W5-A	ibid	Recent eolian fine sand (Lake Erie shore dune): buff and grey, leached (only 4½% CaO soluble in HCl), massive.	18	-0.6 to -1½
W7-C	Relocated Welland Canal Ramey's Bend 436539	Lower till: gravelly, grey sandy silt matrix; overlies dolostone and shale, interbedded, with nodular gypsum (Salina Formation).	0.6	+0.3
W7-E	ibid	Upper till: reddish brown silty clay matrix, incorporated clay and silt; overlies in descending stratigraphic order laminated, grey and red, lower lacustrine clay and silt, and lower till.	6	+0.6

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W7-D	ibid	Upper till.		+1.8
W7-B	ibid	Upper till.		+2.7
W16	Fort Erie Moraine at Cooks Mills 485616	Upper till: reddish brown clayey silt matrix.	3.7	-3.7
W47-A	Fort Erie Moraine Netherby-Cooks Mills 498601	Upper lacustrine beach gravel: interbedded gravel and gravelly sand over fine sand forming a narrow ridge on end moraine; overlies reddish brown silt resting on upper till.	1½	-1.2
W47-B	ibid	Upper till: reddish brown silt matrix; inclusions of reddish brown silt and very fine sand.	2.7	-0.9
W63-A	Townline Tunnel E City of Welland 465578	Upper till: reddish brown silty clay matrix; overlies contorted stratified lower lacustrine grey, red clay and silt.	5½	-0.9
W69-A	Fort Erie Moraine N. of Townline Tunnel E 483587	Upper lacustrine nearshore sand: fine and very fine grained, silty, stratified; overlain by thin layer of clay, grades westward and possibly downward into silt.	0.9	-0.3 to -0.6
W69-B	ibid 484587	Upper lacustrine beach sand: gravelly, massive; forms surficial veneer overlying thin clay.	0.9	-0.6
W69-C	ibid 487585	Upper lacustrine beach sand: medium grained, slightly gravelly, stratified; overlain by very gravelly sand; sands form ridge on end moraine.	4.9	-4.9

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W74	Fort Erie Moraine N. of Townline Tunnel E 485592	Upper lacustrine beach sand: very gravelly, slight cementation; from same ridge as sample W69-C.	0.9	-0.6
W77-A	Fort Erie Moraine Netherby-Cooks Mills 501598	Upper till: reddish- and grey brown clayey silt matrix, boulder-size inclusions of sand and silt; uneven till surface covered by upper lacustrine very fine sand, silt and clay, and upper lacustrine beach deposits.	3	-2.4
W77-B	ibid	Upper till.		-3
W77-C	ibid	Upper lacustrine beach sand: slightly gravelly, fine to medium grained; from lower part of sequence consisting of weathered, massive, gravelly sand (surficial veneer on endmoraine ridge) over horizontally- and cross-stratified gravelly sands (cut-and-fill structure in lacustrine silts).	1.8	-1 to -1½
W150-B	Waverly Beach S. of Fort Erie Moraine, Fort Erie 678498	Upper till: grey brown silt matrix; probably about 1.8m thick and overlying Devonian limestone bedrock; overlain by about 3.7m of stratified upper lacustrine reddish- and grey brown clay and silt.	0.9	-0.3
W156	Onondaga Escarpment at Mulgrave 552534	Upper lacustrine beach sand: very gravelly, weathered, massive; forms thin veneer locally on ridge consisting of upper till and Devonian limestone bedrock.	0.9	-0.3 to -0.9

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W175-D	Highway 3 at Buffalo Road, Town of Fort Erie, distal side Fort Erie Moraine 657520	Upper till: fairly gravelly, grey brown silt matrix; overlies Devonian cherty limestone and shale bedrock; overlain by about 1.2 m of upper lacustrine reddish brown clay and 1.2 m of road-fill.	½	+0.3
W185-A	North of Highway 3 at Onondaga Esc. 603526	Upper lacustrine beach gravel: interbedded gravel and gravelly sand; from ridge on upper till and Devonian limestone bedrock.	2.4	-0.9 to -1.8
W185-B	ibid	Upper lacustrine beach sand: very gravelly, very coarse to coarse grained; from lower part of sequence composed of interbedded gravel and gravelly sand.		-1½
W265	Abino Hills 547458	Recent eolian fine sand (Lake Erie shore dune): buff, massive.	15	-9
W268-B	Distal slope of Crystal Beach Moraine, west of Crystal Beach 556483	Upper till: fairly gravelly, brown sandy silt matrix; overlain by about 0.9 m of upper lacustrine beach gravelly sand underlying terrace wave-cut into upper till of Crystal Beach Moraine.	0.9	-0.3
W276-B	Distal slope of Crystal Beach Moraine at Crystal Beach 575481	Upper till: brown silt matrix.	2.1	-2.1

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W334-A	Buried Onondaga Esc. at re-entrant N. of Gasline 477522	Upper lacustrine beach gravel: very sandy; from lower part of sequence composed of massive gravelly sand in upper part and interbedded fine-,slightly gravelly fine to medium-,and slightly gravelly coarse to very coarse sand, and gravel in lower part; overlies massive and faintly stratified clay.	2.1	-1.7 to -2.1
W334-B	ibid	Upper lacustrine beach sand: from fine grained layer.		-1.7
W334-C	ibid	Upper lacustrine beach sand: from slightly gravelly, fine to medium grained layer.		-1.8
W334-D	ibid	Upper lacustrine beach sand: from slightly gravelly, coarse to very coarse grained layer.		-2.1
W358	Buried Onondaga Esc. at re-entrant N. of Gasline 495517	Upper lacustrine beach gravel: very sandy; from narrow ridge composed of gravelly sand and sandy gravel; overlies upper lacustrine clay and silt.	0.9	-0.8
W456-A	Ridgemount Quarries Ltd. 627530	Upper till: reddish brown silt matrix; overlies Devonian cherty limestone bedrock; undulating upper surface of till may indicate buried Fort Erie Moraine; depression filled with contorted stratified upper lacustrine reddish- and grey brown clay and silt.	3½	+0.3
W474	ibid 628527	Upper till: buff silt matrix; overlies Devonian bedrock.	3½	+0.6

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W528-B	N. of Cassaday-Pine Crest Point area, City of Port Colborne 463490	Lower(?) till: gravelly, greyish brown sandy silt matrix; overlies Devonian cherty (black) limestone in N34E - aligned gouge in bedrock surface; overlain by 0.6m of weathered, gravelly, sandy silt (reworked till).	0.6	+0.3
W556	Gravelly Bay area, City of Port Colborne 445483	Recent eolian fine sand (Lake Erie shore dune): buff and grey, horizontally stratified.	1.8	-1½
W597-A	Pleasant Beach east of Shisler Point 532471	Recent Lake Erie beach sand: mainly fine grained, very slightly gravelly; very fine to medium grained fractions form source of eolian sand in Lake Erie shore dunes.	0.9	-0.3 to -0.6
W600-A	Empire Beach west of Shisler Point 518475	Recent Lake Erie beach gravel: pebble-count from small to large pebble-size gravel layer in inter-bedded gravel and gravelly sand sequence; beach deposits overlie N35E - striated Devonian bedrock surface.	0.9	0
W600-B	ibid	Recent Lake Erie beach gravel: small to large pebble-size gravel.		0
W600-C	ibid	Recent Lake Erie beach gravel: granule-size gravel.		0 to -0.3
W600-D	ibid	Recent Lake Erie beach gravel: pebbly, sandy, granule-size gravel.		0 to -0.3

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W616-B	Buried Onondaga Esc. at Niagara Junction, Town of Fort Erie 673550	Lower(?)till: gravelly, grey sandy silt matrix; with bands of sand possibly incorporated from underlying material; overlies Bertie Formation dolostone bedrock with N40E striated surface; overlain by upper lacustrine clay and silt.	1½	+0.6
W626-A	Fort Erie Moraine west of Queen Elizabeth Way 671528	Upper till: brown silt matrix; near crest of Fort Erie Moraine; adjacent boring indicates 4.6m of brown upper till with bands of sand, gravel in lower part over 4.9m of grey upper till.	3.4	-1.8
W627-C	Distal side Fort Erie Moraine, Queen Elizabeth Way 666522	Upper till: buff silt matrix; overlain by upper lacustrine reworked-till and clay, and road-fill (2.4 m); adjacent boring indicates only 4.3m of drift over bedrock.	0.6	-0.6
W679-A	Fort Erie Moraine at Queen Elizabeth Way, Fort Erie 681529	Upper Till: grey silt matrix; at crest of Fort Erie Moraine; adjacent borings indicate about 9.1m of upper till over bedrock.	6.1	-4.3
W679-B	ibid	Upper till: brown silt matrix;		-3
W679-C	ibid	Upper till: brown silt matrix;		-2.9

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W706-A,-B	Abandoned pit Sherkston Beach Ltd., L.Erie shore along Silver Bay 507483	Recent eolian sand (Lake Erie shore dune): from fine grained layers in horizontally- and cross-stratified, buff and greyish, fine and medium grained sands; upper 2.9m leached of carbonates, buried weathering-profile from -3½m to -5.3m ; eolian sands overlie beach deposits at base of pit.	11½	-3.2
W706-C	ibid	Recent eolian sand (Lake Erie shore dune): medium grained.		-6
W706-D	ibid	Recent eolian sand (Lake Erie shore dune); fine grained.		-10½ to -11½
W706-E	ibid	Recent beach sand (Lake Erie shore): from fine to medium grained layer in horizontally stratified sands with a few interbeds of gravel.	0.6	-12
W731-B	L.Erie shore at Grabell Point 326466	Recent beach gravel (Lake Erie shore): pebble count from gravel layer in interbedded gravel and gravelly sand sequence; overlies Devonian limestone bedrock lake-ward but stratified silts land-ward.	0 to 0.6	0 to -0.2
W732-A	L.Erie shore N. of Rock Island 285476	Recent beach gravel (Lake Erie shore): pebble count from gravel layer in interbedded gravel and gravelly sand sequence.	0.9	0 to -0.2
W732-B	ibid	Recent beach gravel (Lake Erie shore): granule-size.		-0.2

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W762	Fossil dune field W. of Wainfleet 240540	Eolian sand: fine to very fine grained, silty; sand in low, parabolic ridge is weathered orange-brown and massive in upper 0.9m , greyish and horizontally stratified in lower part of section.	1½	-1.2
W763-A	Fossil dune field W.of Wainfleet 233524	Deltaic sand: fine to very fine grained, silty; upper part is near-horizontally stratifed and contains some interlaminated silts, lower part (sample) is current (to E.) cross-stratified and overlies horizontally stratified upper lacustrine clay and silt; this fine to very fine grained deltaic sand was later windblown into dune ridges.	0.9	-0.8
W764	Fossil dune field W.of Wainfleet 229523	Eolian sand: fine to very fine grained, massive; from low, parabolic ridge.	1½	-1½
W765-A	Lake Erie shore near Lowbanks 258471	Upper till: brown, reddish brown clayey silt matrix; overlain by very thin veneer of gravel.	1.2	-1.1
W765-C	ibid	Recent beach gravel (Lake Erie shore): pebble count from gravel layer in interbedded gravel and gravelly sand sequence.	1½	0 to -0.2
W768-A	Lake Erie shore bluff west of Mohawk Point 226445	Upper till: red- and grey brown silty clay matrix; uneven upper till surface (buried end moraine ?) covered by upper lacustrine clay and silt up to about 5½ m thick.	8.2	-2

LIST OF SAMPLES FROM MEASURED SECTIONS IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W768-D	ibid	Upper till: red-and grey brown silty clay matrix.	8.2	-3.7
W768-C	ibid	Recent beach gravel (Lake Erie shore): pebble count from gravel layer in interbedded gravel and gravelly sand sequence overlying upper till at base of shore bluff.	0.9	0 to -0.2
W769-B	Lake Erie shore bluff west of Mohawk Point 231444	Upper till: greyish bluff silt matrix; from till layer within contorted-stratified upper lacustrine clay and silt, up to about 6.1 m thick, in-filling depression in uneven upper till surface (buried end moraine ?).		
W769-C	ibid	Upper till: greyish brown silty clay matrix.	7.6	-2.4
W769-D	ibid	Upper till: greyish brown clayey silt matrix.		-7.3
W784	Lake Erie shore bluff north of Mohawk Point 245451	Upper till: brown, reddish brown, clayey silt matrix; northern flank of till-ridge (end moraine ?) up to 15m high on buried Onondaga Escarpment; till at bluff exposure covered by 1.2 m of upper lacustrine clay, silt with interbedded till.	7.9	-1.8
W1002	Onondaga Esc. north of Morgans Point 351470	Upper lacustrine beach gravel: from interbedded gravel and gravelly sand forming short and narrow ridge ;overlies ½m of massive silt on Devonian bedrock.	1½	-0.6 to -1½

LIST OF SAMPLES FROM MEASURED SECTION IN WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
W1006	Onondaga Esc., R.E. Law Crushed Stone Ltd. quarry W. of Port Colborne 389506	Lower(?) till: gravelly, reddish brown sandy silt matrix; overlain by upper (?) lacustrine reddish brown clay; overlies Devonian cherty limestone bedrock.	1.8	-1.2
W2418	Farr Rd., east of relocated Welland Canal near E. Main St., City of Welland 463618	Upper lacustrine beach gravel: weathered sandy, silty gravel; from interbedded gravel and gravelly sand forming short and narrow ridge on upper till of possibly Fort Erie Moraine.	1½	-0.6 to -1.2

APPENDIX C: LIST OF SAMPLES FROM STRATIGRAPHIC BORINGS IN THE BURIED ST. DAVIDS CHANNEL, NIAGARA MAP-AREA, BY THE DEPARTMENT OF PUBLIC WORKS, OTTAWA, FOR THE GEOLOGICAL SURVEY OF CANADA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
WH3-48	H.E.P.C. Canal #2 east of Whirlpool Road, Niagara Falls 561769	Upper till: brown silt matrix; from silt till with incorporated silt and clay; overlies in descending stratigraphic order 12m of lower? lacustrine stratified reddish brown clay and silt, 1m of gravel, and 1m of lower? till; overlain in ascending stratigraphic order by 1½m of loamy gravel, 11m of upper lacustrine stratified buff, reddish, grey silt, very fine sand, and clay, and 1½m of fill at top.	1½	-0.3
WH3-58	ibid.	Lower till: gravelly, reddish brown sandy-clayey silt matrix; overlies in descending stratigraphic order 21½-22m of Middle-Late Wisconsinan fluviatile-lacustrine deposits (sand, greenish grey clay and silt) the lower part of which is pollen-bearing, and 7-7½m of gravel resting on bedrock (Grimsby Formation?).	1.2	-0.6
WH6-2	Lake Iroquois terrace south-east of Virgil 546857	Upper till: brown silt matrix; from brown (upper 5m), grey, and reddish (at base) silt (upper 13m)-silty clay (lower 6m) till with 2m of intercalated grey silt and silty very fine sand at 8-10m below surface; overlies in descending stratigraphic order 3½-4m of stratified, grey and red lower? lacustrine clay and silt, and 1½m of gravelly lower? till resting on bedrock (Queenston Formation red shale).	19.2	-3.2
WH6-4	ibid.	Upper till: grey silt matrix.		-6.3
WH6-5A	ibid.	Upper till: grey silt matrix.		-7.8

LIST OF SAMPLES FROM STRATIGRAPHIC BORINGS IN THE BURIED ST. DAVID'S CHANNEL, NIAGARA MAP-AREA, BY THE DEPARTMENT OF PUBLIC WORKS, OTTAWA, FOR THE GEOLOGICAL SURVEY OF CANADA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
WII6-7	ibid.	Upper till: grey silt matrix		-11
WII6-8B	ibid.	Upper till: grey silt matrix.		-12½
WII6-9	ibid.	Upper till: grey silty clay matrix.		-13.9
WII6-10	ibid.	Upper till: grey silty clay matrix.		-15.4
WII8-36	Lake Iroquois terrace north-east of Virgil 544884	Upper till: grey silt matrix; from grey silt (upper 2½m)-silty clay till with incorporated clay and silt; overlies 8m of gravelly, buff and grey sandy-silty lower? till resting on bedrock (Queenston Formation red shale); overlain by 3m of stratified sand, silt, and clay deposited in Lake Iroquois.	7.6	-0.2
WII8-37	ibid.	Upper till: grey silt matrix.		-1.8
WII8-38A	ibid.	Upper till: grey silty clay matrix.		-3.2
WII8-38B	ibid.	Upper till: grey silty clay matrix.		-3.4
WII8-40A	ibid.	Upper till: grey silty clay matrix.		-6
WII9-50B	Department of National Defence Rifle Range, Niagara-on-the Lake 543910	Lower? till: gravelly, grey and reddish silt-sandy silt matrix; from gravelly, grey and reddish silt (at top)-sandy till; overlies bedrock (Queenston Formation red shale); is overlain by 0.3m of grey glaciolacustrine clay with interlaminated clast-rich reddish silt, and 4.6m of stratified sand, silt and clay deposited in Lake Iroquois.	4.9	-0.2

LIST OF SAMPLES FROM STRATIGRAPHIC BORINGS IN THE BURIED ST. DAVID'S CHANNEL, NIAGARA MAP-AREA, BY THE DEPARTMENT OF PUBLIC WORKS, OTTAWA, FOR THE GEOLOGICAL SURVEY OF CANADA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
WII9-51	ibid.	Lower till: gravelly, grey and reddish loamy sand matrix; from similar coarse textured till with abundant fragments of Queenston Formation shale.		-1½

APPENDIX D: LIST OF SAMPLES FROM TESTBORINGS BY H.Q. GOLDER AND ASSOCIATES FOR CONSTRUCTION OF THE MAIN ST. EAST TUNNEL, RELOCATED WELLAND CANAL, CITY OF WELLAND, WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
T-101-9	45786142			-5.2
T-101-13	ibid	Upper till: brown, reddish brown clayey silt matrix; samples combined for analysis; overlain by about 7m of upper lacustrine, massive or faintly laminated clay, interbedded silt at base; underlain by about 4m of lower lacustrine, laminated, reddish buff silt and very fine sand.	15	-11.3
T-101-20	ibid	Middle till (?): massive, brown or reddish brown clayey silt; overlies in descending stratigraphic order: lower lacustrine laminated clay (5.2 m), lower till (0.6m), and Salina Formation bedrock.	5	-1.8
T-102-6B	45636141			-0.9
T-102-8	ibid	Upper till: brown, reddish brown clayey silt matrix; samples combined for analysis; overlain by about 7m of upper lacustrine, massive or faintly laminated clay, interlayered silt and sand at base; underlain by about 8m of lower lacustrine, laminated, buff and reddish, silt and sand over clay.	9.2	-3.7
T-102-20	ibid			-0.6
T-102-22	ibid	Middle till (?): massive, brown or reddish brown clayey silt; overlies lower lacustrine clay and silt (5m) and lower till (0.6 m); samples combined for analysis.	7	-4

LIST OF SAMPLES FROM TEST BORINGS BY H.Q. GOLDER AND ASSOCIATES FOR CONSTRUCTION OF THE MAIN ST. EAST TUNNEL, RELOCATED WELLAND CANAL, CITY OF WELLAND, WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
T-104-11	45476137	Upper till: brown, reddish brown clayey silt matrix; samples combined for analysis; overlain by about 5m of upper lacustrine, massive or laminated, brown reddish brown and grey clay; underlain by about 6m of lower lacustrine, brown, red and grey massive clayey silt and laminated clay.	13.4	-8.8
T-104-13	ibid			-11.9
T-104-21	ibid	Lower till: grey, reddish brown sandy silt matrix; thin bands of sand; samples combined for analysis.	6	-4.6
T-104-22	ibid			-6
T-106-19	45156147	Middle till (?): massive reddish brown clayey silt; overlain in ascending stratigraphic order by 3.7m of lower lacustrine reddish buff sandy silts, 9.2m of upper till, and 6.1m of upper lacustrine, brown, red and grey, massive (upper part) and laminated (lower part) clay; underlain in descending stratigraphic order by 5m of lower lacustrine reddish buff and grey fine sands with interlaminated silt in upper part, and 1.8 m of lower till.	8	-5.2
T-107A-10	45086143	Upper till: brown clayey silt matrix; overlain by about 6.7m of brown, reddish and grey upper lacustrine massive clayey silt-silty clay (upper part) and laminated clay.	7.6	-5.2

LIST OF SAMPLES FROM TESTBORINGS BY H.Q. GOLDER AND ASSOCIATES FOR CONSTRUCTION OF THE MAIN ST. EAST TUNNEL, RELOCATED WELLAND CANAL, CITY OF WELLAND, WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
T-108-15	44956139	Lower till: grey, sandy silt matrix; from gravelly till with grey or reddish brown, relatively coarser grained silt matrix; upper contact with grey, very fine grained silty sand (lower lacustrine) at -21.7m .	5½	-0.9
T-123-15	45456140	Upper till: brown clayey silt matrix; samples combined for analysis; overlain by about 6m of brown upper lacustrine massive - faintly laminated silty clay-clayey silt with interlayered silt and very fine sand in lower part; underlain by about 3.7m of brown, red and grey lower lacustrine massive clayey silt and laminated clay, 9.2m of grey, reddish brown lower till, and Salina Formation bedrock.	12½	-3.7
T-123-17	ibid			-5
T-124-20	45366140	Lower till: reddish grey sandy silt matrix; from inclusion within 20.7m thick lower lacustrine sequence with upper- and lower contacts at respectively -13.4m and -34 m .	2.4	-8
T-126-9	45246140	Upper till: reddish brown, clayey silt matrix; samples combined for analysis; overlain by about 6.7m of brown, red and grey upper lacustrine clay, silt; underlain by 8m of lower lacustrine clay and silt over very fine silty sand, 6.7m of reddish brown and grey lower till, and Salina Formation bedrock.	12.8	-5½
T-126-13	ibid			-8½

LIST OF SAMPLES FROM TESTBORINGS BY H.Q. GOLDER AND ASSOCIATES FOR CONSTRUCTION OF THE MAIN ST. EAST TUNNEL, RELOCATED WELLAND CANAL, CITY OF WELLAND, WELLAND MAP-AREA

SAMPLE NO.	LOCATION	DESCRIPTION	THICKNESS m	DEPTH m
T-201-12	45576134	Middle till (?): brown, reddish brown massive clayey silt; samples combined for analysis; upper contact with lower lacustrine silt and very fine sand at - 26m , lower contact with lower lacustrine clay and silt at - 32m .	6	-2.4
T-201-13	ibid			-3
T-201-20B	ibid	Lower till: gravelly, grey and reddish brown sandy silt matrix; samples combined for analysis; upper contact with lower lacustrine clay and silt at - 34½m .	1.2	-0.3
T-201-21	ibid			-0.9
T-202-7	45066149	Lower till: grey, reddish brown sandy silt matrix; thin bands of grey sand; samples combined for analysis; upper contact with reddish buff and grey lower lacustrine fine to very fine grained silty sands at -18.3m .	5	-0.3
T-202-8	ibid			-0.9
T-203-24	45066134	Lower till: gravelly, reddish brown sandy silt matrix; upper contact with reddish buff and grey lower lacustrine very fine grained silty sands at -30½m .	3.7	-3.4

APPENDIX E : RESULTS OF TILL ANALYSES (NIAGARA MAP AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
N32	U	19	57	24	13.0	8.2	-	-	-	-	-	-	2.8
N35	U	15	62	23	11.2	11.0	-	-	-	-	-	-	4.1
N42-A	U	20	65	15	12.8	6.6	-	-	-	-	-	-	4.5
N42-B	U	34	48	18	13.3	7.4	-	-	-	-	-	-	4.1
N42-C	U	29	55	16	13.8	5.3	-	-	-	-	-	-	6.2
N42-D	U	37	44	19	11.6	7.5	-	-	-	-	-	-	3.5
N48	U	25	48	27	9.0	4.0	-	-	-	-	-	-	4.2
N63-A	U	18	58	24	8.3	7.4	-	-	-	-	-	-	4.2
N67	U	28	52	20	7.9	7.4	-	-	-	-	-	-	3.2
N68-C	U	27	52	21	8.8	7.0	-	-	-	-	-	-	4.7
N71-A	U	10	47	43	9.2	8.7	-	-	-	-	-	-	4.3
N73-A	U	5	74	21	8.9	9.7	47	29	76	42	63	11	2.9
N73-B	U	5	70	25	9.7	7.4	-	-	-	-	-	-	-
N73-C	U	11	65	24	9.1	11.0	42	52	86	42	68	10	6.3
N73-D	U	9	65	26	10.2	9.2	-	-	-	-	-	-	-
N73-E	U	24	52	24	9.0	16.9	-	-	-	-	-	-	-
N73-F	U	20	63	17	10.8	11.3	34	29	74	40	64	13	3.5
N165	U	4	42	54	13.6	10.9	-	-	-	-	-	-	2.8
N210	U	28	53	19	9.3	6.6	58	34	99	44	74	14	5.2
N211-A	U	12	73	15	6.5	9.8	58	(25)	94	36	57	11	3.9
N211-B	U	24	61	15	6.7	8.7	-	-	-	-	-	-	4.9
N211-C	U	14	65	21	6.4	10.0	-	-	-	-	-	-	3.6

* U - Upper or Halton Till
L - Lower till

RESULTS OF TILL ANALYSES (NIAGARA MAP-AREA SAMPLES) : TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
N211-D	U	26	63	11	7.9	7.3	52	(25)	74	36	51	11	4.3
N211-E	U	28	56	16	6.6	8.8	-	-	-	-	-	-	4.9
N211-F	U	19	49	32	8.5	8.1	-	-	-	-	-	-	4.2
N211-G	U	32	59	9	6.8	9.4	42	29	74	35	55	11	3.2
N216-A	U	13	54	33	10.3	6.3	49	(25)	87	46	81	14	4.1
N216-B	U	11	49	40	9.2	5.8	-	-	-	-	-	-	4.2
N216-C	U	14	58	28	8.9	7.3	-	-	-	-	-	-	3.3
N216-D	U	13	61	26	8.6	8.6	-	-	-	-	-	-	-
N216-E	U	24	60	16	6.3	8.9	66	27	80	38	58	13	2.8
N230-A	U	15	58	27	8.8	7.6	75	32	107	46	74	13	5.3
N291-A	U	22	58	20	9.0	6.4	50	(25)	84	42	70	10	4.8
N291-B	U	16	55	29	7.4	7.9	41	(25)	80	46	73	15	6.3
N291-C	U	24	58	18	7.0	8.6	45	(25)	78	40	65	13	7.2
N407	U	25	51	24	9.6	5.9	50	29	93	38	64	9	3.4
N419	U	10	46	44	8.6	5.9	40	(25)	84	44	76	13	4.2
N461	U	18	53	29	9.2	8.5	44	31	83	44	76	12	4.5
N466-A	L?	36	54	10	7.4	5.8	43	(25)	71	32	55	10	3.6
N467	U	22	62	16	6.9	6.8	44	(25)	70	40	67	11	3.4
N483	U	18	49	33	7.5	7.1	36	(25)	78	44	80	15	3.9
N491	U	18	49	33	8.8	3.9	39	(25)	79	43	74	12	3.9
N501	U	14	52	34	8.1	6.5	38	38	80	40	74	9	3.0
N839-A	U	12	64	24	9.6	9.2	-	-	-	-	-	-	3.7

* U - Upper or Halton Till
L - Lower till

RESULTS OF TILL ANALYSES (NIAGARA MAP-AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
N839-B	U	37	45	18	9.2	10.6	-	-	-	-	-	-	3.9
N839-C	U	19	57	24	9.6	10.8	-	-	-	-	-	-	3.9
N839-D	U	14	56	30	10.3	10.4	-	-	-	-	-	-	4.7
N855-A	U	28	56	16	8.0	7.8	-	-	-	-	-	-	3.4
N855-B	U	19	55	26	8.2	7.7	-	-	-	-	-	-	3.7
N855-C	L?	38	60	2	6.8	11.8	-	-	-	-	-	-	4.2
N1032	U	16	69	15	9.7	6.3	-	-	-	-	-	-	4.2
N1067-A	U	21	67	12	7.8	9.2	-	-	-	-	-	-	4.6
N1067-B	U	17	64	19	8.8	9.2	-	-	-	-	-	-	4.6
N1067-C	U	19	69	12	8.7	9.7	-	-	-	-	-	-	4.8
N1067-D	U	22	67	11	11.4	9.1	-	-	-	-	-	-	4.6
N1767-6	U	58	30	12	18.8	7.8	-	-	-	-	-	-	5.0
N1814-A	U	8	45	47	12.2	8.2	-	-	-	-	-	-	3.6
N1814-B	U	19	56	25	15.4	9.4	-	-	-	-	-	-	3.8
N1814-C	U	7	45	48	9.6	10.9	-	-	-	-	-	-	4.2
N1887	U	16	55	29	9.4	7.6	-	-	-	-	-	-	4.4
N1896	U	20	61	19	6.5	10.8	-	-	-	-	-	-	4.7
N1972-A	U	21	47	32	10.2	6.7	44	32	80	46	80	13	4.7
N1972-B	U	28	55	17	7.6	6.9	38	31	69	38	57	13	4.8
N2346-A	U	20	57	23	6.5	11.9	-	-	-	-	-	-	5.6
N2346-B	U	19	58	23	7.4	9.7	-	-	-	-	-	-	4.7
N2446	L	31	53	16	6.9	11.1	-	-	-	-	-	-	5.3

*U - Upper or Halton Till
L - Lower till

RESULTS OF TILL ANALYSES (NIAGARA MAP-AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
WH3-48	U	17	61	22	8.7	8.3	-	-	-	-	-	-	5.7
WH3-58	L	33	48	19	9.7	12.9	-	-	-	-	-	-	4.7
WH6-2	U	16	53	31	7.3	11.3	-	-	-	-	-	-	4.1
WH6-4	U	16	53	31	8.5	9.7	-	-	-	-	-	-	4.1
WH6-5A	U	17	57	26	7.3	10.7	-	-	-	-	-	-	4.5
WH6-7	U	21	57	22	6.9	12.0	-	-	-	-	-	-	4.0
WH6-8B	U	22	58	20	6.6	13.3	-	-	-	-	-	-	4.8
WH6-9	U	5	59	36	7.6	11.1	-	-	-	-	-	-	3.9
WH6-10	U	4	58	38	8.9	10.7	-	-	-	-	-	-	5.4
WH8-36	U	17	50	33	8.1	11.1	-	-	-	-	-	-	4.3
WH8-37	U	16	50	34	8.6	11.0	-	-	-	-	-	-	4.7
WH8-38A	U	5	42	53	8.9	9.6	-	-	-	-	-	-	4.5
WH8-38B	U	4	54	42	8.4	10.2	-	-	-	-	-	-	4.8
WH8-40A	U	5	57	38	9.1	9.1	-	-	-	-	-	-	4.3
WH9-50B	L?	33	58	9	8.3	10.8	-	-	-	-	-	-	3.9
WH9-51	L	57	35	8	7.1	9.6	-	-	-	-	-	-	4.5

* U - Upper or Halton Till
L - Lower till

APPENDIX F: RESULTS OF TILL ANALYSES (NIAGARA MAP-AREA SAMPLES): PEBBLE LITHOLOGY

SAMPLE NO.	TILL*	PEBBLE LITHOLOGY 8-32mm						
		% LIMESTONE	% CHERT	% DOLOSTONE	% DOLOSTONE + SAND-SILTSTONE	% SAND-SILTSTONE	% SHALE	% IGNEOUS-METAMORPHIC
N32	U	9	0	53		16.5	18	3.5
N67	U	28.5	0	48.5		5	13	5
N73-A	U	27	0	64.5		4.5	3	1
N73-C	U	15	0	73		5	3	4
N73-F	U	44	0	50		2	4	0
N210	U	41	0	26		9	17	7
N211-A	U	11.5	0		60.5		25	3
N211-F	U	14	0		65		14	7
N211-G	U	12	0		74		12	2
N216-A	U	19.5	0		48		28	4.5
N230-A	U	13	0		67.5		13	6.5
N291-A	U	27	0	40		3	27	4
N291-B	U	22	0		51.5		24	2.5
N437	U	26	0	40		15	13	6
N461	U	10	0		30		56	4
N466-A	L?	15.5	0		81.5		2	1
N483	U	9	0		73		13	5
N863	U	3	0		75		19	3
N1032	U	13	0		44		38	5
N1067-A	U	14	0		62		22	2
N1092	U	0	0		91		2	7
N1767-6	U	6	0		85		1.5	7.5
N1972-A	U	16	0	11		54	15	4

*U - Upper or Halton Till

APPENDIX G: RESULTS OF TILL ANALYSES (WELLAND MAP-AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
W1-A	L	41	39	20	5.2	26.5	21	46	92	25	43	7	4.4
W7-B	U	1	41	58	9.1	9.3	-	-	-	-	-	-	5.0
W7-C	L	36	44	20	7.3	34.0	-	-	-	-	-	-	4.2
W7-D	U	1	40	59	9.0	9.2	-	-	-	-	-	-	4.0
W7-E	U	2	38	60	9.7	8.2	-	-	-	-	-	-	5.2
W16	U	7	59	34	10.9	12.8	-	-	-	-	-	-	-
W47-B	U	22	59	24	9.5	13.2	50	30	196	37	79	16	3.7
W63-A	U	2	56	42	12.4	7.9	48	(25)	85	33	72	16	4.9
W77-A	U	5	61	34	11.4	9.7	39	(25)	87	32	70	16	4.3
W77-B	U	8	60	32	10.4	12.7	36	(25)	88	33	69	16	4.0
W150-B	U	27	45	28	13.4	18.0	39	27	98	27	64	10	5.1
W175-D	U	25	51	24	15.4	12.7	39	25	84	24	55	10	4.9
W268-B	U	31	45	24	9.4	26.3	-	-	-	-	-	-	3.8
W276-B	U	18	55	27	8.2	33.7	58	34	122	21	45	8	2.6
W456-A	U	25	51	24	8.0	27.2	49	28	120	22	51	8	3.5
W474	U	33	50	17	10.9	22.9	38	(25)	112	18	44	5	3.5

* U - Upper or Halton Till
L - Lower till

RESULTS OF TILL ANALYSES (WELLAND MAP-AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
W528-B	L?	40	37	23	4.2	31.6	39	(25)	99	18	35	6	3.2
W616-B	L?	45	46	9	5.1	27.5	32	(25)	126	16	32	6	3.0
W626-A	U	25	50	25	8.4	24.8	32	(25)	104	21	44	6	3.9
W627-C	U	32	50	18	8.9	23.2	28	(25)	104	16	38	6	2.6
W679-A	U	19	49	32	8.6	24.1	32	(25)	94	22	50	10	4.3
W679-B	U	19	47	34	9.3	23.8	29	(25)	88	22	48	6	3.9
W679-C	U	18	44	38	7.9	25.8	30	28	93	22	51	8	4.0
W765-A	U	16	48	36	10.2	18.4	75	(25)	116	30	64	12	3.5
W768-A	U	9	37	54	11.3	14.1	34	(25)	97	27	60	12	4.7
W768-D	U	8	40	52	11.7	14.1	42	25	95	31	67	12	7.7
W769-B	U	26	55	19	9.6	21.3	42	36	136	32	49	8	3.9
W769-C	U	7	38	55	10.6	15.9	34	25	106	29	64	12	4.9
W769-D	U	7	61	32	9.5	14.0	36	(25)	96	28	63	14	4.0
W784	U	19	51	30	8.8	16.0	34	25	91	27	64	10	3.2
W1006	L?	44	47	9	9.1	31.2	49	25	97	18	41	6	4.0
T101-9,-13	U	-	-	-	7.0	11.7	28	32	104	36	68	9	4.1
T102-6B,-8	U	-	-	-	7.5	19.6	96	54	129	29	48	9	4.1
T104-11,-13	U	-	-	-	7.0	16.6	-	-	-	-	-	-	3.5
T104-21,-22	L	-	-	-	5.5	27.6	-	-	-	-	-	-	4.3
T107A-10	U	-	-	-	7.1	16.8	-	-	-	-	-	-	2.8

RESULTS OF TILL ANALYSES (WELLAND MAP-AREA SAMPLES): TILL MATRIX

SAMPLE NO.	TILL*	TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERA 0.105-0.250 %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
T108-15	L	-	-	-	4.4	27.6	-	-	-	-	-	-	4.8
T123-15,-17	U	-	-	-	7.5	13.5	-	-	-	-	-	-	3.5
T124-20	L	-	-	-	6.4	27.4	34	(25)	177	23	34	7	5.2
T126-9,-13	U	-	-	-	7.9	11.1	52	38	106	35	60	11	-
T201-20B,-21	L	-	-	-	6.9	33.0	52	44	127	26	41	5	1.9
T202-7,-8	L	-	-	-	7.5	26.0	26	44	116	24	34	6	2.6
T203-24	L	-	-	-	7.1	26.8	-	-	-	-	-	-	2.8

* U - Upper or Halton Till
L - Lower till

APPENDIX H: RESULTS OF TILL ANALYSES (WELLAND MAP-AREA SAMPLES): PEBBLE LITHOLOGY

SAMPLE NO.	TILL*	PEBBLE LITHOLOGY 8-32mm					
		% LIMESTONE	% CHERT	% DOLOSTONE	% SAND-SILTSTONE	% SHALE	% IGNEOUS-METAMORPHIC
W1-A	L	1.5	0	95	0	0	3.5
W7-C	L	2	0	90	7	0.5	0.5
W47-B	U	11	0	73.5	3.5	1	11
W150-B	U	33	8	41	1	0	17
W456-A	U	7.5	0	80	6.5	1	5
W474	U	14.5	1	71	3.5	0	10
W528-B	L?	8.5	3	86.5	1	0	1
W616-B	L?	6.5	1	69.5	17	0	6
W765-A	U	1	0	93	3.5	0	2.5
W768-D	U	3.5	0	89	6	0	1.5
W784	U	4.5	0	89.5	5	0	1
W1006	L?	2.5	0	88.5	4	0	5

*U - Upper or Halton Till
L - Lower till

APPENDIX I : RESULTS OF ANALYSES ON TILL-LIKE CLAY- SILTY CLAY (NIAGARA-WELLAND MAP-AREA SAMPLES)

SAMPLE NO.		TEXTURE -2mm %			CARBONATES -0.074mm %		TRACE ELEMENTS -0.037mm ppm						HEAVY MINERALS 0.105-0.250mm %
		SAND	SILT	CLAY	CALCITE	DOLOMITE	COPPER	LEAD	ZINC	NICKEL	CHROMIUM	COBALT	TOTAL
N36-B	Upper & lower till-like clay-silty clay in Twelve Mile re-entrant	2	39	59	18.0	6.1	-	-	-	-	-	-	5.1
N36-C		2	37	61	14.7	6.8	-	-	-	-	-	-	5.4
N36-F		6	31	63	14.2	7.7	-	-	-	-	-	-	6.1
N41-A		10	47	43	13.8	4.8	-	-	-	-	-	-	4.3
N41-C		5	47	48	11.9	6.1	-	-	-	-	-	-	4.3
N115-A		2	31	67	13.7	6.3	-	-	-	-	-	-	-
N115-B		2	31	67	12.2	9.4	-	-	-	-	-	-	-
W1-B	Middle till-like clay-silt along new Welland Canal	3	41	56	8.8	7.3	45	(25)	112	44	73	13	-
T101-20		-	-	-	8.6	12.3	-	-	-	-	-	-	4.1
T102-20, -22		-	-	-	7.6	13.1	32	38	107	37	65	9	3.5
T106-19		-	-	-	7.8	10.0	-	-	-	-	-	-	2.2
T201-12, -13		-	-	-	7.7	12.0	35	30	104	40	66	10	3.7

APPENDIX J : RESULTS OF SAND AND GRAVEL ANALYSES (NIAGARA-WELLAND MAP-AREA SAMPLES): TEXTURE

DEPOSITIONAL ENVIRONMENT	SAMPLE NO.	LOCATION	TEXTURE						
			% GRAVEL <-1Ø	% SAND -1Ø to +4Ø	% SILT +4Ø to +9Ø	% CLAY >+9Ø	MEAN* (Ø)	SORTING† (Ø)	SKEWNESS**
BEACH-modern Lake Erie	W597-A	532471	5	94	1	0	+1.65	1.06	-0.92
	W600-B	518475	98	2	0	0	-3.41	0.63	-0.07
	W600-C	518475	76	24	0	0	-1.37	0.54	-0.03
	W600-D	518475	78	22	0	0	-0.90	1.10	+0.62
	W706-E	507483	0	99	1	0	+2.01	0.47	+0.08
	W732-B	285476	97	3	0	0	-1.53	0.39	-0.10
-proglacial lake	W69-B	484587	31	67	2	0	-0.44	2.34	-0.16
	W69-C	487585	1	97	2	0	+1.78	0.39	+0.90
	W77-C	501598	3	94	3	0	+1.78	1.15	-0.06
	W185-A	603526	75	20	4	1	-1.65	2.47	+0.07
	W185-B	603526	46	51	3	0	-0.77	1.94	+0.07
	W334-A	477522	57	41	2	0	-2.14	3.04	-0.30
	W334-B	477522	0	97	3	0	+2.53	0.58	0.00
	W334-C	477522	6	92	2	0	+1.74	0.98	-0.36
	W334-D	477522	12	87	1	0	-0.25	0.68	-0.03
	W358	495517	58	42	0	0	-1.22	1.58	+0.09
	W1002	351470	81	16	3	0	-2.37	1.70	+0.19
	W2418	463618	46	34	13	7	+0.26	4.55	+0.36

RESULTS OF SAND AND GRAVEL ANALYSES (NIAGARA-WELLAND MAP-AREA SAMPLES): TEXTURE

DEPOSITIONAL ENVIRONMENT	SAMPLE NO.	LOCATION	TEXTURE						
			% GRAVEL <-1Ø	% SAND -1Ø to +4Ø	% SILT +4Ø to +9Ø	% CLAY >+9Ø	MEAN* (Ø)	SORTING† (Ø)	SKEWNESS**
BEACH-proglacial lake	P66-51-9-3	424795	6	83	11	0	+3.02	1.27	-0.12
	P66-51-11-4	426794	87	10	3	0	-2.75	1.45	+0.94
	P66-51-15-2	425792	85	14	1	0	-2.62	1.56	+0.95
	P66-51-15-5	425792	26	69	3	2	+0.22	2.01	+0.23
DELTA-ancestral Grand R.	W763-A	233524	0	80	18	2	+3.46	0.67	+0.14
-ice marginal	N1870-A	400690	0	51	46	3	+4.12	1.26	+0.34
	N1871-1A	402692	0	73	24	3	+3.55	1.25	+0.49
DUNE-modern L.Erie shore	W2-A	541467	0	99	1	0	+2.26	0.36	+0.07
	W3-A	541467	0	100	0	0	+2.24	0.36	-0.05
	W3-B	541467	0	100	0	0	+2.23	0.35	-0.08
	W5-A	541467	0	98	2	0	+2.35	0.42	+0.01
	W265	547458	0	96	4	0	+2.17	0.47	+0.10
	W556	445483	0	96	4	0	+2.56	0.39	0.00
	W706-A	507483	0	98	2	0	+2.32	0.31	+0.24
	W706-B	507483	0	96	4	0	+2.46	0.53	+0.31
	W706-C	507483	0	98	2	0	+1.83	0.58	+0.28
	W706-D	507483	0	98	2	0	+2.22	0.47	-0.04

RESULTS OF SAND AND GRAVEL ANALYSES (NIAGARA-WELLAND MAP-AREA SAMPLES): TEXTURE

DEPOSITIONAL ENVIRONMENT	SAMPLE NO.	LOCATION	TEXTURE						
			% GRAVEL < -1Ø	% SAND -1Ø to +4Ø	% SILT +4Ø to +9Ø	% CLAY >+9Ø	MEAN* (Ø)	SORTING† (Ø)	SKEWNESS**
DUNE-fossil, inland	W762	240540	0	76	24	0	+3.43	0.90	+0.13
	W764	229523	0	91	9	0	+2.86	0.87	+0.10
LAKE BOTTOM-proglacial	N1871-3A	402692	0	50	47	3	+4.15	1.07	+0.35
	N1871-3B	402692	0	43	54	3	+4.28	1.11	+0.35
	N1879-14	409682	0	17	80	3	+4.81	1.01	+0.28
NEARSHORE-proglacial lake	W69-A	483587	0	70	28	2	+3.54	1.24	+0.30
	P 64-164-1-2	414844	0	47	52	1	+4.03	1.30	+0.05

*Graphic Mean (Folk and Ward, 1957) $= \frac{Ø16+Ø50+Ø84}{3}$

($Ø = -\log_2 N = -1.44 \ln N$)

†Inclusive Graphic Standard Deviation (Folk and Ward, 1957) $= \frac{(Ø84-Ø16)}{4} + \frac{(Ø95-Ø5)}{6.6}$

**Inclusive Graphic Skewness (Folk and Ward, 1957) $= \frac{Ø16+Ø84-2(Ø50)}{2(Ø84-Ø16)} + \frac{Ø5+Ø95-2(Ø50)}{2(Ø95-Ø5)}$

Sorting Index(based on Inclusive Graphic Standard Deviation)

Ø Interval	Sorting
2.00- 4.00	Very poor
1.00- 2.00	Poor
0.71- 1.00	Moderate
0.50- 0.71	Moderately well
0.35- 0.50	Well
0.00- 0.35	Very well

Skewness Index(based on Inclusive Graphic Skewness)

Interval	Skewness
+ 1.00 - + 0.30	Strongly fine
+ 0.30 - + 0.10	Fine
+ 0.10 - - 0.10	Near-symmetrical
- 0.10 - - 0.30	Coarse
- 0.30 - - 1.00	Strongly coarse

APPENDIX K : RESULTS OF BEACH SAND AND GRAVEL ANALYSES (NIAGARA-WELLAND MAP-AREA SAMPLES): PEBBLE LITHOLOGY

SAMPLE NO.	LOCATION	PEBBLE LITHOLOGY 8-32mm						
		% LIMESTONE	% CHERT	% DOLOSTONE	% DOLOSTONE SAND-SILTSTONE	% SAND-SILTSTONE	% SHALE	% IGNEOUS-METAMORPHIC
N1090	469821	4	0		81		10	5
N1877	410677	0	0		68		22	10
N1881	409674	0	0		70		24	6
N2526	555743	0	0		71		18	11
W47-A	498601	23	0	58		7	1	11
W74	485592	14.5	0	67		10	0.5	8
W156	552534	32	0	52		11	0	5
W185-A	603526	18	2	23		36	1	20
W600-A	518475	32	20	35		4.5	0	8.5
W731-B	326466	53.5	37	8.5		1	0	1
W732-A	285476	7	6.5	69.5		8	0	9
W765-C	258471	4.5	2.5	79		8.5	0	5.5
W768-C	226445	4.5	0	90.5		1.5	0	3.5
W1002	351470	10	3	78.5		4	0	4.5
W2418	463618	0.5	0		87		1	11.5

APPENDIX L: RESULTS OF BEACH AND DUNE SAND ANALYSES (WELLAND MAP-AREA SAMPLES): SAND LITHOLOGY

SAMPLE NO.	LOCATION	LITHOLOGY MEDIUM-COARSE SAND FRACTION							
		% ROCK FRAGMENTS					% MINERAL FRAGMENTS		
		LIMESTONE + DOLOSTONE	CHERT	SANDSTONE	SHALE + SILTSTONE	IGNEOUS + METAMORPHIC	QUARTZ	FELDSPAR	OTHERS†
W69-C	487585	35.5	0	0	11.5	2	34.5	14	1.5
W77-C	501598	29.5	0	4.5	12	0.5	38	15	0.5
W334-A	477522	34	0	6.5	24.5	3	23	8	1
W334-C	477522	33.5	0	2	19	2	30.5	13	0
W556*	445483	16.5	1	1.5	5.5	3	48.5	21.5	2.5
W597-A	532471	9	19	0.5	0.5	0.5	54.5	15.5	0.5
W600-D	518475	18	13	0	6	0	44	19	0.5
W706-A*	507483	8	1	0.5	2	0.5	61.5	26.5	0
W706-B*	507483	10	0.5	0	2.5	0.5	65	21	0.5
W706-C*	507483	18	1.5	0.5	3	4	48	23	1
W706-D*	507483	12	0.5	0	4	1.5	58	24	0
W706-E	507483	15	1	0	4	0.5	62	14	3.5
W2418	463618	0	0	0	30	0	48	17	2

† Epidote, Hornblende, Garnet, Magnetite, Mica, Pyroxene

*Sample of dune sand

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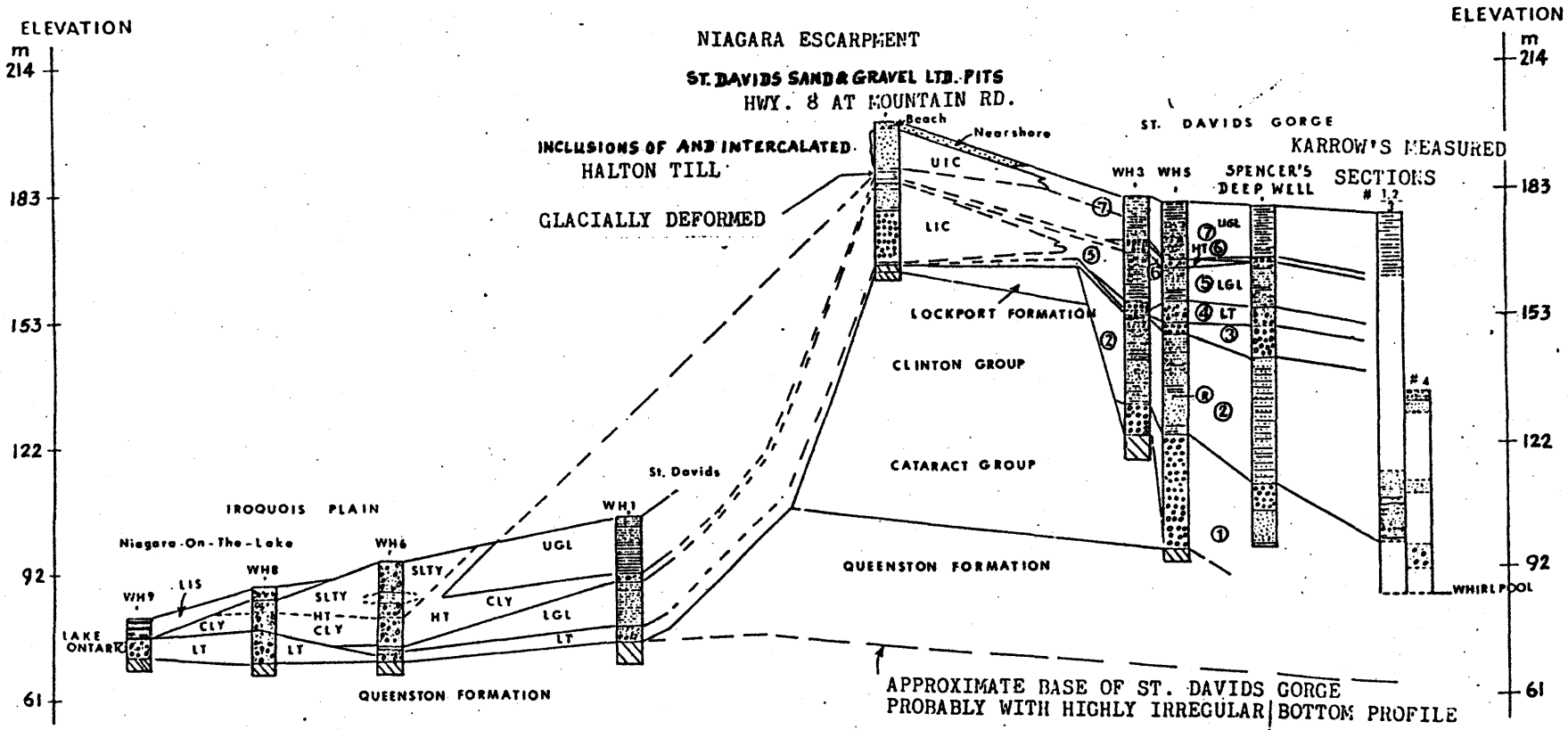
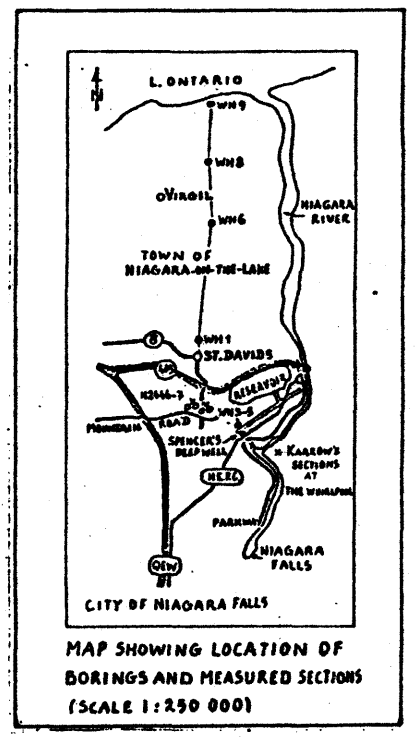
UGL = Upper Glaciolacustrine
LGL = Lower Glaciolacustrine
LIC = Lower Ice-Contact
UIC = Upper Ice-Contact
⑱ = 22 800 ± 450 years BP (^{14}C-date GSC-816)

② Unit Number
Clay
Silt
Sand
Gravel
Till
Bedrock

LIS = Lake Iroquois Sediments
LT = Lower Till
HT = Halton Till
CLY = Clayey
SLTY = Silty

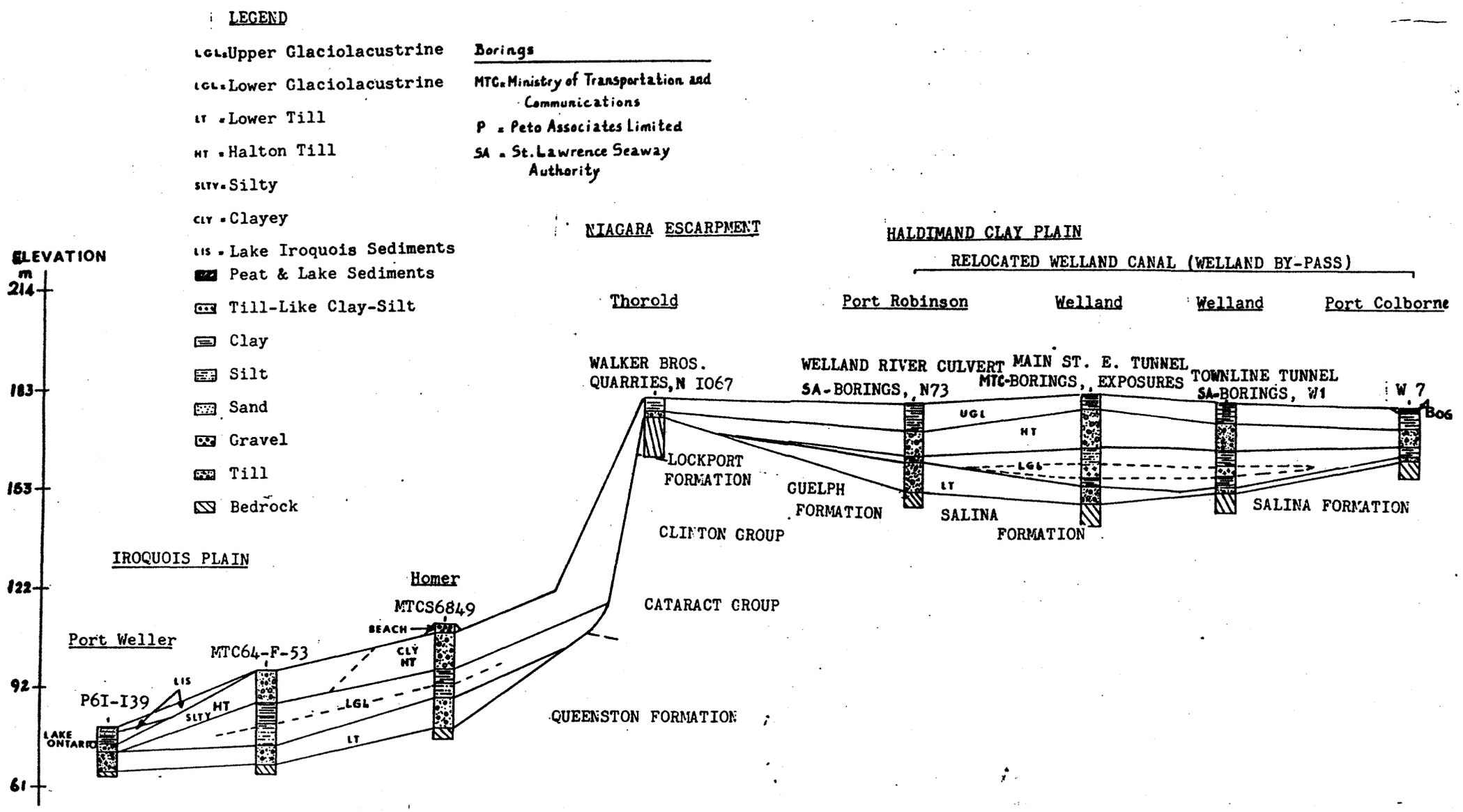
WH = Stratigraphic boring by the Department of Public Works, Ottawa, for the Geological Survey of Canada.
SPENCER'S DEEP WELL: see Spencer 1907.
KARROW'S MEASURED SECTIONS: see Karrow and Terasmae 1970.

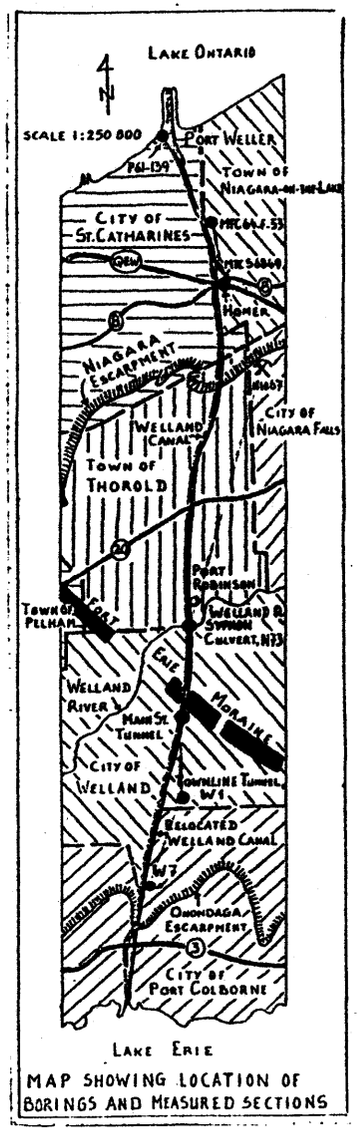




MAP SHOWING LOCATION OF BORINGS AND MEASURED SECTIONS (SCALE 1:250 000)

Chart A/Figure 7 - Correlation of Quaternary Deposits Encountered in Borings and Exposures Between Lake Ontario at Niagara-On-The-Lake and The Whirlpool at Niagara River.





MAP SHOWING LOCATION OF BORINGS AND MEASURED SECTIONS

Chart B/Figure 8. - Correlation of Quaternary Deposits Encountered in Borings and Exposures Between Port Weller and Port Colborne.

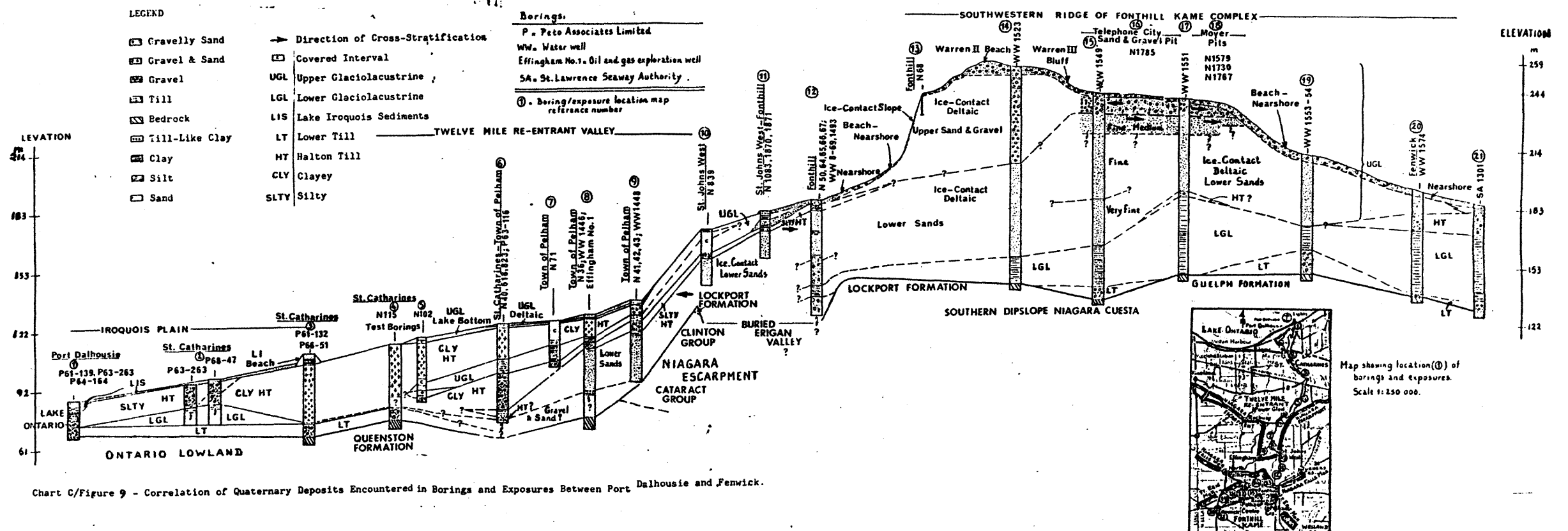
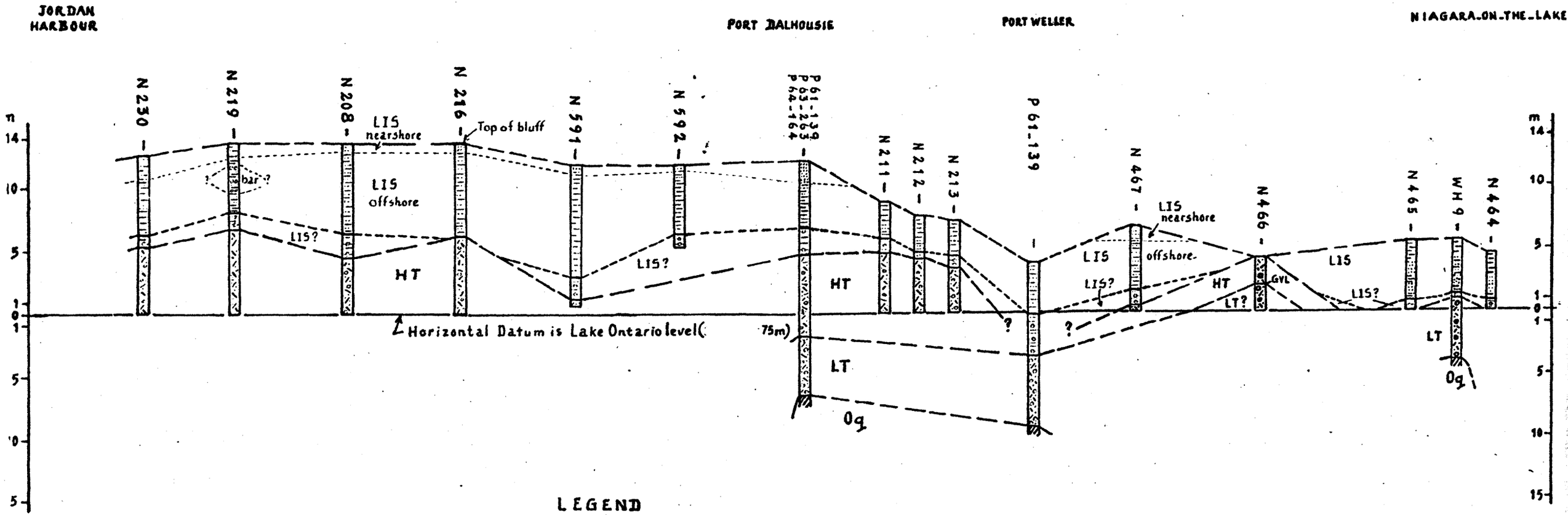


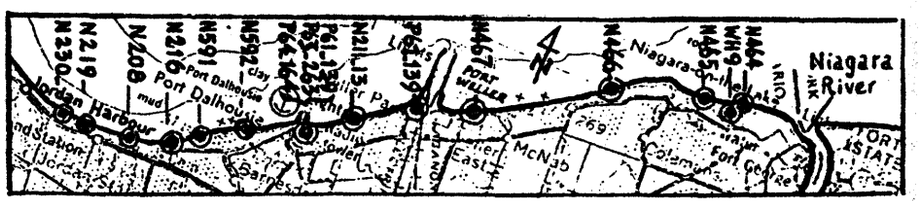
Chart C/Figure 9 - Correlation of Quaternary Deposits Encountered in Borings and Exposures Between Port Dalhousie and Fenwick.



LEGEND

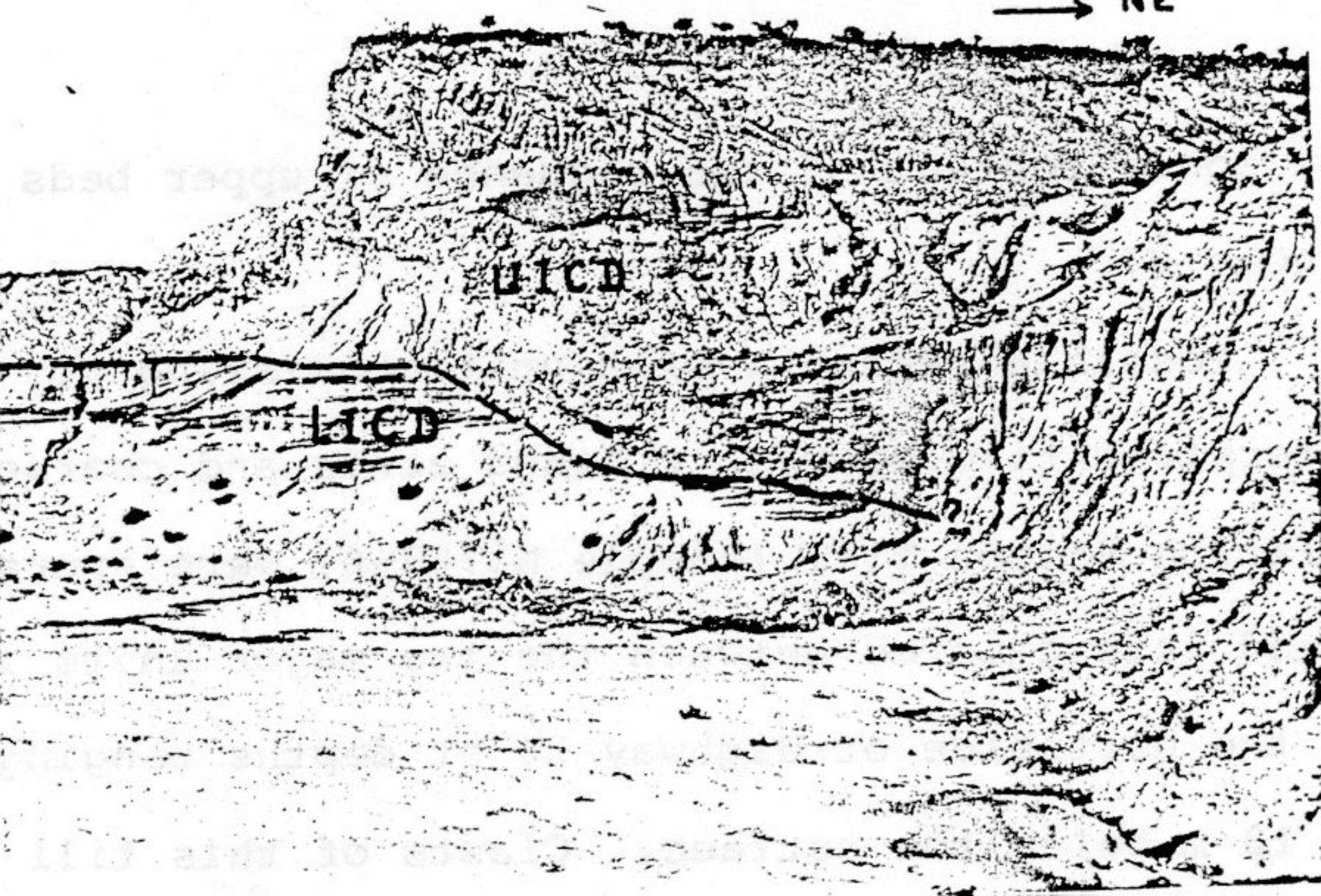
- Sand
- Gravel
- Silt & Sand
- Clay & Silt
- Silty Clay, pebbly
- Till
- Bedrock

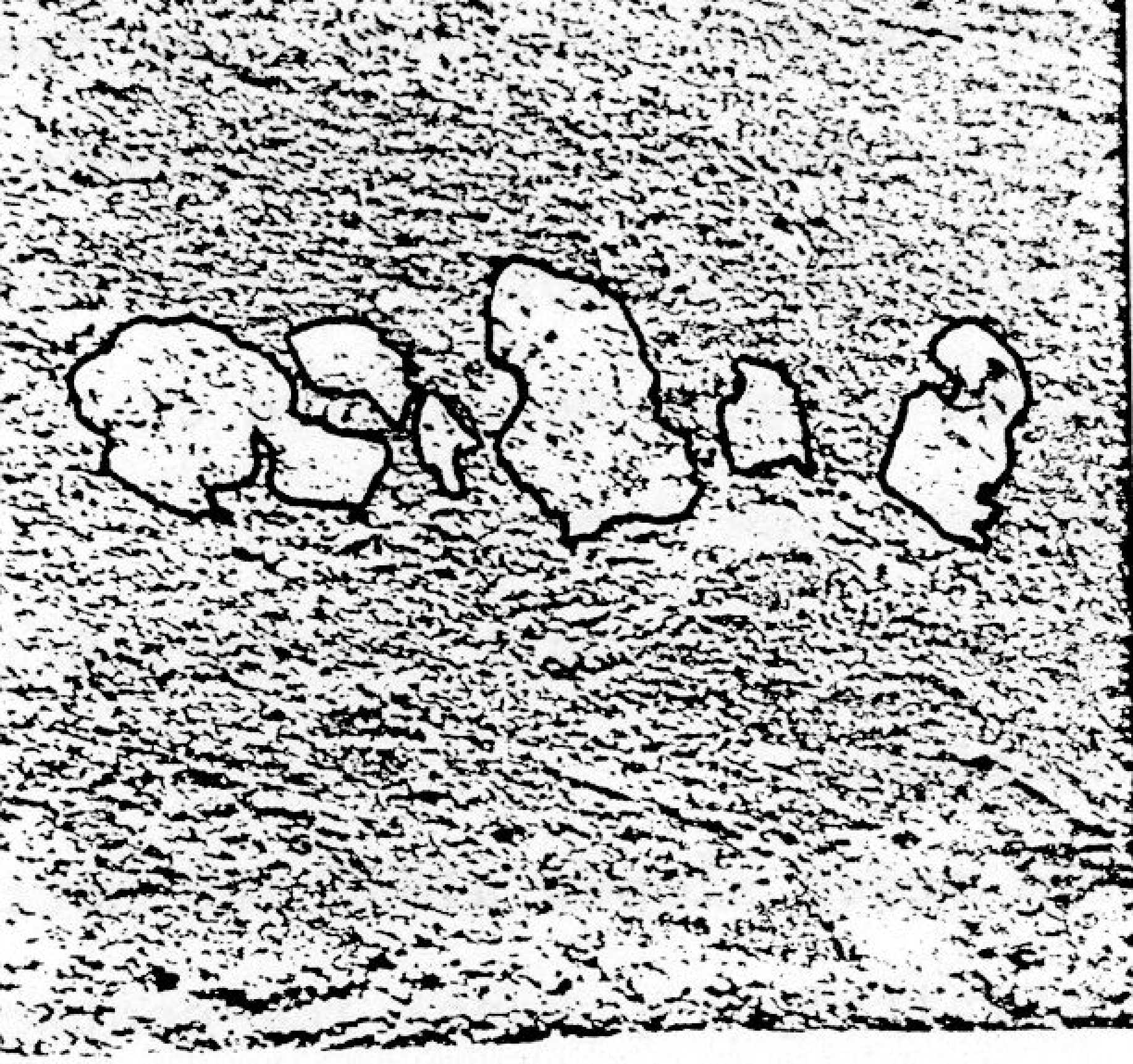
LIS = Lake Iroquois sediments
HT = Halton Till
LT = Lower Till
Oq = Ordovician Queenston Formation
N592 = Measured section Niagara Area 592
P61-139 = Borings for Peto Associates Limited Project 61-139
WH 9 = Stratigraphic boring no.9 by the Department of Public Works, Ottawa, for the Geological Survey of Canada

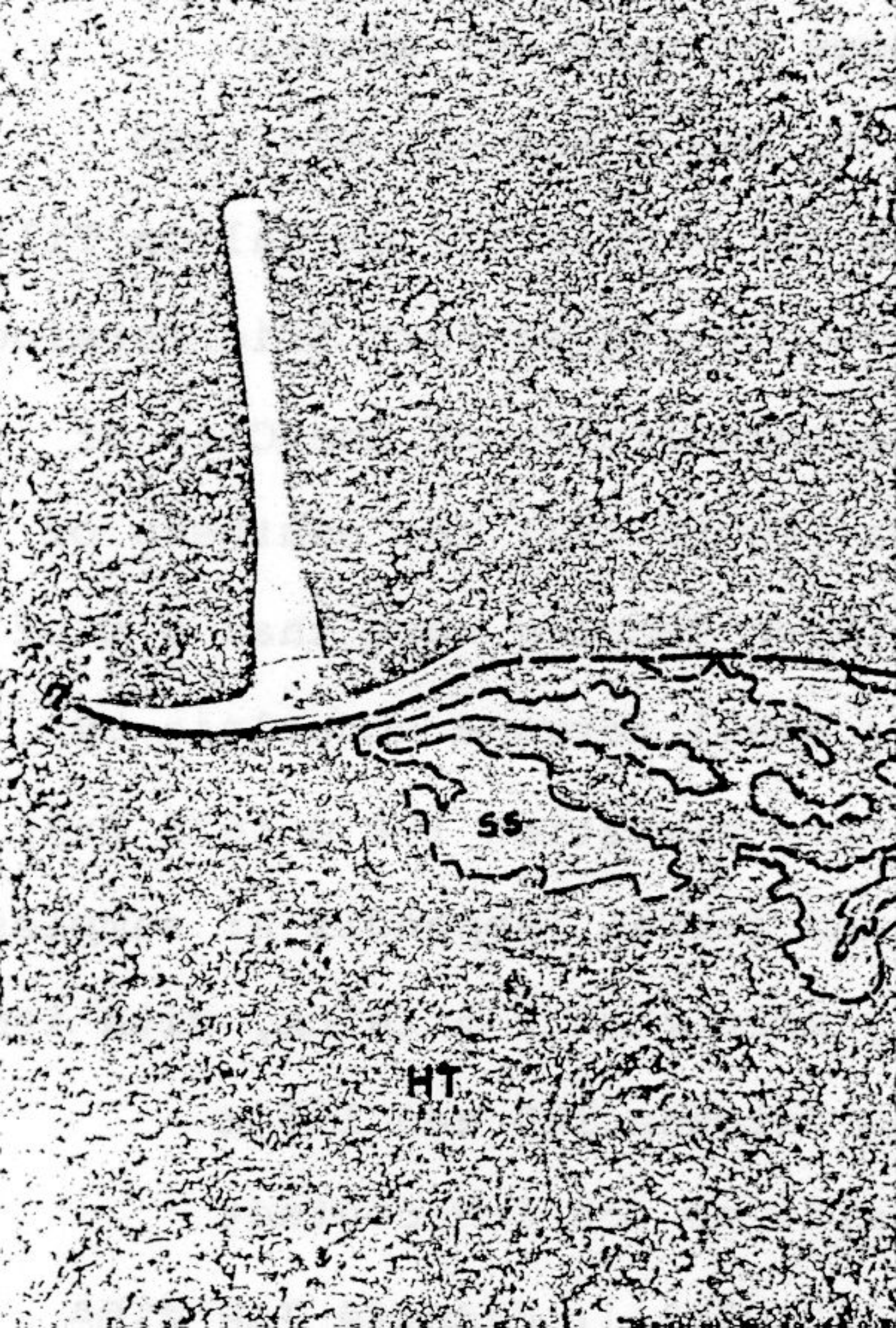


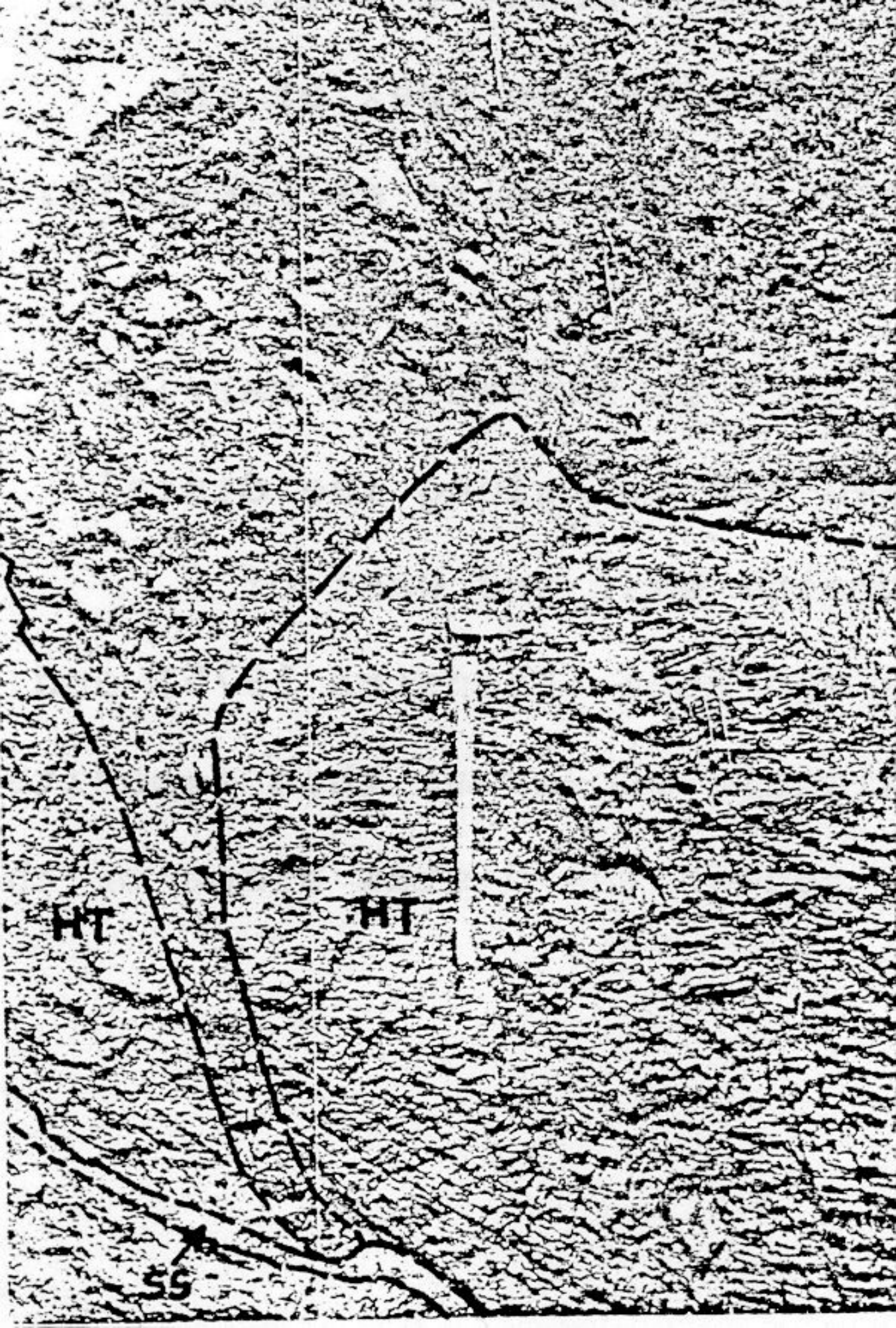
Location map of measured sections and borings. Scale 1: 50 000.

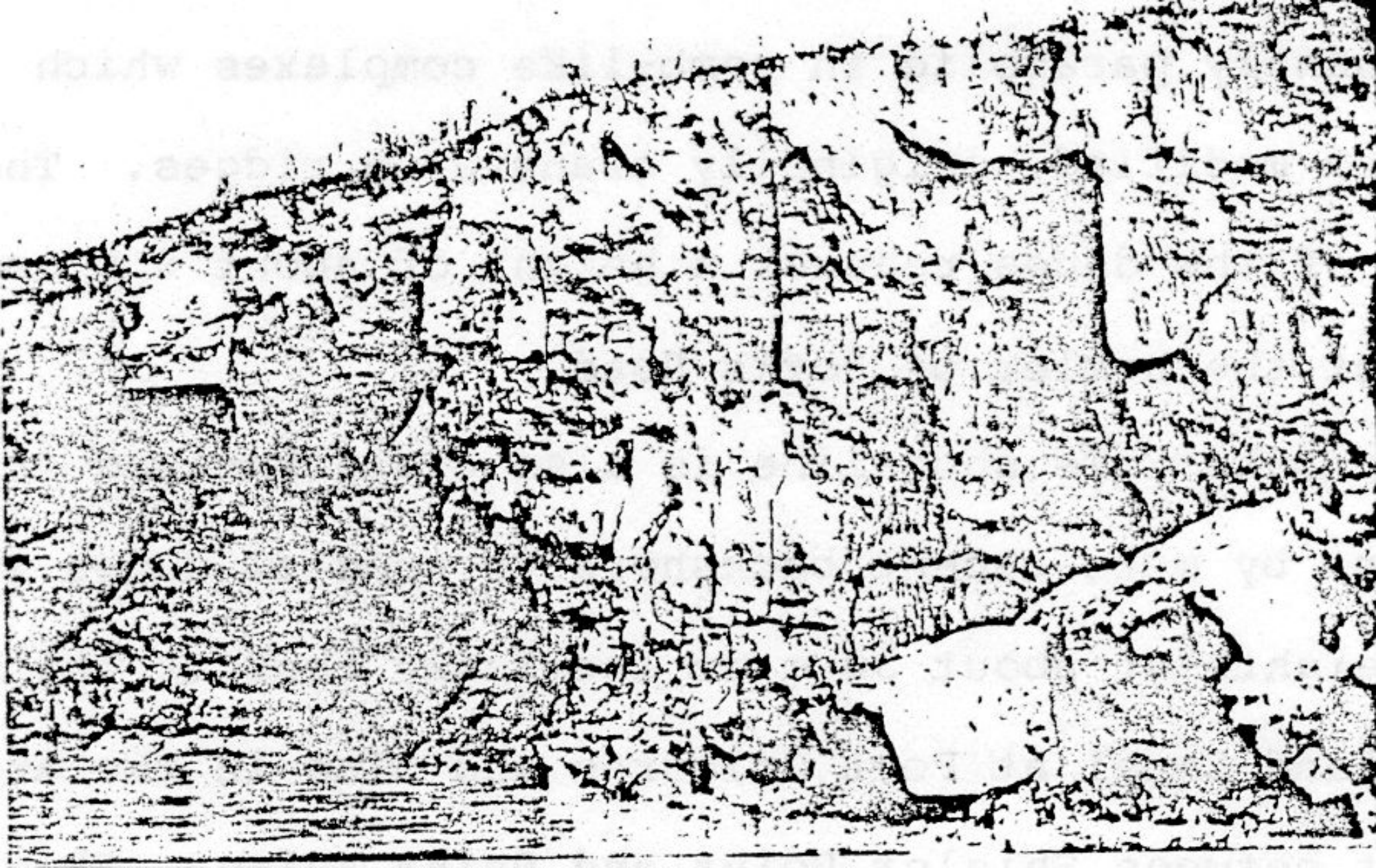
Chart D/ Figure 10. Correlation of Quaternary Deposits encountered at measured sections and borings along/near Lake Ontario shorebluff between the Niagara River and Jordan Harbour.

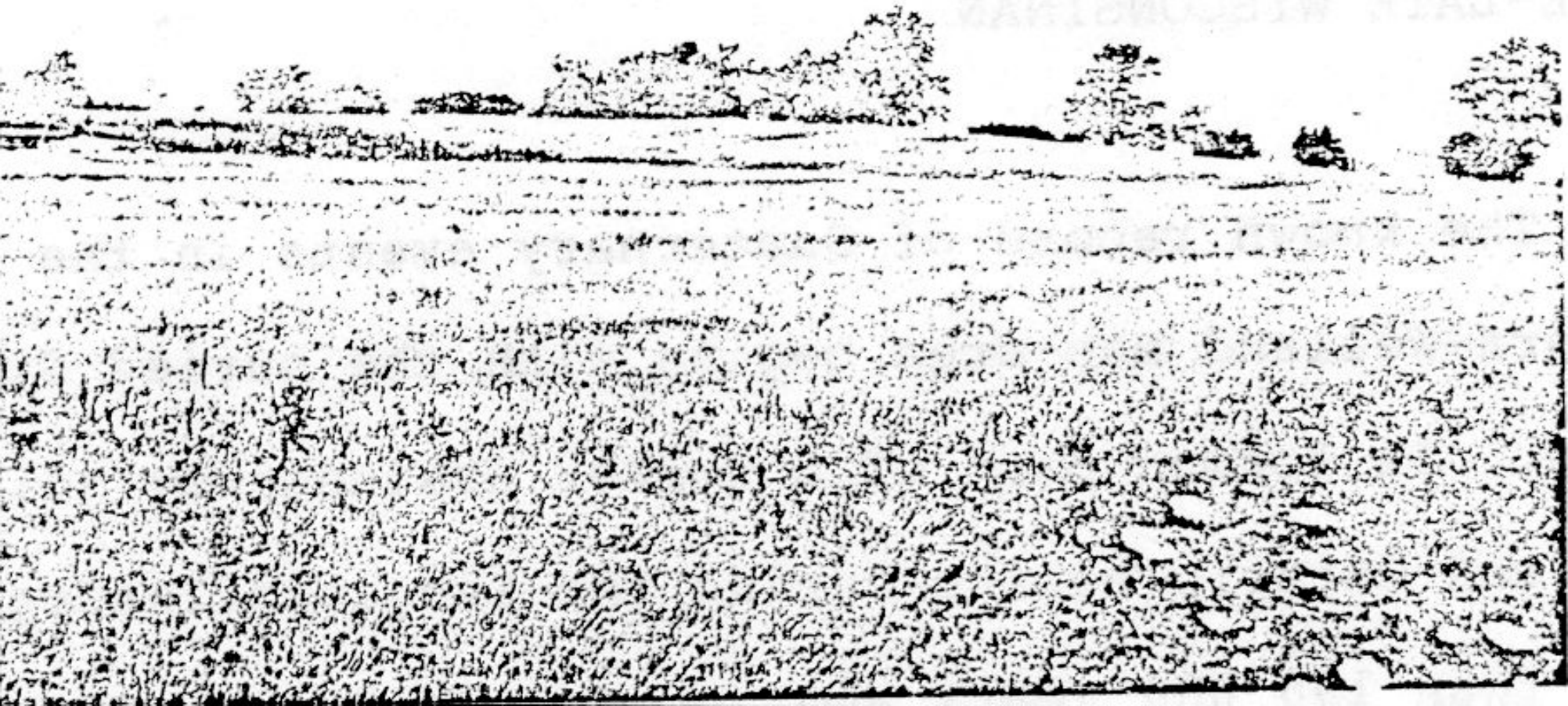

UICD
LICD

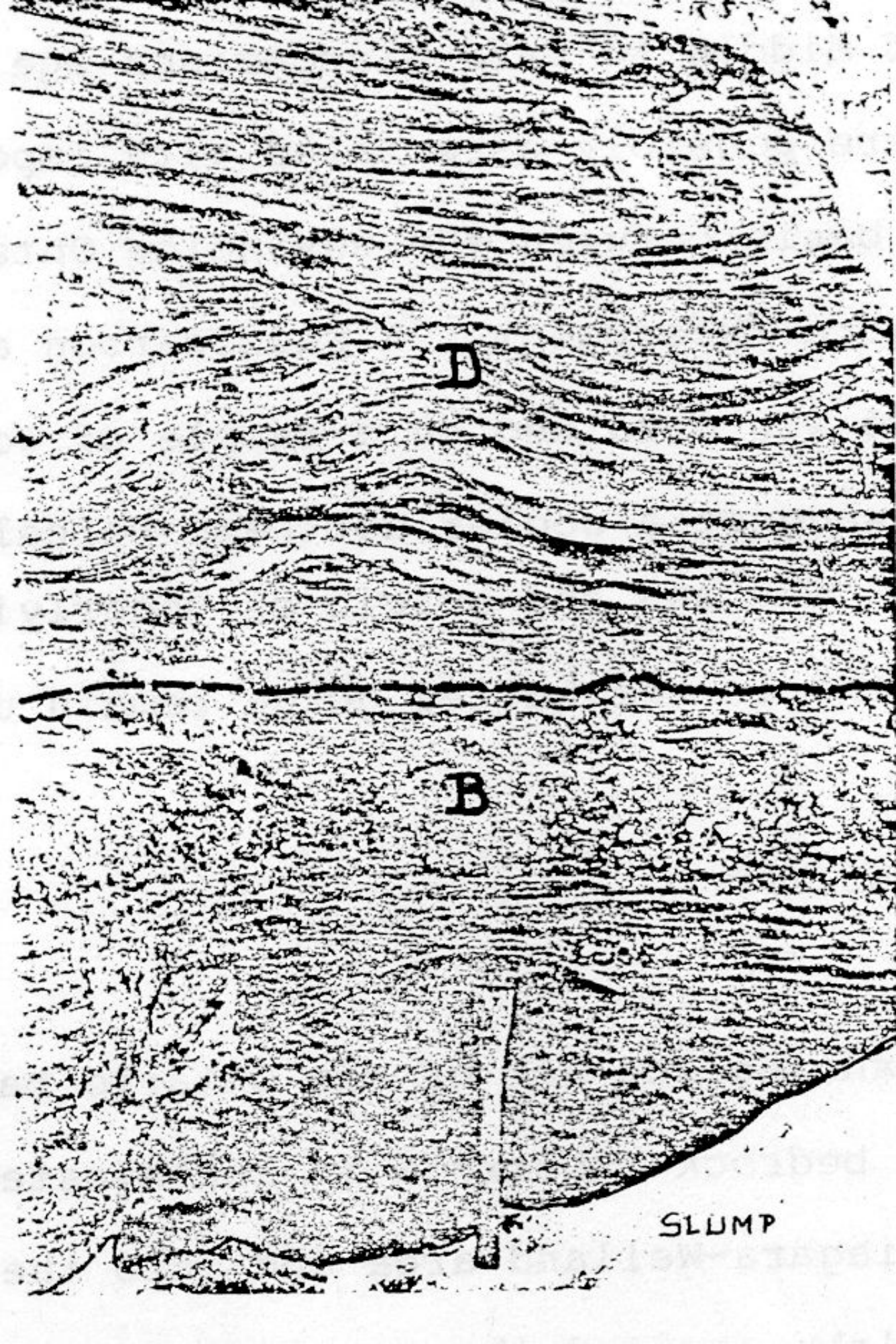


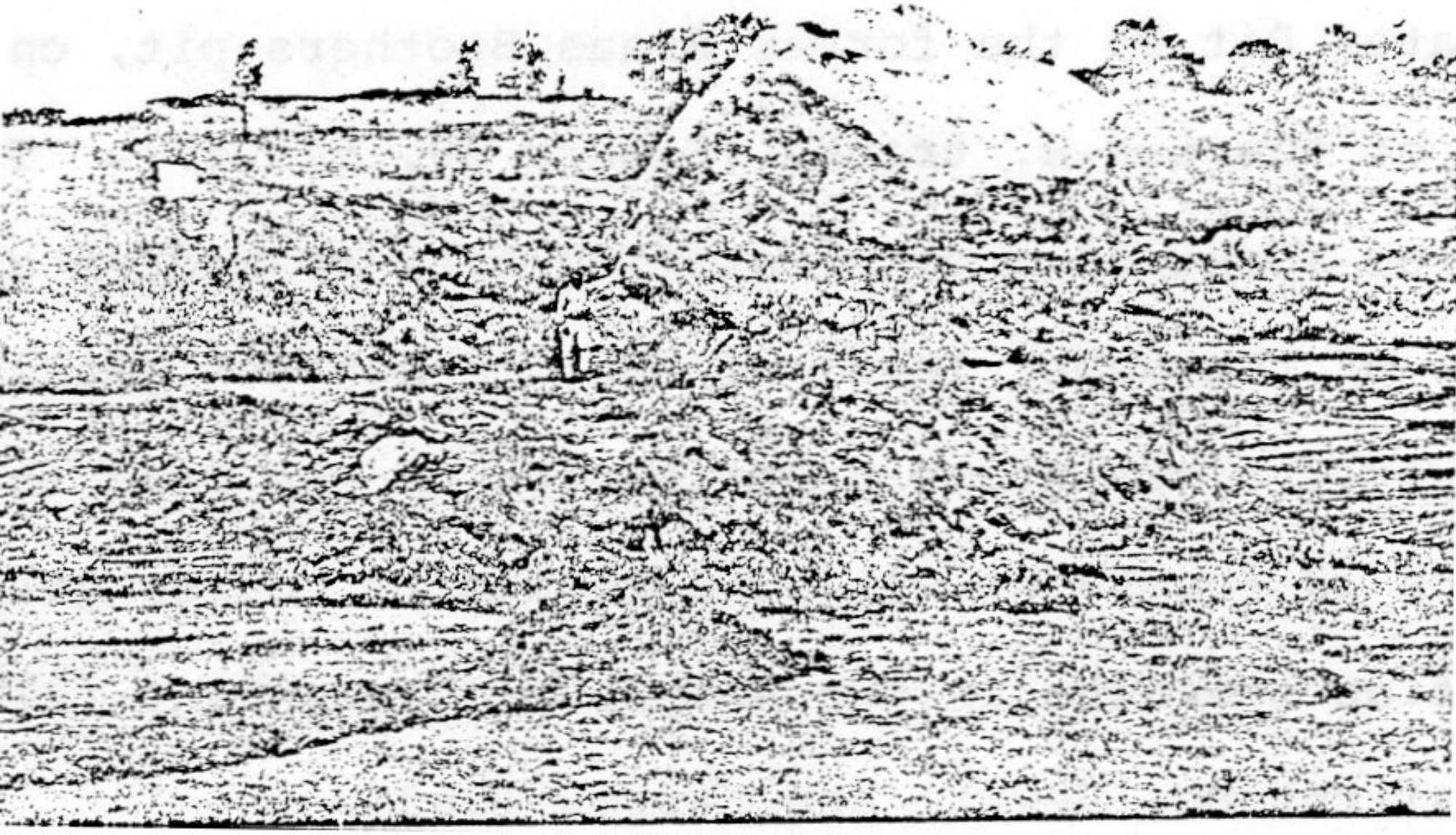

SS
HT

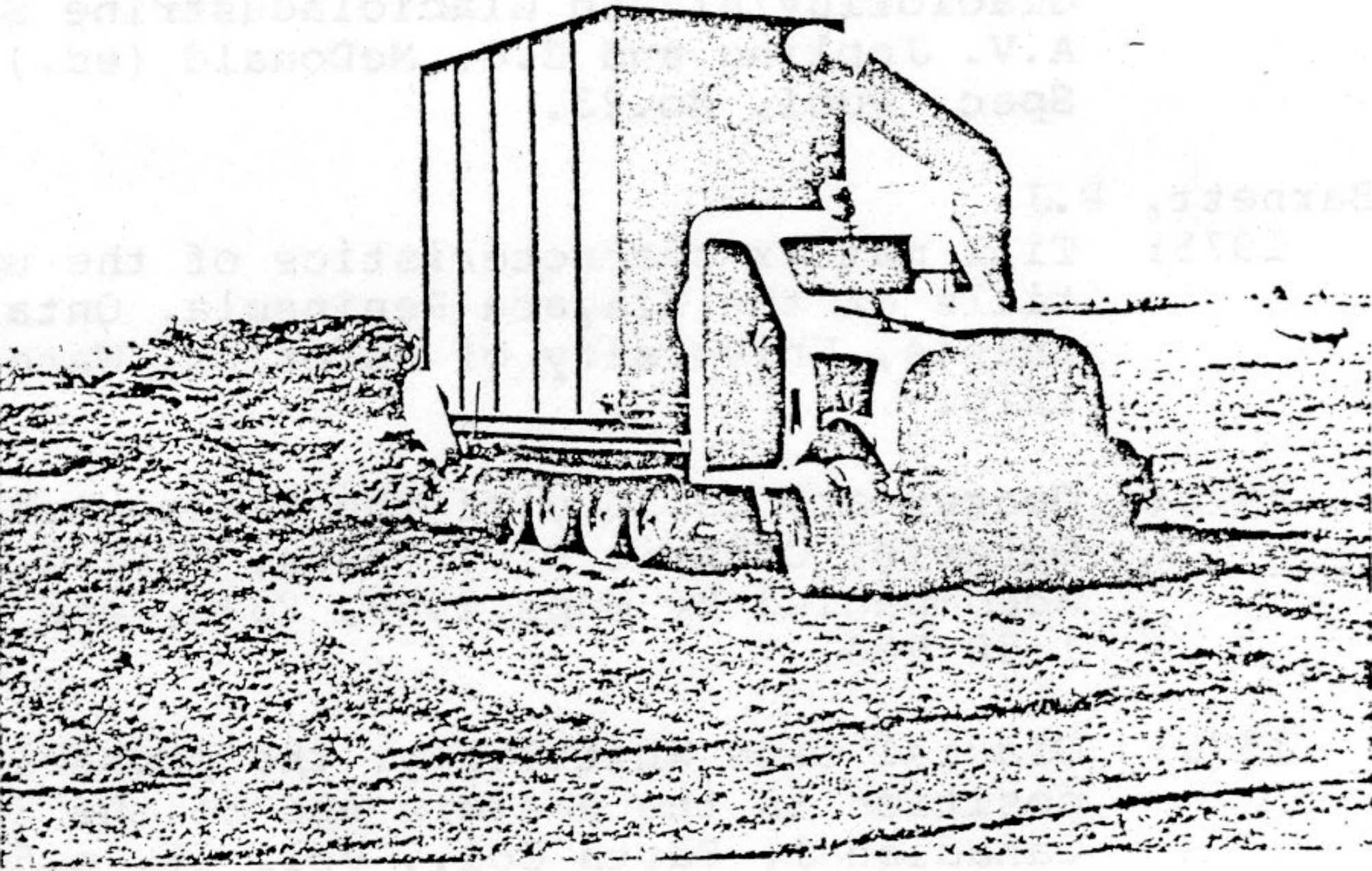

HT
HT
SS

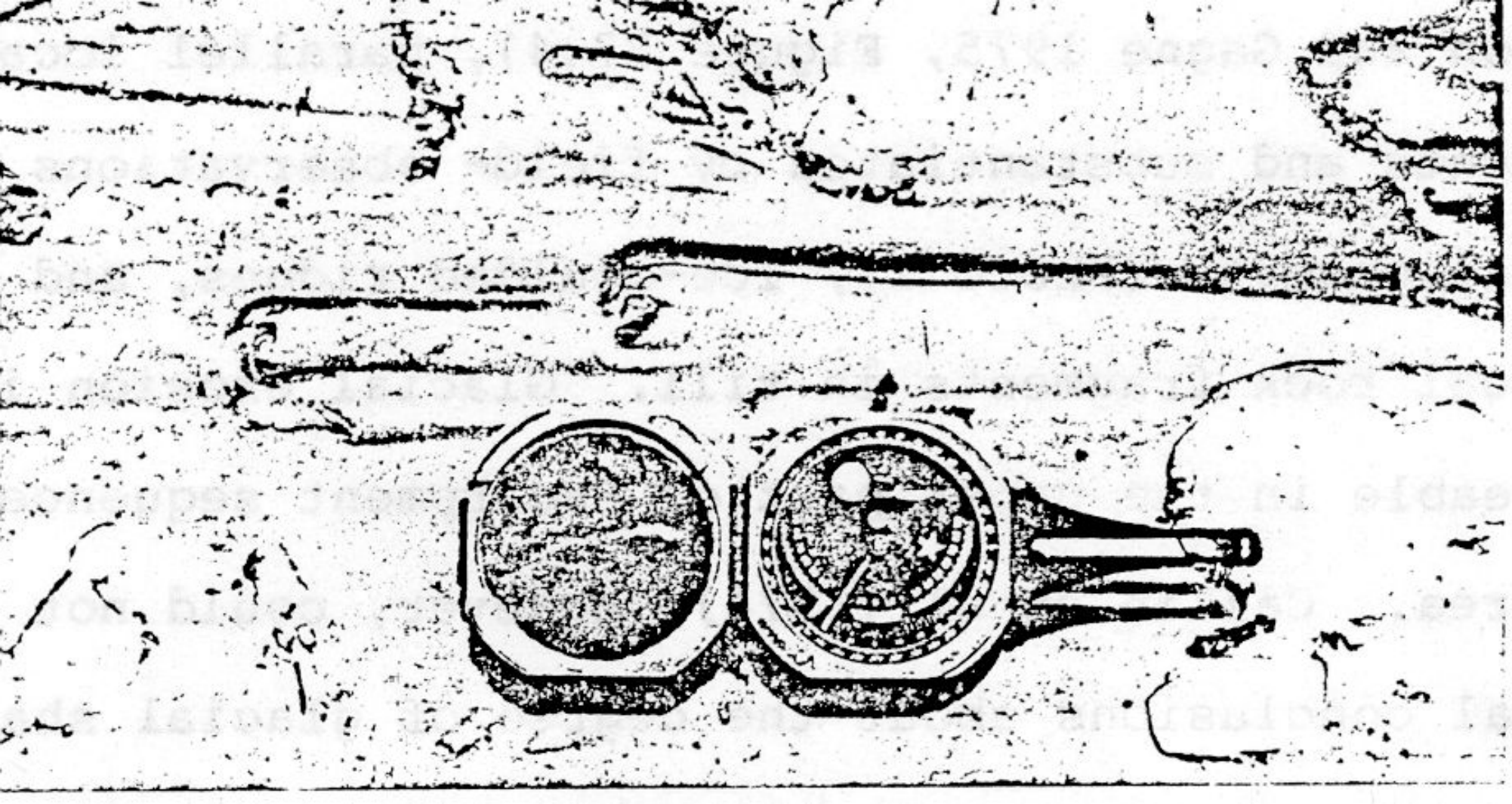


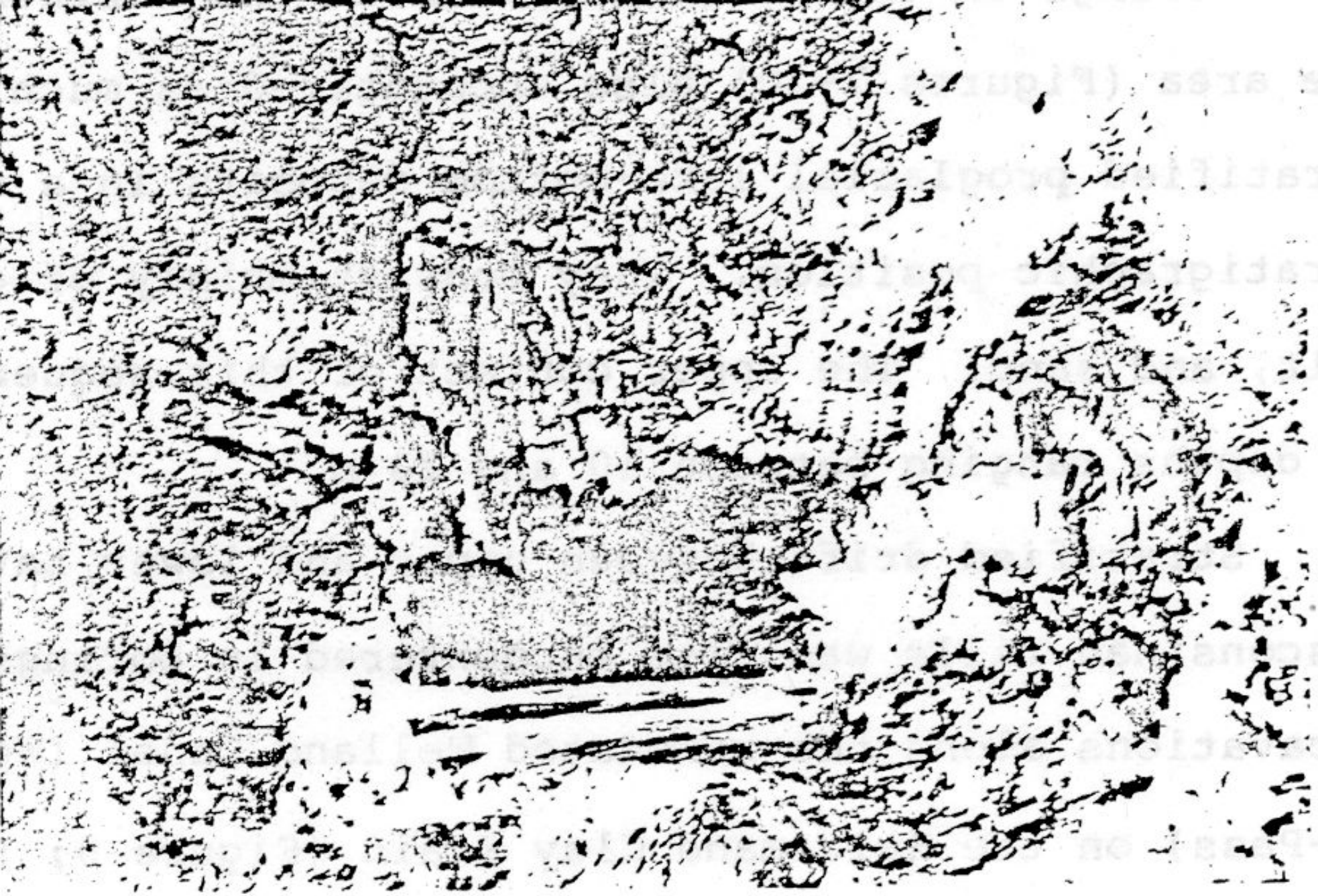


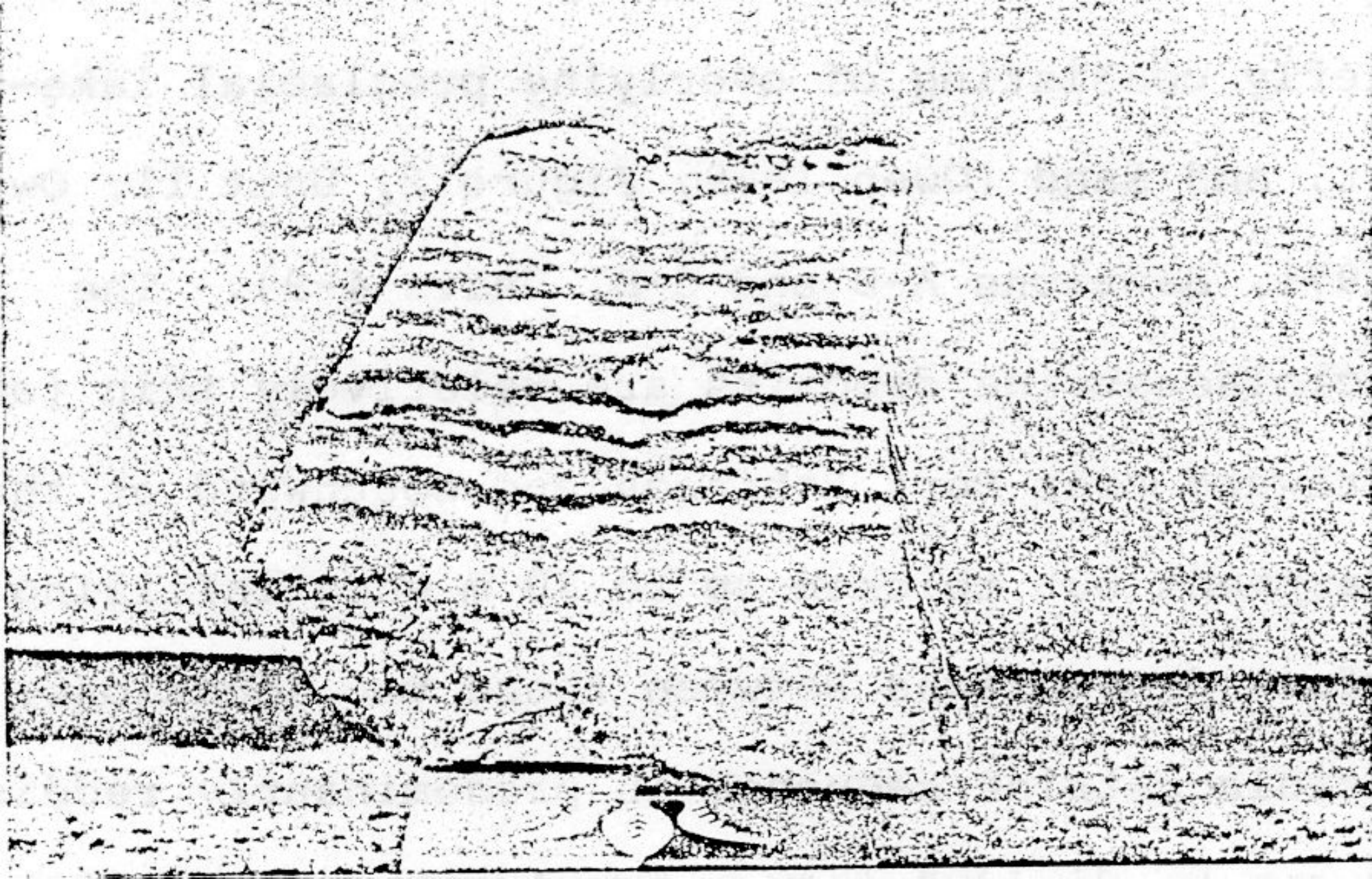

D
B
SLUMP

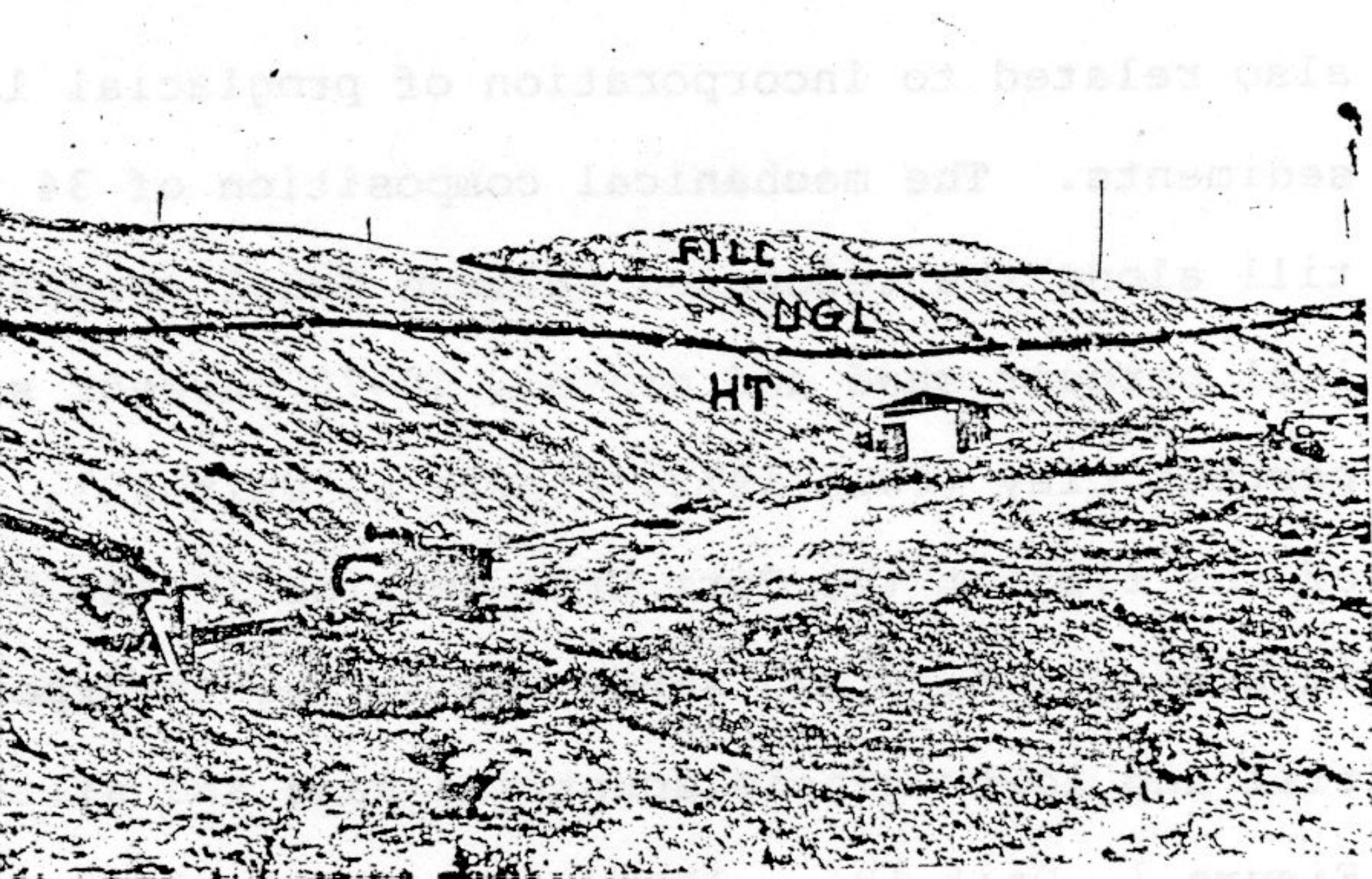


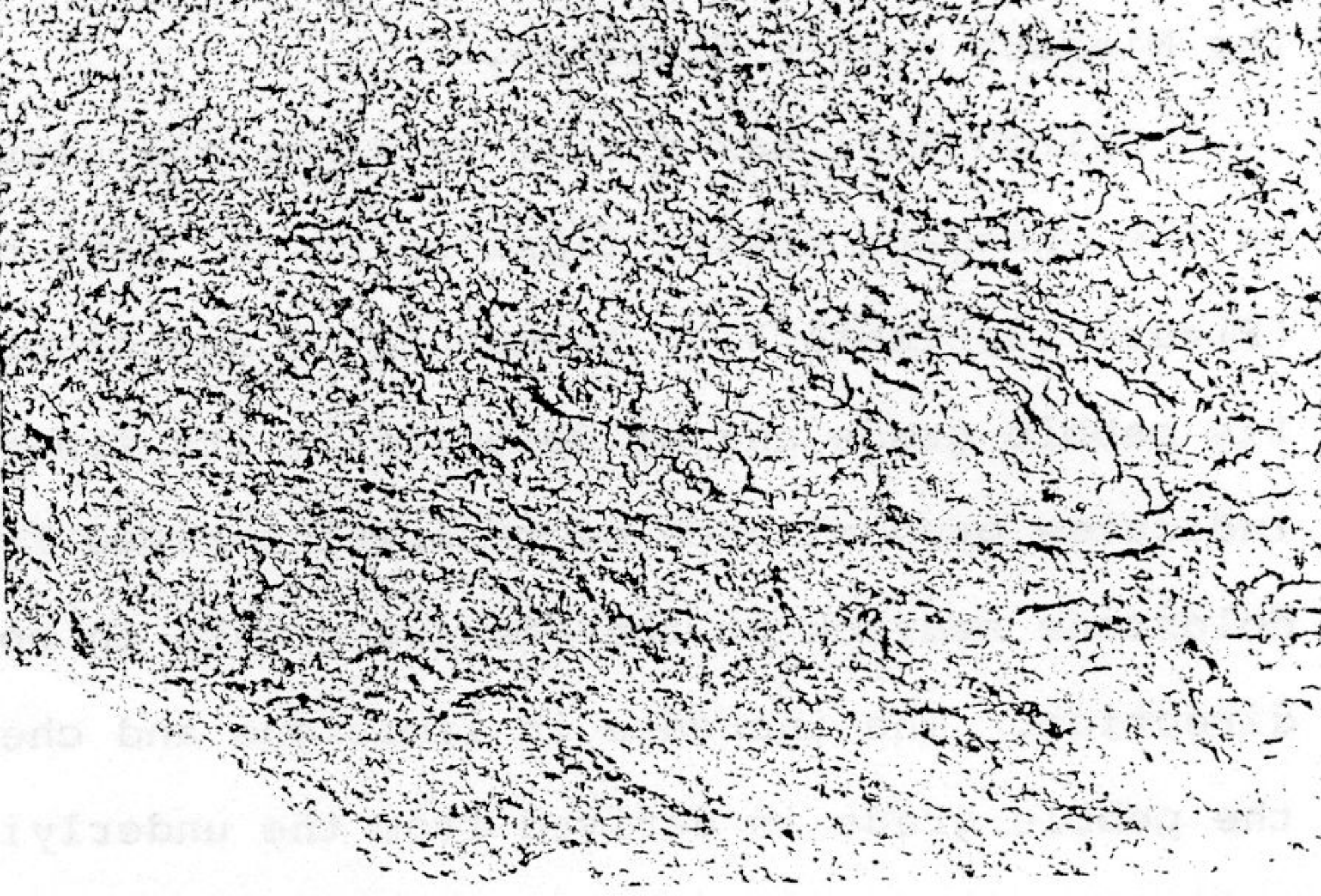









FILL
NGL
HT



ONTARIO DEPARTMENT OF MINES

PRELIMINARY MAP NO. P. 537

NIAGARA SHEET

SOUTHERN ONTARIO

DRIFT THICKNESS SERIES

Scale 1:50,000

1.25 Inches to 1 Mile approximately

0 2 Miles

N.T.S. Reference: 30 M/3

SYMBOLS

- 04 — Drift thickness in feet with location of well from water well information.
- (20) — Approximate drift thickness in feet. Value of two or more wells averaged.
- >5 — Over 5 feet of drift.
- <5 — Less than 5 feet of drift.
- ···25··· — Drift thickness contours representing 25-foot and 50-foot thicknesses.
- Dolomite overlain by less than 25 feet of drift.

EXPLANATION

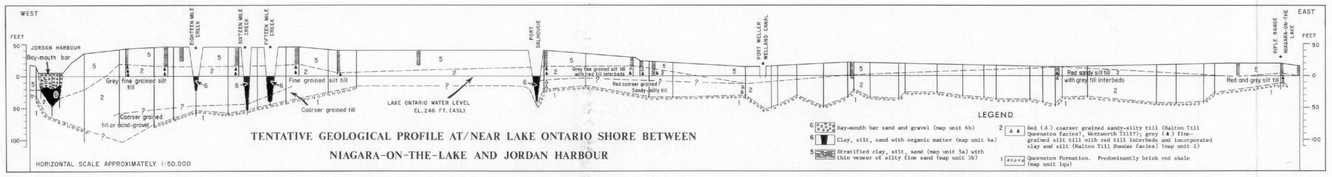
In locating a quarry property a very important consideration is drift thickness overlying the bedrock to be quarried. This map shows spot drift thicknesses determined in wells in the area. The drift thicknesses over parts of the area are outlined by 25-foot and 50-foot contours. The areas where drift thicknesses are less than 25 feet are of economic interest for bedrock quarry locations. These are stippled on the accompanying map. The stippled areas above the escarpment are of interest for quarrying dolomite.

After an area of potential interest is chosen, further drilling would be required to detail the drift thicknesses and rock sections to be found in the area.

Compilation by M.A. Vos, 1968.

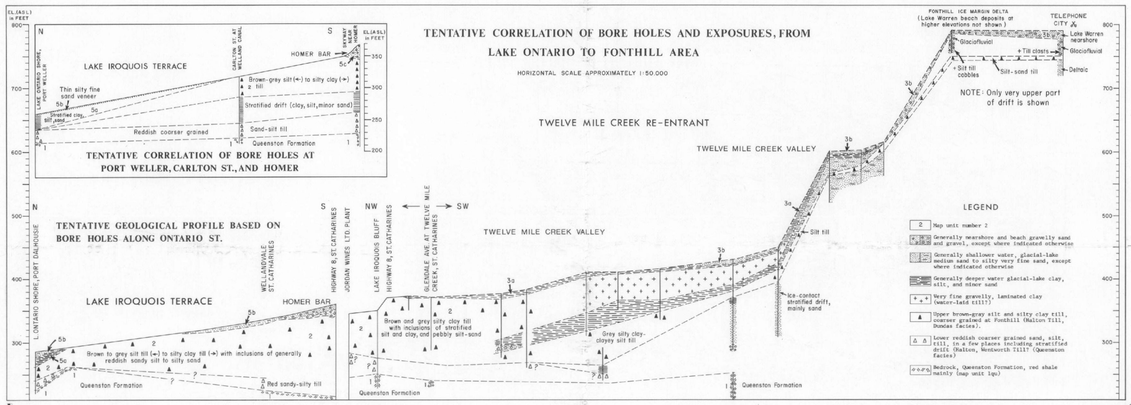
Issued 1969.

ODM 4371



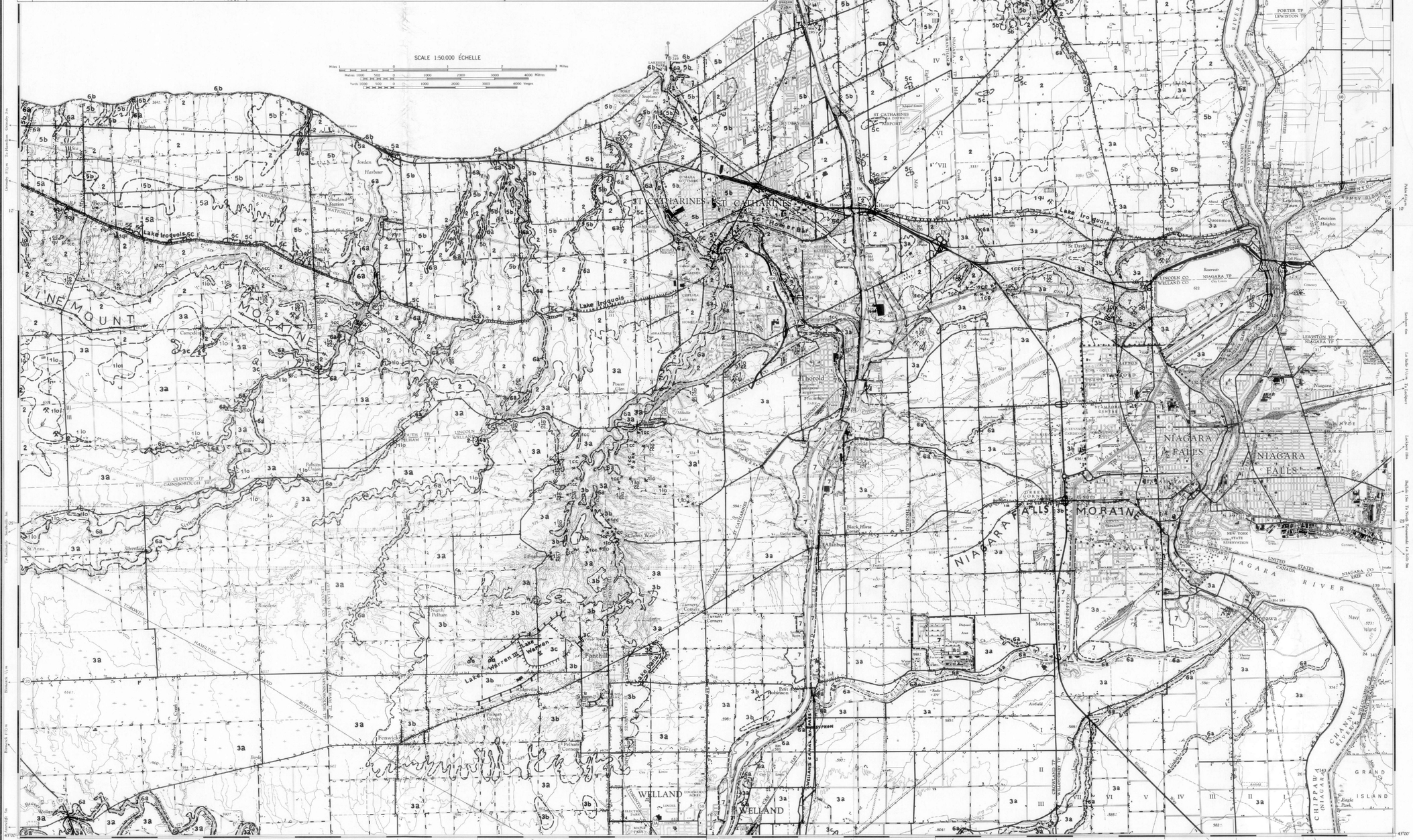
TENTATIVE GEOLOGICAL PROFILE AT/NEAR LAKE ONTARIO SHORE BETWEEN NIAGARA-ON-THE-LAKE AND JORDAN HARBOUR

HORIZONTAL SCALE APPROXIMATELY 1:50,000



TILL DESCRIPTION	LOCATION	TEXTURE -2mm fraction percent			CARBONATES -0.074mm Fraction Calcite and Dolomite total percent ratio		TRACE ELEMENTS -0.037mm fraction ppm				PEBBLE LITHOLOGY 8-32mm fraction percent				
		No. analyses	Sand	Silt	Clay	No. analyses		No. analyses	Cu	Zn	Cr	Ni	No. analyses	Limestone	Dolostone Siltstone Sandstone	Shale	Igneous and Metamorphic
Grey silt till	L. Ontario bluff	13	18 11-28	58 49-73	24 12-40	13	15.8 16.2-16.7	1.2 0.7-1.7	7	53 36-75	87 69-107	68 51-81	42 36-46	6	19 11.5-41	57 35-67.5	19 13-28	5 5-7
Red sandy-silty till	L. Ontario bluff	2	35.5 34-37	34.5 32-37	30 9-51	2	14.5 13.2-15.8	1.0 0.6-1.3	2	42.5 42-43	72.5 71-74	55 55	33.5 31-35	2	14 12-15.5	84 82-86.5	6.5 1-12	1.5
Brown, grey silt till	West of St. Catharines	5	16 10-20	48 40-55	34 25-44	5	14.0 12.6-14.5	1.4 1.3-1.5	5	39 36-44	81 78-84	76 74-80	43 40-44	2	9.5 9-10	51.5 50-53	36.5 13-46	4.5 4-5
Grey lower silt till	Vinemount Mor. Vineland Quarries	4	21.5 15-31	53.5 47-58	25 18-32	4	16.0 15.2-17.4	0.9 0.8-1.1	2	43 41-45	79 78-80	69 65-73	43 40-46	1	22	51.5	24	2.5
Brown silty clay till	St. Catharines	2	1.5	31.5	67	2	19.9 18.5-21.2	1.8 1.3-2.2	2	43 41-45	79 78-80	69 65-73	43 40-46	1	22	51.5	24	2.5
Brown upper silt till	Vinemount Mor. Vineland Quarries	1	22	58	20	1	15.2	1.5	1	50	84	70	42	1	27	63	27	4
Brown silt till below, within map unit 3a	Southeast Vinemount Mor.	2	22 19-25	54 51-57	24	2	18.3 15.3-21.2	1.7	1	50	93	66	38	1	9	53	16.5 18	3.5
Grey, red, brown silt till	Twelve Mile Creek re-entrant	4	27 17-35	52 45-64	17 15-19	4	19.6 19.1-20.7	2.0 1.6-2.6	1	50	93	64	38	1	9	53	16.5 18	3.5
Brown silt till	Fonthill area	3	24 23-25	50 40-51	26 20-27	3	14.7 13-15.8	1.5 1.1-2.2	1	50	92	64	38	1	28.5	48.5	5 13	5
Upper brown-reddish brown silt till	Welland Canal By-Pass at Syphon, south of Port Robinson	6	12 4.5-23.5	65 53-74	23 17-26	6	20.6 16.8-25.6	0.9 0.6-1.3	3	41 34-47	79 74-86	65 63-68	41 40-42	3	29 15-44	62 50-73	3 2-5	2 1-4

PARTIAL RESULTS OF TILL ANALYSES NIAGARA AREA
(average and range of values)



ONTARIO
DIVISION OF MINES

HONOURABLE LEO BERNIER, *Minister of Natural Resources*
W. Q. MACNEE, *Deputy Minister of Natural Resources*
Division of Mines — E.G.Pye, *Director, Geological Branch*

PRELIMINARY MAP P.764
GEOLOGICAL SERIES

QUATERNARY GEOLOGY OF THE NIAGARA AREA

SOUTHERN ONTARIO

Scale 1:50,000
1.25 inches to 1 mile approximately

MTS Reference: 30 M/6E, 30 M/3W, 30 M/3E

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LEGEND

CENOZOIC
QUATERNARY
Recent

7 — Cultural features. Predominantly fill

6 — 6b Lake Ontario beach and bar deposits. Stratified gravel and sand
6a Stream and pond deposits. Stratified gravel, sand, silt, and clay, with organic matter

Pleistocene
Late Wisconsin

5 — 5c Lake Iroquois beach and bar deposits. Stratified gravel and sand
5b Lake Iroquois stratified sands. Predominantly silty fine sand
5a Lake Iroquois stratified clay, sand, and silt

4 — Stream or pond deposits. Stratified fine sand with some silt and clay

3 — 3c Lake Warren and younger pre-Iroquois beach and bar deposits. Stratified gravel and sand
3b Lake Warren and younger pre-Iroquois stratified silty very fine to gravelly sands
3a Lake Warren and younger pre-Iroquois stratified clay, silt, and sand

2 — Halton Till. Silt to clay till.

PALEOZOIC
SILURIAN

1 — 1 o Lockport Formation
1cc Clinton and Cataract Groups

ORDOVICIAN

1qu — Queenston Formation

Note: Generally only that part of a map unit with a thickness equal to or greater than 5 feet is outlined.

SYMBOLS

- Geological boundary (actual or interpreted).
- Limit of geological mapping.
- Small bedrock outcrop.
- Rock quarry, operating.
- Sand and(or) gravel pit, operating.
- Glacial striations on bedrock, direction of ice movement known.
- Glacial striations with trend varying between limiting arrows, includes crossing sets.
- Trend of moraine crest.
- Shoreline of former glacial lake marked by scarp.

For other conventional symbols refer to 1:50,000 National Topographic Map Series.

MARGINAL NOTES

Geological mapping of the Niagara area was initiated in 1969 and for the most part completed in 1971 under the supervision of B.H. Feenstra. Competent assistance in the field was given by D. Walling and A. Lenay in the fall of 1969, by D. Allen, R. DiLabio, A. Cooper, R. Elliott, and E. Sado in the summer of 1970, and by A. Cooper, E. Fraser, and K. Blewett in the summer of 1971.

Field techniques included hand augering, the use of a sampling tube driven with a sledge hammer, and the examination of natural and man-made exposures. Additional information was obtained from the published literature, from examination of bore hole samples, and from logs of bore holes and wells provided by several Federal and Provincial Government agencies and private companies.

Bedrock Geology: The Paleozoic geology of the area is described and shown on maps by Caley (1940) and Sanford (1969); the Silurian formations of the Niagara Escarpment in particular are described by Bolton (1957). The area is underlain from north to south by the Ordovician Queenston Formation (a red shale mainly; map unit 1qu) and the following Silurian groups and formations: the Cataract and Clinton Groups (sandstone, shale, and carbonate rocks; map unit 1cc); the Lockport Formation (dolostone mainly; map unit 1 o); the Guelph Formation (dolostone) and the Salina Formation (dolostone, shale, gypsum) which do not occur in outcrop in the area mapped. The area mapped as bedrock along the face of the Niagara Escarpment includes fine- and coarse-grained material, generally more than 3 feet thick, that developed as a result of mass wastage of bedrock and Quaternary drift.

Bedrock Topography and Drift Thickness: Bedrock surface topography and drift thickness maps of the Niagara area are in preparation. Such maps and diagrams have been previously constructed by Sanford (1956), Hobson and Terasmae (1969), and Vos (1969) but do not include the entire Niagara area.

Quaternary Geology: Glacial ice moved out of the Lake Ontario basin to the southeast and south across the Niagara Escarpment area, as shown by numerous glacial erosional features. Mid-Wisconsin interstadial and older drift has been recognized between topographic depths of 100 and 290 feet below surface in bore holes and exposures in the buried St. Davids bedrock valley (Terasmae 1965; Karrow and Terasmae 1970). The silt to silty clay till (map unit 2) exposed at surface throughout much of the northern part of the Niagara area is believed to be a correlative of Karrow's (1963) late Wisconsin Halton Till. Lower, coarser grained tills found in exposures as well as indicated by bore holes in the St. Catharines area and along the Welland Canal By-Pass could be correlatives of Karrow's (1963) late Wisconsin Wentworth Till. The older limit of the glacier depositing Halton Till is thought to be south of the Niagara area as an upper fine-grained silt to clay till, present between an upper (map unit 3a) and a lower sequence of fine-grained glacial lake sediments; it can be traced consistently along the Welland Canal By-Pass to the vicinity of Port Colborne. Several younger positions of this fluctuating ice margin, possibly grounded as well as floating in glacial lake waters, are present in the map-area. Two advances are recorded by stratified, very fine gravelly silty clay units intercalated between glacial lake clay, silt, and fine sand, with few clasts, in the Twelve Mile Creek re-entrant. The two stratified gravelly silty clay units can be traced northward to massive silty clay till in the St. Catharines area. The earlier advance may be correlated with the formation of an ice margin delta in Lake Warren (now covered by a veneer of glacial lake deposits) at Fonthill. The later advance may be correlated with a grounded ice margin forming the Vinemount Moraine to the west at the top of the Niagara Escarpment. Correlation between the ice marginal positions in the west half with those possibly present in the east half at the Niagara Falls Moraine and between Stanford and Port Dover moraines is not clear. Lake sediments intercalated with deep-water glacial lake sediments (map unit 3a) below or in which such positions have not been recognized, the ice margin may have been strongly lobate and floating. Bore holes along the Niagara Falls Moraine indicate a rise in the bedrock surface as well as an increase in drift thickness. At least the upper part of the drift consists of glacial lake sediments (map units 3a, 3b). Bore holes north of St. Davids show the presence of a silt to clay till believed to be Halton Till separated southward into two till units intercalated between and apparently terminating farther south in fine-grained glacial lake sediments (map unit 3a). The upper till layer is exposed at surface south of Virgil (map unit 2).

The Niagara area is for the most part covered with deeper and shallower-water glacial lake sediments (map units 3a, 3b, 5a, 5b). The presence of former lake levels (Warren to Iroquois) is recorded by beaches and bars (map units 3c, 5c), terraces and scarps. The multiple beach ridges between 825 and 850 feet as well as a wave-cut scarp, with a lower elevation of 810 feet, and a terrace between 790 and 810 feet on top of the delta at Fonthill are features of Lake Warren (11, 1217). The Lake Dana level is recorded by very short beach ridges, a spit, and terraces found at elevations near 650 feet in the vicinity of Fonthill, on the distal slope of the Vinemount moraine south of Beamsville, and at a pit on top of the Niagara Escarpment south of St. Davids. Shore features of Lake Iroquois are well developed along the Niagara Falls Moraine and in the area north of Queenston. An erosional scarp below the spit near Fonthill as well as short ridges south of the Vinemount Moraine in the vicinity of Campden, and east of Welland are found at lower elevations (610 to 620 feet) and may represent a lower lake level or shallow water features in Lake Dana. Lake levels intermediate between Warren and Dana are recorded at the Fonthill delta by the base of a scarp between 730 and 750 feet, and by a short beach ridge at 690 feet at the village limits. The latter level is also recorded at Lundy's Lane at a slightly lower elevation (Chapman and Putnam 1966). Shallow-water sands (map unit 3b) in the re-entrant at Twelve Mile Creek and at St. Davids are possibly derived from adjacent higher source areas to the south by run-off into a lake(s) with a much lower elevation but higher than that of Lake Iroquois. The shoreline of Lake Iroquois is mainly an erosional bluff. The Homer Bar (Coleman 1936) with an elevation at top of 372 feet and small, thin accumulations of sand and gravel, at approximately 10 feet lower elevations along the shoreline, form its beach deposits (map unit 5c). Various small ridges of sand and gravel below the shoreline are probably off-shore bars (map unit 5c).

Recent sediments mapped in the area are divided into stream and pond deposits (map unit 6a) and Lake Ontario deposits (map unit 6b). Rising of the water level in Lake Ontario caused flooding and the construction of baymouth bars ponding at the mouths of several streams, for example Twenty Mile Creek (Jordan Harbour). The baymouth bar at Jordan Harbour is built over bog bore holes penetrated a unit of sand and gravel overlying silts with organic matter resting on what is believed to be Halton Till. The area of the Twelve Mile Creek re-entrant between De Cew Falls and Rockway south of the Lake Iroquois shoreline and a small area behind the Homer Bar east of the Welland Canal contain small shallow depressions filled with bog sediments. A radiocarbon sample (Brock University Sample, BGS52) of wood more or less from the central part of such a sequence near Power Glen was dated at 5,214±80 years. The cultural features (map unit 7) consist predominantly of rock and earth fill associated with ship and power canal construction.

Industrial Mineral Resources: Queenston shale exposed north of the Lake Iroquois shoreline cast of St. Catharines, near St. Davids, is used for the manufacture of brick (Guillet 1967). A similar resource area exists between Vineland and the western margin of the area where Queenston shale is overlain by Halton Till through a generally thin clay veneer (map unit 5a). The Lockport Formation is quarried for building stone near Queenston and primarily for aggregate at Thorold, St. Catharines, south of Niagara Falls and in the area of exposed bedrock knolls and thin drift cover to the west and southwest of Campden (Hewitt and Vos 1969). The main commercial sources of sand and gravel are limited to the ice marginal deposits, glaciofluvial and glacial lake near-shore and beach deposits at Fonthill and south of St. Davids (Hewitt and Karrow 1963). Other deposits of sand and gravel are small, thin, silty, below thick "overburden", or built over. The total reported mineral production in 1969 amounted to $5,379,971 (Statistical Files, ODM).

Physiography, Soils, and Engineering Properties: A description of the landforms in the area is given by Chapman and Putnam (1966). The geological map units may be compared with the soils classification and distribution as shown in Ontario Soil Survey Reports (Ontario Agricultural College 1935; Wicklund and Matthews 1963). Engineering properties of till and glacial lake sediments along the Welland Canal By-Pass south of Port Robinson are provided, among others, by Owen (1969).

Selected References:

Bedrock Geology:
Caley, J.F. (1940): Paleozoic geology of the Toronto-Hamilton area, Ontario; Geol. Surv, Canada, Mem.224, 284p. (reprinted 1961). Accompanied by 2 maps.
Bolton, T.E. (1957): Silurian stratigraphy and paleontology of the Niagara Escarpment in Ontario; Geol. Surv, Canada, Mem.289, 145p. Accompanied by plates and charts.
Sanford, B.V. (1969): Geology, Toronto-Windsor area, Ontario; Geol. Surv, Canada, Map 1263A, scale 1 inch to 3.95 miles.
Bedrock Topography and Drift Thickness:
Sanford, B.V. (1956): Two preliminary maps of Welland County, Ontario, showing drift-thickness and bedrock contours; Geol. Surv, Canada, Paper 55-20, Maps 55-20A and 55-20B, scale 1 inch to 2 miles.
Hobson, George D., and Terasmae, J. (1969): Pleistocene geology of the buried St. Davids gorge, Niagara Falls, Ontario; Geophysical and Palynological studies; Geol. Surv. Canada, Paper 68-67, 19p.
Engineering Geology:
Owen, G.R. (1969): Stratigraphy and engineering description of the soils exposed on a section of the Welland Canal By-Pass project (Contract 743); Ontario, Canada, Geol. Surv. Canada, Paper 69-51, 22p. Accompanied by chart.
Industrial Mineral Resources:
Guillet, G.R. (1967): The clay products industry of Ontario; Ontario Dept. Mines, IMR22, 206p. Accompanied by 2 maps.
Hewitt, D.F. (1960): The limestone industries of Ontario; Ontario Dept. Mines, IMR5, 177p. Accompanied by 2 maps and several sections. Updated in Ontario Dept. Mines, IMR11, 1964, 77p. Accompanied by 1 map.
Hewitt, D.F., and Gowan, W.R. (1969): Sand and gravel in southern Ontario; Ontario Dept. Mines, IMR29, 105p. Accompanied by 1 map.
Hewitt, D.F., and Karrow, P.F. (1963): Sand and gravel in southern Ontario; Ontario Dept. Mines, IMR11, 151p. Accompanied by 5 maps.
Vos, M.A. (1969): Stone resources of the Niagara Escarpment; Ontario Dept. Mines, IMR31, 68p. Accompanied by 5 maps and 1 chart. Reprinted 1972, with some specifications revised.
Pedology:
Ontario Agricultural College, Guelph, and Dominion Department of Agriculture, Ottawa (1935): Soil survey map of Welland County; Ontario Soil Survey Rept. No.3, scale 1 inch to 2 miles.
Wicklund, R.E., and Matthews, B.C. (1963): The soil survey of Lincoln County; Ontario Soil Survey Rept. No.36, Guelph, Ontario, 68p. Accompanied by 1 map, scale 1 inch to 1 mile.
Physiography:
Chapman, L.J., and Putnam, D.F. (1966): The physiography of southern Ontario; University of Toronto Press, 2nd Ed., 386p. Accompanied by 1 map.
Quaternary Geology:
Calkin, P.E. (1970): Strand lines and chronology of the glacial Great Lakes in northwestern New York; Ohio J. Sci., Vol.70, p.79-96.
Coleman, A.P. (1936): Lake Iroquois; Ontario Dept. Mines, Vol.45, pt.7, p.1-36 (published 1937). Accompanied by 1 map.
Karrow, P.F. (1963): Pleistocene geology of the Hamilton-Galt area; Ontario Dept. Mines, GR16, 68p. Accompanied by 4 maps.
Karrow, P.F., and Terasmae, J. (1970): Pollen-bearing sediments of the St. Davids buried valley fill at the Whirlpool, Niagara River gorge, Ontario; Canadian J. Earth Sci., Vol.7, pt.2, p.539-542.

SOURCES OF INFORMATION

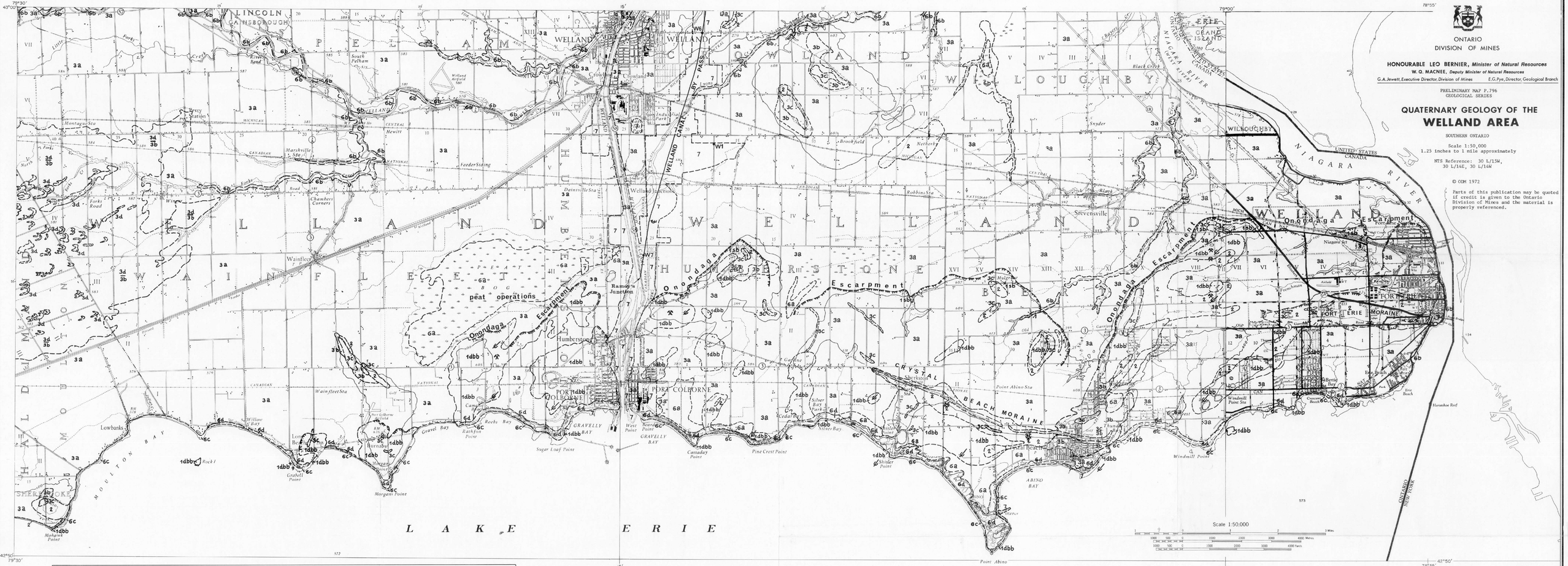
Geology by B.H. Feenstra and assistants, 1969, 1970, 1971.
Topography from Map 30 M/3 and Map 30 M/6 of the National Topographic Series.
Aerial Photography: Ontario Department of Lands and Forests.

Issued 1972.

Parts of this publication may be quoted if credit is given to the Ontario Division of Mines. It is recommended that reference to this map be made in the following form:

Feenstra, B.H. (1972): Quaternary geology of the Niagara area, southern Ontario; Ontario Div. Mines, Prelim. Map P.764, Geol. Ser., scale 1:50,000. Geology 1969, 1970, 1971.

ODM 4924



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DIVISION OF MINES

HONOURABLE LEO BERNIER, *Minister of Natural Resources*
W. Q. MACNEE, *Deputy Minister of Natural Resources*
G.A. Jewett, *Executive Director, Division of Mines* E.G. Pye, *Director, Geological Branch*

PRELIMINARY MAP P.796
GEOLOGICAL SERIES

QUATERNARY GEOLOGY OF THE WELLAND AREA

SOUTHERN ONTARIO

Scale 1:50,000
1.25 inches to 1 mile approximately

NTS Reference: 30 L/15W, 30 L/14E, 30 L/14W

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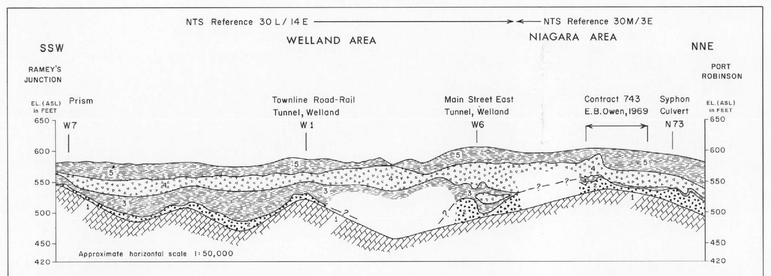


GENERALIZED GEOLOGICAL PROFILE ALONG THE WELLAND CANAL BY-PASS BETWEEN PORT ROBINSON AND RAMEY'S JUNCTION BASED ON BORINGS AND EXCAVATIONS

QUATERNARY

PLEISTOCENE

Late Wisconsin

5 — Upper glaciolacustrine unit consisting predominantly of clay and silt (corresponds to map unit 3a)

4' — Upper till unit with cloyey silt matrix (~2mm fraction) (Unit 8 of E.B.Owen,1969; map unit 2) Halton Till?

3 — Lower glaciolacustrine unit consisting predominantly of clay, silt, and sand; lens (?) of till with cloyey silt matrix at Main St.E Tunnel

2 — Lower till unit with silt-sand matrix (~2mm fraction) (Unit 8a of E. B. Owen,1969) Wentworth Till ?

SILURIAN

1 — Salina Formation: dolostone, shale, and gypsum
Guelph Formation: dolostone (in the vicinity of Port Robinson)

W6, N73 Pleistocene section number in Welland and Niagara area respectively

Additional sources of information:
St.Lawrence Seaway Authority
Geological Survey of Canada Paper 69-31 by E.B.Owen, 1969
Ontario Ministry of Transportation and Communications

TILL	SECTION NO.	TEXTURE <2mm fraction, Percent			CARBONATES <0.074mm fraction, Percent				HEAVY MINERALS 0.25ø-0.105mm fraction, Percent		TRACE ELEMENTS <0.037mm fraction, ppm						PEBBLE LITHOLOGY 8-32mm fraction, Percent								
		No. Analyses	Sand	Silt	Clay (<.002mm)	No. Analyses	Calcite	Dolomite	Total	Ratio Calcite/Dolomite	No. Analyses	Total	No. Analyses	Cu	Zn	Pb	Co	Ni	Cr	No. Analyses	Limestone	Dolostone	Chert	Shale	Siltstone	Igneous and Metamorphic	Limestone and Dolostone undifferentiated	Ratio Limestone/Dolostone
Upper till at	N73	6	12	65	23	6	9.6	11.0	20.6	0.95	3	4.2	34	74	29	10	40	63	1	21	69	–	8	2	90	0.3
			(5-24)	(52-74)	(17-26)		(8.6-12.6)	(7.4-16.5)	(16.8-25.6)			(2.9-6.3)	42	76	29	11	42	68								
													47	86	52	13	42	68	1	44	50	–	6	–	94	0.9
at	W6	–				6	7.3	14.6	21.9	0.5	5	3.6	28	104	32	9	29	48	–								
							(7-7.7)	(11.0-19.2)	(18.4-26.7)	(0.4-0.7)		(2.8-4.1)	52	106	38	9	35	60								
													96	129	54	11	36	68								
Middle till at	W6	–				4	8.0	11.7	19.7	0.7	4	3.4	32	104	30	9	37	65	–								
							(7.5-8.7)	(10.0-12.8)	(17.8-20.7)	(0.6-0.8)		(2.2-4.1)	35	107	38	10	40	66								
Lower till at	W6	–				6	6.3	27.9	34.1	0.2	6	3.6	26	116	44	5	23	34	–								
							(5.4-7.2)	(25.8-32.6)	(31.9-39.4)	(0.17-0.3)		(1.9-5.2)	34	127	44	6	24	34								
													52	177		7	26	41								
at	W1	1	41	39	20	1	5.2	26.0	31.2	0.2	1	4.4	21	92	46	7	25	43	1	1.5	95	–	–	3.5	96.5	0.02
at	W7	1	36	44	20	1	7.4	34.2	41.6	0.2	1	4.2	–							2.5	90.5	–	6.5	0.5	93	0.03

RESULTS OF TILL ANALYSES, WELLAND CANAL BY-PASS
(average and range of values)

ODM 4960

MARGINAL NOTES

Geological mapping of the Welland area was initiated and completed in 1972 under the supervision of B.H. Feenstra. Competent assistance in the field was given by Brian D. Cairns, who mapped the largest part of the area, Philip Rizzuto, and Richard J.R. Hoskin.

Field techniques included hand augering, the use of a sampling tube driven with a sledge hammer, and the examination of natural and man-made exposures. Additional information was obtained from examination of borehole samples and from logs of boreholes provided by several Federal and Provincial Government agencies.

Bedrock Geology: The Paleozoic geology of the area, where exposed at surface or covered by less than 3 feet of drift, has been mapped following descriptions by Caley (1940) and Best (1953). Numerous exposures of the Silurian Bertie Formation dolostones (map unit 1sb) and the Devonian Bois Blanc Formation cherty, fossiliferous limestones (map unit 1dbb), including a few of the basal Springvale sandstone member, occur in an east-west-trending belt across the southern part of the map-area from the Onondaga Escarpment south to Lake Erie.

Bedrock Topography and Drift Thickness: Drift thickness values range up to 25 feet from the Onondaga Escarpment southward to Lake Erie, except along the narrow strip of dunes (map unit 6d). Drift thickness values of 25 feet or less occur also in a small area to the northeast of Stevensville. Preliminary maps showing drift thickness and bedrock contours have been published by the Geological Survey of Canada (Sanford 1956).

Quaternary Geology: Throughout the southern part of the area, striations and small-scale directional features consistently indicate that ice movement was from the northeast (N35 to 47E). Re-entrants in the Onondaga Escarpment are parallel to that direction.

Borings and examination of excavations for the Welland Canal By-Pass Project revealed the following generalized Pleistocene lithostratigraphic sequence from top to botton (see profile section below): an upper glaciolacustrine clay and silt unit (map unit 3a), upper clayey silt till (map unit 2; unit 8 of Owen 1969), lower glaciolacustrine clay, silt, and sand unit with a large lens(?) of clayey silt till, similar to the upper till at the Main Street East Tunnel area in Welland, and a lower gravelly till with silt-sand matrix (unit 8a of Owen 1969) resting on dolostone, shale, and gypsum of the Silurian Salina Formation. This sequence is also present in the Fort Erie area. It is thought that the two different tills were deposited by glacial ice moving out of the Lake Ontario basin in a predominantly southwesterly direction during the Late Wisconsin Port Huron Stadial (Dreimanis and Karrow 1972). The lower till, having the lithological character of the local bedrock, is possibly a correlative of the Wentworth Till (Karrow 1963) and was deposited by glacial ice predominantly moving over bedrock. The upper till, a correlative of the Halton Till (Karrow 1963), was deposited during a readvance of glacial ice into the Lake Erie basin, predominantly moving over previously deposited glaciolacustrine sediments. Striations indicate a more west of southwest local ice movement direction during deposition of the lower till. Till unit 2? occurrences, which are scarce in the glacial lake plain, usually take the form of sleeder ridges perpendicular to ice movement and consist of upper till. From northeast to southwest they are: 1) the Fort Erie Moraine (Taylor 1913) and possible correlatives in the form of two 1- to 1½-mile long ridges in the eastern part of the City of Welland, covered by beach and shallow-water sediments (map units 3c and 3b); 2) the Crystal Beach Moraine (Taylor 1913); 3) a 1¼-mile long ridge west of the City of Port Colborne, covered by beach and shallow-water sediments; and 4) a slightly shorter ridge at Mohawk Point which could be part of the Port Maitland Moraine (Rukavina and St.Jacques 1971). The till in these ridges is massive except for the occasional presence of some interbedded clay in the Crystal Beach Moraine. The ice margin delta at Fonthill (Feenstra 1972) may be the correlative of the Fort Erie Moraine and the Niagara Falls Moraine.

The map-area is covered most extensively by glaciolacustrine clay and silt (Lake Warren to pre-Lake Dana, map unit 3a). A washboard pattern, discernible on air photographs, has a relief of only 1 to 2 feet. The pattern, trending obliquely to original ice movement, extends southward to the Onondaga Escarpment. A few sections show contorted, stratified glaciolacustrine clay and silt. LeKen and Leahy (1964) suggest this pattern is formed by "small moraines" (De Geer Moraines). The origin proposed by Henderson (1967), and favoured by the writer, suggests that the oriented ridge topography is formed when crevassed floating ice, attached to land-based ice, is lowered onto the glaciolacustrine clay and silt during shallowing of the water.

Shallow-water glaciolacustrine sand and silt (map unit 3b) as well as numerous relatively short beach and(or) off-shore bars consisting of gravelly sand and gravel (map unit 3c) are located on till ridges and on bedrock rises at elevations ranging from 600 to 650 feet above mean sea level. Whereas in northwestern New York, Calkin (1970) recognizes some 9 to 10 strandlines of glacial lakes of the Erie basin, mapping in the Niagara and Welland areas in Ontario results in the recognition of only 5 at the following approximate elevations: 830-850 feet and 810 feet (Lake Warren II and III?), 690-700 feet (Lake Lundy?), 635-655 feet (Lake Dana?), and at 605-625 feet (unnamed?). These lake levels apparently precede that of the non-glacial Early Lake Erie (Lewis 1969).

West of the Village of Wainfleet, a field of parabolic and longitudinal fossil dunes indicates prevailing westerly winds. These dunes, consisting of fine sand (map unit 3d) reach a maximum height of 20 feet and rest on shallow-water or deltaic (map unit 3b) sediments from which the dune sand may have been derived.

During the Holocene, peat (map unit 6a) accumulated in depressions in front of the Onondaga Escarpment, the largest accumulation being the Welland Bog. A profile section of its sediments as well as a pollen profile was published by the Geological Survey of Canada (Auer 1930). A narrow strip of longitudinal sand dunes (map unit 6d), best developed in the Point Abino area, extends behind the modern Lake Erie beach (map unit 6c) from Fort Erie to just west of Grabell Point. The growth of these dunes extends into bedrock-controlled depressions which are now filled with peat, organic-rich silt and clay, and dune sand (map unit 6a).

Industrial Mineral Resources: The dolostones and limestones of the Bertie and Bois Blanc Formations are at present being extracted primarily for crushed stone which is used in road construction, concrete aggregate, and railway ballast. The following are four quarry localities: two in the Ridgemount area southeast of Stevensville, one in the City of Port Colborne, and one just west of Port Colborne along the north side of Highway 3 (Hewitt 1960).

The following Quaternary map units are considered as commercial sand and gravel resources:

Map unit no.	Probability of locating economic granular deposits
6d	moderate to good
6c	moderate
3d	moderate
3c	poor to moderate

Peat, used as soil conditioner, is extracted at two localities in the Welland Bog west to northwest of the City of Port Colborne.

The total reported mineral production in 1970 amounted to $2,426,850 (Statistical Files).

ERRATA FOR PRELIMINARY MAP P.796

QUATERNARY GEOLOGY OF THE WELLAND AREA

By

B.H. Feenstra

Please paste the accompanying description of Quaternary Geology over the description of Quaternary Geology printed in the map surround. The accompanying copy contains corrected information.

Also:

Please add the following to the list of Selected References:

Feenstra, B.H.
1972: Quaternary Geology of the Niagara Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.796, scale 1:50,000. Geology 1969, 1970, 1971.

Selected References:

Bedrock Geology:
Best, E.W.
1953: Pre-Hamilton Devonian Stratigraphy of Southwestern Ontario; unpublished Ph.D. thesis, University of Wisconsin, Madison, Wisconsin.
Caley, J.F.
1940: Paleozoic Geology of the Toronto-Hamilton Area, Ontario; Geol. Surv. Canada, Mem.224, 284p. (reprinted 1961). Accompanied by 2 maps.
Bedrock Topography and Drift Thickness:
Sanford, B.V.
1956: Welland County, Ontario, Showing Drift Thickness and Bedrock Contours; Geol. Surv. Canada, Paper 55-20. Two Preliminary Maps, 55-20A and 55-20B, scale 1 inch to 2 miles.
Engineering Geology:
Conlon, R.J., Tanner, R.C., and Coldwell, K.L.
1971: The Geotechnical Design of the Townline Road-Rail Tunnel; Canadian Geotech. J., Vol.8, p.299-314.
Kwan, D.
1971: Observations of the Failure of a Vertical Cut in Clay at Welland, Ontario; Canadian Geotech. J., Vol.8, p.283-298.
Owen, E.B.
1969: Stratigraphy and Engineering Description of the Soils Exposed on a Section of the Welland Canal By-Pass Project (Contract 743), Ontario, Canada; Geol. Surv. Canada, Paper 69-31, 22p. Accompanied by chart, report and 17 figures.
Industrial Mineral Resources:
Auer, Vaino
1930: Peat Bogs in Southeastern Canada; Geol. Surv. Canada Mem.162, 32p. Accompanied by 3 maps.
Hewitt, D.F.
1960: The Limestone Industries of Ontario; Ontario Dept. Mines, IMR3, 177p. Accompanied by 2 maps and several sections. Updated in Ontario Dept. Mines IMR13, 1964, 77p. Accompanied by 1 map.
Pedology:
Ontario Agricultural College, Guelph, and Dominion Department of Agriculture, Ottawa
1935: Soil Survey Map of the County of Haldimand, Province of Ontario. Ontario Soil Survey Rept. No.4, scale 1 inch to 2 miles.
1935: Soil Survey Map of the County of Welland, Province of Ontario. Ontario Soil Survey Rept. No.5, scale 1 inch to 2 miles.
Physiography:
Chapman, L.J., and Putnam, D.F.
1966: The Physiography of Southern Ontario; University of Toronto Press, 2nd edition, 386p.
Quaternary Geology:
Calkin, P.E.
1970: Strand lines and Chronology of the Glacial Great Lakes in Northwestern New York; Ohio J. Sci., Vol.70, p.79-96.
Dreimanis, A., and Karrow, P.F.
1972: Glacial History of the Great Lakes-St. Lawrence Region, the Classification of the Wisconsin(an) Stage and Its Correlatives; p.5-15 in Proceedings, Section 12, 24th IGC, edited by J.E. Gill.
Henderson, E.P.
1967: Surficial Geology North of the St. Lawrence, Kingston to Prescott; p.199-209 in Guidebook, Geology of Parts of Eastern Ontario and Western Quebec, ed. by S.E. Jenness.
Karrow, P.F.
1963: Pleistocene Geology of the Hamilton-Galt Area; Ontario Dept. Mines, GR16, 68p.
Lewis, C.F.M.
1969: Late Quaternary History of Lake Levels in the Huron and Erie Basins; p.250-270 in Proc. 12th Conf. Great Lakes Res., International Assoc. Great Lakes Res.
LeKen, O.H., and Leahy, E.J.
1964: Small Moraines in Southeastern Ontario; The Canadian Geographer, Vol.8, p.10-22.
Rukavina, N.A., and St. Jacques, D.A.
1971: Lake Erie Nearshore Sediments, Fort Erie to Mohawk Point, Ontario; p.133-134 in Proc. 14th Conf. Great Lakes Res.
Taylor, F.B.
1913: The Moraine Systems of Southwestern Ontario; Royal Canadian Inst. Trans., Vol.10, p.1-23.

LEGEND

CENOZOIC
QUATERNARY
HOLOCENE
7 — 7 Cultural features. Predominantly fill
6 — 6d Dune sand
6c Lake Erie beach sand and gravel
6b Alluvium; predominantly clay and silt
6a Peat; clay, silt, and sand with organic matter
PLEISTOCENE
Late Wisconsin
5 — 5 Lake Iroquois deposits[1]
4 — 4 Stream/pond deposits[1]
3 — 3d Dune sand
3c Glaciolacustrine beach/off-shore bar sand and gravel
3b Glaciolacustrine sand and silt, minor clay (deltaic?)
3a Glaciolacustrine clay and silt, minor sand
2 — 2 Unsubdivided predominantly clayey and occassionally sandy silt tills

Unconformity

PALEOZOIC
DEVONIAN
1 — 1dbb Bois Blanc Formation: cherty fossiliferous limestone, minor dolostone, sandstone and shale
SILURIAN
1 — 1sb Bertie Formation: dolostone and shale
1 — Unsubdivided Bertie and Bois Blanc Formations

1. Not present in Welland map-area.

Note: Generally, only that part of a map unit with a thickness equal to or greater than 3 feet is outlined.

SYMBOLS

- Geological boundary (actual or interpreted).
- Small bedrock outcrop.
- Rock quarry, operating.
- Sand pit, operating.
- Glacial striations on bedrock, direction of ice movement known.
- Bedrock escarpment and scarp cut by former glacial lake.
- ●W 8 Quaternary section number, Welland area.

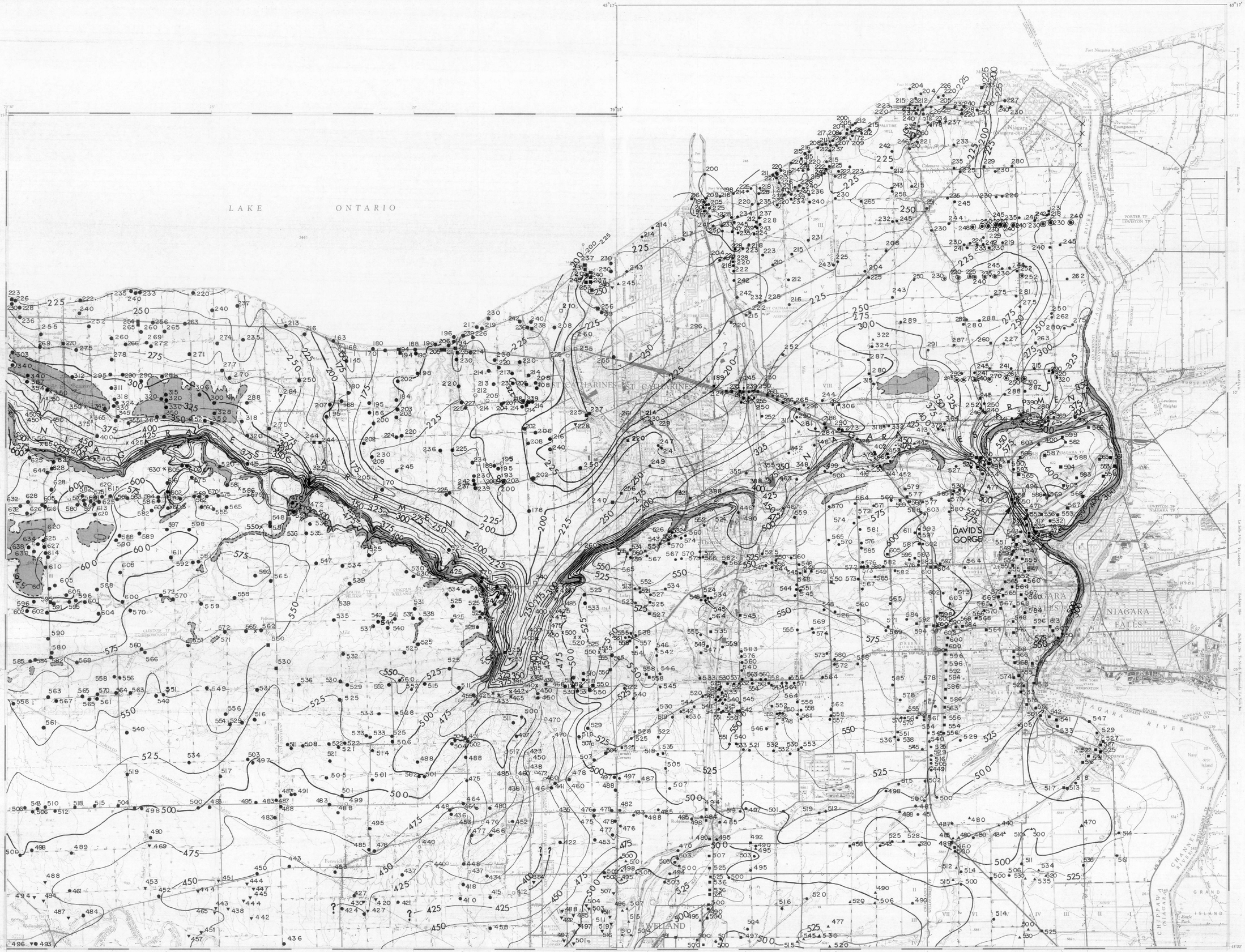
SOURCES OF INFORMATION

Geology by B.H. Feenstra and assistants, 1972.
Topography from Map 30 L/15W, 30 L/14E, and 30 L/14W of the National Topographic Series.
Aerial photography: Ontario Division of Forests.

Issued 1972.

Parts of this publication may be quoted if credit is given to the Ontario Division of Mines. It is recommended that reference to this map be made in the following form:

Feenstra, B.H.
1972: Quaternary Geology of the Welland Area, Southern Ontario; Ontario Div. Mines, Prelim. Map P.796, Geol. Ser., scale 1:50,000. Geology 1972.



Ministry of Natural Resources
Ontario

Hon. James A.C. Auld
Minister

W.T. Foster
Deputy Minister

ONTARIO GEOLOGICAL SURVEY
PRELIMINARY MAP P.2400
BEDROCK TOPOGRAPHY SERIES

NIAGARA and NIAGARA-ON-THE-LAKE AREA

SOUTHERN ONTARIO

Scale 1:50 000

Mile 1 0 1 Mile
Metres 1000 0 1 Kilometre

NTS Reference: 30 M/3, 6E

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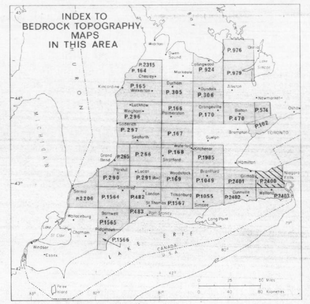
INDEX TO BEDROCK TOPOGRAPHY MAPS IN THIS AREA



SYMBOLS

- 240 — Elevation, in feet, of bedrock surface in water well.
- 421 — Elevation, in feet, at base of water well not reaching bedrock surface.
- ▲ 455 — Elevation, in feet, of bedrock surface in oil and gas exploration well.
- ■ 321 — Elevation, in feet, of bedrock surface in boring for geotechnical or stratigraphic purposes.
- □ 566 — Elevation, in feet, at base of boring for geotechnical purposes, not reaching bedrock surface.
- ⊙ 250 — Elevation, in feet, of bedrock surface, determined from seismic study.
- Bedrock surface outcrop and area covered generally by less than three feet of drift.
- Bedrock surface outcrop (small).
- 225 — Bedrock surface contour (inferred; interval 25 feet).

SOURCES OF INFORMATION

Surficial geology by B.H. Feenstra and assistants, 1969-1971.

Water well data supplied by the Ontario Ministry of the Environment.

Oil and gas exploration well data supplied by the Ontario Ministry of Natural Resources.

Test boring data supplied by the Ontario Ministry of Transportation and Communications, Ontario Hydro, Peto Associates Limited, and the St. Lawrence Seaway Authority.

Pleistocene Geology of the Buried St. Davids Gorge, Niagara Falls, Ontario - Geophysical and Palynological Studies; Geological Survey Canada Paper 68-67, by G.D. Hobson and J. Terasmae, 1969.

Metric Conversion Factor: 1 foot = 0.3048 m.

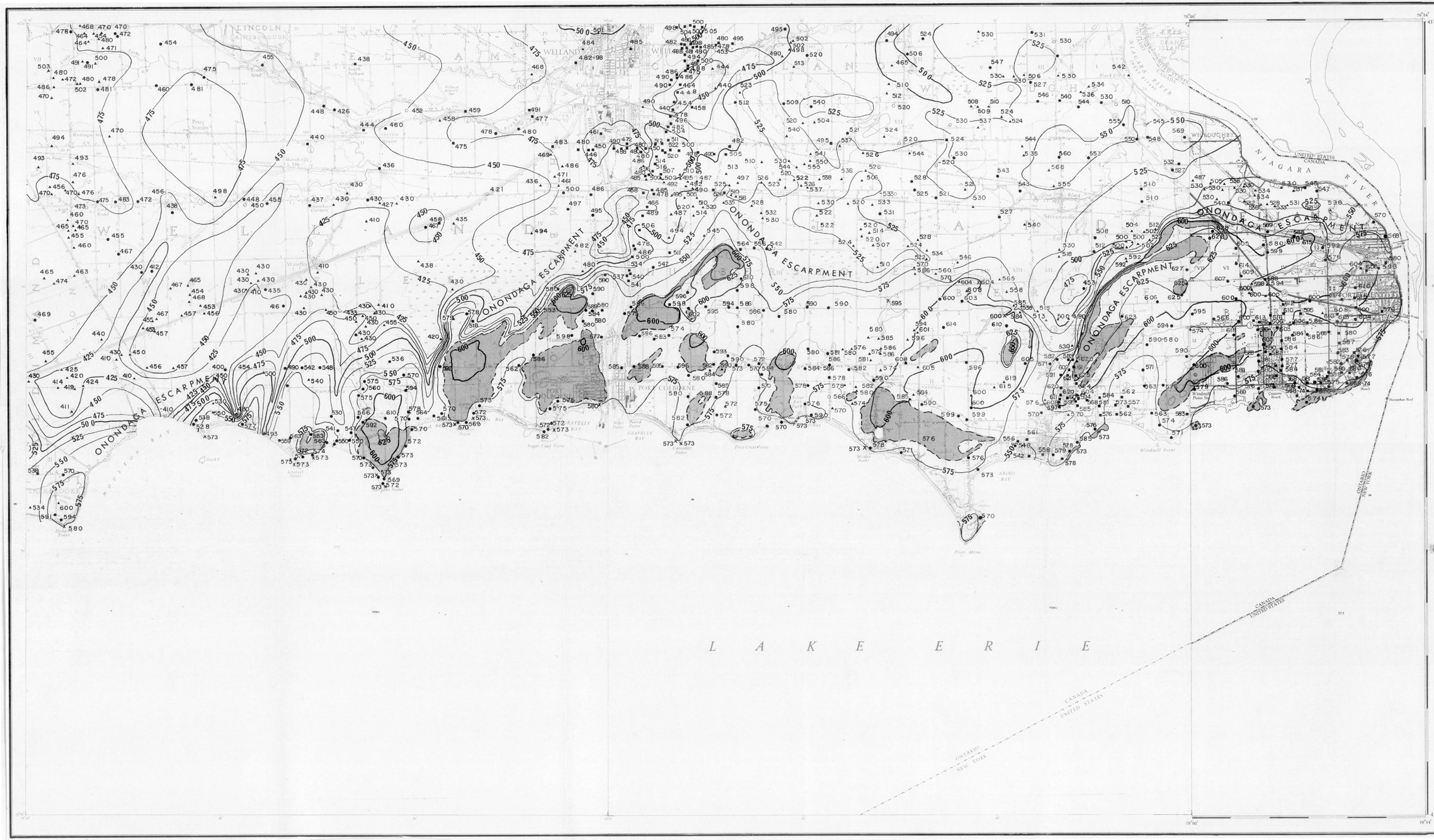
CREDITS

Compilation and contouring by B.H. Feenstra and assistants, 1973-1975.

Issued 1981

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

Feenstra, B.H.
1981: Bedrock Topography of the Niagara and Niagara-on-the-Lake Area, Southern Ontario; Ontario Geological Survey Preliminary Map P.2400, Bedrock Topography Series. Scale 1:50 000.



Ministry of Natural Resources

Ontario

Hon. James A.C. Auld
Minister

W.T. Foster
Deputy Minister

ONTARIO GEOLOGICAL SURVEY

PRELIMINARY MAP P.2403

BEDROCK TOPOGRAPHY SERIES

WELLAND–FORT ERIE AREA

SOUTHERN ONTARIO

Scale 1:50 000

Mile 1 0 1 Mile

Metres 1000 0 1 Kilometre

NTS Reference: 30 L/14, 16W

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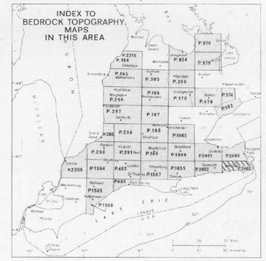
INDEX TO BEDROCK TOPOGRAPHY MAPS IN THIS AREA



SYMBOLS

- ● 586 — Elevation, in feet, of bedrock surface in water well.
- ○ 421 — Elevation, in feet, at base of water well not reaching bedrock surface.
- ▲ 455 — Elevation, in feet, of bedrock surface in oil and gas exploration well.
- ■ 440 — Elevation, in feet, of bedrock surface in boring for geotechnical purposes.
- Bedrock surface outcrop and area covered generally by less than three feet of drift.
- × — Bedrock surface outcrop (small).
- 600 — Bedrock surface contour (inferred; interval 25 feet).

SOURCES OF INFORMATION

Surficial geology by B.H. Feenstra and assistants, 1972.

Water well data supplied by the Ontario Ministry of the Environment.

Oil and gas exploration well data supplied by the Ontario Ministry of Natural Resources.

Data from test borings for geotechnical purposes supplied by the Ontario Ministry of Transportation and Communications, Peto Associates Limited, and the St. Lawrence Seaway Authority.

Haldimand County and parts of Brant, Wentworth and Lincoln Counties Ontario, Showing Drift Thickness and Bedrock Contours; Geological Survey Canada Paper 53-30, by B.V. Sanford, 1954.

Welland County, Ontario, Showing Drift Thickness and Bedrock Contours; Geological Survey Canada Paper 55-20, by B.V. Sanford, 1956.

Hobson, G.D., Owen, E.B., and Gagné, R.M., 1972: Bedrock Topography and Seismic data, Welland, Port Colborne Area, Ontario; *in* Owen, E.B., Geology and Engineering Description of the Soils in the Welland Port Colborne Area, Ontario, Fig. 7, scale 1: 25 000; Geological Survey Canada Paper 71-49.

Metric Conversion Factor: 1 foot = 0.3048m.

CREDITS

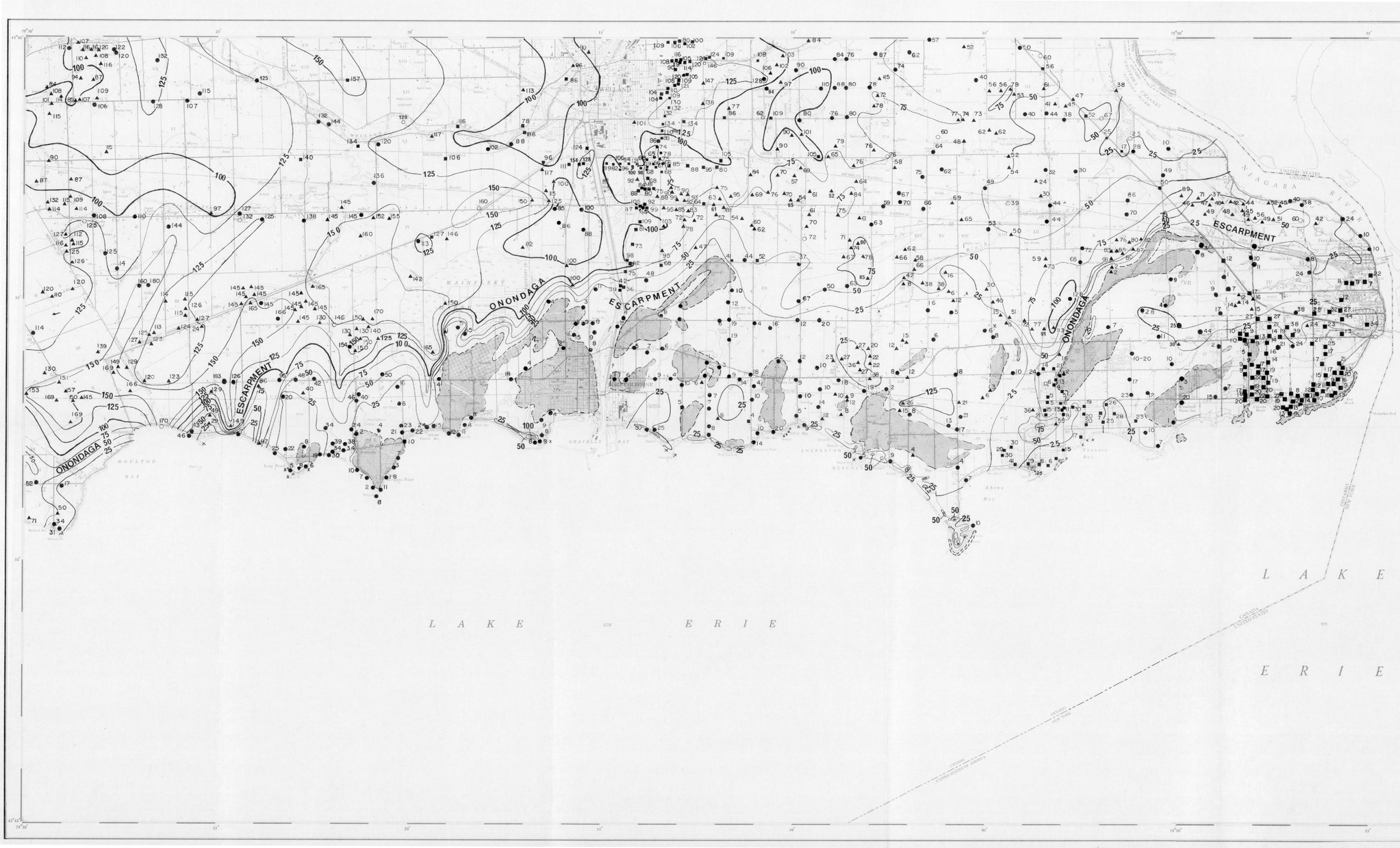
Compilation and contouring by B.H. Feenstra and M. Troper, 1975.

Issued 1981

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

Feenstra, B.H.

1981: Bedrock Topography of the Welland - Fort Erie Area, Southern Ontario; Ontario Geological Survey Preliminary Map P.2403, Bedrock Topography Series, Scale 1:50 000.



Ontario

Ministry of Natural Resources

Hon. Alan W. Pope, Minister

W.T. Foster, Deputy Minister

ONTARIO GEOLOGICAL SURVEY

MAP P.2486

DRIFT THICKNESS SERIES

WELLAND-FORT ERIE AREA

SOUTHERN ONTARIO

Scale 1:50 000

Mile 0 1 Mile

Metres 1000 0 1 Kilometre

NTS Reference: 30 L/14, 30 L/15W

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Parts of this publication may be quoted if credit is given and the material is properly referenced.

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INDEX TO DRIFT THICKNESS MAPS IN THIS AREA JANUARY 1982

SYMBOLS

● 10	Drift thickness, in feet, at water well.
○ 40	Minimum drift thickness, in feet, at water well not reaching bedrock.
▲ 77	Drift thickness, in feet, at oil and gas exploration well.
■ 88	Drift thickness, in feet, at test boring for geotechnical purposes.
	Bedrock surface outcrop and area covered generally by less than three feet of drift.
×	Bedrock surface outcrop (small).
25	Drift thickness contour (inferred; interval 25 feet).

Metric conversion factor 1 ft = 0.3048 m

SOURCES OF INFORMATION

Surficial geology by B.H. Feenstra and assistants, 1972.

Water well data supplied by the Ontario Ministry of the Environment.

Oil and gas exploration well data supplied by the Ontario Ministry of Natural Resources.

Test boring data supplied by the Ontario Ministry of Transportation and Communications, Peto Associated Limited, and the St. Lawrence Seaway Authority.

Haldimand County and parts of Brant, Wentworth and Lincoln Counties, Ontario, Showing Drift Thickness and Bedrock Contours; Geological Survey of Canada Paper 53-30 (2 maps, scale 1:126 720), by B.V. Sanford, 1954.

Welland County, Ontario, Showing Drift Thickness and Bedrock Contours; Geological Survey of Canada Paper 55-20 (2 maps, scale 1: 126 720), by B.V. Sanford, 1956.

Bedrock Topography and Seismic Data, Welland-Port Colborne Area, Ontario; in Geology and Engineering Description of the soils in the Welland-Port Colborne Area, Ontario by E.B. Owen; Geological Survey of Canada Paper 71-49, Fig. 7, scale 1:25 000, by G.D. Hobson, E.B. Owen, and R.M. Gagne, 1972.

CREDITS

Compilation and contouring by B.H. Feenstra and M. Troper, 1975.

Issued 1982

Information from this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Feenstra, B.H. and Troper, M.
1982: Drift Thickness of the Welland-Fort Erie Area, Southern Ontario; Ontario Geological Survey Map P.2486, Drift Thickness Series. Scale 1: 50 000.