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Ontario Geological Survey

Report 220

Quaternary Geology
of the
Tillsonburg Area
Southern Ontario

by

P.J. Barnett

1982

Ontario

Ministry of
Natural
Resources

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1982: Quaternary Geology of the Tillsonburg Area, Southern Ontario; Ontario Geological Survey Report 220, 87p. Accompanied by Map 2473, Scale 1:50 000.

1000-300-82-Thorn

FOREWORD

TILLSONBURG AREA

Ontario's Quaternary deposits are being mapped by the Ontario Geological Survey because a knowledge of the character and distribution of these materials is important in the search for construction materials and ground-water supplies as well as in the design and construction of roads, buildings, and utilities, and in land-use planning.

This report deals with an area of about 1100 km^2 of Ontario centred about the community of Tillsonburg. It describes the physiography of the area particularly as created by the action of glacial ice, and the origin, distribution, and physical and chemical characteristics of the Quaternary deposits.

E.G. Pye
Director
Ontario Geological Survey

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(back pocket)

Map 2473 (coloured) - Quaternary Geology of the Tillsonburg Area, Southern Ontario.
Scale 1:50 000.

CHARTS

(back pocket)

Chart A - Figures 2,3,4,7,10, and 12.

Chart B - Figures 8,13,14,15, and 17.

SMC 14943

Figure 1–Location of the Tillsonburg map-area.
Scale 1:3 168 000 (1 inch to 50 miles).

ABSTRACT

Quaternary deposits of the Tillsonburg area range from 7 m to over 100 m thick. These sediments overlie dominantly carbonate bedrock of Silurian and Devonian age, which does not outcrop within the map-area. The Quaternary deposits observed at the surface are of Late Wisconsinan age, but sediments of Mid-Wisconsinan age are present at depth. The oldest till, Catfish Creek Till (Nissouri Stadial) which outcrops in the northern part of the map-area, is a dense, stoney, sandy silt till and represents a major ice advance from the northeast. The younger tills, the Port Stanley and Wentworth Tills, represent subsequent readvances into the area from the southeast and east, their direction being controlled by the Erie basin.

The Port Stanley Till (Port Bruce Stadial), the surficial deposit covering approximately half the map-area, is a silty clay to clayey silt till with a low to moderate clast content. This till is the major component of the Ingersoll, Westminster, St. Thomas, Norwich, Tillsonburg, Courtland, and Mabee Moraines. Stratigraphic studies of natural exposures along the major creeks and of water-well records suggest a complex interfingering of this relatively impermeable fine-grained till with glaciolacustrine sands in the southern half of the map-area. This situation is the result of oscillating advances of the ice front into proglacial lakes (Maumee stages?) during retreat of the ice sheet into the Erie basin.

The Wentworth Till (Port Bruce Stadial), a sandy silt to silt till with a moderate stone content, is found in the southeast corner of the map-area. It is the till of the Paris Moraine.

Approximately one third of the map-area has a surficial cover of glaciolacustrine sediment. During the Port Huron Stadial the Tillsonburg area was inundated by the waters of glacial Lake Whittlesey and a large portion of the Norfolk Sand Plain was deposited. Sediments of Glacial Lakes Maumee and Arkona are also present.

Granular resources of the Tillsonburg area are dominantly associated with the Port Stanley Till and are mainly outwash in origin. Coarse aggregate will probably not be sufficient to meet local needs in the future. Most of the sand and gravel deposits throughout the map-area contain significant quantities of chert, which is generally considered to be deleterious.

Quaternary Geology of the Tillsonburg Area, Southern Ontario, by P.J. Barnett, Ontario Geological Survey Report 220, 87p., Published 1982. ISBN 0-7743-6983-3.

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

If the reader wishes to convert imperial units to SI (metric) units or SI units to imperial units the following multipliers should be used:

CONVERSION FROM SI TO IMPERIAL			**CONVERSION FROM IMPERIAL TO SI**		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

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

Quaternary Geology
of the
Tillsonburg Area
Southern Ontario

by

P.J. Barnett[1]

INTRODUCTION

Present Geological Survey

The purpose of this geological survey of the Tillsonburg area is to determine the areal extent and distribution of the various geological materials which occur at or near the surface (within 1 m). This is accomplished by the use of soil probes, hand augers, test pits, and the examination of natural and man-made exposures, and through the extensive use of air photographs.

Observations of natural and man-made sections plus the utilization of water-well and gas-well information aid in determining the relationships of these various materials, with respect to their distribution at depth and their time of deposition. Physical characteristics of the materials observed during field examinations are augumented through laboratory investigations.

This information is useful in outlining the natural geological resources of this area and determining their availability and quality; potentially hazardous areas related to geological conditions can be delineated as well.

The information is also useful as a basis for land-use planning, environmental, engineering, hydrological, and soil studies.

Geological mapping of the area was completed during the summer of 1976 by C.K. Girard and the author, and a preliminary map of the work was published in 1976 (Barnett *et al.* 1976).

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[1] Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Mineral Resources Group.

Manuscript approved for publication by the Chief, Engineering and Terrain Geology Section, July 18, 1980.

Location and Access

The Tillsonburg area (Figure 1) is located in the south central part of southern Ontario (Latitude 42°45'N to 43°00'N, and Longitude 80°30'E to 81°00'E). Topographic coverage is by the National Topographic Series sheet 40 I/15 at a scale of 1:50 000, and topographic maps at a scale of 1:25 000 are also available.

The Tillsonburg map-area covers about 1100 km^2 and includes parts of Brant, Elgin, Middlesex, and Oxford Counties, plus a small portion of the Regional Municipality of Haldimand-Norfolk. Tillsonburg, Aylmer, Delhi, Norwich, and Otterville are the major communities in this area. Road access is via Highways 3, 19, 59, 73, and 401 (MacDonald–Cartier Freeway), and by a network of regional and county roads. Canadian National, Canadian Pacific, and Michigan Central Railways serve this area. The Tillsonburg Airport, about 6 km north of Tillsonburg, allows access to the area by small aircraft.

Acknowledgments

The author would like to thank the staff of several public and private agencies and the many individuals who gave their time and assistance throughout the progress of this project.

Subsurface information was gained through the use of water-well data supplied by the Water Resources Division, Ontario Ministry of Environment, oil-well and gas-well data supplied by Petroleum Resources Section, Ontario Ministry of Natural Resources, and engineering reports made available by the Ontario Ministry of Transportation and Communications.

Lab analyses were conducted by the Geoscience Laboratories, Ontario Geological Survey, Toronto.

Special thanks go to C.K. Girard (senior assistant) who mapped the eastern half of the map-area and to Gordon Spratt and Christine Kmiecik, all of whom supplied competent field assistance during the summer of 1976. The author also extends his thanks to the residents of the area who permitted access to their land and participated in many interesting discussions.

Previous Work

LOCAL STUDIES

The Ontario Department of Planning and Development (1951, 1957, 1958) produced three conservation reports dealing in part with the Tillsonburg area: Catfish Creek in 1951, Big Otter Creek in 1957, and the Big Creek Region in 1958. A brief and generalized description of the Quaternary deposits of the area is given in the latter two reports, while a very detailed description of the Quaternary deposits is given in the Catfish Creek report. These reports are useful in providing an account of the history, forestry, and water resources of the Tillsonburg area.

The Ontario Water Resources Commission (now part of the Ontario Ministry of the Environment) has published reports on the water resources of Big Creek (Yakutchik and Lammers 1970) and Big Otter Creek (Sibul 1969) drainage basins. Again, descriptions of the Quaternary geology and history form parts of these reports as well as maps and discussions on the drift thickness, bedrock geology, bedrock topography, and the availability of ground water. Other studies on ground water in the Tillsonburg area include those of Sklash *et al.* (1976), Sklash (1975), and Novakovic and Farvolden (1974).

Previous reports on the Quaternary geology of the Woodstock (Cowan 1975), Brantford (Cowan 1972), and Simcoe areas (Barnett 1978), and preliminary maps of the Lucan (Sado and Vagners 1975), St. Thomas (Dreimanis 1964, 1970a) and the Port Stanley (Dreimanis 1970b, 1972) areas describe the Quaternary deposits and their interrelationships in adjacent map-areas.

Detailed studies by A. Dreimanis (University of Western Ontario) and University of Western Ontario students on the Lake Erie bluffs, and river sections in the Plum Point, Port Bruce, and London areas of southern Ontario, have been instrumental in the development of many of the stratigraphic relationships pertaining to the deposits of the Tillsonburg area. Some papers published on this area include Dreimanis (1958), de Vries and Dreimanis (1960), Morner and Dreimanis (1973), Dreimanis and Karrow (1965), Dreimanis and Reavely (1953), and Dreimanis *et al.* 1966.

Sand and gravel operations in the Tillsonburg map-area have been discussed by Hewitt and Karrow (1963) and Hewitt and Cowan (1969a, 1969b).

Clay production from three areas within the Tillsonburg map-area has been discussed by Guillet (1967, 1977).

The distribution of soil types in the counties of Norfolk, Elgin, and Middlesex was mapped by the Ontario Agriculture College (*circa* 1928, 1929, 1931 respectively), and in Oxford County by Wicklund and Richards (1961).

REGIONAL STUDIES

Several regional studies have incorporated information based on the Quaternary deposits of the Tillsonburg area. The major moraines in southwestern Ontario were discussed by Taylor (1913) and later by Chapman and Putnam (1943a). Chapman and Putnam (1943b, 1951, 1966) also suggested a glacial history of the area and have discussed the physiographic regions of the area.

The deposits of the Erie glacial lobe have been discussed by Goldthwait *et al.* (1965) and those of the Huron, Erie, and Ontario lobes by Dreimanis and Goldthwait (1973).

Leverett and Taylor (1915), MacLachlan (1938), and Chapman and Putnam (1951, 1966) located several raised shorelines in the map-area and have commented on their age, and the corresponding ice-front positions.

Physiography

The Tillsonburg map-area can be divided into two distinct physiographic regions (Chapman and Putnam 1951, 1966): the tobacco-growing sand plain in the southeast (Norfolk Sand Plain), and the rolling morainic clayey silt till area of the northwest (Mount Elgin ridges) where livestock farming dominates.

The Norfolk Sand Plain, within the Tillsonburg map-area, is a level to gently rolling abandoned lake plain interrupted by several long linear ridges. Local relief of these ridges is generally 12 m above the sand plain but does reach as much as 21 m. These ridges are the geomorphic expressions of the Tillsonburg and Courtland Moraines. Deep dissection of the Norfolk Sand Plain, to as much as 38 m, has occurred along Big Creek and Big Otter Creek, and their tributaries.

The sand of the Norfolk Sand Plain ranges in thickness from a very thin veneer to thicknesses of 27 m reported by drillers in the Tillsonburg map-area. This sand plain developed during several high-level glacial lakes in the Lake Erie basin (Lakes Whittlesey and Warren) after the glacial ice had retreated from the Tillsonburg map-area. Some of the thicker sequences of sand, however, can be in part attributed to older glaciolacustrine events.

The Mount Elgin ridges physiographic region consists of a series of morainic ridges which trend generally parallel to the present-day Lake Erie shoreline. These morainic ridges are composed mainly of clay-silt till and represent minor standstills of the ice front of a continental glacier shrinking into the Lake Erie basin. From north to south these moraines are the Ingersoll, Westminster, St. Thomas, and Norwich Moraines.

Between these ridges are flat meltwater channels which conveyed the runoff from this glacier into glacial lakes located farther west in the Erie basin. Relief within this region reaches a value of 37 m between the St. Thomas Moraine and the meltwater channel in front of this moraine. Local relief within the moraine area can reach 7.5 m because of the hummocky topography.

The highest point of elevation in the Tillsonburg map-area occurs 2.4 km northwest of Zenda at 1080 feet above sea level (a.s.l.). The lowest is 610 feet a.s.l. about 2.5 km southwest of Bayham (Richmond). Maximum relief of the area is 470 feet.

Drainage

The Tillsonburg map-area is drained by five major creeks: Big Creek, Big Otter Creek, Catfish Creek, and Kettle Creek which drain directly into Lake Erie; and Reynolds Creek which joins the Thames River at Putnam and eventually flows into Lake St. Clair.

Big Creek is located along the eastern boundary of the map-area and drains approximately 220 km^2 of the Tillsonburg area. The various hydrological characteristics of this creek are discussed by Yakutchik and Lammers (1970).

Big Otter Creek drains approximately half the map-area and flows through the towns of Otterville, Tillsonburg, Bayham (Richmond), and Vienna, and then enters Lake Erie at Port Burwell. Hydrological information about this creek is presented by Sibul (1969).

Catfish Creek and its tributaries drain about 175 km^2 of the Tillsonburg map-area. Its headwaters drain the south slope of the Norwich Moraine and also the intermorainal troughs between the St. Thomas and Norwich Moraines, and the Culloden and Brownsville limbs of the Norwich Moraine. High stream-gradient values (up to 13 m/km) occur in the small tributary streams that drain the slopes of the moraines, but the gradient of Catfish Creek along the Aylmer–Brownsville depression (Dreimanis 1951) is about 1.3 m/km.

Approximately 26 km^2 of the Tillsonburg map-area between the Westminster and St. Thomas Moraines are drained by the headwaters of Kettle Creek. Within this area its gradient is about 1.1 m/km.

Reynolds Creek and the Thames River drain about 170 km^2 of the map-area. Both the Thames River and Reynolds Creek occupy abandoned meltwater channels. Reynolds Creek has been artifically altered and straightened throughout most of its length.

BEDROCK GEOLOGY

Lithology and Distribution

No outcrop of Paleozoic rocks has previously been reported and none was observed during mapping. The bedrock geology has been mapped, however, by Stauffer (1915), Caley (1941), and Sanford (1969) using information from oil-well and gas-well logs and cuttings. Stauffer (1915) suggested that rocks of the Devonian Onondaga (grey to bluish limestone, portions of it very cherty) and the Delaware Formation (blue to brownish limestone often with interbeds of brown shale) subcrop within the area. Caley (1941) combined these formations together and suggested the term Norfolk Formation (grey bluish and brown limestone, calcareous sandstone, chert). The most recent Paleozoic map of the area (Figure 2, Chart A, back pocket) by Sanford (1969) shows that the Silurian Bass Islands as well as the Devonian Bois Blanc, Amherstburg, Lucas, Dundee, and Marcellus Formations subcrop within the Tillsonburg area.

Sanford (1969) described the Silurian Bass Islands Formation as a "cream and tan oolitic microsucrosic dolomite." The Devonian Bois Blanc Formation was described by Sanford (1969) as a "grey and greyish-brown dolomite, limestone and nodular chert."

In the Tillsonburg area, the Detroit River Group is represented by the Amherstburg Formation, a "grey to dark brown crinoidal limestone and dolomite, locally cherty, bituminous and biostromal" and the Lucas Formation "brown and tan microcrystalline and sublithographic limestone, locally biostromal" (Sanford 1969).

The Devonian Dundee Formation subcrops below approximately three quarters of the map-area. Sanford (1969) divided this unit into an upper member "medium brown microcrystalline limestone", and lower member "light brown and tan crinoidal limestone, containing quartz sand grains and chert."

To the southwest, between Summers Corners and Bayham, "black bituminous shale and minor limestone" of the Marcellus Formation (Sanford 1969) lie beneath the Quaternary deposits.

Bedrock Topography

Several bedrock topography maps which cover parts of the Tillsonburg map-area have been published. Dreimanis (1951) prepared a bedrock topography map of the Catfish Creek drainage basin and Sibul (1969) and Yakutchik and Lammers (1970) prepared bedrock topography maps for Big Otter Creek and Big Creek drainage basins respectively. Sanford (1953, 1954) published preliminary maps showing bedrock surface contours for Elgin County, and parts of Middlesex County and Norfolk County.

Barnett and Starkoski (1978a) published a bedrock topography map of the entire Tillsonburg map-area which has been generalized for presentation here as Figure 3 (Chart A, back pocket).

The bedrock surface slopes gently towards the south with a local relief of generally less than 6 m. Local relief of up to 24 m, however, has been reported and coincides with buried valleys. These valleys are difficult to trace over any great distance. The maximum relief of the bedrock surface in the Tillsonburg map-area is 350 feet.

Economic Geology

LIMESTONE

At present there are no quarrying operations in the Tillsonburg map-area. The main reason for this is the thick accumulation (generally 23 to 78 m thick) of glacial drift over the bedrock surface. There are two areas that have a drift cover of less than 15 m. One area, outlined by Sibul (1969), is located along Big Otter Creek 3.5 km south of Springford. Here the Dundee Formation subcrops within 7 m of the surface.

The other area is along the Thames River valley where the drift along the banks is less than 19 m thick and can be as thin as 10 m. A large portion of this drift cover may be sand, gravelly sand, or gravel, which could be used for granular aggregate. In this area the upper sandy facies of the Lucas Formation subcrops, the Columbus Formation of Hewitt (1960), and is underlain by the high-calcium facies of the Lucas Formation. This high-calcium limestone is presently being extracted at Zorra and in the Beachville area within the Woodstock map-area (Hewitt 1960; Hewitt and Vos 1972; Cowan 1975). More than 18 m of overburden is being removed to mine up to 30 m of the high-calcium limestone in these areas. Thicknesses of high-calcium limestone in the order of 30 m have been reported within 5 km of the Tillsonburg map-area by Hewitt (1960).

To determine the actual thickness of the high-calcium rock and the thickness of the overlying sandy facies, test holes will be required. Reported thicknesses of the upper sandy facies of the Lucas Formation are up to 16.5 m (Hewitt 1960) but the thickness varies greatly throughout the subcrop area.

Removal of the overburden along the Thames River in the Tillsonburg map-area in order to quarry this high-calcium limestone may be economical in the future, but further test drillings are required for proper assessment of this area for possible extraction.

OIL AND GAS

Natural gas has been produced from four separate gas pools located in the Tillsonburg map-area: the Verschoyle West pool (Cambrian), and Brownsville, Eden, and Norwich South pools (Silurian). Part of the Norfolk (Silurian) gas field is also within the map-area. In 1974 only the Norwich South gas pool and the Norfolk gas field were in production and they accounted for less than one percent of Ontario's total gas production.

Oil has been produced from the Verschoyle oil pool within the map-area, but in 1974 the proven remaining recoverable reserves were reported as nil (Ontario Ministry of Natural Resources 1977).

QUATERNARY GEOLOGY

Introduction

The nomenclature and stratigraphic relationships of Quaternary deposits in Southern Ontario have been summarized by Dreimanis and Karrow (1972), Karrow (1974), and Cowan *et al.* (1975). The classification of the Wisconsinan Stage as presented by Dreimanis and Karrow (1972) is followed in this report. Several publications (Cowan 1972, 1975; Dreimanis 1964, 1970a, 1970b, 1972; Sado and Vagners 1975; and Barnett 1978) describe the Quaternary geology and stratigraphic relationships in adjacent map-areas.

The Quaternary deposits observed during the summer and fall of 1976 are of Late Wisconsinan and Recent Age. Sediments representing the Nissouri, Port Bruce, and Port Huron Stadials, the Erie and Mackinaw Interstadials, and the Recent can be found within the Tillsonburg map-area. Table 1 is a summary of the Quaternary deposits and events of the Tillsonburg map-area that will be discussed in detail. Deposits that may represent the Plum Point or Port Talbot Interstadial, have been reported by E. Hoover using data from a well 1650 m west-northwest of the Aylmer Station on the Michigan Central Railway (Dreimanis 1951). The log of the well as reported by Hoover from memory is presented in Table 2.

TABLE 1 | SUMMARY OF QUATERNARY DEPOSITS AND EVENTS IN THE TILLSONBURG AREA

Age	Time Stratigraphic Unit	Rock Stratigraphic Unit	Deposit or Event*	Materials	Morphologic Expression
Recent			modern alluvium	sand, silt, clay, gravel	present-day flood plains
			bog and swamp deposits	muck, peat, marl	filled depressions
Late Wisconsinan			older aluvium	sand, gravelly sand	remnant river and creek terraces
	Two Creeks Interstadial?		eolian sediments	sand	transverse and parabolic dunes
	Port Huron Stadial		Lake Warren	gravel, sand	bars, lake plain
			Lake Whittlesey	gravel, sand, silt clay	bars, spits, delta, lake plain, lake bluffs
	Port Bruce Stadial	Wentworth Drift	Wentworth Till	sandy silt to silt till	end moraine
			Lake Arkona (s)	gravelly sand	bars, lake bluffs, lake plain
		Port Stanley Drift	Lake Maumee III	sand, silt, clay	lake bluff, lake plain
			outwash, glaciolacustrine	gravel, sand, silt clay	delta, lake plain, mainly buried
			outwash	gravel, sand, silt	meltwater channels
			Port Stanley Till	clayey silt to silty clay till	till plain, end moraines drumlins
			ice-contact stratified drift	sand, silt, gravel	kames, end moraines
			outwash	gravel, sand, silt	meltwater channels
		Tavistock Drift (?)	Tavistock Till (?)	sandy silt till,	end moraine ?
			outwash	gravel, sand	buried
	Erie Interstadial		lacustrine deposits	silt, clay	buried
	Nissouri Stadial	Catfish Creek Drift	outwash	gravel, sand	buried
			Catfish Creek Till	sandy silt till	ground moraine, end moraine?
			outwash	gravel, sand	buried
Middle Wisconsinan			lacustrine	clay with wood sticks	buried (report in well)

* vertical bars denote that deposition of specified material occurred throughout time span indicated.

TABLE 2 WATER-WELL LOG FROM AYLMER STATION (after Dreimanis 1951)

Depth (ft.)	Thickness (ft.)	Material	Possible Stratigraphic Relation as Interpreted by P.J. Barnett.
0-180	180	clay (till?)	Port Stanley Drift (mainly till) and Erie Interstadial Material.
180-220	40	yellow sand	Erie Interstadial Material or Catfish Creek Drift.
220-240	20	hardpan (till?)	Catfish Creek Drift (mainly till).
240-265	25	blue clay with sticks	Plum Point Interstadial Material or possibly Port Talbot Interstadial Material or both.
265+		bedrock	Devonian Dundee Limestone.

Drift Thickness

Maps of drift thickness, prepared by Dreimanis (1951), Sanford (1953, 1954), Sibul (1969), and Yakutchik and Lammers (1970), cover portions of the Tillsonburg map-area. A generalized version of the drift thickness map by Barnett and Starkoski (1978b) is provided in Figure 4(Chart A, back pocket).

The drift cover thickens towards the southwest and along the various morainic ridges of the area. Water-well records indicate a drift thickness of over 91 m along the Tillsonburg, Norwich, St. Thomas, and Ingersoll Moraines. Drift, less than 31 m thick, occurs along the valleys of the Thames River, Big Creek, and Big Otter Creeks.

Glacial Deposits and Features

TILL

Till is an unsorted and unstratified mixture of clay, silt, sand, gravel, and boulders which was directly deposited from the glacial ice with no subsequent reworking by glacial meltwater.

The three tills that are exposed in the Tillsonburg map-area were deposited during the Late Wisconsinan Substage. No evidence for pre-Late Wisconsinan tills was found in the area. The oldest till, Catfish Creek Till, generally represents a major glacial advance from the northeast. The subsequent Port Stanley and Wentworth Tills were deposited by glacial ice entering the Tillsonburg map-area from the southeast and east (Ontario–Erie lobe tills).

Textural descriptions follow the scheme proposed by Elson (1961), however, only the matrix fraction of the till (<2 mm), and a silt-clay boundary of 2 microns were used in this study. Average and range values for several properties of these tills are presented in Table 3. Results for individual samples, as located on Map 2473 (back pocket), can be found in Appendix B. Figure 5 displays the grain-size distribution of several till samples from the area.

Catfish Creek Till

The oldest till exposed within the Tillsonburg map-area is a stony sandy silt to silt till. It occurs as buried ground moraine throughout most of the map-area and occasionally it is found in overridden drumlins as in the northwestern corner of the map-area. The maximum observed thickness of this till was 2.5 m, however, similar material (hardpan sand stone, hardpan, gravel) believed to be Catfish Creek Till has been reported up to 23 m in water-well records.

This till has been traced into the Woodstock, St. Thomas, and Lucan map-areas and appears to correlate with the Catfish Creek Till identified in those areas (Cowan 1975; Dreimanis 1970a; Sado and Vagners 1975). The name *Catfish Creek Till* was first used by Dreimanis (de Vries and Dreimanis 1960) to identify the lower till exposed along Catfish Creek and Lake Erie shore bluffs in the Port Stanley–London area of southern Ontario. This till was previously referred to only as "the lower till" (Dreimanis 1951).

The Catfish Creek Till in the Tillsonburg map-area is quite variable in colour. When compared to the Munsell Soil Colour Chart, the colour ranges from a greyish brown (10YR 5/2) to brown (10YR 5/3) to dark brown (10YR 4/3) to yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4). The extremely compact nature of the till and the high percentage of stone (up to 25 percent), make it very difficult to excavate. Carbonate content of the silt–clay fraction averages about 40 percent, with a carbonate ratio (calcite:dolomite) of usually less than one.

Approximately 4 percent of the fine sand fraction of this till is made up of heavy minerals. Garnets and magnetics each account for about 13 percent of

TABLE 3 SUMMARY OF TILL ANALYSES IN THE TILLSONBURG AREA

Till	Matrix Grain Size Analysis* (< 2 mm)									Matrix Carbonates (< 0.74)				
	n	% Clay		% Silt		% Sand		Md. (μ)		n	% Total		Ratio $\frac{\text{Calcite}}{\text{Dolomite}}$	
		$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R		$\bar{x}$	R	$\bar{x}$	R
Wentworth	4	17	15-20	66	61-70	17	14-20	20	15-29	4	38	28-47	1.3	0.92-1.8
Port Stanley	54	32	6-51	56	33-67	12	3-61	9	2-100	54	39	35-47	1.5	0.59-2.3
Catfish Creek	9	10	7.5-12	46	24-61	44	30-67	70	30-130	9	43	38-61	0.70	0.47-1.2

Till	Pebble Lithologies (4.75-25 mm)														
	n	% Limestone		% Dolostone		% Chert		% Clastics		% Ingeous & Metamorphic		Ratio $\frac{\text{limestone}}{\text{dolostone}}$		Ratio $\frac{\text{limestone + chert}}{\text{dolostone}}$	
		$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R
Wentworth	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Port Stanley	21	58	28-88	24	3-58	9	0-31	4	0-24	5	0-13	4.4	0.49-29	5.0	0.56-61
Catfish Creek	7	42	34-57	38	26-48	4	2-8	3	0-7	13	5-22	1.2	0.71-2.0	1.3	0.87-2.

Till	Heavy Minerals (2.50-1.25 mm)									
		% Total		% Magnetics		n	% Garnets		Garnet Ratio $\frac{\text{Purple}}{\text{Red}}$	
		$\bar{x}$	R	$\bar{x}$	R		$\bar{x}$	R	$\bar{x}$	R
Wentworth	4	3.6	2.5-5.3	9.8	7.8-11.6	2	15	13-17	1.2	0.97-1.5
Port Stanley	54	4.0	1.3-11.0	14.1	6.9-34.8	30	15	6-29	1.4	0.44-2.6
Catfish Creek	9	4.2	2.5-5.4	12.5	8.8-17.0	8	14	7-20	0.73	0.56-1.1

Till	Trace Element Concentration** (—400 mesh) (in ppm)														
	n	Copper (Cu)		Nickel (Ni)		Zinc (Zn)		Chromium (Cr)		Manganase (Mn)		Cobalt (Co)		Lead (Pb)	
		$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R	$\bar{x}$	R
Wentworth	2	27	26-28	15	15-16	63	61-66	43	40-46	675	590-760	7	7-8	14	11-16
Port Stanley	23	26	22-29	21	16-25	72	54-75	53	42-64	660	550-720	10	8-16	13	<10-27
Catfish Creek	4	20	16-24	15	8-19	52	38-64	37	24-45	533	380-630	7	5-10	12	10-15

n = number of samples; Md = median; $\bar{x}$ = mean; R = range

* sand-silt boundary of 0.062 mm and a slit-clay boundary of 2μ were used

** accuracy ± 5 ppm for all elements except Mn (± 20 ppm)

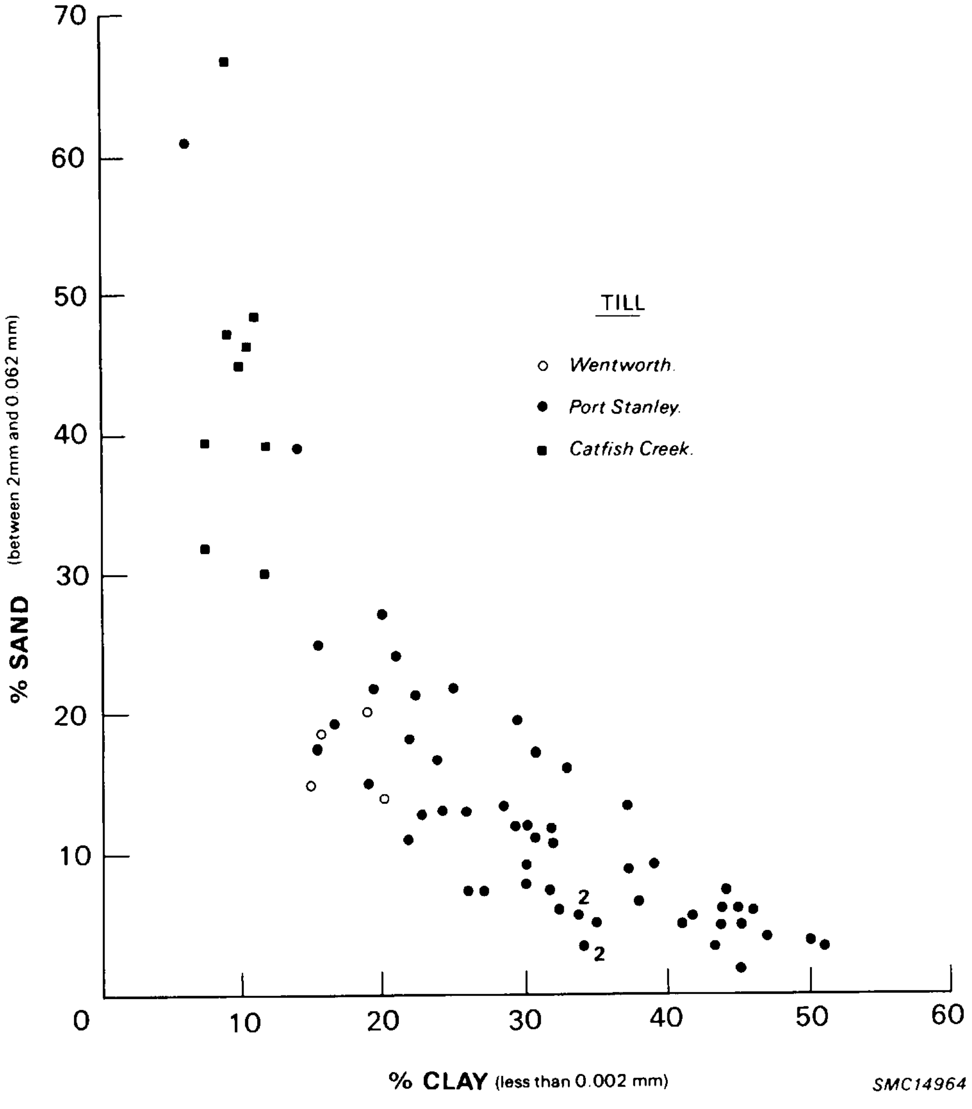

Figure 5–Grain-size distribution of tills, Tillsonburg map-area.

the total heavy minerals. For Catfish Creek Till within the map-area, the garnet ratios (purple and white; red and orange) are usually less than one.

Carbonate clasts, the dominant pebble lithology, average about 80 percent, with a mean limestone to dolostone ratio of 1.2. The content of igneous and metamorphic pebbles is quite high, averaging 13 percent. Tillite pebbles are present occasionally.

Very similar properties have been reported by Cowan (1975, p.18) for the Catfish Creek Till in the Woodstock area and only minor differences have been reported for this till in the London–Lake Erie area (Dreimanis and Karrow 1965; Dreimanis 1961). The percentage of garnets in the heavy mineral fraction is slightly less in the London–Lake Erie area, but the garnet ratios are similar and usually less than one. The carbonate ratios in the pebble grade are slightly higher in the London–Lake Erie area than the Tillsonburg map-area, but this is to be expected, because a greater area of limestone bedrock had been traversed by glacial ice.

Values of trace element content (Table 3) are lower, especially for chromium, when compared to those presented by Terasmae *et al.* (1972).

The Catfish Creek Till represents a major glacial advance from the northeast during the Nissouri Stadial, between 23 000 and 16 000 years B.P. (Dreimanis and Karrow 1972). The outer limit of this advance is thought to be represented by the Cuba and Hartwell Moraines in Ohio and Indiana (Goldthwait *et al.* 1965). During retreat, lobation of the ice sheet occurred and minor oscillations of the ice imparted a southeast-trending fabric in the upper part of this till (Westgate and Dreimanis 1967; Dreimanis 1971). The Dorchester Moraine located in the St. Thomas, Lucan, and Woodstock map-areas is believed to have been formed during a readvance from the Erie basin (Dreimanis 1961, 1964; Westgate and Dreimanis 1967). Dreimanis (1971, p.159) reported an even earlier phase of the "Catfish Creek" ice advance "coming from north and northwest (the Huron Lobe?)."

Although no evidence was observed to support the earlier advance from the north or northwest, the percentage of total garnets and garnet ratios of samples of Catfish Creek Till from the Tillsonburg map-area support ice movement from the northeast and suggest a western Grenville source for this till (*see* criteria of Gwyn 1971; Gwyn and Dreimanis 1979).

Evidence of the subsequent advances of the glacial ice that deposited Catfish Creek Till from the southeast is found in the orientation of the overridden drumlins that are cored with Catfish Creek Till.

A small area of till 4.5 km east of Putnam has been mapped as Catfish Creek Till, but may be equivalent to the Tavistock Till (Karrow 1974). The Tavistock Till which represents a later glacial ice advance from the northeast during the Port Bruce Stadial, has similar properties to the Catfish Creek Till in this area. Without stratigraphic sections it is difficult to tell them apart (Cowan 1975).

Two layers of sandy silt till are exposed in a gravel pit, 3 km southeast of Putnam in front of the Ingersoll Moraine. The lower unit (Photo 1) probably corresponds to the Catfish Creek Till, however, the upper till layer associated with southward flowing proximal outwash gravels may be the Tavistock Till (E.V. Sado, Ontario Geological Survey, Toronto, personal communication, 1980). Neither one of these till layers is of mappable extent.

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Photo 1–Coarse-grained till in the Ingersoll Moraine, near Putnam. Till layer overlies outwash sediment.

Port Stanley Till

The next oldest till identified in the Tillsonburg map-area has been correlated to the Port Stanley Till (de Vries and Dreimanis 1960). This correlation is based on the similarity in properties, as well as the mappable continuity of the till exposed in the Tillsonburg map-area to the Port Stanley Till described in the adjacent London–Lake Erie and Woodstock–Brantford areas (Cowan 1972, 1975; Dreimanis 1964, 1970a, 1972; Dreimanis and Karrow 1965; Terasmae *et al.* 1972).

Within the Tillsonburg map-area the Port Stanley Till is a silt to silty clay till with a low clast content. Its colour is quite variable and ranges from brown to dark brown (10YR 5/3, 10YR 4/3) to yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4, 10YR 4/6) when oxidized, and from grey (10YR 5/1) to dark grey (10YR 4/1) to greyish brown (10YR 5/2) to dark greyish brown (10YR 4/2) when unoxidized. Depth of oxidation is highly variable, but generally occurs between 3 and 7 m below the ground surface.

The Port Stanley Till is the surface till of approximately half of the Tillsonburg map-area and is the major component of the Ingersoll, Westminster, St. Thomas, Norwich, Tillsonburg, Courtland, and Mabee Moraines. It can also be found in the subsurface throughout most of the remaining areas of the map. This till has been observed up to a thickness of 15 m and similar material, (clay stones, clay) believed to be Port Stanley Till, has been reported by water-well drillers to be up to 46 m thick.

Total matrix carbonate content is similar to that of the Catfish Creek Till (Table 3), however, the ratio of calcite to dolomite is usually greater than one for the Port Stanley Till samples, and averages 1.48. One reason for this difference is that the glacial ice masses which deposited these two tills entered the map-area from different directions (Figure 6), thus incorporating different proportions of the underlying carbonate bedrock.

Heavy minerals account for about 4 percent of the fine sand fraction of this till. Magnetics make up 14 percent of the heavy mineral fraction, and garnets make up 15 percent. The average garnet ratio for the Port Stanley Till in the Tillsonburg map-area is 1.35 but values range from 0.44 to 2.6.

Atterberg limits were determined for 16 samples of Port Stanley Till within the Tillsonburg area. Values of liquid limits range from 17 to 32 (mean 24); plastic limits, 11 to 23 (mean 15); and values for the plasticity index range from 4 to 16 (mean 8). Natural moisture contents of about 15 to 20 percent have been reported for Port Stanley Till in the map-area in various engineering studies done for the Ontario Ministry of Transportation and Communications.

An ablation till facies of the Port Stanley Till can be seen along the Norwich, Tillsonburg, and St. Thomas Moraines. In general, this material contains a higher stone content (usually angular) and a coarser matrix, and often contains red shale fragments which impart a reddish hue (englacial debris — Queenston Formation?). The ablation till is usually thin (0.5 m) and discontinuous, so it does not occur as a separate map unit. Matrix grain-size analyses were performed on two samples of ablation till from the Tillsonburg and St. Thomas Moraines (T23, T36; Appendix B). The sand contents range from 39 to 62 percent in the two samples of ablation till, while the mean value of sand content for the basal Port Stanley Till is 12 percent (Table 3).

The Port Stanley Till represents a glacial ice advance out of the Erie–Ontario basin during the Port Bruce Stadial (Dreimanis and Karrow 1972). This ice mass advanced as far as the Ingersoll Moraine in the St. Thomas (Dreimanis 1970a) and Tillsonburg map-areas, and the Powell Moraine in the United States (Goldthwait *et al.* 1965). In the Woodstock area, Cowan (1975, p.24) has suggested that "the ice that deposited this till sheet may have advanced as far west as Embro (beyond the Ingersoll Moraines) but this is not entirely certain."

Based on evidence from along the north shore of Lake Erie, Dreimanis (1971, p.159) reported that "the Port Stanley Drift, consists of at least three major till sheets and several minor till layers, interbedded with varved lacustrine sediments of Lake Maumee." These multiple Port Stanley Till sequences resulted from "re-advances of the Erie lobe which was partly afloat, like an ice shelf, in Lake Maumee."

Within the Tillsonburg map-area, two layers of Port Stanley Till, separated by an intercalated layer of stratified drift, were identified by Dreimanis (1951) in the Tillsonburg Moraine. Sibul (1969, p.12), while mapping in the Big Otter Creek drainage basin, also identified two layers of Port Stanley Till: a younger "typically a silt to clay till with moderate amounts of stones and peb-

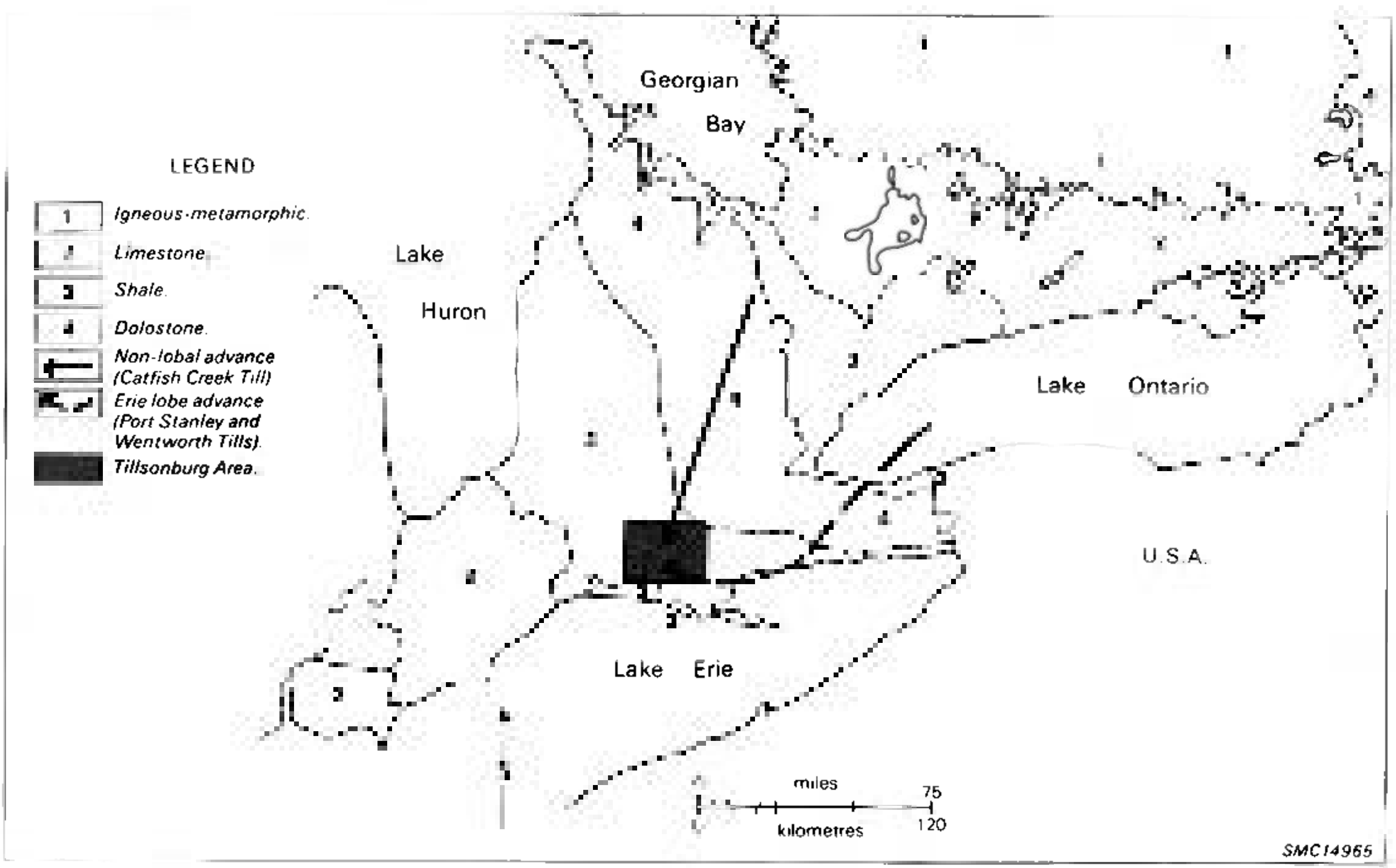

Figure 6—Ice flow directions into the Tillsonburg map-area (40 I/15). Arrow A indicates direction of non-lobal advance (Catfish Creek Till) and arrow B indicates Erie lobe advance (Port Stanley and Wentworth Tills).

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Photo 2–Port Stanley Till, divided into 3 layers by a more stoney layer in the middle and boulder pavement at base of the stoney layer. Scale is approximately 1 m. (See Appendix A, numbers T 869a and b for description of section.)

bles" forming the Tillsonburg Moraine; and an older layer of "silty clay to clayey silt with local gradations to sandy silt" till found in the St. Thomas and Norwich Moraines. Sibul (1969) described another till layer, south of Tillsonburg, which was found to overlie 12 to 15 m of sand along Big Otter Creek, and suggested that it represented a post-Whittlesey glacial advance.

The author has identified at least four major till sheets and several minor till layers of Port Stanley Till in the Tillsonburg map-area (Photo 2). The major till sheets which occur south of the Norwich Moraine are separated by glaciolacustrine and deltaic sands and minor amounts of silts and clays deposited in Glacial Lake Maumee (*see* section on *Glaciolacustrine Deposits and Features*). These inter-till glaciolacustrine sediments are correlatives of the varved lacustrine sediments described by Dreimanis (1971, 1972) along the north shore of Lake Erie.

The individual till layers exposed along Big Otter Creek and as surface till throughout most of the map-area have quite similar properties and for this reason have not been given separate names in the past or at present. In general, the till found along morainic ridges is coarser than the ground moraine associated with these moraines.

A summary of several properties of the individual layers of Port Stanley Till is presented in Table 4. Slight differences occur in some of these properties. The till associated with the St. Thomas Moraine contains 10 percent less clay than the till associated with the other moraines. This is probably due to the removal of clay by excess water during deposition (ablating environment), a theory partly supported by the presence of intercalated outwash sand between layers of till along this moraine. The till of the Courtland and Mabee Moraines contains about 10 percent more clay than the mean value for Port Stanley Till in the entire map-area. This higher clay content is probably due to incorporation of very fine grained glaciolacustrine sediments which were deposited in front of the ice, prior to the readvances which formed these moraines.

Several other differences in properties appear to be systematic and change gradually from the oldest layer to the youngest. These include a small increase in the carbonate ratio of the matrix; an increase in the carbonate ratio and chert content of the clasts; and an increase in the garnet ratio, from values of less than one to those greater than 1.5.

The oldest till associated with the Ingersoll Moraine has properties that suggest a western Grenville source (low garnet ratios but high total garnet content). The lower values of the matrix carbonate ratios and the clast carbonate ratios also suggest an ice-flow direction from the northeast similar to the ice-flow direction of the ice that deposited the Catfish Creek Till (direction **A**, Figure 6). However, the ice-flow direction indicated by streamlined drift forms (drumlins and flutings), and the orientation of the Ingersoll Moraine suggest an ice flow from the southeast.

The youngest end member, represented by the tills of the Courtland and Mabee Moraines, indicate an eastern Grenville source (because of its high garnet ratio and total garnet content). Higher values for matrix carbonate ratios, higher chert content, and higher carbonate ratio of the pebbles suggest that the glacial ice traversed a greater area of cherty limestone, suggesting ice flow out of the Erie basin from the southeast and east.

Till samples from the other end moraines and associated ground moraines generally fall within these two end members, in order, from north to south.

There are several possible explanations for the above changes observed in the till properties, and for the apparent conflict in ice-flow directions indicated by the till properties and by the geomorphology of the older till layers:

1. Incorporation of older drift, i.e. Catfish Creek Till, would impart lower values for matrix and pebble carbonate ratios, and garnet ratios in the tills of the outer or more northerly moraines. This does not seem likely because there is no apparent coarsening of the Port Stanley Till to the north. This coarsening would be expected if Catfish Creek Till had been incorporated.

2. Incorporation of the glaciofluvial and/or glaciolacustrine material associated with Catfish Creek Till (Catfish Creek Drift) may better explain the variations recorded above in the Port Stanley Till. Sediments from beneath Port Stanley Till (sampled in a borehole near Bayham) do contain a greater amount of dolomite than calcite in the less than 200 mesh fraction and this could explain the matrix carbonate variations observed in the Port Stanley Till.

TABLE 4 PROPERTIES OF INDIVIDUAL LAYERS OF PORT STANLEY TILL

	Textural Analyses				Carbonate Content		Heavy Minerals		Pebble Counts							Trace Element Concentrations**				Garnet Content		Atterberg Limits		
	% Clay	% Silt	% Sand	Median (mm)	% Total	Calcite: Dolomite	% Total	% Magnetics	% Limestone	% Dolostone	% Chert	% Clastics	% Precambrian	Limestone: Dolostone	Limestone + Chert: Dolostone	Copper (ppm)	Nickel (ppm)	Zinc (ppm)	Chromium (ppm)	% Total Garnets	Garnet Ratio	Liquid Limit	Plastic Limit	Plasticity Index
Ingersoll Moraine and Associated Ground Moraine	31	54	15	0.008	38.8	1.34	4.4	14.0	45	43	5	2	5	1.05	1.16	24	21	64	49	19.2	0.73	24	15	9
	(6)*				(6)		(6)		(3)							(4)				(3)		(3)		
St. Thomas Moraine and Associated Ground Moraine	22	60	18	0.013	37.9	1.40	3.1	12.7	50	35	7	2	6	1.44	1.63	25	20	64	52	10.7	0.67	26	14	12
	(8)				(8)		(8)		(1)							(2)				(3)		(2)		
Norwich Moraine and Associated Ground Moraine	32	60	8	0.006	36.1	1.48	3.0	17.0	60	25	7	4	4	2.64	2.92	27	24	68	58	16.3	0.90	25	15	10
	(11)				(11)		(11)		(7)							(3)				(2)		(2)		
Tillsonburg Moraine and Associated Ground Moraine	33	54	13	0.011	39.8	1.53	4.7	12.8	63	16	12	4	5	6.82	7.72	26	20	77	53	14.7	1.52	24	26	8
	(23)				(23)		(23)		(10)							(12)				(17)		(8)		
Courtland Moraine and Associated Ground Moraine	41	54	5	0.004	38.8	1.50	4.2	16.1								27	20	70	55	16.8	1.71	27	27	0
	(6)				(6)		(6)									(2)				(5)		(1)		
Port Stanley Till Tillsonburg Map-area	32	56	12	0.009	38.5	1.48	4.0	14.1	58	24	9	4	5	4.4	5.0	26	21	72	53	15.2	1.35	24	26	8
	(54)				(54)		(54)		(21)							(23)				(30)		(16)		

*(6) number in brackets indicates number of samples used to calculate the mean
**trace element values have ± 5 ppm accuracy

3. The third possibility (favoured by the author) is that this gradational change in till properties from north to south (oldest to youngest) is the result of a gradual change eastward in the source area of the glacier, as well as an increasing influence of the Lake Erie basin on the direction of ice flow throughout the Port Bruce Stadial. During the initial advance, the amount of flow out of the Erie basin was small and debris entrained in the glacial ice reflected a western Grenville source (to the northeast). During subsequent advances, as the ice mass thinned, the component of ice flow controlled by the Erie basin increased and the source of the debris in the ice shifted eastward (eastern Grenville source).

The numerous layers of Port Stanley Till in the Tillsonburg area record the advance and recession of a glacial ice mass in the Erie basin during the major part of the Port Bruce Stadial. The Port Stanley Till is probably the equivalent of several tills of the Huron and Georgian Bay areas. Based on preliminary glacial lake correlations, the suite of tills from "southern" till (Cooper 1979) to Tavistock Till (Karrow 1974) in the Huron basin may be the equivalent of the Port Stanley Till.

Wentworth Till

The Wentworth Till (Karrow 1959) is the youngest till found within the Tillsonburg map-area. It is confined to the southeast corner of the area in the vicinity of Delhi and Lynedoch. There are very few natural exposures of this till for it is usually buried beneath the glaciolacustrine sands of the Norfolk Sand Plain. Its farthest extent appears to be the Paris Moraine. This moraine is not well defined within the Tillsonburg area (*see* section on *Paris Moraine*).

Where exposed, the Wentworth Till is a silt till with an average total carbonate content of 38 percent and a calcite to dolomite ratio of 1.3. Garnet ratios are usually greater than one. Wentworth Till in other areas of Ontario (Karrow 1963; Cowan 1972; White 1975; Barnett 1978) has been described generally as a coarser grained till. It has been previously recognized (Dreimanis 1961; Barnett 1978) to become finer grained southward towards the Lake Erie basin; probably due to the incorporation of nonconsolidated glaciolacustrine deposits.

Wentworth ablation till can be observed along the Paris Moraine, 2 km north of Lynedoch. This till is extremely bouldery (angular fragments) with very little matrix.

The Wentworth Till probably represents a readvance of limited extent out of the Erie basin during the later part of the Port Bruce Stadial, rather than a major advance during the Port Huron Stadial (Barnett 1979).

END MORAINES

Within the Tillsonburg map-area, there are eight morainic ridges. Seven of these moraines are aligned roughly parallel to the present-day Lake Erie

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Photo 3–Hummocky topography along the Ingersoll Moraine, southeast of Putnam.

shore. They represent standstills or minor readvances of the "Port Stanley" ice during its advance and subsequent retreat of the ice front into the Erie basin during the Port Bruce Stadial. The eighth moraine, the Paris, was deposited when ice reentered the Tillsonburg map-area during the later stages of the Port Bruce Stadial (Wentworth Till). The position and extent of these moraines can be seen in Figure 7 (Chart A, back pocket).

Ingersoll Moraine

Taylor (1913) first proposed the name Ingersoll Moraine for the morainic ridge which trends along the south side of the Thames River east of London, and suggested that it probably continued as the high ridge at Mount Elgin. Chapman and Putnam (1943a, 1966) retained the name; but suggested that the Ingersoll Moraine continued along the south side of the Thames River to the boundary of West Oxford County where it swings eastward away from the river. Chapman and Putnam (1943a, 1966) correctly related the ridge at Mount Elgin to the St. Thomas Moraine.

The Ingersoll Moraine, within the Tillsonburg map-area, (Figure 7, Photo 3) can be traced northeastward from Mossley towards Putnam. At Putnam the moraine is breached by a meltwater tributary of an ancestral Thames River. It continues eastward towards Salford, along the map-area boundary to just north of Zenda, where it bends northward and leaves the Tillsonburg map-area. The highest point (1080 feet a.s.l.) in the map-area occurs along this moraine, 2.4 km northwest of Zenda. The elevation of the crest west of Salford is generally only 970 feet a.s.l.

Dreimanis (1970a) reported that the moraine marks the extent of the Port Stanley Till in the St. Thomas map-area. This is also true for this moraine in the Tillsonburg map-area, however in the Woodstock map-area to the north, Cowan (1975) has possibly traced the Port Stanley Till beyond the moraine as far northwest as Embro.

Dreimanis (1964) has also reported that Catfish Creek Till is encountered beneath the Ingersoll Moraine. Water-well drillers in the Tillsonburg map-area report thickness of what may be Port Stanley Till (i.e. clay, clay stone) generally between 12 to 33 m thick along this moraine, usually overlying sand and gravel which is underlain by Catfish Creek Till (hardpan). More recently, Dreimanis (Terasmae *et al.* 1972) suggested that this moraine is cored by Catfish Creek Drift in the London area, thereby making it in part a palimpset feature.

Beyond the Ingersoll Moraine, but adjacent to it, two areas of proximal outwash or ice-contact gravels and sands were found. These deposits appear to be related to the Catfish Creek Till and possibly the Tavistock Till (E.V. Sado, Ontario Geological Survey, Toronto, personal communication, 1980) and may be covered in places by a thin layer of Port Stanley Till. These deposits have not been included as part of the Ingersoll Moraine in this report because they appear to be older than the Port Stanley Till, and their major current features suggest deposition from the north. They may core the moraine in places, and if the proximal outwash sediments are of Tavistock drift, then an interlobate origin is suggested for part of this moraine. However, throughout most of this moraine in the Tillsonburg area, the core is Port Stanley Till.

Westminster Moraine

The Westminster Moraine (Chapman and Putnam 1951) is the next major moraine south of the Ingersoll Moraine. The two are separated by Dingman Creek and a small tributary of Reynolds Creek. Chapman and Putnam (1951, 1966) have traced this moraine into the Tillsonburg map-area to within 1.5 km of Crampton, where it meets the Reynolds Creek meltwater channel. East of this meltwater channel it has not been identified. Dreimanis (1970a) traced the moraine westward across the St. Thomas east map-area. The hill 1 km north of Avon may be an extension of this moraine.

Dreimanis (1970a) and Terasmae *et al.*(1972) suggested that the Westminster Moraine is probably an overridden moraine, older than Port Stanley Till. Minor evidence from roadcuts along this moraine in the Tillsonburg map-area support this and suggest that Catfish Creek Drift may be the core. Elsewhere, water-well drillers report thicknesses of apparent Port Stanley Till (clay, clay stones, clay sand) of up to 38 m.

St. Thomas Moraine

The St. Thomas Moraine (Taylor 1913) is separated from the previously described moraines to the north by Kettle and Reynolds Creeks. This moraine can be traced within the Tillsonburg map-area from 3.75 km north of Newark; westward through Mount Elgin, 2.5 km north of Culloden, 0.8 km north of Mount Vernon (Mount Burnham); to 3.5 km north of Lyons where it has been traced previously by Dreimanis (1970a) in the St. Thomas map-area. It is a very distinct ridge, rising from 930 feet where it crosses Highway 73, to over 1010 feet 2 km north of Cullodon. At Mount Elgin, the crest is near 980 feet and it remains at about this elevation until it enters the Woodstock map-area. The St. Thomas Moraine is breached by several meltwater channels along its length in the Tillsonburg map-area; 2 km northeast of Mount Elgin, 0.8 km southwest of Mount Elgin, 1.5 km northwest of Dereham Centre, and 2.75 km north-northeast of Culloden.

This moraine is believed to have been constructed during several minor oscillations of the "Port Stanley" ice. In the St. Thomas area Dreimanis (1970a) reported that "one of the glacial readvances overrode the Maumee II beach deposits 2 miles southeast of Glanworth" and one roadcut along the crest of the moraine in the Tillsonburg map-area revealed three "tongues" of Port Stanley Till separated by thin layers of outwash sand and gravelly sand. Cowan (1975, p.32) reported thicknesses of up to 90 feet of Port Stanley Till in this moraine in the Woodstock map-area, and drillers in the Tillsonburg map-area recorded thicknesses of up to 41 m of probable Port Stanley Till (clay, clay stones).

Norwich Moraine

The Norwich Moraine was named and traced by Chapman and Putnam (1951, 1966) who identified two parallel crests of this moraine which they called the Culloden and Brownsville strands. The Culloden strand can be traced from Mapleton in the St. Thomas map-area (Dreimanis 1970a) into the Tillsonburg map-area just north of Lyons near the trailer camp along Highway 73. Here the crest has an elevation of close to 900 feet a.s.l. and rises eastwards to over 950 feet a.s.l. where it crosses the Elgin–Oxford County line. At Culloden the crest of the ridge is just over 930 feet a.s.l. and remains near this elevation to within 1.5 km of Highway 59.

The Brownsville strand is first identifiable south of Lyons. Here the crest is at an elevation of about 850 feet a.s.l. and rises gradually eastward to 920 feet a.s.l. at the Elgin–Oxford County line. The Brownsville strand rises more than 30 m above the abandoned lake plain to the south, while relief along the northern flanks of this strand is only 3 to 6 m. The Culloden strand has 9 to 12 m of relief along the southern flank and 6 to 9 m of relief along the northern flank.

East of Tillsonburg the Norwich Moraine bends northward, trending parallel to the Dereham–South Norwich town line west of the airport, with the two strands being separated by Spittler Creek. At approximately 1.5 km north of the North Norwich–South Norwich town line this moraine bends northeastward toward Newark. The moraine enters the Woodstock map-area about 1.5

km northwest of Norwich. In the Woodstock map-area the Norwich Moraine is not well defined and is commonly associated with ablation deposits (Cowan 1975).

In the Tillsonburg map-area, the moraine appears to be composed predominantly of Port Stanley Till. Minor layers and lenses of sand were observed in the field, but these were not traceable through any major distance, even with the aid of water-well logs. Up to 15 m of Port Stanley Till were observed in a section through this moraine at Stoney Creek. In the Tillsonburg area the Norwich Moraine probably resulted from a minor fluctuation within the Erie basin while in the Woodstock area, the ice was grounded and may have retreated gradually, depositing areas of ablation till.

Tillsonburg Moraine

The Tillsonburg Moraine (Taylor 1913) is best developed in the northeastern corner of the Tillsonburg map sheet, where relief is up to 21 m along the northwestern edge of this moraine. It appears to be a complex feature that separates into two ridges about 2.5 km west of Bookton. The southernmost ridge passes through Summerville and becomes buried to the west beneath the Norfolk Sand Plain. It may be represented by the drainage divide between Big Otter Creek and Little Otter Creek north of Highway 3. The northernmost ridge crosses Highway 59, 1.5 km north of Summerville, and continues westward through Cornell to Tillsonburg.

South and west of Tillsonburg, only segments of the Tillsonburg Moraine are visible above the Norfolk Sand Plain. Two, and possibly three, crests of this moraine can be traced here. The most northerly ridge passes 0.8 km south of Delmer, 1 km north of Corinth, and can be traced southwestward 4 km from there. Whether or not the morainic segment at Summers Corners is the extension of this ridge is questionable. It is more likely related to one of the more southerly ridges of the Tillsonburg Moraine which passes through Tillsonburg Junction and continues along Highway 3. The morainic segment at Summers Corners may be the continuation of the Sparta Moraine (Dreimanis and Karrow 1965) and hence may be a correlative of the southern ridge of the Tillsonburg Moraine as suggested by Chapman and Putnam (1951, 1966).

Throughout its length the Tillsonburg Moraine has been washed by the waters of Glacial Lake Whittlesey. This moraine was found to be capped by Port Stanley Till and is partly composed of Port Stanley Drift in the Simcoe map-area (Barnett 1978). Cowan (1972, Brantford map-area) and Barnett (1978, Simcoe map-area) have suggested that older drift may core the Tillsonburg Moraine in these map-areas. Within the Tillsonburg map-area, however, this moraine appears to be cored with Port Stanley Drift. Two layers of Port Stanley Till, separated in places by sand or gravel, were found in the map-area by Dreimanis (1951). Although no complete section was observed, the Tillsonburg Moraine south and west of Summersville appears to be composed of two layers of a clayey silt till (Port Stanley Till) separated in places by a thick sequence of glaciolacustrine deltaic sediments dominantly composed of sand. This sequence of materials suggests that the several ridges of this moraine in the Tillsonburg map-area were formed during minor readvances over glaciolacustrine deltaic material that was being deposited along the ice front into a glacial lake in the Erie basin (possibly an early phase of Maumee III. The subsequent Courtland and Mabee Moraines were also deposited during fluctuations of the "Port Stanley" ice in a similar environment. The eventual retreat from the Mabee Moraine position may have resulted in the end of Maumee III.

Courtland Moraine

The Courtland Moraine (Barnett *et al.* 1976) is located approximately 8 km south of, and aligned parallel to, the Tillsonburg Moraine. It is a distinct ridge from Eden to Courtland rising between 6 to 9 m above the surrounding abandoned lake plain. Westward, its extension is buried, but it probably acts as the drainage divide between Big Otter and Little Otter Creeks between Bayham (Richmond) and Eden. Eastward from Courtland it lies parallel to Highway 3 and can be traced to within 2.5 km of Delhi.

This moraine has been recognized previously but left unnamed (Chapman and Putnam 1943a, 1951, 1966; Ontario Department of Planning and Development 1957). Sibul (1969) suggested that it may be a continuation of the Paris Moraine (Wentworth Till), but because this ridge is composed of up to 25 m of Port Stanley Till, this cannot be possible. It was formed during a minor readvance of the "Port Stanley" ice during the later stages of the Port Bruce Stadial. Most of this moraine was submerged in Lake Whittlesey, except for the stretch between Eden and Courtland which was an island during this lake stage.

Mabee Moraine

The Mabee Moraine (Barnett *et al.* 1976) is also composed of Port Stanley Till. This moraine has very little topographic expression because it has been buried to varying degrees by sand of the Norfolk Sand Plain. Water-well records indicate a definite increase in till thickness in this moraine, with the overlying sand thickening to the north and south. This moraine is subparallel to the Courtland Moraine and is located 0.8 km south of the hamlet of Mabee, for which it was named. The Mabee Moraine is younger than the Courtland Moraine and was formed by a minor readvance or standstill as the glacial ice front receded into the Erie basin.

Paris Moraine

Taylor (1913) traced and named the Paris Moraine and described the portion south of Delhi as "scarcely perceptable as a ridge, but exerting some control over minor drainage." In the Tillsonburg map-area this moraine has very little or no topographic expression and it can be only vaguely delineated by the presence of the slightly coarser Wentworth Till.

This moraine trends south-southwesterly between Delhi and Lynedoch, and probably extends to the Lake Erie shore just west of Port Rowan, as suggested by Taylor (1913). The Paris Moraine was deposited during the latter part of the Port Bruce Stadial and marks the outer limit of the Wentworth Till. Taylor (1913) has suggested that it has little expression for several miles north of Port Rowan because it was formed in Lake Whittlesey. Another possible explanation for its lack of topographical expression, is that it was subsequently buried by glaciolacustrine and glaciofluvial sediments.

TILL PLAINS

Three areas of drumlinized and fluted till plains occur in the Tillsonburg map-area (Figure 7). They are found between the Ingersoll and St. Thomas Moraines in the northwestern corner of the map-area. The drumlinized and fluted till plains are separated from each other by younger meltwater channel sediments.

The orientations of the long axes of these streamlined landforms range from 297°N to 305°N Azimuth (12 readings), and they control the local drainage of these areas. Elongate swamps and bogs are common. These positive relief features average 6 to 10 m high, 0.5 km wide, and up to 3 km long.

There are possibly two ages of formation of these features. Some of the drumlins appear to be composed of the coarse-grained till correlated with the Catfish Creek Till, while others are definitely composed of the finer grained Port Stanley Till. Similar orientations for drumlins of both ages occur, possibly because either glacial ice flow was controlled by the Erie basin, or perhaps because the strongly lineated ground surface of the older drumlin field helped control the flow direction of the ice which deposited the younger streamlined forms.

Bevelled till plains are located south of the Norwich Moraine (Figure 7). In these areas the till surface has been smoothed or flattened by wave action of glacial lakes which occupied the Erie basin during glacier recession. A veneer of sand, and the occasional lag concentrations of pebbles and cobbles can be found overlying the till in these areas. The largest area of bevelled till plain is found between the communities of Aylmer, Lyons, and Delmer.

Glaciofluvial Deposits and Features

ICE-CONTACT STRATIFIED DRIFT

Deposits of ice-contact stratified drift are confined to some of the morainic ridges which cross the map-area, and to a few isolated kames north of the St. Thomas Moraine. In general these deposits are small in extent and are composed dominantly of sand. Small pockets were observed in the Ingersoll, St. Thomas, and Tillsonburg Moraines. Several kames can be found in the area

OGS 10 417

Photo 4–Port Stanley Till overlying outwash sand and gravel, 2.5 km south of Putnam.

north of Verschoyle (1.6 km north; 4 km northwest; 3 km northeast).

A large area north of the Ingersoll Moraine which is mapped as ice-contact stratified drift, is composed dominantly of sand but contains area of sandy silt till (Tavistock or Catfish Creek). Further information is presented in the section on *Economic Geology, Sand and Gravel.*

OUTWASH

Deposits of outwash sand and gravel are found in three stratigraphic positions within the Tillsonburg map-area: beneath the Catfish Creek Till, beneath the Port Stanley Till, and above the Port Stanley Till. The latter are by far the most extensive outwash deposits in the area.

Outwash sediments associated with the Catfish Creek Till are buried, and for this reason their extent is difficult to determine using conventional field mapping techniques. Outwash sand and gravel beneath Catfish Creek Till was observed 3 km south of Verschoyle.

Sand and gravel of outwash origin was found beneath Port Stanley Till at two localities: 2.5 km south of Putnam (Photo 4), and in two pits 0.9 km and 1.8

km west of Zenda (shown incorrectly as a surface deposit on Map 2473). The actual extent of these sand and gravel deposits is unknown because they are beneath the till cover. In deposits buried by till, cementation may occur in the upper layers of the sand and gravel. Information on grain-size distribution and lithologies are presented in the sand and gravel discussion in the section on *Economic Geology*.

Outwash deposits laid down during the recession of the "Port Stanley" ice front are for the most part located north of the Norwich Moraine, in the northwestern quarter of the map-area. During retreat, meltwater streams from the ice must have breached the Ingersoll Moraine at Putnam to allow northward flow through this moraine to join a major river which flowed westward down the Thames River valley to the Komoka delta.

Areas of the outwash sediment accumulation include the Thames River valley and two areas along Reynolds Creek (north of Mount Elgin and southwest of Verschoyle). These meltwater channels, as well as several others which are erosional and contain little sediment, can be seen in Figure 7.

Outwash sediments deposited along the Thames River valley average 6 m in thickness with a stone content ranging between 20 and 40 percent. The deposit near Mount Elgin is probably less than 3 m thick and the stone content decreases from 70 to 0 percent westward. This deposit formed as the ice stood along the St. Thomas Moraine. Meltwater was flowing westward along a confined channel between the Ingersoll and St. Thomas Moraines at Zenda. When the meltwaters reached the area where the moraines diverge, they were able to spread out, depositing their sediment load and dropping the coarser fraction at the apex.

The second area along Reynolds Creek, west of Dereham Centre, is younger than the previously mentioned deposit because the meltwater channel which fed this deposit has breached the St. Thomas Moraine. A gravel pit operator working in this deposit reported a thickness of about 4.5 m of gravelly sand with a 1 m "clay" layer at the base, overlying more gravel.

Northward drainage and the deposition of outwash sediments occurred in the Tillsonburg map-area until the glacial ice retreated from the Norwich Moraine position. After this event, several ancestral great lakes of the Erie basin began to occupy the southwestern part of the map-area and meltwater drained along the ice front into these lakes.

Another deposit of outwash or possibly older alluvial sand and gravel is located southwest of Brownsville. This deposit is buried by Lake Whittlesey sand, and from limited data it appears to be less than 3 m thick.

Glaciolacustrine Deposits and Features

Deposits and features of high-level ancestral lakes in the Erie basin are quite abundant within the Tillsonburg map-area. Almost half of the map-area has a surficial cover of glaciolacustrine sand, silt, or clay. Shoreline features of at least three glacial lakes have been identified.

LAKE MAUMEE

Three levels of Lake Maumee have been previously recognized within the Erie and Huron basins. Lake Maumee I, the oldest and highest, existed in the western end of the Erie basin, beyond the Tillsonburg map-area. Dreimanis (1964) has suggested that this lake existed prior to the formation of the Ingersoll Moraine, however, it may have existed during the early part of the Port Bruce Stadial when the glacial ice stood at the Ingersoll Moraine. The Thames River meltwater channel may have been initiated during this lake stage.

Glacial Lake Maumee II has been reported by Dreimanis (1964) to be contemporaneous with the St. Thomas Moraine. Dreimanis (1970a) noted that "the glacial margin oscillated along the St. Thomas Moraine, and one of the glacial readvances overrode the Maumee II beach deposits 2 miles southeast of Glanworth" (St. Thomas map-area). Outwash deposits in front of the St. Thomas Moraine, 1.5 km west of Zenda have also been overridden by advancing glacial ice during these ice-margin oscillations. Within the Tillsonburg map-area, during Lake Maumee II, the Reynolds Creek meltwater channels were tributaries of the Thames River. This ancestral Thames River issued into Lake Maumee II, forming part of the large, complex delta at Komoka (Dreimanis 1964).

During periods of high meltwater discharge from the ice, the narrow channel through the Ingersoll Moraine at Putnam probably restricted flow into the Thames River, causing a lake to form upstream between the Ingersoll Moraine and the ice front. A thin veneer of fine-grained sediments, generally confined to below an elevation of 925 feet a.s.l., outline the extent of this proglacial lake. Northward drainage of meltwater from the ice front along Reynolds Creek towards the Thames River, occurred in the Tillsonburg map-area until the glacial ice retreated from the Norwich Moraine.

Although glacial Lake Maumee III waters covered more than half of the map-area, shoreline features are rare and only one short length of abandoned shorebluff was identified. This is located 3.5 km north of Bookton at an elevation of between 890 and 900 feet a.s.l. This feature is located along the proximal side of the Tillsonburg Moraine and therefore was formed during or after the retreat of the glacial ice from this moraine. A small beach bar 1.5 km northwest of Delmer may also be at a Maumee III level.

The deposits of silt and clay (map units 7 and 8), located generally south of the Norwich Moraine are probably related to this lake level. Most of these deposits are located above the Lake Whittlesey level, and have therefore been assigned to Lake Maumee III. Dreimanis (1970a) reported that lacustrine clay, silt, and sands at "St. Thomas and south of Highway 3 in the Catfish Creek valley were deposited probably in Lake Maumee III" as well. Dreimanis (1970a) also reported that the maximum number of varves in the Orwell–Aylmer area is 13, and that these deposits suggest a short-lived lake stage.

The deep-water glaciolacustrine clay deposits associated with this lake level are dark brown to yellowish brown, massive to laminated clay to silty clay (Photo 5). Silt and very fine sand are the common constituents of the laminations, and occasionally grits and concretions are present. The deep-water silt deposits are yellowish brown to brown (occasionally grey). Silt to clayey silt de-

OGS 10 418

Photo 5–Lake Maumee well laminated clays and silts overlying Port Stanley Till, 1 km east of Bayham.

posits are usually laminated, with clay and fine sand laminations. The lateral contact between areas mapped as glaciolacustrine silt or clay is gradational and is somewhat arbitrary.

Dreimanis (1951) identified six levels of Lake Maumee along the south side of the Norwich Moraine within the Catfish Creek watershed. The present survey found it difficult to locate these shoreline features. They were originally described as being weak, and without associated beach sediments. The southern flank of this moraine has been modified by water, but the exact location of the water level was indiscernable.

Thick sequences of glaciolacustrine nearshore and deltaic sand exposed along Big Otter Creek between layers of Port Stanley Till suggest the existence of a lake level or levels (probably older than Lake Maumee III) in the Erie basin, as the glacial ice front retreated from the Norwich Moraine (*see* Figures 18a, b, c, d). As the oscillating ice margin retreated from this moraine, the minor readvances formed the Tillsonburg, Courtland, and Mabee Moraines. The water level in the Erie basin during this time probably fluctuated quite rapidly, hindering the formation of shoreline features. Some of the weak shoreline features identified by Dreimanis (1951) may be associated with these levels.

LAKE ARKONA

Much confusion has existed concerning the identificaton of Arkona shoreline features in Ontario. Cooper (1979, p.28) has presented a summary of the existing literature and has attempted to clarify some of the problems. He concluded that "both Lake Arkona and Lake Whittlesey [features] are present at Arkona; the Lake Arkona shoreline is at approximately 229 m (750 feet) and can be traced through the centre of the town of Arkona; the Lake Whittlesey shoreline is parallel to it at approximately 238 m (780 feet) and is found on the eastern edge of the town." In the Grand Bend–Parkhill area, the Arkona shoreline features are approximately 9 m below the elevation of the Lake Whittlesey features.

Shoreline features of Lake Arkona have usually been modified by Glacial Lake Whittlesey waters and have been buried below its sediments. This makes it difficult to trace Lake Arkona shoreline features and to obtain good estimates on the elevation of its water plane.

In the Tillsonburg map-area several shoreline features have been identified approximately 11 m below Lake Whittlesey features, and have been tentatively assigned to Lake Arkona. An abandoned shore bluff 1 km southeast of Mabee has been covered by Whittlesey silts and sands of eolian origin. The bluff separates two distinct lake plains, about 3 m apart in elevation. This shore bluff defines a water level between 760 and 770 feet a.s.l. (National Topographic Series 40 I/15b, scale 1:25 000) approximately 11 m below the Lake Whittlesey shoreline features of this area. In Figure 8 (Chart B, back pocket) the above-mentioned shorebluff is located at "A".

Buried sand and gravel deposits with beach sediment characteristics extend intermittently along a line from Bayham through Mabee towards Delhi. These deposits probably mark the shoreline of Lake Arkona in the Tillsonburg map-area. The Arkona shoreline rises from 755 feet a.s.l. up to 770 feet a.s.l. within the map-area, at a rate of uplift similar to that of Lake Whittlesey.

Lake Arkona's relationship to the Paris Moraine is difficult to determine, for the deposits of both are buried below Lake Whittlesey sands in the critical areas. Although Lake Arkona may predate, postdate, or be contemporaneous with the formation of the Paris Moraine, most of the recent literature suggests that Lake Arkona existed prior to the glacial advance to the Paris Moraine, approximately 13 600 years B.P. (Dreimanis 1966).

LAKE WHITTLESEY AND YOUNGER LAKES

The deposits of Lake Whittlesey are by far the most economically important glaciolacustrine sediments of the map-area. Almost all of the tobacco produced in this region is grown on the sandy bottom sediment of this lake (Photo 6). This extensive blanket of sand (map unit 9) which forms the Norfolk Sand Plain and which covers almost the entire southeastern half of the map-area, was deposited in Glacial Lake Whittlesey.

The sand is generally orange brown to brown (brownish grey to grey unoxi-

OGS 10 419

Photo 5–Tobacco growing on the Lake Whittlesey Plain.

dized) fine- to medium-grained sand. This sand is usually massive in the upper metre and below this becomes laminated with fine sand, silt, heavy minerals, or clay. In places, along narrow stretches, slightly coarser sand with the occasional pebble can be found.

The thickness of Lake Whittlesey sands is difficult to determine, because older sands are often present beneath them, or the sand has been blown up into dunes. Thicknesses of sand up to 27 m have been reported by drillers in the sand plain region of the Tillsonburg map-area. Shoreline features of this lake level are quite numerous, especially along the southeastern flanks of morainic ridges which were islands in this lake (Figure 8). Along the north shore of Lake Whittlesey "from north of Aylmer eastward to Tillsonburg the shore features resulted from the action of feeble waves that were generated in the protected waters of a narrow lagoon. The Tillsonburg Moraine...effectively protected the north shore against the strong waves of the open lake, and the shoreline features which developed are consequently but poorly defined" (MacLachlan 1938).

From Tillsonburg to Norwich, no shoreline features were observed, however, Lake Whittlesey can be essentially delineated by the distribution of sand. The water level between the Tillsonburg Moraine and the main shoreline appears to have been slightly higher than in the main body of Lake Whittlesey, possibly because the water level was controlled by three gaps in the Tillsonburg Moraine, at Tillsonburg, Otterville, and 5 km east of Otterville.

Figure 8 outlines Lake Whittlesey in the Tillsonburg and Simcoe map-areas. The Whittlesey shoreline features are tilted and rise from 790 feet a.s.l. in the southwest to 825 feet a.s.l. along the eastern edge of the Tillsonburg map-area. Isobases on Figure 8 are very approximate and are interpolated from a regional diagram of Lake Whittlesey with a 25-foot isobase interval (Barnett 1979, p.571).

Lake Whittlesey is believed to have existed 12 900 years B.P. (Dreimanis and Karrow 1972), supported by glacial ice standing at the Port Huron and Wyoming Moraines in the northwestern end of the lake, and an ice margin which was retreating eastward from the Galt Moraine in the eastern end of the Erie basin. Barnett (1978, 1979) has presented evidence to suggest that Lake Whittlesey existed during the subsequent advance of the glacial ice represented by the Halton Till. No new evidence in the Tillsonburg map-area was found to support or disprove either theory.

Very little evidence of post-Whittlesey glacial lakes was found within the Tillsonburg map-area. Lake Warren, with a water level approximately 13 m below the Whittlesey level, may have occupied a small area in the southeastern corner of the map. The surficial sand in this area, may have been deposited in Lake Warren, however, shoreline features of the lake were not observed.

Non-Glacial Deposits and Features

OLDER ALLUVIAL DEPOSITS AND FEATURES

Abandoned high-level flood plains were identified along Big Otter and Big Creeks during field mapping. Four terrace levels are present along Big Otter Creek and four levels of terraces were previously identified along Big Creek (Barnett 1978).

These abandoned flood plains or river terraces were formed by older rivers which flowed into high-level glacial lakes in the Erie basin. Each terrace level represents a different stage in the general lowering sequence of glacial lakes in the Erie basin between Glacial Lake Whittlesey and Early Lake Erie. Actual correlation of terrace levels to glacial lakes was not attempted.

Older alluvial sediments generally range between coarse- and fine-grained sand with a gravel content of usually less than 10 percent. Observed thicknesses of older alluvium range from 0.3 to 10 m.

EOLIAN DEPOSITS AND FEATURES

A large portion of the area mapped as glaciolacustrine sand has been modified to varying extents by wind. Large transverse or modified transverse dunes (Lindross 1972) greater than 6 m high are present throughout the southeastern half of the map-area. These dunes are composed of fine- to medium-grained sand. Figure 9 displays the cumulative grain-size curves for three samples of dune sand overlying the organic beds of the Bouchaert Site discussed be-

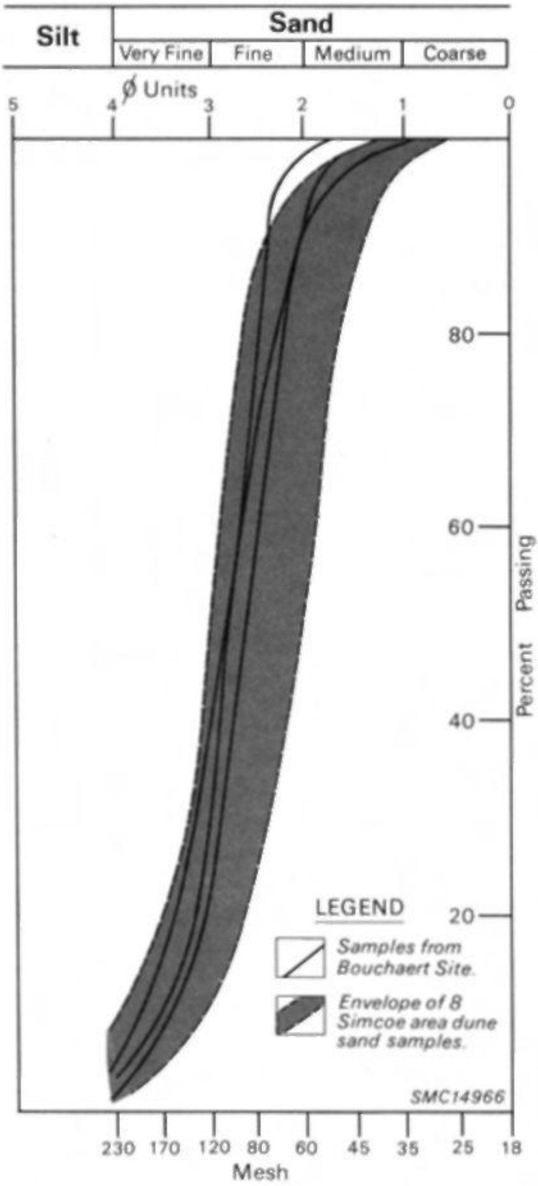
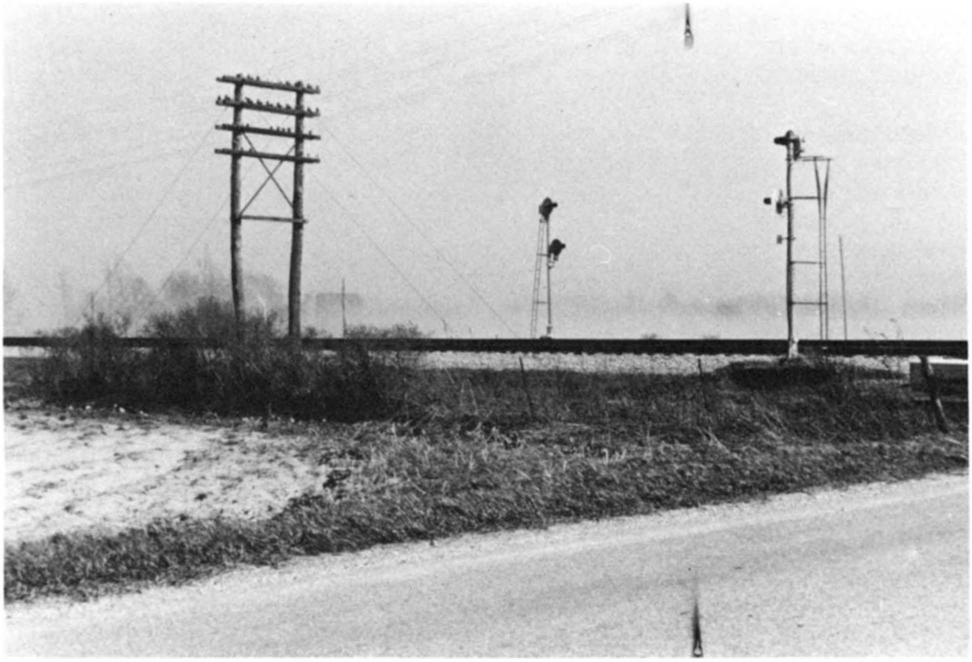


Figure 9—Grain-size distribution curves for eolian sands. Solid curves indicate samples from the Bouchaert Site. Dashed curves indicate limits of 8 dune sand samples from the Simcoe map-area (40 I/16).



OGS 10 420

Photo 7–Dust Storm, May 5, 1976.

low (*see* section on *Bogs and Swamps*) and the envelope of grain-size curves for samples from the adjacent Simcoe map-area.

Barnett (1978) suggested that dune formation closely followed the lowering of the glacial lakes, however, evidence from the Bouchaert Site suggests that some dune formation may have been the result of the clearing of the land by early settlers.

During a dust storm on May 5, 1976, the ability of the wind to transport sand and topsoil from recently plowed fields became evident (Photo 7). During this storm vegetation in some ditches was completely covered by windblown sand (Photo 8).

BOG AND SWAMP DEPOSITS

Numerous bogs and swamps occur on the surface of the Tillsonburg map-area. These occurrences are the result of the following geomorphic features: abandoned ice-block depressions (kettles) and glacial flutings in a relatively impermeable till surface; and abandoned meltwater channels and lake plains which are broad and flat.

OGS 10 421

Photo 8–Evidence of recent eolian activity: sand transported during May 5 storm has covered up the vegetation along the ditch. Note also height of fence post beside assistant. Part of it has been buried by previous dust storms.

In general the thickness of organic accumulations in kettle holes can be large (observed to be up to 6 m) but the areal extent is usually small (less than 4 hectares). On flutes, organic accumulation is thin (0.5 to 2 m) and areal extent is small (4 hectares). On the other hand, organic deposits on abandoned lake plains and in meltwater channels tend to be thin (1 to 2 m) but areally extensive (up to 80 hectares).

Vegetational History

Palynological investigations of organic accumulations at three sites in the Tillsonburg area were performed by C.E. Winn and detailed information is available (Winn 1977). A description of the geological settings and palynological results are presented here. The three sites are the Cornell Bog, Bouchaert Site, and Mabee Site.

The Cornell Bog is located approximately 400 m north of Cornell. At this locality, over 6 m of peat, organic clay, and clayey gyttja have accumulated in a kettle hole situated along the crest of the Tillsonburg Moraine (Figure 8). During the existence of Glacial Lake Whittlesey this kettle hole was located above the lake level and could have functioned as a separate drainage basin immediately after the draining of Lake Maumee III.

The pollen diagram of the lower 2 m of a core from this bog is presented in Figure 10 (Chart A, back pocket). In a preliminary probe hole, grey sand containing seeds, some shells, and wood, was encountered beneath the clayey gyttja sediment in which the core for the pollen diagram terminates.

Winn (1977) reported that the pollen assemblage in the lowermost sediment of this core (480 to 646 cm interval, Figure 10) represents an open spruce parkland paleovegetational zone where spruce pollen dominates; some oak, pine, and willow (minor) are present and the non-arboreal component is less than 50 percent. This zone persisted from at least 12 950 ± 220 years B.P. (BGS-421) until approximately 9 840 ± 140 years B.P. (BGS-419) when a closed boreal forest became dominant (450 to 480 cm interval, Figure 10). This date of approximately 13 000 years would suggest a minimum date for the lowering of Lake Maumee when the Cornell Bog became an independent lake basin (Winn 1977).

Work done by R.F. Winn (1975) on a kettle lake, Lake Hunger, along the Tillsonburg Moraine in the adjacent Simcoe map-area suggests that the draining of Lake Maumee may have occurred prior to 15 180 ± 200 years B.P. (BGS-266). The correlative open spruce parkland zone in the Lake Hunger area existed soon after 12 480 ± 170 years B.P. (BGS-265) and remained until approximately 9 830 ± 230 years B.P. (BGS-233B), when it was replaced by a closed boreal forest (Winn 1977).

This vegetation zone correlates fairly well between these bogs. In the Lake Hunger core two older vegetational zones are present: forest tundra and tundra (Winn 1975).

The Bouchaert Site is located in a gravel pit along the southern flank of the Tillsonburg Moraine, 1 km southeast of Summers Corners (Figure 8). This site of organic material accumulation differs from the Cornell Bog Site in that it is located below the level of Glacial Lake Whittlesey, and in fact, the original gravel pit was developed in a beach bar of this lake. At this site, several layers of peat containing branches and twigs were found below up to 4 m of fine- to medium-grained sand (Photo 9). The organic layers overlie medium-grained sand, which in turn overlie the clayey silt till (Port Stanley) which forms the Tillsonburg Moraine. The medium-grained sand beneath the organic layers is nearshore Lake Whittlesey sand and the sand above the organic layers is of eolian origin.

Wet depressions developed on the irregular till surface beneath the thin sand cover after Lake Whittlesey drained from the area. Accumulation of organic material could have begun in these wet areas just after Lake Whittlesey lowered because subsequent glacial lakes in the Erie and Huron basins (Lakes Warren, Wayne, Grassmere etc.) were at lower elevations than the Bouchaert Site. Part of the eolian sand overlying the organic material was deposited during the last 100 years (BGS-418, 10 ± 80 years B.P.), possibly when the surrounding land was cleared for farming.

Pollen abundance and preservation were poor at this site, however, an open spruce parkland appears to have been present at least 12 130 ± 150 years B.P.

OGS 10 422

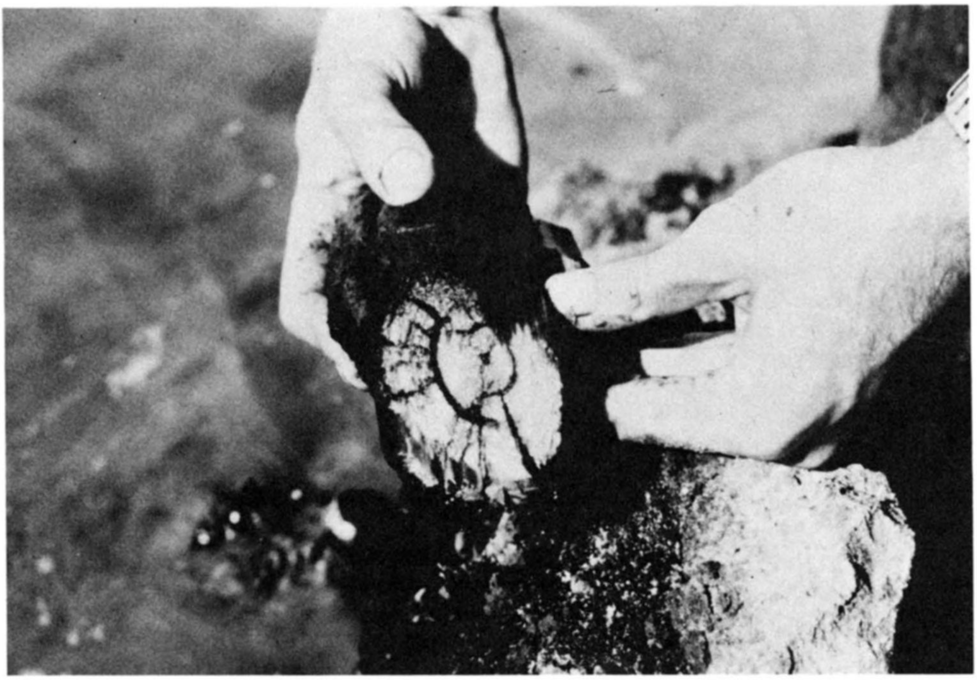
Photo 9—Buried organic material at the Bouchaert Site. Sand above is eolian and has in part been deposited since settlement times.

(BGS-375) and was still in this area 11 070 ± 140 years B.P. (BGS-377) (Winn 1977). Two other pieces of wood from intermediate stratigraphic positions were dated at 11 200 ± 140 years B.P. (BGS-376) and 11 660 ± 140 years B.P.(BGS-374). All five dates at this site increased in age with depth. Older organic material exists at this site but has not yet been collected for radiocarbon dates. Photo 10 shows one of many logs present at this site. The date of 12 130 ± 150 years B.P. is a minimum date for the draining of Lake Whittlesey and the establishment of vegetation on its abandoned lake plain.

The Mabee Site is located 1 km southeast of Mabee along the southern flank of the Mabee Moraine (Figure 8). Like the Bouchaert Site, this site is located below the water level of Lake Whittlesey, but above the level of subsequent glacial lakes.

At this site, organic material was found beneath approximately 2 m of fine- to medium-grained eolian sand and overlying approximately 0.3 m of glaciolacustrine silt and sand thought to have been deposited in Lake Whittlesey. The Whittlesey silt and sand, in turn, overlies Port Stanley Till. At the southern end of the exposure, a buried Lake Arkona shore bluff and thin beach bar can be seen (Figure 11).

At this location, Lake Arkona waters cut the shore bluff into the southern flank of the Mabee Moraine and deposited the beach bar sediments at its base.



OGS 10 423

Photo 10–A piece of wood from the organic material at the Bouchaert Site. This log was dated at 11 000 to 12 000 years B.P.

After the waters in the Erie basin rose to the Whittlesey level, thin deposits of Whittlesey silts and sands partially buried this Arkona shoreline feature. As at the Bouchaert Site, organic accumulations could begin when the water level lowered from the Lake Whittlesey level. The eolian activity may have resulted in part from the clearing of the land for farming, as is the case at the Bouchaert Site.

Two pollen diagrams were constructed by Winn (1977) for this section (Figure 12, Chart A, back pocket). Winn suggested that an open spruce parkland vegetation zone also existed at this site while the bog was developing. Two radiocarbon dates, 11 150 ± 140 years B.P. (BGS-412, peat) and 11 660 ± 140 years B.P. (BGS-407, wood), are both reasonable for this pollen zone (Winn 1977).

Based on these three sites and eight more from outside the Tillsonburg map-area, Winn (1977) presented a vegetational history for southwestern Ontario. In general, tundra and forest tundra conditions, possibly 15 000 years old, were identified in the Lake Hunger area, but this may represent local conditions only. By 13 000 years B.P. an open spruce parkland was widespread on exposed land surfaces. This environment persisted until approximately 10 000 years ago when the area was covered by a closed boreal forest. Winn (1977, p.126) further suggested "that the marshy areas continued to support open spruce parkland for a short period (perhaps approximately 500 years) after the

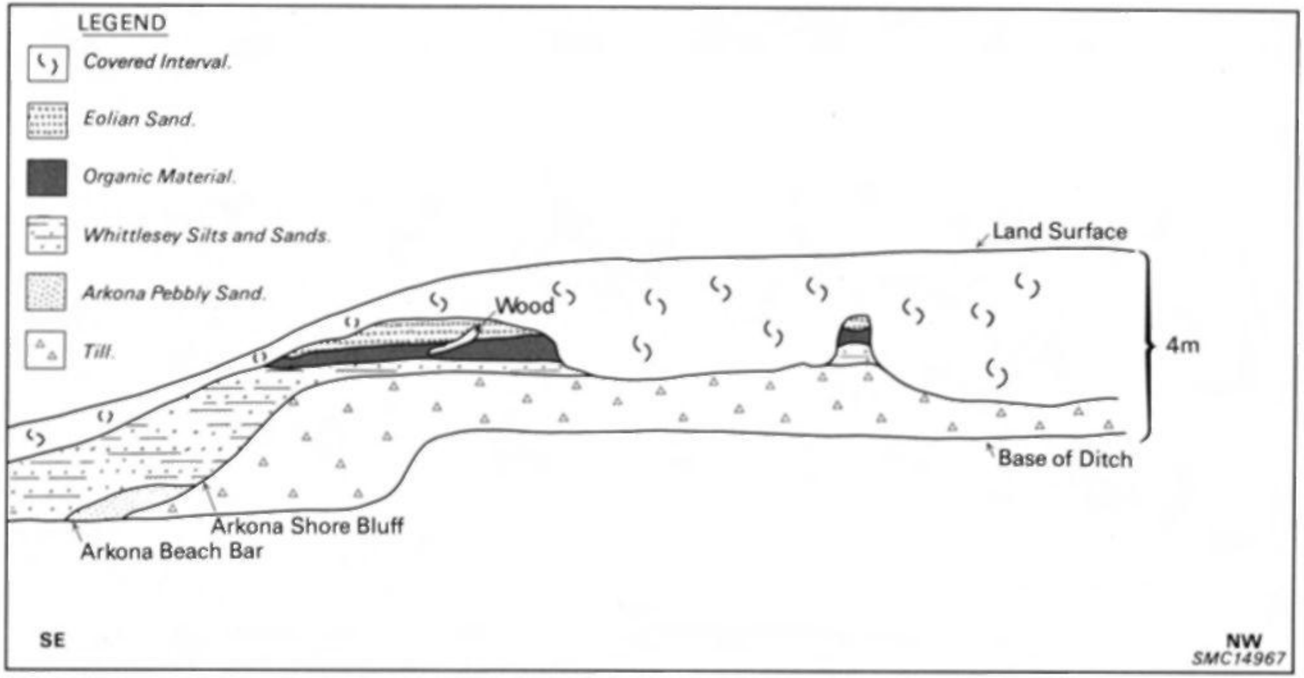


Figure 11–Section through buried organic site near Mabee.

regional vegetation pattern changed to a closed boreal forest." A predominantly hardwood forest existed in the Tillsonburg area by approximately 8000 years B.P. (Winn 1977).

MODERN ALLUVIAL DEPOSITS AND FEATURES

Modern alluvium is the sediment which has been deposited along rivers and streams in the recent past. This deposition occurs by lateral growth on point bars in the stream channel as well as vertical accretion on the flood plain surface. The texture of this sediment is generally dependent on the glacial and bedrock deposits in the drainage basin area, as well as its mode of deposition.

Modern alluvium in rivers and streams in the Norfolk Sand Plain area (southeastern half of the map-area) is commonly silt, sandy-silt, or sand, with organic debris. In the northwestern half of the map-area, modern alluvium is more variable, ranging from a gravel, through sandy silt to clayey silt, and also containing organic detritus. The greater variability is a result of the rivers and streams eroding large areas of Port Stanley Till. Modern alluvium of up to 7 m thick was observed along Big Otter Creek near Bayham (Richmond), but throughout most of the area it is considerably thinner (0.5 to 2 m).

Stratigraphy

The correlation of natural river exposures along the valleys of Big Otter Creek, Big Creek, and Little Jerry Creek has been attempted and is presented in Figures 13, 14, and 15 (Chart B, back pocket). The cross section in Figure 16 is based on water-well records (provided by the Ontario Ministry of the Environment) for the area between Salford and Mabee. A stratigraphic record to bedrock is afforded by one bore hole, drilled near Bayham (Richmond). A record of this well, plus some of the properties of the materials encountered, is presented in Figure 17 (Chart B, back pocket).

The stratigraphic sections and water-well records indicate the multiplicity of Port Stanley Till layers in the southern half of the Tillsonburg map-area. The presence of large wedge-shaped sand bodies which pinch out towards the south is also indicated. These sand bodies are confined on top and bottom by relatively impermeable layers of clayey silt to silty clay till and glaciolacustrine deeper water sediments (clayey silts and clays). They are either exposed at the surface towards their northern end, or are covered by a thin veneer of permeable Lake Whittlesey sands.

BIG OTTER CREEK SECTIONS, OTTERVILLE TO TILLSONBURG

The river exposures between Otterville and Tillsonburg contain two layers of till separated by glaciolacustrine silts and clays. Figure 13 illustrates the similarity of the textural and chemical properties of the various till layers and indicates the difficulty of correlation from the southwest to the northeast along

Big Otter Creek, using the available information. These two layers of till have been identified as Port Stanley Till. The till layer in the river sections near Otterville noticeably thickens towards the Tillsonburg Moraine.

BIG OTTER CREEK SECTIONS, TILLSONBURG TO BAYHAM (RICHMOND)

Sketches of the sections exposed along Big Otter Creek and along Little Jerry Creek are shown in Figure 14. Big Otter Creek flows between the Tillsonburg and Courtland Moraines and continues south of Bayham (Richmond). The stream dissects the Courtland Moraine.

In the river sections along Big Otter Creek, multiple till layers were observed. These layers of till, for the most part, are quite similar in texture and in chemical properties. At least three fairly continuous layers of till separated by deltaic and shallow-water glaciolacustrine sand have been assigned to the Port Stanley Drift. The upper till layer (i.e. the surface till on the west side of the Big Otter Creek) represents a readvance over deltaic sands at least to the southern limb of the Tillsonburg Moraine. This is demonstrated by the exposed sections along Little Jerry Creek, discussed below.

The upper till at sections Tc4, T1761, T1587, T1588 and T1910 (Figure 14) is believed to correlate with the upper till at Tc7 along Little Jerry Creek, and be older than the till exposed at T1904 which is associated with the Courtland Moraine. The upper till at section TRA is probably the correlative of the till layer at T1900.

The correlation of the lower tills is more speculative, but an attempt has been made (Figure 14). The sections along Big Otter Creek suggest an oscillating ice front in contact with a glacial lake or lakes, during the recession of the ice front from the Norwich Moraine position in the Tillsonburg map-area. The result of this, as indicated by the sediments deposited, is that large wedge-shaped sand bodies, which pinch out towards the southeast, exist between relatively impermeable layers of clayey silt to silty clay till and glaciolacustrine deep-water sediments of silt and clay. These sand bodies may become exposed at the surface towards the north, allowing for ground-water recharge by surface waters.

LITTLE JERRY CREEK SECTIONS

Little Jerry Creek flows between the northern and southern limbs of the Tillsonburg Moraine and then bends southward and crosses the southern limb of this moraine, southeast of North Hall. The river section at Tc7 exposes two layers of Port Stanley Till. The upper two metres are waterlain and contain large amounts of englacial erratic material. The entire till unit represents a minor readvance of the glacial ice front during retreat, overriding glaciolacustrine or deltaic sands, probably to the position of the southern limb of the Tillsonburg Moraine. During recession of the ice front, the waterlain till was deposited into the glacial lake which fronted the glacier. A correlative of this till was not found in the section north of the southern limb of the Tillsonburg Moraine (T1945, Tc5, Tc6).

BIG CREEK SECTION, LYNEDOCH TO DELHI

Several sections were observed along Big Creek during the summer and fall of 1976. A cross section along Big Creek from Lynedoch to Delhi is shown in Figure 15. In general, glaciolacustrine sands (probably of Glacial Lake Whittlesey) overlie a silt till (56 percent silt) which is probably the Wentworth Till. This till is only present in sections above 220 m a.s.l. along this portion of Big Creek and it is overlain by glaciolacustrine sediments (clay, silt, sand, and gravel). A clayey silt till (Port Stanley) was observed below this glaciolacustrine unit and it was separated from a lower silty clay till by well laminated glaciolacustrine sands. At station Ex5 (Figure 15) there is a slightly coarser grained till layer which may be related to the Port Stanley Drift.

CROSS SECTION, SALFORD TO MABEE

A cross section through the Tillsonburg map-area between Salford and Mabee was constructed using water-well records presented in Sibul (1969, Appendix A) and additional water-well records supplied by the Ministry of the Environment. A schematic version of this cross section is presented in Figure 16.

Differentiating fine-grained till layers from layers of glaciolacustrine silts and clays is difficult when analyzing water-well records, so no attempt was made to do this when preparing the cross section. However, the cross section is useful in outlining the wedge-shaped bodies of deltaic and glaciolacustrine sands which are potential ground-water aquifers. From the stratigraphic sections along the rivers (Figures 13, 14) and from surface mapping, at least one Port Stanley Till layer is known to be present in the areas identified as Port Stanley Drift (till, silt, and clay) on the schematic cross section (Figure 16). Thus, the hypothesis of a fluctuating ice margin, fronted by a glacial lake during retreat, is supported by the water-well records. The minor advances and standstills of the ice front formed the Tillsonburg, Courtland, and Mabee Moraines.

In the above-mentioned cross section the lower materials assigned to the Port Stanley Drift may in fact represent Erie Interstadial deposits. No Catfish Creek Till was recognized in the water-well records for the area along the cross section south of Tillsonburg. Probable Catfish Creek Till and drift were encountered in the borehole drilled near Bayham (Richmond) which is located to the west of this cross section.

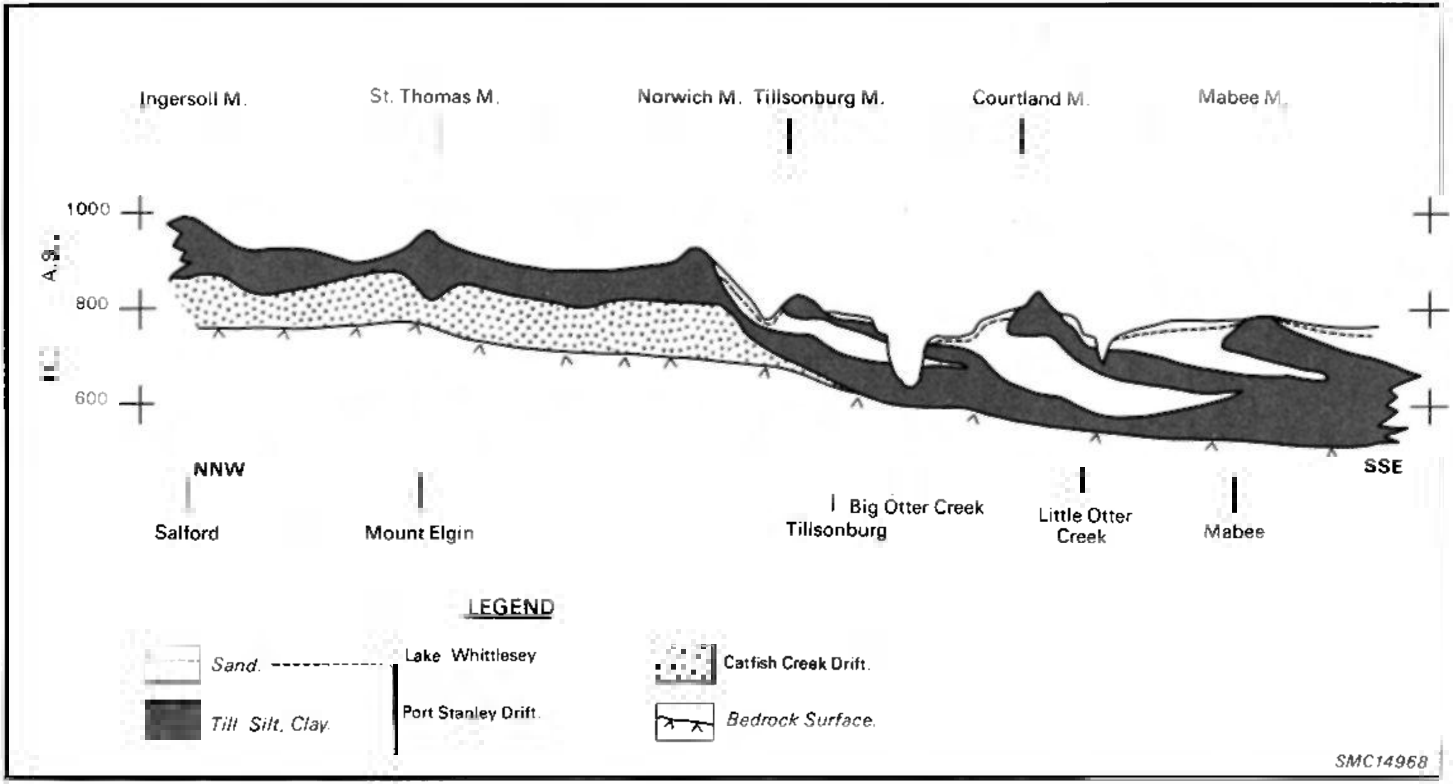


Figure 16–Schematic cross section from Salford to Mabee, based on information in Sibul (1969) and data from Ontario Ministry of the Environment.

BAYHAM (RICHMOND) BOREHOLE

One borehole was drilled during the winter of 1978 on the flood plain of Big Otter Creek, to obtain information on the stratigraphy, composition, and behaviour of the glacial drift below the level of natural exposure. An additional purpose of the borehole was to obtain a core of the bedrock, the Marcellus Shale, which does not outcrop in Ontario. The stratigraphic information gained from drilling is useful in interpreting preexisting water-well data.

The drill site was located approximately 600 m east of Bayham at an elevation of approximately 189 m a.s.l. Bedrock was encountered at a depth of about 34.5 m and a one-metre core of Marcellus Shale was obtained and given to P.G. Telford, Ontario Geological Survey, Toronto, for further investigation. In general, the following sequence of material was encountered: 7 m of alluvial sediments of Big Otter Creek; 4 m of Port Stanley Till; 2 m of outwash or deltaic sands believed to be Port Stanley Drift; 14 m of lacustrine silts, clays, and sands possibly of the Erie Interstadial; 4 m of glaciolacustrine clay of Catfish Creek Drift; and approximately 2 m of Catfish Creek Till (? — a very "local" till).

A detailed log of the borehole and several properties (texture, penetration, Atterberg Limits, carbonate content, and carbonate ratios) of the materials encountered are presented in Figure 17. The assignment of the different glaciolacustrine sediments to either Port Stanley Drift, Erie Interstadial, or Catfish Creek Drift is very tentative and is based on texture, structure, and carbonate ratios. The glaciolacustrine sediments assigned to the Catfish Creek Drift contain several small pebbles and grits (ice rafted?) and are high in matrix calcite, with a ratio of greater than one. This is similar to the till, identified as Catfish Creek Till, located at the base of the hole. The lacustrine sediments immediately above the Catfish Creek glaciolacustrine sediments contain more dolomite than calcite (ratio is less than one) and vary between well laminated silt and clay to massive silty clay. No ice-rafted debris was noted. The sediment record implies an early deep-water phase, followed by a shallow phase, which then deepened. This may be a record of the succession of lakes which probably occupied the Erie basin during the Erie Interstadial (Dreimanis 1969). The shallow-water sand unit is, however, at a lower elevation than the proposed low-level Lake Leverett stage (Morner and Dreimanis 1973).

The sharp break in texture at the top of the lacustrine sequence (clay–sand contact) has been related to the advancing ice mass which deposited the Port Stanley Till throughout most of the Tillsonburg map-area.

Glacial History

Materials observed during mapping of the Tillsonburg map-area were deposited during Late Wisconsinan and Recent times, approximately 23 000 radiocarbon years B.P. to present. Pre-Late Wisconsinan deposits were reported by Dreimanis (1951) in a water-well log near Aylmer Station, in which 8 m of blue clay with sticks occurred below hardpan (Catfish Creek Drift). These buried organic materials probably represent the Plum Point or Port Talbot Interstadial (Dreimanis and Karrow 1972).

The oldest glacial deposits observed in the Tillsonburg map-area were of Catfish Creek Drift (Catfish Creek Till, outwash sand and gravel and glaciolacustrine silt and clay). The Catfish Creek Till represents a major ice advance (during the Nissouri Stadial) which extended beyond the Tillsonburg area and into Ohio and Indiana (Goldthwait *et al.* 1965; Dreimanis and Goldthwait 1973).

Indications from the adjacent Woodstock area (Cowan 1975) are that the initial ice movement during this stadial was controlled by the Great Lake basins. Ice movement changed to a more regional flow (from the north-northeast) during the major part of this stadial. As the ice thinned during recession, lobation occurred and a late readvance out of the Erie basin to the Dorchester Moraine imparted a southeast-trending fabric on the upper part of the Catfish Creek Till (Dreimanis 1961, 1964; Westgate and Dreimanis 1967; Cowan 1975).

Although no till fabric analyses were done in the Tillsonburg map-area, the lithology and chemical properties of the Catfish Creek Till indicate a western Grenville source area and a flow direction from the north-northeast. Several drumlins which appear to be cored by Catfish Creek Till probably represent a later readvance from the southeast out of the Erie basin.

As this ice sheet receded during the Erie Interstadial, a series of high-level glacial lakes occupied the Erie basin (Dreimanis 1969; Morner and Dreimanis 1973). At approximately 15 500 years B.P., Lake Leverett is believed to have existed in the Erie basin during the maximum retreat in this interstadial (Morner and Dreimanis 1973). As the ice sheet readvanced during the early part of the Port Bruce Stadial, lake levels in the Erie basin rose again. These fluctuations in lake level are recorded in the lacustrine sediment sequence in the borehole at Bayham (Richmond).

The advancing ice sheet was controlled by the Erie basin and ice flowed outwards overriding the lacustrine sediments. Incorporation of these fine-grained sediments into the ice resulted in the deposition of the fine-grained Port Stanley Till (Dreimanis 1961). The time period of this event is referred to as the Port Bruce Stadial (Dreimanis and Karrow 1972).

This glacial advance formed the major deposits and features of the Tillsonburg area, and is responsible for the local topography. The ice sheet crossed the Tillsonburg map-area from southeast to northwest to the position of the Ingersoll Moraine. The Tavistock Till was deposited in the adjacent Woodstock area by an ice advance from the Huron–Georgian Bay basins at almost the same time as the Port Stanley Till was being deposited along its outer margin, the Ingersoll Moraine (Cowan 1975, 1976).

As the ice front retreated from the Ingersoll Moraine, waters issuing from the ice dissected the Ingersoll Moraine near Putnam and flowed southwestward down the Thames River Valley towards the Komoka delta. Northward flow of the glacial meltwater along Reynolds Creek to Putnam occurred during the construction of the Westminster and St. Thomas Moraines. During the period of fluctuation along the ice front and construction of the St. Thomas Moraine, the outwash sediments near Zenda were overridden. Dreimanis (1964) suggested that Lake Maumee II existed in the Erie and Huron basins during marginal fluctuations along the St. Thomas Moraine. Northward flow of meltwater to the ancestral Thames River probably continued until the two limbs of the Norwich Moraine were constructed (Figure 18a).

As the glacier retreated from the Norwich Moraine, a high-level glacial lake flooded the ground between the Norwich Moraine and the ice front. Drainage to the Thames River valley became limited, and part of the exposed land area drained towards the glacial lake (Figure 18b). At this time nearshore or deltaic sands were being deposited into the lake at the ice front. The ice front receded to the area south of the Tillsonburg Moraine position. A readvance (Figure 18c) to a position of the "northern limb" of the Tillsonburg Moraine overrode these glaciolacustrine sediments and minor fluctuations during recession formed the "middle" and "southern" limbs of the Tillsonburg Moraine. The ice front receded to a position south of the Courtland Moraine and glaciolacustrine and deltaic sediments continued to be deposited between the ice front and the shoreline (along the Norwich Moraine?). Readvance of the ice formed the Courtland Moraine (Figure 18d), and the Mabee Moraine was probably formed in this fashion also.

During these readvances the ice sheet was most likely grounded, because no waterlain till was observed at the base of the till layers; however, the upper part of the till was waterlain in places, suggesting that the lake was in contact with the margin during recession.

With an oscillating ice margin fronting on a glacial lake, the water level in the basin was probably fluctuating as well. The large area of bevelled till plains and the lack of shoreline features support the theory of fluctuating water levels. Possible weak shoreline features identified by Dreimanis (1951) along the Norwich Moraine may represent some of these levels. On the basis of the Maumee III shoreline feature on the crest of the Tillsonburg Moraine, Maumee III probably lasted slightly longer and the lake could possibly be correlated to the ice front position along the Courtland Moraine.

During the latter part of the Port Bruce Stadial the ice sheet reentered the Tillsonburg map-area for the last time, depositing Wentworth Till and forming the Paris Moraine.

Glacial Lake Arkona occupied the southern part of the Tillsonburg map-area approximately 13 600 years B.P. (Dreimanis 1966), and several fragments of an abandoned shoreline remain west of the Paris Moraine. A thick blanket of younger Lake Whittlesey sediments masks the age relationship of Lake Arkona to the Paris Moraine: this lake could be older, younger, or of a similar age.

About 13 000 years B.P. (Port Huron Stadial) the water in the Erie basin rose to the Lake Whittlesey level and part of the large expanse of deltaic sand of the Norfolk Sand Plain (Chapman and Putnam 1951, 1966) was deposited. At the same time an open spruce parkland was beginning to be established on the exposed land surface (Winn 1977). During the time of Lake Warren, a small portion of the map-area may have been inundated and the remaining part of the sand plain was deposited. Eventually, the entire map-area was exposed to soil development, erosion, vegetational changes, and settlement; giving rise to the present-day landscape.

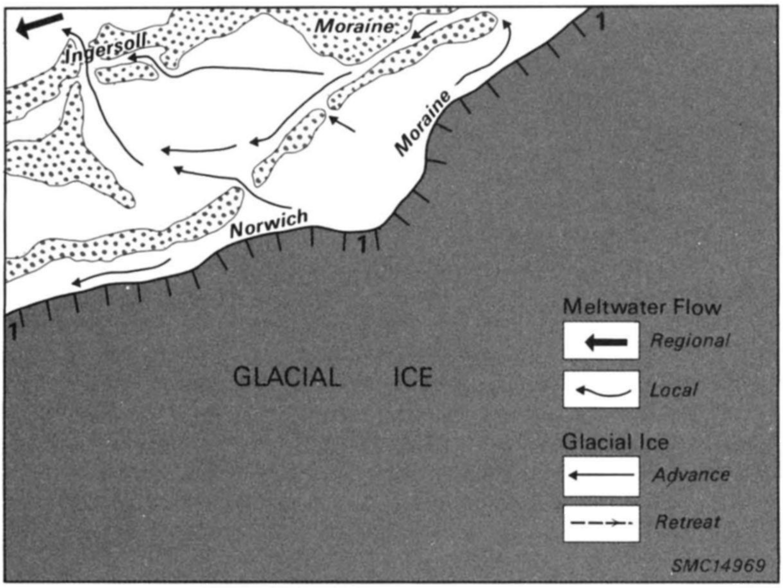


Figure 18a–Meltwater drained northward during the retreat of the ice front from the Ingersoll Moraine to the Norwich Moraine positions.

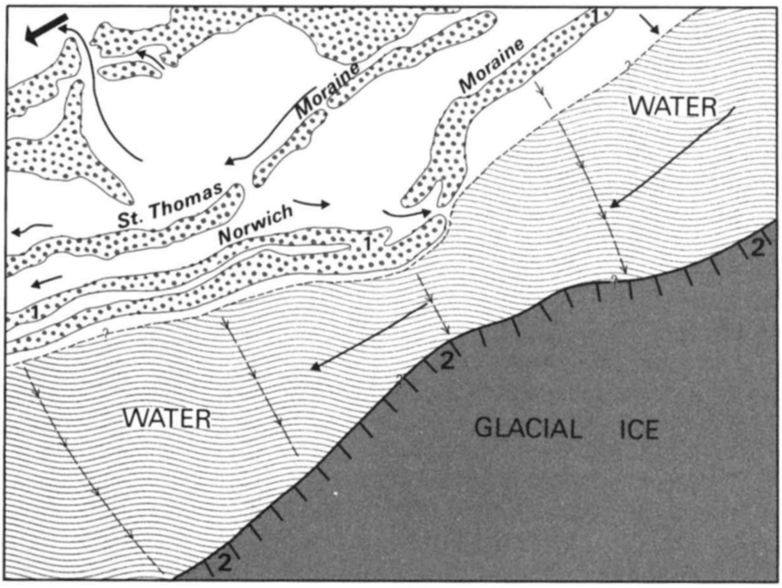


Figure 18b–Once the ice front retreated from the Norwich Moraine, drainage in the area south of the St. Thomas Moraine was to the south into a glacial lake in front of the ice.

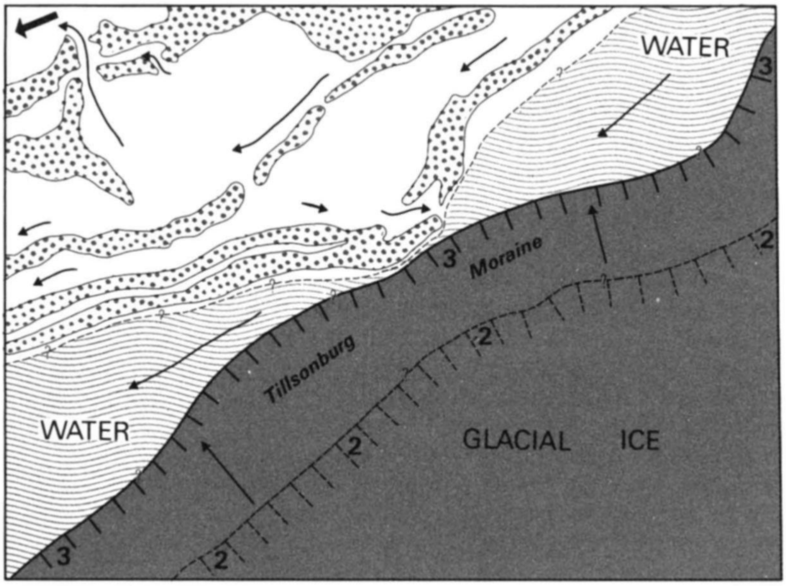


Figure 18c–A minor readvance of the glacier from position 2 to position 3, overrode deltaic sands deposited in the proglacial lake and formed the Tillsonburg Moraine.

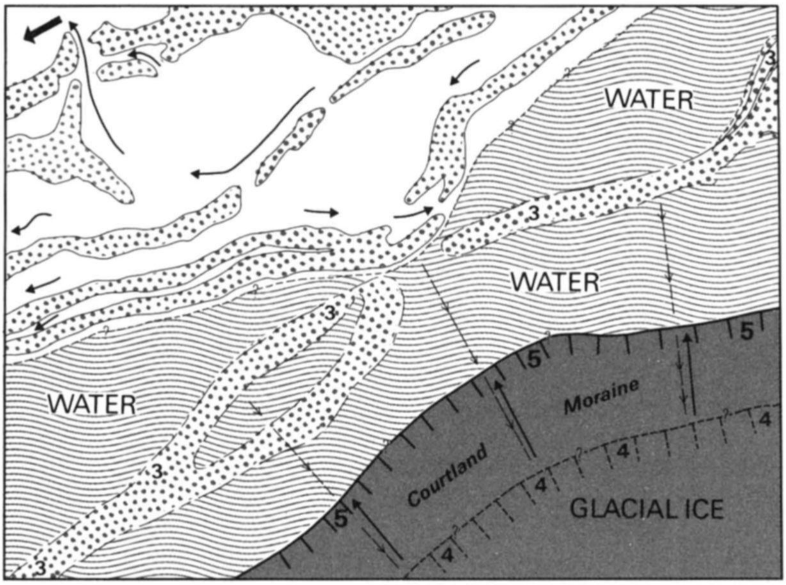


Figure 18d–The ice front retreated to approximately position 4 and the lake level probably lowered. The ice readvanced to position 5 to form the Courtland Moraine, again overriding the deltaic sand. Submerged portions of the Tillsonburg Moraine are delineated by dashed boundaries.

APPLIED QUATERNARY GEOLOGY

Agricultural Soils

Soils within the Tillsonburg map-area have developed in Quaternary deposits of Late Wisconsinan age. The deposits in the northwestern half of the area have been exposed to weathering processes since the Mackinaw Interstadial, 13 300 years B.P. (Dreimanis and Karrow 1972), and the deposits in the southwestern half (glaciolacustrine sands) have been exposed since the lowering of the water level in the Erie basin from the Glacial Lake Whittlesey level, shortly after 12 900 years B.P. (Dreimanis and Karrow 1972). The sand plain areas that were modified by eolian processes may have been subjected to weathering processes only during the last hundred years.

Soil maps for Norfolk, Elgin, Middlesex, and Oxford Counties were prepared by staff of the Ontario Agricultural College (*circa* 1928, 1929, 1931, and 1961 respectively). Because several soil series names used on some of these maps are no longer in use (Hoffman *et al.* 1964), Table 5 was compiled, to relate soil series to the glacial deposits described in this report.

The Ontario Soil Survey is presently remapping Norfolk County and preliminary maps will be published with tentative numerical designations for the soil series. These numerical designations, which are also presented in Table 5, will be converted to soil series names on the final publications.

Economic Geology

SAND AND GRAVEL

Excavation for sand and gravel has occurred throughout the map-area in glaciofluvial outwash and ice-contact deposits, abandoned beach material, and in stabilized dunes. During the summer of 1976, only four pits were active when visited. These pits were owned or operated by Walmsley Brothers Limited, J.E. Marshall and Sons Limited, J.N. Corbett Gravel Supply, and Bouchaert Gravel Supply (pits 9, 11, 6, 19, Tables 6, 8).

Most townships within the map-area have only a few possible sources of sand and gravel, and they are often too small or thin to develop. Sand and gravel extraction is mainly for local use at present and these resources will probably not be sufficient to meet local needs in the future. Sand and gravel deposits within the map-area are discussed below, according to their mode of deposition.

TABLE 5 RELATIONSHIP OF SOIL SERIES TO QUATERNARY DEPOSITS OF THE TILLSONBURG MAP-AREA

Geological Unit	Soil Series					
	Good Drainage		Imperfect Drainage		Poor Drainage	
Till:						
Port Stanley Till	Huron	(024)*	Perth	(025)	Bookton	(026)
Wentworth Till	Fox gravelly loam	(012)	—	(015)	—	(016)
Glaciofluvial sediments (outwash, older alluvium):						
gravel	Burford	(132)	Brisbane	(135)	Gilford	(136)
sand	Fox	(112)	Brady	(115)	Granby	(116)
gravelly sand and coarse sand	Fox coarse sand series					
		(132)		(135)		(136)
		(112g)		(115g)		(116g)
Glaciolacustrine sediments:						
sand	Fox	(112)	Brady	(115)	Granby	(116)
silt	Brant	(203)	Tuscola	(205)	Colwood	(206)
silty clay	Brantford	(054)	Beverly	(055)	Toledo	(056)
clay, heavy clay	—	(064)	Haldimand	(065)	Lincoln	(066)
thin sand over silt	Miami loam	(403)	—	(405)	—	(406)
thin silt over silty clay	Miami silt loam	(544)	Binbrook	(545)	—	(546)
thin sand over silty clay	Bookton	(534)	Berrien	(435)	Wauseon	(536)
thin sand over Port Stanley Till	Bookton	(513)	Berrien	(515)	Wauseon	(516)
thin sand over Wentworth Till	Fox gravelly loam	(502)		(505)		(506)
		(502g)		(505g)		(506g)
Eolian sediments:						
dune sand	Plainfield	(302)				
eolian sand over lacustrine sand	Plainfield	(313)	—	(315)	Watrin	(316)
Recent alluvium:	— — — — — — — —Bottomland (90), variable drainage— — — — — — — —					
Organic sediments:					muck	(997)

*Tentative designations from Ontario Soil Survey preliminary maps. Final Soil Survey names will be assigned, however, they may not correspond exactly to the names presented in this table. Information was supplied in part by E.W. Presant, Pedologist, Ontario Institute of Pedology, Guelph, Ontario.

Glaciofluvial Outwash Deposits

Sand and gravel deposits of glaciofluvial outwash origin are the most desirable for aggregate extraction because of their generally uniform texture and structure, and their usually well defined areal distribution. Several bodies of outwash gravel and sand are located in Zorra Township (North Oxford), North Dorchester Township, and Southwest Oxford Township (Dereham) (Table 6). These deposits are of several ages: older than the Catfish Creek Till, older than the Port Stanley Till, and younger than the Port Stanley Till.

The deposits older than the Catfish Creek and Port Stanley Tills are scattered, and because they are buried their extent is difficult to determine. In the gravel pits, where Catfish Creek Till overlies the gravel, cementation is a problem. Cemented blocks of gravel up to 2 m in diameter can be seen, e.g. pits 5, 11 (Hewitt and Cowan 1969a, p.34). Only minor cementation was found in the outwash gravels covered by Port Stanley Till (pits 1, 2, 12, Table 6).

TABLE 6 SAND AND GRAVEL PITS IN OUTWASH DEPOSITS

Location				Composition							Pebble Lithology (%)							
Pit Number (see Map 2473)	Township	Concession	Lot	overburden (feet)	observed or reported thickness (feet)	% stone (estimated)	% sand (estimated)	% stone (> 1 inch)	% stone (> 4 inches)	maximum boulder size (feet)	Limestone	Dolostone	Chert	Sandstone	Siltstone	Shale	Precambrian (competant)	Precambrian (weathered)
1	Dereham	III	2	8	23	60	40	30	1	0.5								
2	Dereham	III	4	4	9	70	30	30	1	0.5	39	47	3	–	1	1	8	1
3	Dereham	IV	7	2	5+	70	30	20	5	4	35	45	9	3	–	–	8	–
4	Dereham	IV	10	1	5	55	45	25	6	1	47	34	7	2	–	–	8	2
5	Dereham	VI	20	5	12	70	30	25	<1	3	50	33	3	2	1	–	11	1
6	Dereham	VI	27	2	15	60	40	20	<<1	0.5	43	35	10	2	1	–	9	–
7	Dereham	VII	22	0	10	60	40	20	<1	0.5								
8	North Dorchester NTR	V	18	0	10	30	70	15	<1	0.5								
9	North Dorchester STR	B	5,6	0	20	80	70	15	<<1	0.5	40	38	6	3	3	1	7	2
10	North Dorchester STR	B	4	0	22	30	70	15	<1	0.5								
11	North Dorchester STR	I	9	0	60	35	65	15	5	4	42	38	5	2	1	–	11	1
12	North Dorchester STR	II	5	4	20	50	50	20	1	0.5	29	55	4	–	–	–	9	3

The most extensive outwash deposits are younger than the Port Stanley Till. These materials were deposited in meltwater channels which were fed by the retreating "Port Stanley" ice. These meltwater streams flowed northward through a gap in the Ingersoll Moraine at Putnam and joined the major stream which flowed westward down the Thames River to the Komoka delta. The Thames River valley has been occupied by glacial meltwater several times during glacial retreat in southern Ontario (Dreimanis 1964).

The principal source of sand and gravel is in the Thames River meltwater channel. These deposits average 6 m in thickness, with a stone content of between 20 to 40 percent. Less than one percent of the clasts are greater than 10 cm in diameter and only a small fraction of the stone is suitable for crushing. Chert contents of 4 percent and 7 percent were obtained in two pebble counts taken at the Walmsley Brothers pit (pit 9, Table 6). Clastics, and soft, weathered, Precambrian and dolostone pebbles and cobbles average 8 percent in the same deposits.

Along Reynolds Creek, there are two major areas of outwash gravel accumulation. These areas are both located north of the St. Thomas Moraine: one north of Mount Elgin (pits 3, 4) and one west of Dereham Centre (pits 6, 7). In the deposits near Mount Elgin, stone content decreases from 70 to 0 percent westward, and away from the St. Thomas Moraine. Chert is present in most deposits, averaging 8 percent. In general this deposit is thin, probably less than 3 m, although no true thickness was observed because the water table occurs approximately 2 m below the surface.

The second area of outwash gravel along Reynolds Creek, west of Dereham Centre, has been reported by local operators to be about 4.5 m thick with a 1 m "clay" layer at the base, overlying more gravel. The water table in this area is approximately 2 m below the present land surface. Stone content of this deposit has been reported as high as 85 percent (Hewitt and Cowan 1969b, p.53). Chert is present throughout this deposit as well.

Another deposit of outwash sand and gravel is located southwest of Brownsville along Catfish Creek. This deposit is buried by Lake Whittlesey sands, and for the most part is found below the water table. From limited data, this deposit appears to be less than 3 m thick and has a stone content of less than 25 percent.

Glaciofluvial Ice-Contact Deposits

Glaciofluvial ice-contact deposits are not as desirable for aggregate extraction as outwash deposits because of the wide range and the abrupt change in grain size; the nonuniformity due to deformation (faulting, folding, and slumping); and the presence of finer textured materials, such as clay and silt layers as well as the possibility of large amounts of till.

In the Tillsonburg area these problems are compounded by the small size of the deposits and a generally low percentage of crushable sizes. Information on four pits which are located in ice-contact material is presented in Table 7. The chert content of the material in pit 13 is low, probably because of the association of this deposit with the ice which deposited the Catfish Creek Till.

TABLE 7 SAND AND GRAVEL PITS IN ICE-CONTACT DEPOSITS

Location				Composition								Pebble Lithology (%)							
Pit Number (see Map 2473)	Township	Concession	Lot	overburden (feet)	observed or reported thickness (feet)	% stone (estimated)	% sand (estimated)	% stone (>1 inch)	% stone (>4 inches)	maximum boulder size (feet)	Limestone	Dolostone	Chert	Sandstone	Siltstone	Shale	Precambrian (competant)	Precambrian (weathered)
13	Dereham	III	21	3	6	30	70	10	<1	0.5	30	48	3				17	2
14	Dereham	IV	21	0	45	5	95	3	<<1	—								
15	North Dorchester	B	B	0	20	50	50	20	2	3								
16	South Dorchester	VII	12	0	8	25	75	10	<1	0.5								

Glaciolacustrine Beach Deposits

Sand and gravel deposits of beach origin are generally of a desired texture and structure for aggregate but in the Tillsonburg map-area they tend to be found in linear bodies less than 5 m thick. These beach ridges were formed during Glacial Lakes Arkona and Whittlesey. Stone content consists mainly of small pebbles (6 to 25 mm in diameter) and is usually high (about 50 percent) except when the overlying dune sand is included; however, actual beach bar thickness in these cases is usually less than 3 m. Chert is present in the beach gravels as well, as these gravels are directly related to the till (Port Stanley averages 9 percent chert) from which they developed. Several selected properties of the pits located in beach materials are listed in Table 8.

Older Alluvial Deposits

Very few pits are located in older alluvial terraces in the Tillsonburg area. Generally this is because these deposits usually contain less than 20 percent of gravel sized material of which less than one percent is greater than 2.5 cm.

Eolian Deposits

Numerous pits are located in the stabilized dunes of the Tillsonburg area. The sand is used primarily for fill.

CLAY

Three areas of clay extraction for brick and tile production were described by Guillet (1967, 1977) within the Tillsonburg map-area: Deller Tile Limited (Guillet 1967, p.140-141; Guillet 1977, p.75); Norwich Brick and Tile Limited (Guillet 1967, p.181-182); and the former plant of W. McCredie (Guillet 1977, p.76). Deller Tile Limited is located at Brownsville Station (lot 21, concession XL, Dereham Township) but is no longer in production. The W. McCredie plant (lot 13, concession IX, south Dorchester Township) produced "salmon-coloured bricks, drain and wall tile...prior to 1940" (Guillet 1977, p.76). Norwich Brick and Tile Limited is located about 3 km northwest of Norwich (lot 11, concession III, north Norwich Township) and was active during the summer of 1976. Information on this operation and the properties of the clay excavated have been previously presented by Guillet (1967) and Cowan (1975). Cowan (1975, p.65) suggested that this deposit of laminated clay and silt was "the result of a local ponding during the retreat of the ice sheet which laid down the Port Stanley Till", rather than being deposited in Glacial Lakes Whittlesey and Warren as suggested by Guillet (1967). Chemical and mineral analyses and the

TABLE 8 | SAND AND GRAVEL PITS IN BEACH OR DUNE AND BEACH DEPOSITS

Location				Composition								Pebble Lithology (%)							
Pit Number (see Map 2473)	Township	Concession	Lot	overburden (feet)	observed or reported thickness (feet)	% stone (estimated)	% sand (estimated)	% stone (> 1 inch)	% stone (> 4 inches)	maximum boulder size (feet)	Limestone	Dolostone	Chert	Sandstone	Siltstone	Shale	Precambrian (competant)	Precambrian (weathered)
17	Bayham	VIII	6	0	20	10	90	5	<1	0.5								
18	Houghton WNR	W	137	0	4	50	50	20	2	0.5								
19	Malahide	VI	22	0	15	10	90	5	0	0.25								
20	Malahide	VII	35	0	8	20	80	5	<1	0.5	48	30	8	2	—	1	7	4
21	Middleton NTR	I	27	2	6	45	55	16	0	0.25	59	26	1	5	3	—	6	—
22	Middleton NTR	II	16	0	4	45	55				57	26	8	2	—	—	6	1
23	Middleton STR	II	17	3	6	65	35	5	0	0.25	65	20	9	1	—	—	5	—
24	Middleton STR	II	34	0	9	10	90	5	<1	6								
25	Windham	IV	21	0	4	50	50	10	<1	0.75	46	23	23	2	—	—	6	—

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Photo 11–Muck and peat extraction (W.B. Whitehead, Greenhouse Muck) 2 km west of Verschoyle. Organic material from site is used in greenhouses and gardens.

fired characteristics of the clays from the W. McCredie plant are presented by Guillet (1977, p.74-76).

Clay reserves within the Tillsonburg map-area are limited to the glaciolacustrine clay deposits of Lake Maumee (unit 7, south of the Norwich Moraine as in the Deller Tile Limited pit), local pondings, and possibly the Port Stanley Till if the grits and pebbles were removed.

PEAT, MUCK, AND MARL

Three areas of muck and peat excavation were in operation during the summer of 1976, the main product being organic material for the greenhouses and gardens of the area. Two areas of operation (2 km west and 2 km northwest of Verschoyle) were operated by W.B. Whitehead Greenhouse Muck, R.R. #1, Norwich (Photo 11). In both these areas the muck is usually less than 1 m thick and has accumulated on outwash sands and silts along abandoned meltwater channels. The third operation is also located in a thin muck accumulation on an abandoned meltwater channel 2 km south-southeast of Dereham Centre. This deposit, although thin (usually less than 1 m), is spread over a large area.

Other potential peat and muck sources generally correspond to map unit 12 (muck, peat, and marl) and usually occur in poorly drained abandoned meltwater channels. These other deposits are usually thin. Thin deposits can also be found in poorly drained areas of the Norfolk Sand Plain, sometimes being buried below stablized sand dunes. Thicker deposits of peat and muck up to 6 m thick occur in kettles along several of the morainic ridges of the area, but these are of limited areal extent.

No large accumulations of marl were observed during the field season. Thin marl, less than 1 m thick, was observed below peat, along West Catfish Creek, 3.5 km northeast of Lyons.

ENVIRONMENTAL GEOLOGY

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

The numerous bogs and swamps in the northwestern quarter of the map-area and in the kettle holes along several of the morainic ridges may also cause construction problems. The presence of buried organic materials in the sand dune areas should be kept in mind.

The very compact nature and stoniness of the Catfish Creek Till may increase excavation costs in areas where this till outcrops or is close to the surface. The surface of the Port Stanley Till is, in places, susceptible to frost heaving as is the surface of the glaciolacustrine silt deposits.

The complex stratigraphy and the many steep valley walls in the southwest half of the map-area, may also pose problems to construction and may result in economic losses and possible fatalities. Seepage and contact springs along valley walls where relatively impermeable fine-textured tills, silts, and/or clays are interbedded with permeable sands may increase the potential for failure and possible piping of the sands may cause land subsidence. Novakovic and Farvolden (1964) suggested a very close association of springs with slumps and minor landslides in the Big Creek and Big Otter Creek drainage basins. Construction should be avoided near the valley edges in these areas when possible, otherwise detailed engineering, ground-water, and geological investigations should be undertaken.

Along with the numerous other considerations in the selection of waste disposal sites, caution should be used in the southern half of the map sheet especially, to avoid contamination of the ground-water aquifers in the confined wedge-shaped deltaic sand bodies. These aquifers possibly recharge from the surface in the intermorainal areas of the sand plain.

Another problem in the southeastern half of the Tillsonburg map-area is the susceptibility of the topsoil to wind erosion, enhanced by mismanagement of the land. In contrast, good land management practices have led some land-

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Photo 12–Partial sand dune: top soil and dune sand have been removed manually from the fields on the right, up to the fence line. Topsoil has been replaced and arable acreage has been increased.

owners to remove the topsoil from stabilized dunes, excavate the dune sand for fill, and then replace the topsoil on the now-level fields (Photo 12) in order to increase the workable acreage of the property.

Geochemistry

Trace elements were determined on several samples of unweathered Catfish Creek Till, Port Stanley Till, and Wentworth Till, and a few samples of possible Erie Interstadial clays. Trace element values for the tills are presented in Table 3 and results of individual samples are given in Appendix C. The following range of trace element values were obtained on three samples of lacustrine clays: Cu, 24 to 36 ppm; Ni, 21 to 40 ppm; Cr, 56 to 86 ppm; Zn, 52 to 78 ppm; Pb, 20 to 23 ppm; Co, 11 to 17 ppm; and Mn, 560 to 760 ppm. No geochemical results were obtained on the glaciolacustrine sand which is the surficial cover of approximately half of the map-area, however, values for several trace elements in soils derived from these sands (dominantly A horizon) around Lake Lisgar have been presented by Winn (1975). Winn also discussed some of the effects that urbanization has had on the environment in respect to lake sediment and soil geochemistry.

APPENDIX A

DESCRIPTION OF MEASURED SECTIONS

Little Jerry Creek (locations on Figure 14)

Station Number	U.T.M. Coordinates	Thickness (m)	Description of Material (listed in order from top of section)
Tc 5	1198 3860	0.6	orange brown, fine- to medium-grained sand
		6	brown to grey brown, massive, silty clay with occasional grits and pebbles — Till
Tc 6	1190 3840	0.6	orange brown, medium-grained sand
		6.5	brown to grey, blocky to massive, silty clay with occasional grit and pebble — Till
T 1945	1158 3806	1.5	yellow brown and greyish brown, horizontally laminated clay with silt
		6	dark grey to dark greyish brown, blocky, silty clay with grits and pebbles — Till
		1.5	dark grey and grey, contorted, very fine grained sandy silt and clay
Tc 7	1180 3640	0.6	brown, weathered, silty clay
		0.3	brown, weathered, gravelly (not competent), clayey silt
		0.6	brown, well laminated, clayey silt, silt and clay, with dropstones
		0.5	light brown, clayey silt with grits and pebbles — Flow Till
		2.5	brown, clayey silt, with occasional grit and pebble, massive — Till (sharp contact with sand below)
		7	silty, fine- to medium-grained sand, current laminated, occasional layer of silty clay
		3	covered interval
		6	grey, blocky, silty clay with a few grits and pebbles — Till; sharp but irregular contact with sand unit below
		4.5	fine- to medium-grained sand, horizontally laminated with heavy minerals
		3	covered interval

Big Otter Creek, south of Tillsonburg (locations on Figure 14)

Station Number	U.T.M. Coordinates	Thickness (m)	Description of Material (listed in order from top of section)
T 1924	1263 3371	2	horizontally interbedded clay and silt

Station Number	U.T.M. Coordinates	Thickness (m)	Description of Material (listed in order from top of section)
T 1924 continued		6	dark brown, silty clay with occasional grit and pebbles; becoming siltier and slightly sandy downwards — Till
		3	brown silty clay with very occasional grit; containing very contorted streaks and laminations of silt
		3	brown, horizontally laminated clay with silt
		3	current laminated, very fine to fine grained sand
TRA	1340 3445	1.5	brown silty clay to clayey silt, with occasional grit and pebble — Till
		3	very fine sand and silt with minor clay laminations
		2	grey silty clay with occasional grit and pebbles — Till
		2	silt and very fine sand, minor clay, fine-grained sand; faintly laminated and contorted
		3	covered inverval
TRB	1310 3415	—	see figure 17 for description of units
T 1904	1381 3444	1.2	faintly laminated clay and silt, appears well laminated on weathered surface
		0.7	yellow brown, fine- to medium-grained sand with occasional clay layer
		2	brown silty clay with some grits and pebbles — Till
		1	grey medium-grained sand
		1	sandy silt with clay; occasional silt layer, occasional grit
		2	grey brown, fine- to medium-grained sand; occasional clay layer and very fine grained sand layer
T 1794	1514 3548	4	yellow brown to brownish grey, horizontally laminated clay, silt, and fine sand
		6.5	silty clay with occasional grit and pebble, massive — Till: sample T-58
		3	gritty silt to clayey silt with pebbles — Till: sample T-59
		5	highly contorted, interbedded fine-grained sand and silt till; similar to unit above
T 1793	1710 3682	4	yellow brown fine- to medium-grained sand;
		5	brown silty clay with grits and pebbles — Till: sample T-60

Station Number	U.T.M. Coordinates	Thickness (m)	Description of Material (listed in order from top of section)
T 1793 continued		0.1	yellow brown, medium-grained sand
		8	grey gritty silt; massive, compact — Till; sample T-61
		0.3	brown, compact fine- to very fine grained sand
		1.5	yellowish brown, fine-grained sand
		3	yellowish brown, fine-grained sand containing contorted clay and very fine grained sand layers
		3	covered interval
T 1792	1705 3710	0.5	yellow brown, fine- to medium-grained sand
		2	dark brown, weathered, clayey silt with some grits and pebbles — Till
		15	generally horizontally bedded, fine- to medium-grained sand and very fine grained sand; occasional clay layer
T 1791	1755 3737	5	greyish brown, fine- to medium-grained sand
		10.5	fine- to very fine grained sand, horizontally laminated in places; contains an occasional small pebble and clay ball
		1.2-3	massive, blocky, silty clay with some grits and pebbles — Till, contains large lens of sand
T1790	1741 3775	18	current laminated, fine- to medium-grained sand with thin layers of clay and very fine grained sand throughout
		4	covered interval
T 1789	1753 3751	15	current laminated fine-grained sand; occasional very fine grained sand layer and clay lamination; at very base of unit a thin layer of pebbles present
		1.5	compact, very fine grained sand with contorted clay layers
		2	covered interval
		1	grey massive silt, some clay and sand; occasional grit and pebble — Till
T 1788	1790 3780	7.5	light greyish brown, fine-grained sand; horizontally bedded containing ripple laminations
		3	brown to grey, very fine grained sand, with occasional ball of clay and clay layer
		3	covered interval

Station Number	U.T.M. Coordinates		Thickness (m)	Description of Material (listed in order from top of section)
T 1910	1797	3786	1.2	yellow brown, fine- to medium-grained sand
			3	dark reddish brown, blocky, silty clay, with some grits and pebbles — Till, gradational contact
			2	dark greyish brown, gritty, clayey silt, becoming slightly sandy downwards — Till
			14	fine- to medium-grained sand with occasional very fine grained sand layers
T 1588	1776	3851	3	brown clayey silt, gritty with some pebbles and cobbles — Till
			4	brown gritty silt in places, sand with lenses and layers of fine- to medium-grained sand — waterlain Flow Till: sample T-48
			4	fine- to medium-grained sand, compact immediately below contact due to cementation
T 1587	1771	3879	1.5	dark brown, weathered silt, with minor sand and clay, grits and pebbles — Till
			1	light brown, fine- to medium-grained sand, faintly laminated (with heavy minerals)
			5	light brownish grey, fine- to medium-grained sand, ripple and cross laminated
			2	grey brown, fine- to very fine grained sand with occasional medium-grained sand layer
			2	covered interval
			11	grey silty clay with occasional grit and pebble — Till: sample T-49
			4	covered interval
T 1761	1852	4008	0.5	massive, clayey silt with grits and pebbles — Till
			15	fine- to medium-grained sand with one 5 cm clay layer; sand ripple laminated in lower 4 m
T 1796	1932	3981	6	yellow brown, fine- to medium-grained sand with ripple laminations; occasional layer of very fine grained sand and clay
			2	interbedded clay, silt, and sand
			1.5	grey silty clay to clay, with occasional grit; very blocky — Till
			7	covered interval

Station Number	U.T.M. Coordinates		Thickness (m)	Description of Material (listed in order from top of section)
T 1796 continued			1.5	brown silty clay with occasional grit and pebble — Till
			2	contorted, interbedded clay, silt, and fine-grained sand
Ex 13	1930	4010	10	fine- to medium-grained sand
			4	clayey silt with pebbles — Till
			3	covered interval
Ex 12	2080	4100	4	fine- to medium-grained sand
			1	silt with clay laminations
			2	clay with pebbles — Till?
			2.5	clayey silt with grits and pebbles — Till
			8.5	fine- to medium-grained sand
			3	clay with silt laminations and occasional grit
			1	covered interval
Tc 4	2005	4195	1.3	massive silty clay with occasional grit and pebble — Till
			1.5	interbedded very fine grained sand and fine-grained sand; slightly contorted and containing the occasional drop stone
			6	light brown, fine- to medium-grained sand with heavy mineral current laminations
			0.3	reddish brown, silty clay, coarse sand (shale fragment) laminations, occasional pebble — Flow Till
			8	fine- to medium-grained sand, current laminated
Ex 11	2120	4235	0.7	clayey silt with pebbles and grits — Till: sample T-64
			0.3	clayey silt with numerous grits and pebbles, some sand — Till: sample T-63
			0.3	gravelly silt, with sand and clay: sample T-62
Ex 10	2170	4260	4	fine- to medium-grained sand with ripple marks and heavy mineral laminations
			0.2	pea-size gravel
			3.5	silty clay with grits and pebbles — Till
			2	silt with contorted clay laminations
			5.5	covered interval
Ex 9	2195	4330	1	orange brown, fine- to medium-grained sand with thin lag at base of unit

Station Number	U.T.M. Coordinates	Thickness (m)	Description of Material (listed in order from top of section)
Ex 9 continued		2.5	clayey silt with grits and pebbles — Till: sample T-67
		1	silt with clay laminations
		6	fine-grained sand
		1	silt with clay laminations
		0.7	clay to silty clay — Till: sample T-65
		1	sandy silt with numerous pebbles — Till: sample T-66
		2.5	clayey silt with pebbles — Till
		7.5	clay with silt laminations and occasional pebble and grit
Big Otter Creek, Tillsonburg to Otterville (locations on Figure 13)			
T 1085	2582 4681	1.5	orange brown to brown, fine- to medium-grained sand
		2.5	brown clayey silt with pebbles — Till: sample T-11
		2.5	yellow brown to brown clay, with silt laminations, becoming silt with clay laminations towards base
		3	brown to grey, slightly clayey and sandy silt, with numerous pebbles — Till: sample T-12
T 1088	2675 4763	1.2	brown clayey silt with grits and pebbles — Till
		3	brown to grey, fine-grained sand to silt to clay downwards; contorted in places and containing an occasional pebble and grit
T 1087	2702 4778	0.6	orange brown to brown, fine- to medium-grained sand
		1.5	brown to grey clay with occasional gritty band with soft sediment clasts
		2	brown clayey silt with pebbles and grits — Till
		1.5	brown to grey with contorted clay laminations becoming a fine-grained sand at base
		1.5	brown to grey silt with numerous pebbles and grits — Till: sample T-13
		7	grey clay with occasional gritty layer
T 1084	3043 4879	3	medium- to coarse-grained sand with pebbles; brown
		2.5	reddish grey to grey clay with occasional silt lamination and soft sediment clast

Station Number	U.T.M. Coordinates		Thickness (m)	Description of Material (listed in order from top of section)
Tc 2	3085	4910	4.5	yellow-brown, fine- to medium-grained sand with occasional thin gravel layer
			2	clay, laminated with silt and sand
			1.2	massive clayey silt with occasional grit and pebble — Till
			6	fine- to medium-grained sand; becoming clay and silt downwards
			1.5	covered interval
T 449	3105	4934	7	yellow brown to grey sand; becoming varved and giving way to clay towards base
			1.4	reddish brown to brown massive silt with numerous pebbles — Till
			3	brown, fine- to medium-grained sand with occasional clay and silt lamination
T 448	3115	4958	11.8	yellow brown, interlaminated, fine-grained sand, silt, and clay; clay dominant near base
			2	brown to red brown silt with grits and pebbles — Till: sample T-33
			5.5	grey, very fine grained sand with silt and clay laminations
T 488	3182	4939	5	brown, fine- to medium-grained sand
			1.2	grey and reddish grey clay with silt and sand laminations
			6	grey clayey silt with pebbles and grits — Till
T 475	3231	5037	0.75	orange brown, fine- to medium-grained sand
			0.5	very poorly sorted gravel in coarse sand matrix
			1.7-5	clayey silt with pebbles — Till: sample T-35
			2	fine-grained sand with clay laminations; becoming clay with sand laminations with depth; contorted
Additional Measured Sections				
T 309	1091	5644	2	dark brown (10YR 3/3), massive, clayey silt with some stones and grits — Till (P.S.T)*
			3	yellowish brown (10YR 5/4), sandy silt, with grits and numerous pebbles — Till (C.C.T.): sample T-4
			3	covered interval

Station Number	U.T.M. Coordinates		Thickness (m)	Description of Material (listed in order from top of section)
T 712	1552	4751	4	dark brown, massive, clayey silt with grits and pebbles — Till
			2.5	yellow brown to brown, dominantly fine-grained sand; faintly laminated in places; contact with till sharp but irregular
T 718	1582	4843	15	clayey silt appears stoney on weathered surface; occasional fine- to medium-grained sand lens — Till (P.S.T.)
T 869 a + b	2684	5471	1.2	grey-brown, mottled, clayey silt to silty clay; less than 1% stone content Till?: sample T-71
			2	brown, slightly sandy, clayey silt; approximately 2% stone, with boulder pavement at base — Till (P.S.T.): sample T-72
			8	yellow brown gritty silt, massive, blocky; less than 1% stone; oxidized 3 m — Till: sample T-73 - lower 5 m is grey unoxidized massive silt, gritty till (P.S.T.): sample T-74
			3	brown clay with contorted silt laminations
T 938	0060	5667	4.4	yellow brown, fine-grained sand with thin clay laminations
			1.5	buff brown, very stony, silty sand till (C.C.T.): sample T-3
			6	cobbles and pebbles (rounded); closed framework gravel in a medium- to very coarse grained sand matrix containing an occasional till ball
			3.1	very coarse sand with occasional cobble and pebble; crossbedded in places
T 1460	4004	4432	3.8	brown sandy silt with numerous grits and pebbles; blocky, with occasional sand lens — Till (W.T.): sample T-41
			1.2	grey cobble gravel with a coarse-grained sand matrix
			1.3	brown massive silt with occasional pebble and cobble: sample T-42
			1.8	yellow brown fine-grained sand to silt, with occasional cemented layer
Tc 8	4040	3860	6	light brown, fine-grained sand; ripple laminated in places; becoming silty sand towards base
			3	covered interval

Station Number	U.T.M. Coordinates		Thickness (m)	Description of Material (listed in order from top of section)
Tc 8 continued			2	silty clay and clay; silty sand in places; horizontally interlaminated
			0.6	covered interval
			1	horizontally laminated, silty fine-grained sand with clay; occasional grit
			0.6	clean; pea-size and small-pebble gravel
			0.1	red and grey laminated clay; some gritty laminations
			2	red brown and grey, massive silty clay with grits and pebbles — Till (P.S.T.)
			4	fine- to medium-grained sand becoming fine- to very fine grained sand downwards; horizontally laminated
			1	medium sand, with laminations (slightly contorted) of clayey silt
			0.6	grey silty clay with occasional grit and pebble — Till (P.S.T.)
Ex 1	4016	4364	6.5	covered interval
			2.5	laminated silt and clay
			0.3	fine- to medium-grained sand
			0.5	massive sandy silt with numerous pebbles — Till (W.T.)
			1.2	medium-grained sand
			1.2	clay and silt
			1	massive clayey silt with pebbles — Till (P.S.T.)
			1	silt with occasional pebble
Ex 5	3998	4281	0.1	fine-grained sand
			0.3	sand and gravel
			0.3	medium sand
			5	laminated silt and clay
			0.6	silty clay with pebbles — Till: sample T-46
			1	silt with pebbles — Till: sample T-47

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

APPENDIX B

Sample Analyses (sample locations are plotted on Map 2473, back pocket).

Notes:

1) Except for pebble counts, all analyses were carried out by the Geoscience Laboratories, Ontario Geological Survey, Toronto.

2) Sand-silt boundary 0.062 mm; silt-clay boundary 0.002 mm; Md. is median diameter in mm.

3) Pebble counts on pebbles retained on a No. 4 and passing a 1-inch Tyler screen.

4) Carbonate analyses were done on material finer than 200 mesh (0.074 mm) using the Chittick apparatus.

5) Heavy mineral separation on the <60 to ≥ 140 mesh fraction. Acetylene tetrabromide (S.G. 2.96) was the heavy liquid used.

6) Till identification:
C.C.T. — Catfish Creek Till
P.S.T. — Port Stanley Till
T.T. — Tavistock Till
W.T. — Wentworth Till

Sample Number	N.T.S. Grid Reference	Type of Material	Texture				Pebble Lithology %								Carbonates				Heavy Minerals		Colour Fresh	Field Number
			% Clay	% Silt	% Sand	Median Diam. (mm)	Limestone	Dolostone	Chert	Sandstone	Siltstone	Shale	Precambrian	Limestone: Dolostone	% Calcite	% Dolomite	Total %	Calcite: Dolomite	Total %	% Magnetics		
T1	0788 5578	C.C.T.	11	41	48	0.06	41	44	1	—	—	—	14	0.9	15.1	27.0	42.1	0.56	4.8	12.8	10YR5/2	T992-A
T2	1222 5247	C.C.T.	9	24	67	0.13									15.5	23.7	39.2	0.65	4.1	8.8	10YR4/4	T527
T3	0060 5667	C.C.T.?*	10.5	43.5	46	0.05	38	36	5	—	—	—	21	1.0	32.8	28.1	60.9	1.17	3.8	11.9	10YR5/4	T938
T4	1091 5644	C.C.T.	7.5	60.5	32	0.04	34	48	7	1	—	—	10	0.7	13.1	27.7	40.8	0.47	5.4	12.1	10YR5/3	T309
T5	0720 5925	C.C.T.	9	44	47	0.06									13.5	25.3	38.8	0.53	5.0	13.1	10YR5/4	T910
T6	0222 5768	Silt	13	74	13	0.018	47	35	2	—	—	4	12	1.3	17.1	23.3	40.4	0.73	3.7	11.1	10YR5/4	T794
T7	3356 5950	C.C.T.	12	49	39	0.039	39	42	7	5	2	—	5	0.9	19.1	21.8	40.9	0.88	3.3	13.4	10YR4/3	T223
T8	2866 6009	C.C.T.	7.5	53	39.5	0.041	42	40	3	3	1	—	11	1.0	17.2	20.7	37.9	0.83	3.6	17.0		T690
T9	3208 5897	P.S.T.	16.5	64.5	19	0.013	41	31	11	8	—	—	9	1.3	20.2	18.4	38.6	1.10	2.9	14.8	10YR5/3	T84
T10	3256 5587	P.S.T.	23	64	13	0.01	73	20	5	—	—	—	2	3.7	19.6	15.3	34.9	1.28	1.3	14.3	10YR5/3	T262
T11	2582 4681	P.S.T.	32	59.5	8.5	0.0056	69	17	9	2	—	—	3	4.0	24.3	15.9	40.2	1.53	4.5	15.6	10YR5/4	T1085-B
T12	2582 4681	P.S.T.	29.5	58.5	12	0.007	72	20	6	—	—	1	1	3.7	28.2	17.7	45.9	1.59	3.2	12.8	10YR5/4	T1085-D
T13	2702 4778	P.S.T.	32.5	61.5	6	0.0054									21.5	13.6	35.1	1.58	4.8	12.0	10YR4/2	T1087-E
T14	0501 5278	C.C.T.	10	45	45	0.05	57	29	2	1	1	1	9	1.9	17.8	26.0	43.8	0.69	4.9	11.2	10YR5/3	T1310
T15	1526 6053	P.S.T.	30	58	12	0.006	42	53	—	—	—	—	5	0.7	22.6	15.4	38.0	1.47	4.3	11.9	7.5YR4/2	T107
T16	0470 5732	P.S.T.	37.5	54	8.5	0.0042									23.9	14.0	37.9	1.71	4.2	14.0	10YR5/4	T795
T17	0116 5662	P.S.T.	39	52	9	0.0038	65	18	9	—	—	2	6	3.6	21.6	15.9	37.5	1.36	4.8	16.0	10YR4/4	T941
T18	1484 5880	P.S.T.	30.5	58.5	11	0.006	28	58	4	—	5	—	5	0.4	21.1	16.1	37.2	1.31	3.4	14.6	7.5YR4/2	T145
T19	0735 5552	P.S.T.	20	53	27	0.02									22.6	21.0	43.6	1.07	4.6	12.6	10YR 4/3	T973
T20	0280 5116	P.S.T.	29.5	51	19.5	0.0075									20.5	18.1	38.6	1.13	4.8	14.8	10YR4/2	T1140
T21	0040 4571	P.S.T.	38	55	7	0.0038									24.8	13.2	38.0	1.88	3.7	14.6	10YR5/1	T1336
T22	0584 4844	P.S.T.	28	58.5	13.5	0.0072									23.0	15.4	38.4	1.49	6.3	13.2	10YR5/3	T1303
T23	1199 5096	P.S.T.**	14	47	39	0.02									20.8	16.3	37.1	1.28	2.6	11.8	10YR4/4	T572-A
T24	1246 5103	P.S.T.	19.5	58.5	22	0.012									23.7	16.1	39.8	1.47	2.7	14.5	10YR4/4	T579
T25	1444 5379	P.S.T.	15.5	67.0	17.5	0.015									19.5	19.5	39.0	1.00	3.1	14.8	10YR5/4	T514
T26	2072 5851	P.S.T.	22	67	11	0.0088									21.6	15.0	36.6	1.44	2.5	11.3	10YR4/4	T170
T27	2623 5957	P.S.T.	19	66	15	0.014	51	35	6	—	2	—	6	1.4	20.4	15.2	35.6	1.34	2.4	13.9	10YR5/3	T698
T28	1488 4968	P.S.T.	15.5	59.5	25	0.021									21.7	16.8	38.5	1.29	1.6	7.5	10YR4/2	T571
T29	1602 4762	P.S.T.	30	61	9	0.0058	65	20	9	—	2	—	4	3.3	22.2	17.3	39.5	1.28	3.3	13.4	10YR4/3	T714
T30	1252 4540	P.S.T.	35	60	5	0.0042									21.4	13.6	35.0	1.57	3.4	14.0	10YR4/2	T308
T31	2220 5048	P.S.T.	34	60.5	5.5	0.0048	63	26	3	1	1	2	4	2.4	22.8	12.9	35.7	1.76	3.4	13.4	10YR5/3	T1018
T32	2722 5310	P.S.T.	34.5	62.0	3.5	0.005	49	39	1	—	5	2	4	1.2	21.6	13.7	35.3	1.58	5.3	13.2	10YR4/2	T8891
T33	3182 4939	P.S.T.	34	60.5	5.5	0.005									30.3	16.8	47.1	1.80	4.2	12.3	10YR4/2	T488
T34	3410 5199	P.S.T.	25	53	22	0.0095	68	13	11	1	—	2	5	5.2	23.0	16.6	39.6	1.39	3.4	10.8	10YR5/4	T493-E

T35	3231 5037	P.S.T.	30	62	8	0.006	86	7	5	—	—	—	2	12.3	23.7	15.7	39.4	1.51	3.5	14.3	10YR5/3	T475
T36	3440 5156	P.S.T.**	6	33	61	0.10	36	15	18	22	2	—	7	2.3	15.1	25.8	40.9	0.59	11.0	21.3	10YR4/3	T466
T37	3832 5522	P.S.T.	22.5	59.5	18	0.01	47	17	31	1	—	—	4	2.7	22.6	21.6	44.2	1.05	3.0	16.9	10YR5/4	T406
T38	4062 5976	P.S.T.	24	59	17	0.01	41	36	18	2	—	—	3	1.1	21.3	18.4	39.7	1.16	3.4	15.0	10YR4/3	T93
T39	1586 3338	P.S.T.	44	51	5	0.003									23.9	14.4	38.3	1.66	3.5	9.4	10YR4/3	T105-A
T40	1572 3338	P.S.T.	42	52.5	5.5	0.0034									20.7	14.7	35.4	1.41	3.5	9.3	10YR5/3	T105-B
T41	4004 4432	W.T.	19	61	20	0.016									21.2	19.7	40.9	1.08	3.1	11.6	10YR5/4	T1460-A
T42	4004 4432	Clayey silt	21	63.5	15.5	0.012									27.8	19.5	47.3	1.43	1.2	5.3	10YR4/6	T1460-B
T43	3868 4478	W.T.	20	66	14	0.015									27.1	19.8	46.9	1.37	2.5	9.2	10YR5/4	T1458
T44	3980 4108	W.T.	15	70	15	0.029									17.0	18.4	35.4	0.92	3.4	10.5	10YR4/4	T1475-D
T45	3980 4108	P.S.T.	34	63	3	0.0056									23.2	17.5	40.7	1.33	5.2	15.4	10YR5/2	T1475-F
T46	3999 4280	P.S.T.	45	49	6	0.0034									23.9	18.6	42.5	1.28	3.8	19.0	10YR4/1	Ex5-A
T47	3999 4280	Till	21	55	24	0.023									20.7	20.7	41.4	1.00	1.7	13.5	2.5Y6/2	Ex5-B
T48	1776 3851	P.S.T.	32	56	12	0.0082									24.3	15.5	39.8	1.57	4.8	8.1	10YR4/2	T1588
T49	1771 3879	P.S.T.	45	53	2	0.0024	59	18	10	—	—	—	13	3.4	24.0	12.0	36.0	2.00	4.4	7.1	10YR5/4	T1587-B
T50	0565 4100	P.S.T.	50	46	4	0.002									24.1	10.6	34.7	2.27	3.7	34.8	10YR4/3	T1524
T51	0566 3435	P.S.T.	31	52	17	0.007									24.1	13.7	37.8	1.76	7.4	12.8	10YR4/3	T1548
T52	0921 4198	C.C.T.	12	58	30	0.03	46	30	3	—	—	1	20	1.5	13.4	27.2	40.6	0.49	2.5	12.3	2.5YR5/4	T1561
T53	3084 3781	W.T.	16	66	18	0.018									18.2	10.1	28.3	1.80	5.3	7.8	10YR5/4	T1497
T54	1509 3708	P.S.T.	22.5	55.5	22	0.019	70	15	8	—	1	1	5	4.5	20.7	16.4	37.1	1.26	3.2	11.1	10YR4/4	T1900
T55	2797 4288	P.S.T.	41	54	5	0.0034									23.0	15.5	38.5	1.48	4.4	13.8	10YR4/3	T1846
T56	2282 3750	P.S.T.	43	54	3	0.003									23.9	13.2	37.1	1.81	4.7	29.4	10YR5/3	T2202
T57	1577 3771	P.S.T.	29	59	12	0.0075	88	3	6	—	—	—	3	29.3	24.8	15.5	40.3	1.60	5.9	16.4	10YR4/4	T1775
T58	1514 3548	P.S.T.	45	50	5	0.0026									22.7	12.1	34.8	1.88	5.1	16.6	10YR4/2	T1794-A
T59	1514 3548	P.S.T.	44	50	6	0.003									20.8	17.1	37.9	1.22	5.3	10.3	10YR4/2	T1794-B
T60	1710 3682	P.S.T.	37	50	13	0.012									23.4	12.8	36.2	1.83	5.5	7.7	10YR5/3	T1793-A
T61	1710 3682	P.S.T.	47	49	4	0.0024									23.0	18.8	41.8	1.22	4.7	10.8	10YR6/2	T1793-B
T62	2116 4238	Gravel Matrix	26	43	31	0.012	82	8	8	—	—	—	2	10.3	28.9	14.4	43.3	2.01	3.7	8.5	10YR4/3	Ex11-1
T63	2116 4238	P.S.T.	33	51	16	0.0061									29.6	14.1	43.7	2.10	3.6	15.6		Ex11-2
T64	2116 4238	P.S.T.	44	49	7	0.003									23.9	13.9	37.8	1.72	3.2	6.9	10YR4/2	Ex11-3
T65	2195 4334	P.S.T.	46	48	6	0.0029									22.6	13.9	36.5	1.63	4.6	12.5	10YR4/2	Ex9-F
T66	2195 4334	P.S.T.	32	57	11	0.007									27.8	17.7	45.5	1.57	3.6	12.8	10YR4/2	Ex9-G
T67	2195 4334	P.S.T.	26	61	13	0.010									22.8	14.1	36.9	1.62	3.7	14.3	10YR4/4	Ex9-B
T68	0650 3370	Sand	—	4	96	0.14													5.2	6.9		T1554-1
T69	0650 3370	Sand	—	2	98	0.175													3.4	5.1		T1554-2
T70	0650 3370	Sand	—	4	96	0.135													4.5	8.7		T1554-3
T71	2684 5471	P.S.T.	51	46	3	0.0019													2.3	17.8		T869B-A
T72	2684 5471	P.S.T.	24	63	13	0.010	60	22	14	2	—	1	1	2.7	21.3	14.8	36.1	1.44	1.7	19.6		T869B-B
T73	2684 5471	P.S.T.†	26	67	7	0.008									19.8	16.1	35.9	1.23	3.4	16.6		T869B-C
T74	2684 5471	P.S.T.††	27	66	7	0.008	66	18	9	3	—	—	4	3.6	20.7	14.5	35.2	1.43	2.9	15.3		T869B-D

* possibly Tavistock Till
** ablation Till
† oxidized
†† unoxidized

ANALYSES FOR BAYHAM (RICHMOND) BOREHOLE*

		Texture				Carbonates				Heavy Minerals		Water Content	Atterberg Limits			Field No.
Sample Number	Type of Material	% Clay	% Silt	% Sand	Median Diam. (mm)	% Calcite	% Dolomite	Total %	Calcite: Dolomite	Total %	% Magnetics	%	Liquid Limit	Plastic Limit	Plasticity Index	
TR-1	Till	25.5	62	12.5	0.010	23.2	17.0	40.2	1.36	.095	7.76		22	15	7	R-6
TR-2	Till	24.5	64	11.5	0.012	21.5	18.4	39.9	1.17	.076	8.43					R-8
TR-3	Till	24	59	17	0.018	23.7	17.9	41.6	1.32	.140	8.49	17				R-9
TR-4	Till	48	48	4	0.0024	23.4	13.5	36.9	1.73	.061	8.95					R-9
TR-5	Till	21.5	48.5	30	0.016	22.8	15.2	38.0	1.50	.290	9.09					R-10
TR-6	Till	13.5	52.5	34	0.023	38.7	14.7	53.4	2.63	.079	0.00		22	17	5	R-32
TR-7	Silty clay	49	50.5	0.5	0.0022	14.7	21.4	36.1	0.69				34	20	14	R-13
TR-8	Silty clay	66.5	33	0.5	0.001	11.2	21.2	32.4	0.58			30	40	22	18	R-15
TR-9	Silty clay	61	38.5	0.5	0.001	11.5	23.9	35.4	0.48			32	44	21	23	R-16
TR-10	Silty clay	56.5	43.5	—	0.0014	12.1	16.1	28.2	0.75			29	40	20	20	R-18
TR-11	Silty clay	66	43.5	0.5	0.001	13.3	15.9	29.2	0.84			22	44	24	20	R-20
TR-12	Clayey silt	24	67	9	0.013	5.5	15.8	21.3	0.35				25	18	7	R-24
TR-13	Clayey silt	38	51.5	10.5	0.0046	11.2	19.8	31.0	0.57			32	31	19	12	R-28
TR-14	Silty clay	76	22.5	1.5	—	19.9	8.8	28.7	2.27				46	26	20	R-30
TR-15	Clay	72	24.5	3.5	—	19.2	11.8	31.0	1.63							R-31

*N.T.S. Grid Reference is 1329 3441

APPENDIX C

TRACE ELEMENT ANALYSES

Sample Number	UTM Grid	Type of Material*	Clay Content %	Trace elements ppm						
				Cu	Ni	Zn	Cr	Mn	Co	Pb
T1	0788 5578	C.C.T.	11	16	14	41	40	510	5	10
T2	1222 5247	C.C.T.	9	24	19	64	45	630	10	15
T3	0060 5667	C.C.T.	10.5	18	8	38	24	380	5	10
T7	3356 5950	C.C.T.	12	24	19	64	38	610	7	11
T11	2582 4681	P.S.T.	32	22	17	60	50	590	8	27
T12	2582 4681	P.S.T.	29.5	22	16	55	44	570	8	<10
T15	1526 6053	P.S.T.	30	24	25	63	54	670	10	16
T17	0116 5662	P.S.T.	39	25	22	66	56	650	9	12
T19	0735 5552	P.S.T.	20	24	20	62	42	630	9	<10
T20	0280 5116	P.S.T.	29.5	25	22	66	56	670	10	10
T21	0040 4571	P.S.T.	38	25	23	66	57	650	10	13
T25	1444 5379	P.S.T.	15.5	26	17	61	46	630	8	12
T29	1602 4762	P.S.T.	30	26	23	64	53	590	9	11
T32	2722 5310	P.S.T.	34.5	28	24	67	56	700	10	<10
T33	3182 4939	P.S.T.	34	22	16	54	46	550	8	11
T40	1572 3338	P.S.T.	42	27	21	75	61	640	11	14
T41	4004 4432	W.T.	19	27	16	66	46	590	8	11
T44	3980 4108	W.T.	15	28	15	64	40	760	8	16
T45	3980 4108	P.S.T.	34	28	18	65	48	710	10	13
T48	1776 3851	P.S.T.	32	26	19	64	53	690	14	12
T49	1771 3879	P.S.T.	45	28	25	70	61	720	16	16
T50	0565 4100	P.S.T.	50	28	25	73	64	650	10	14
T58	1514 3548	P.S.T.	45	28	24	72	59	700	12	15
T59	1514 3548	P.S.T.	44	26	17	62	46	710	10	15
T62	2116 4238	Gravel	26	42	24	196	53	850	14	22
T63	2116 4238	P.S.T.	33	27	22	66	56	690	11	15
T64	2116 4238	P.S.T.	44	27	24	71	60	710	12	20
T65	2195 4334	P.S.T.	46	28	24	70	58	690	13	15
T66	2195 4334	P.S.T.	32	26	19	62	50	670	12	13
T67	2195 4334	P.S.T.	26	29	20	74	52	680	13	16
TR3	1329 3441	P.S.T.	24	26	24	63	60	740	11	61
TR6	1329 3441	C.C.T.	13.5	25	23	42	50	540	7	61
TR7	1329 3441	Silty clay	49	24	21	52	56	560	11	20
TR9	1329 3441	Silty clay	61	30	24	61	57	580	11	20
TR11	1329 3441	Silty clay	66	36	40	78	86	750	17	23

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

Notes:

1) All analyses were carried out by the Geoscience Laboratories, Ontario Geological Survey, Toronto, on material passing the 400 mesh Tyler screen (stainless steel).
2) A total extraction (HNO_3-HF) was used.
3) Concentrations were determined by Atomic Absorption.

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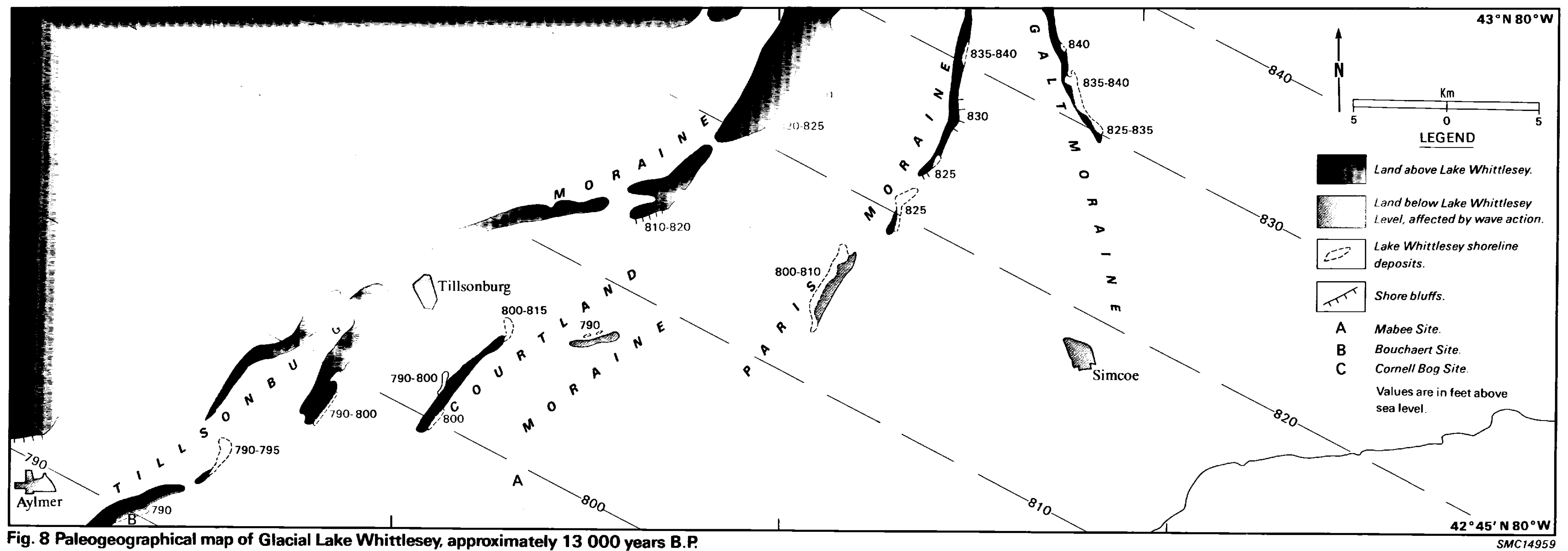

Fig. 8 Paleogeographical map of Glacial Lake Whittlesey, approximately 13 000 years B.P.
The isobase lines are approximate and are shown only as a guide. They are taken from a water-plain profile constructed on a 027°30′N azimuth line (Barnett 1979).

SMC14959

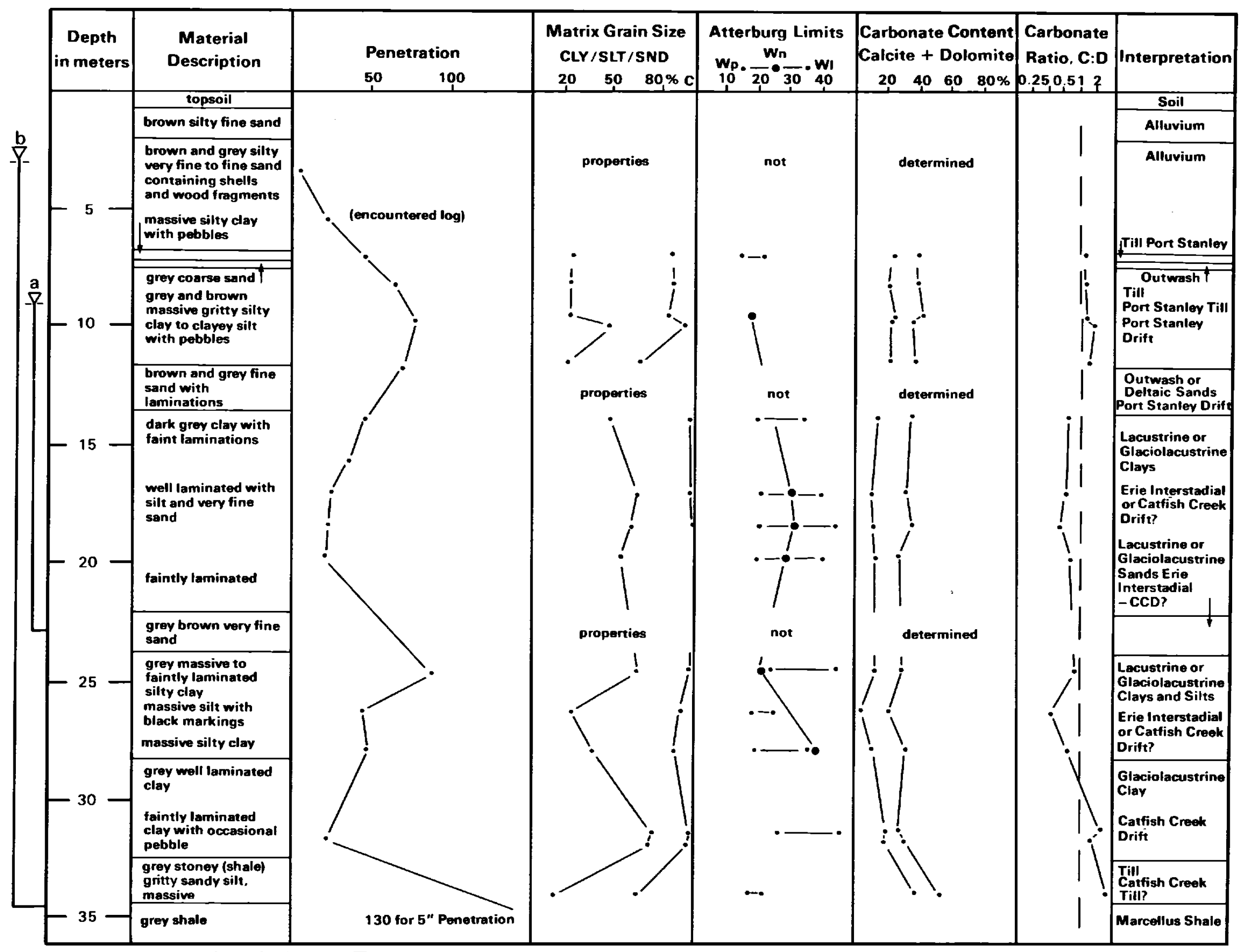

Fig. 17. Bayham borehole log, Tillsonburg map-area.

SMC14963

Borehole: TR1
Location: 6000 m east of Bayham (Richmond)
Elevation: 189 m a.s.l. approx.

Method: CME 75 hollow stem auger, split spoon sampling
(Dominion Soils Ltd.)

∇ water level in confined aquifers encountered during drilling
a—January 19, 1978
b—January 20, 1978

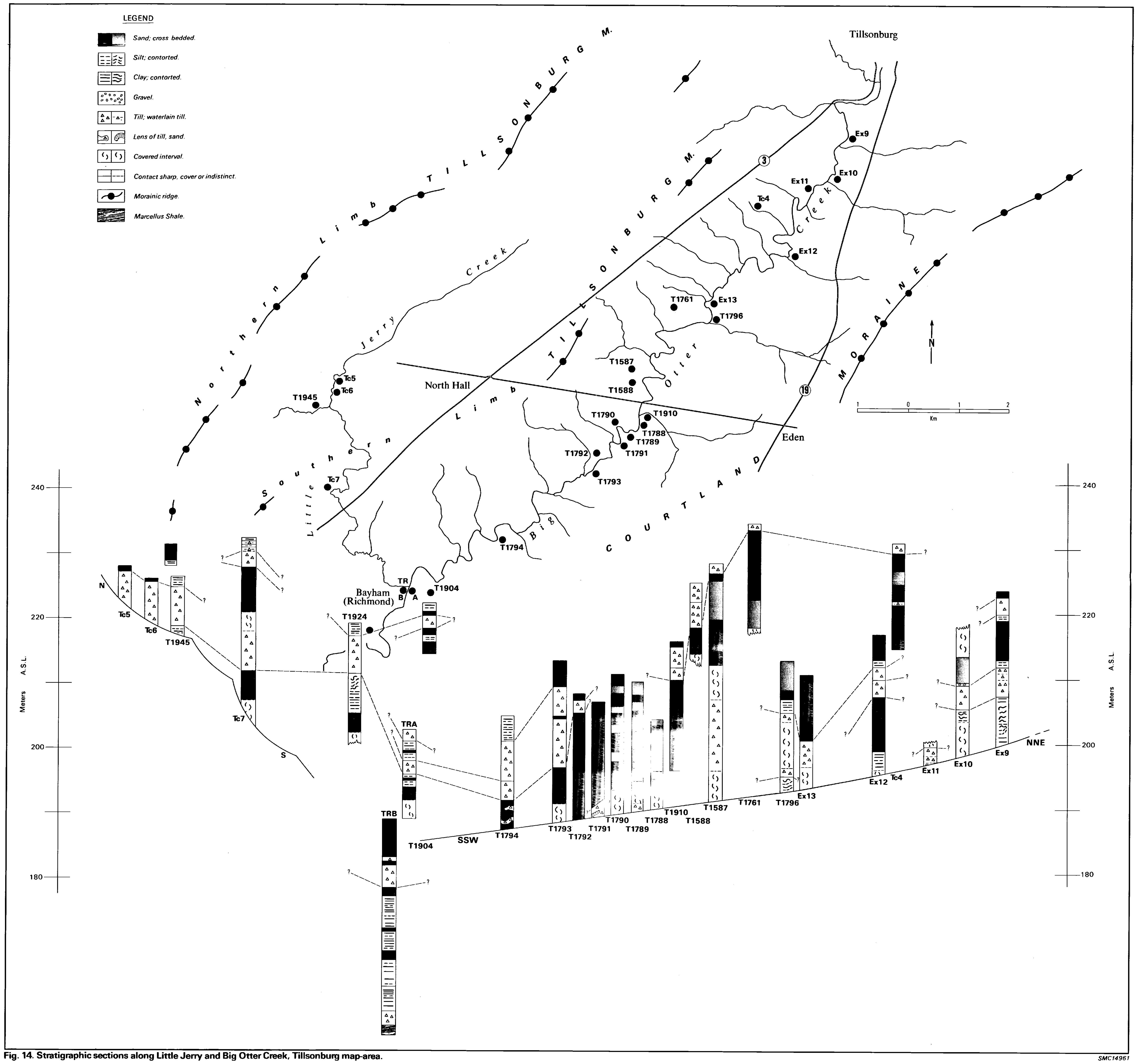

Fig. 14. Stratigraphic sections along Little Jerry and Big Otter Creek, Tillsonburg map-area.

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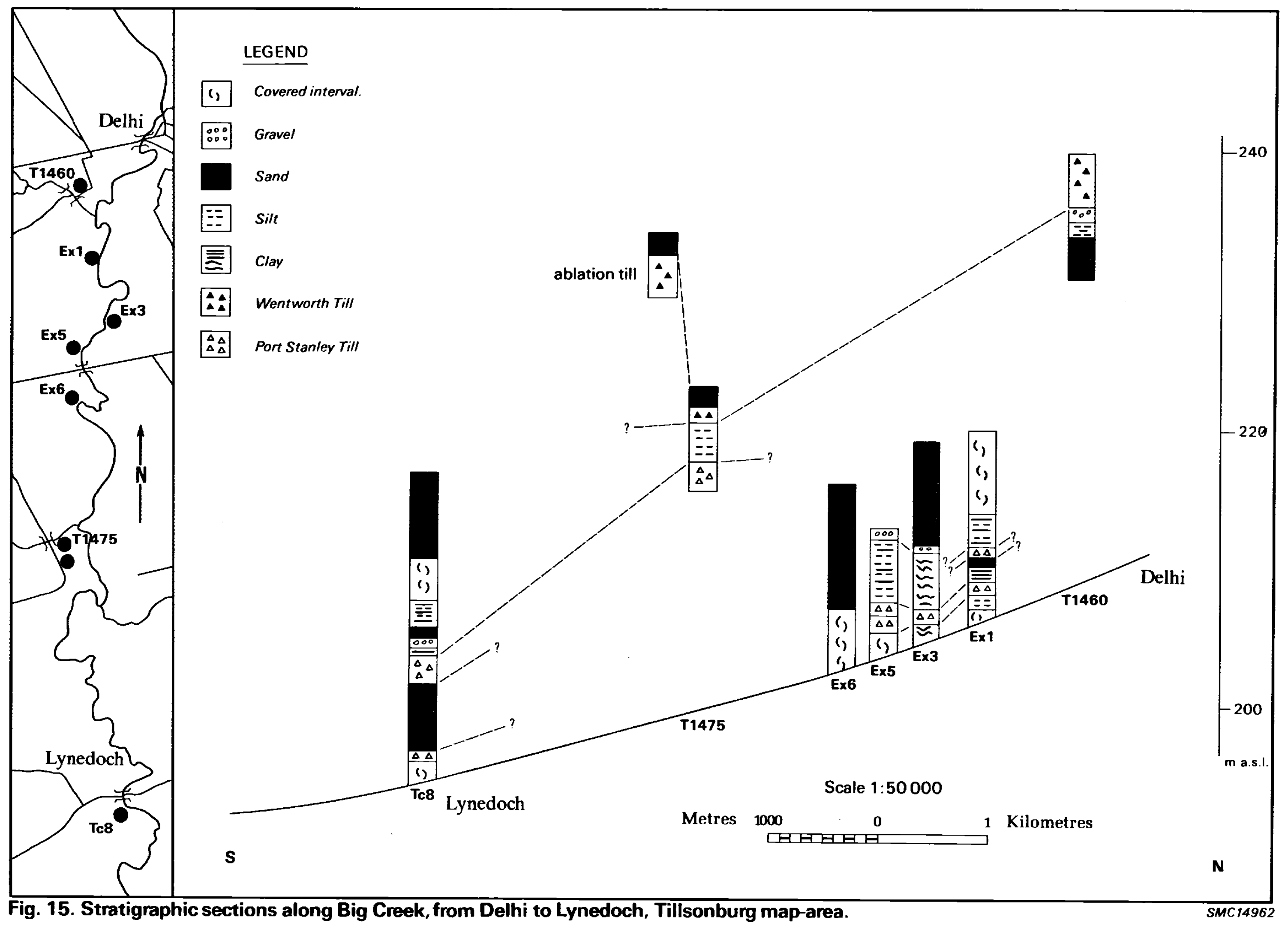

Fig. 15. Stratigraphic sections along Big Creek, from Delhi to Lynedoch, Tillsonburg map-area.

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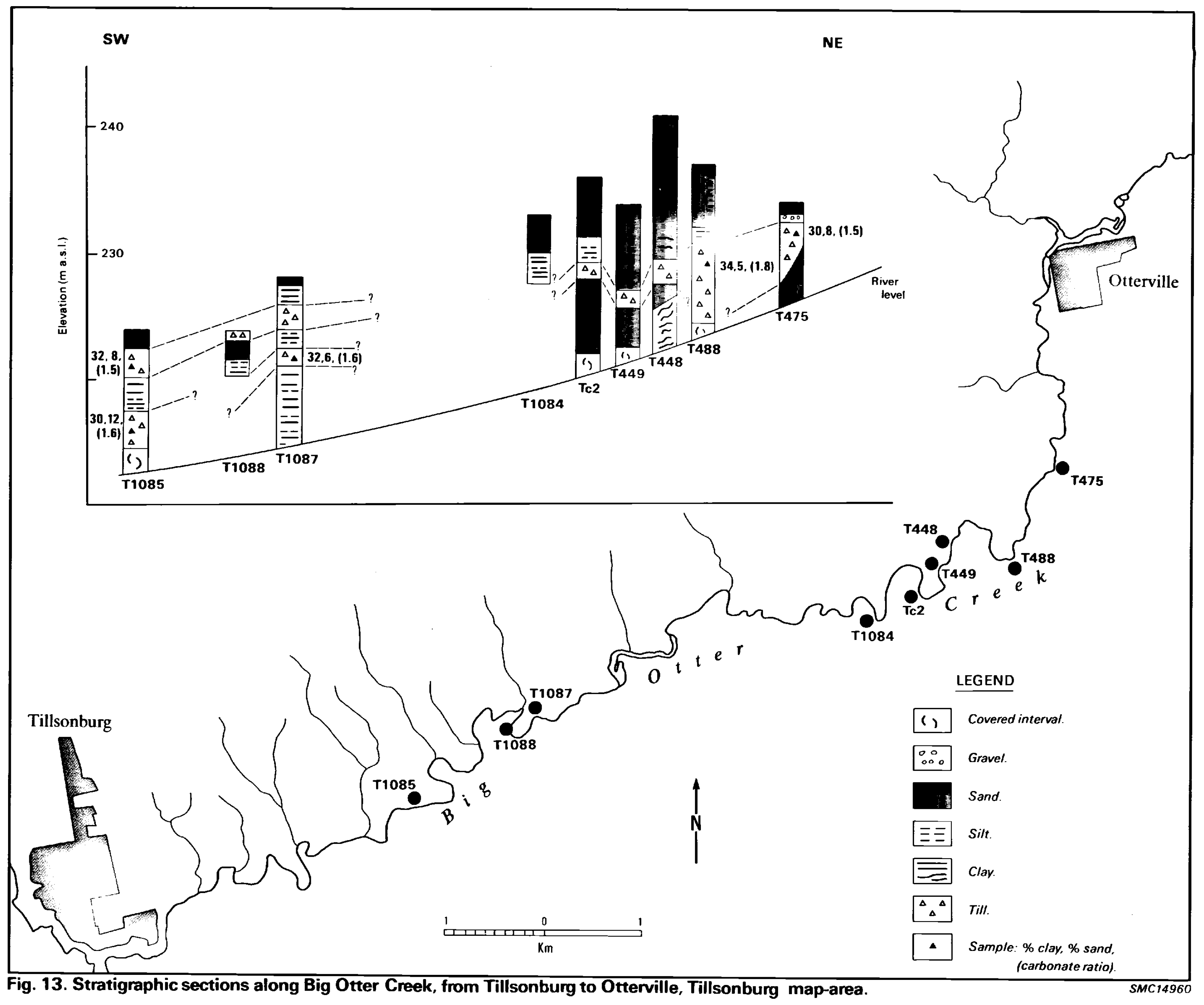


Fig. 13. Stratigraphic sections along Big Otter Creek, from Tillsonburg to Otterville, Tillsonburg map-area.

SMC14960

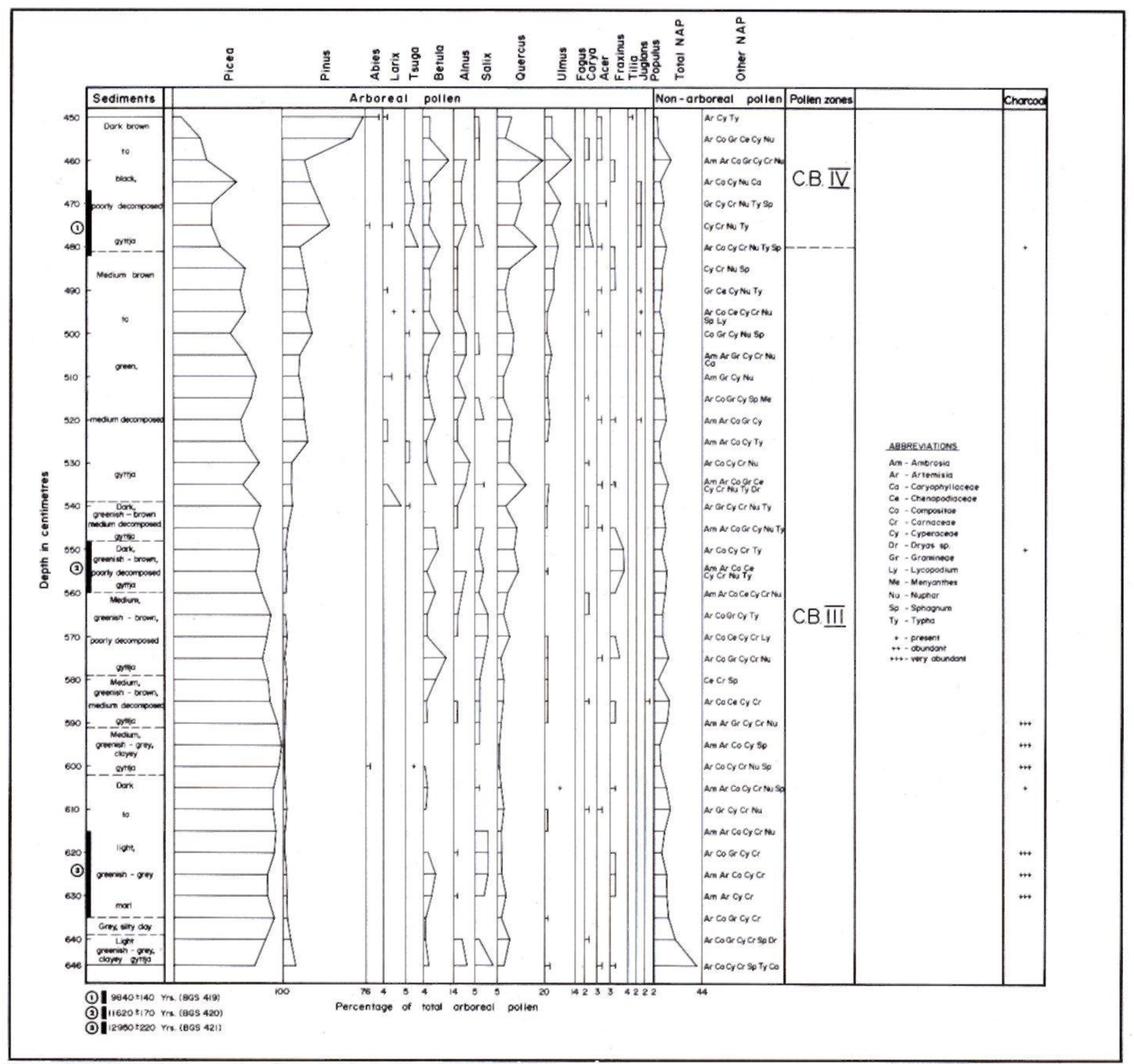


Fig. 10 Pollen diagram for Cornell Bog (from C. E. Winn, 1978). SMC14957

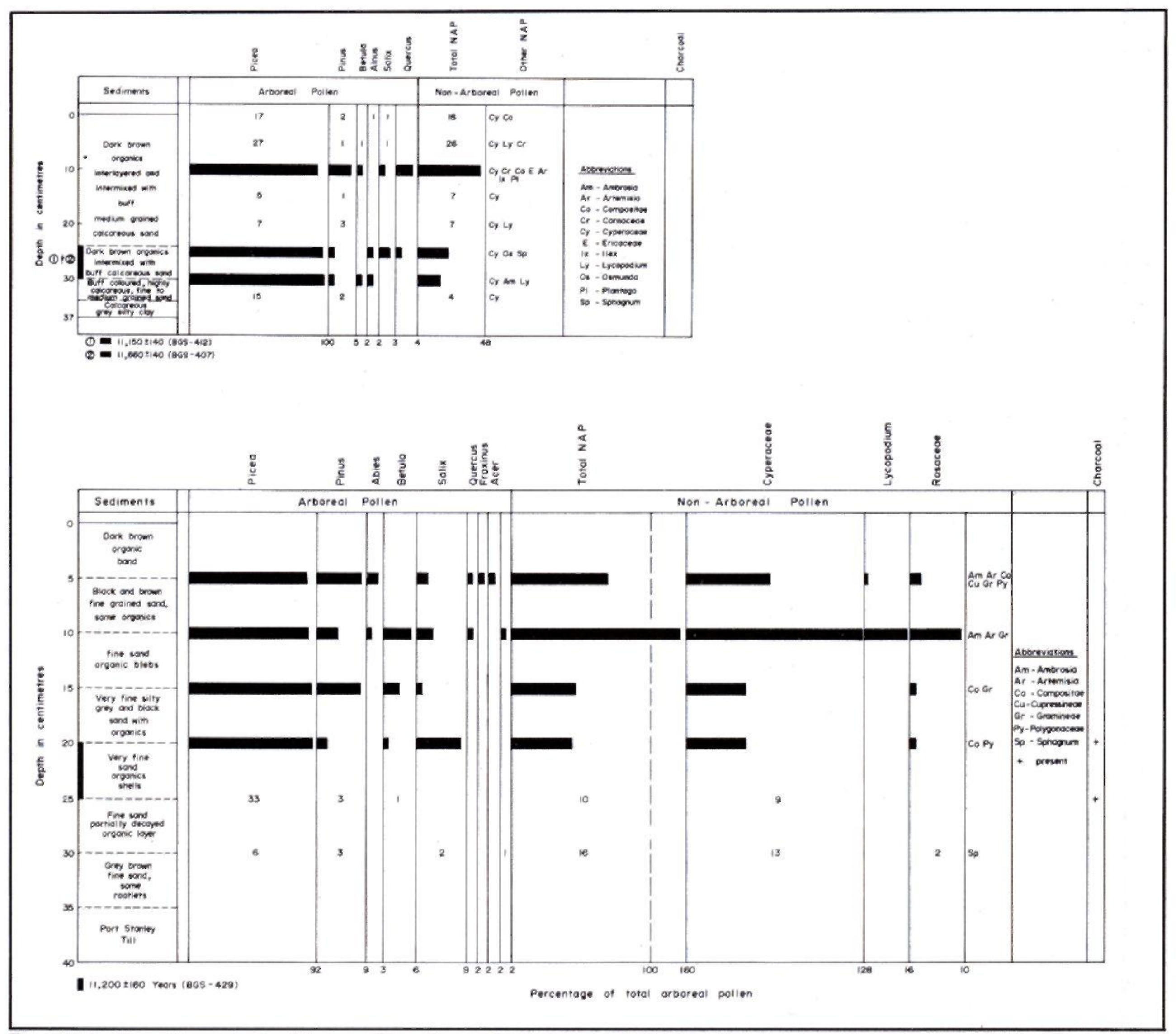


Fig. 12 Pollen diagram for Mabee Site (from C. E. Winn, 1978). SMC14958

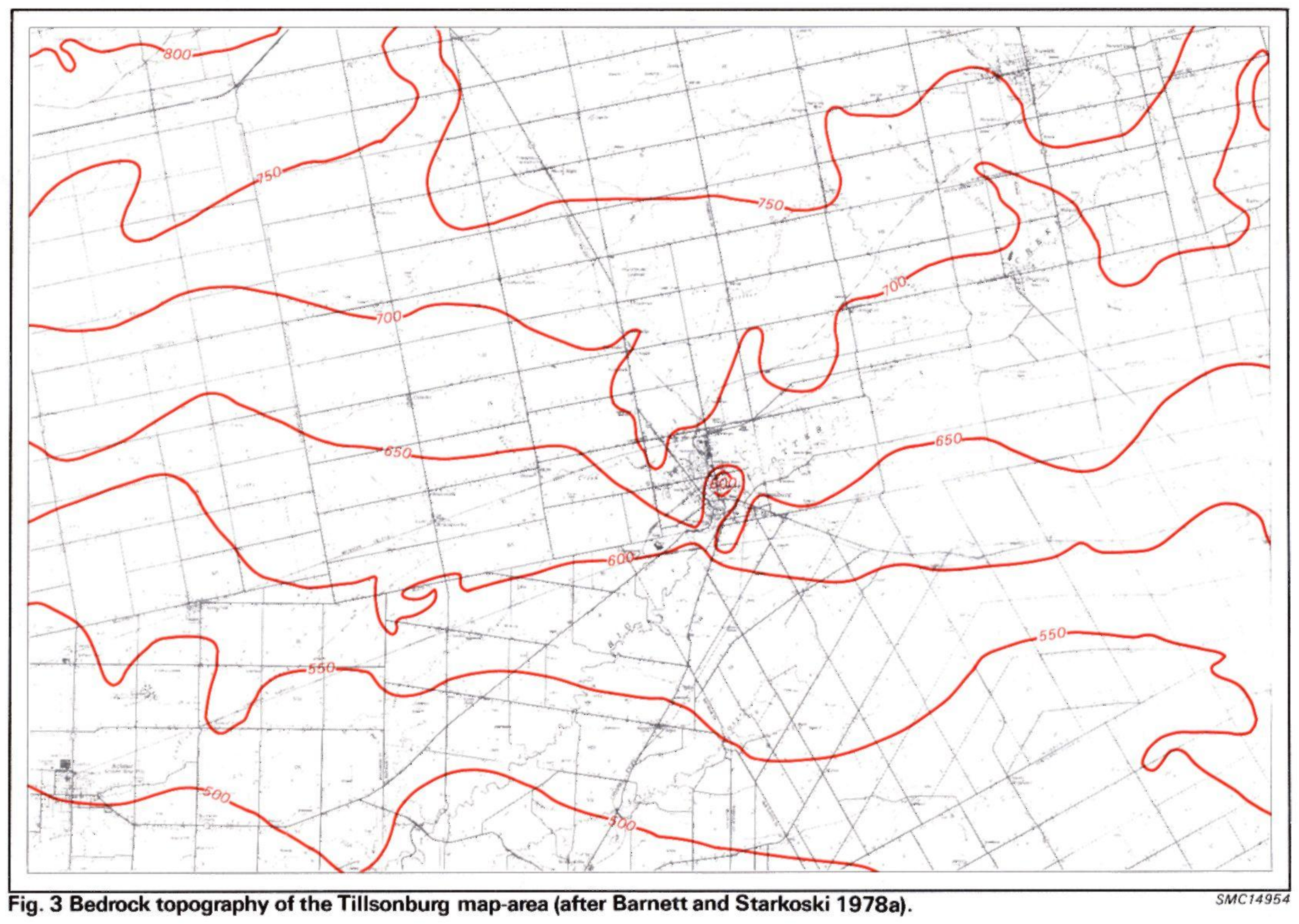


Fig. 3 Bedrock topography of the Tillsonburg map-area (after Barnett and Starkoski 1978a). SMC14954

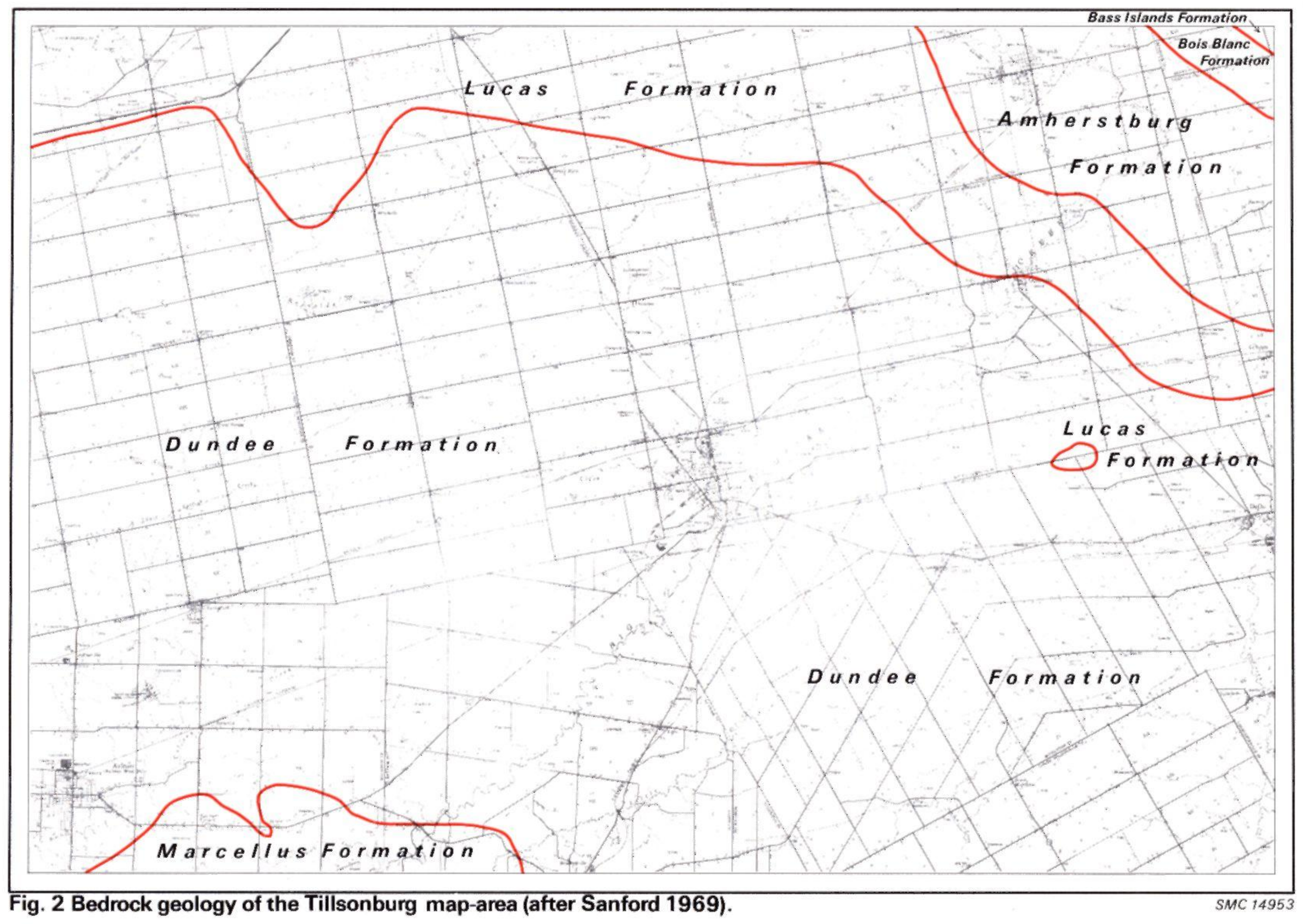


Fig. 2 Bedrock geology of the Tillsonburg map-area (after Sanford 1969). SMC 14953

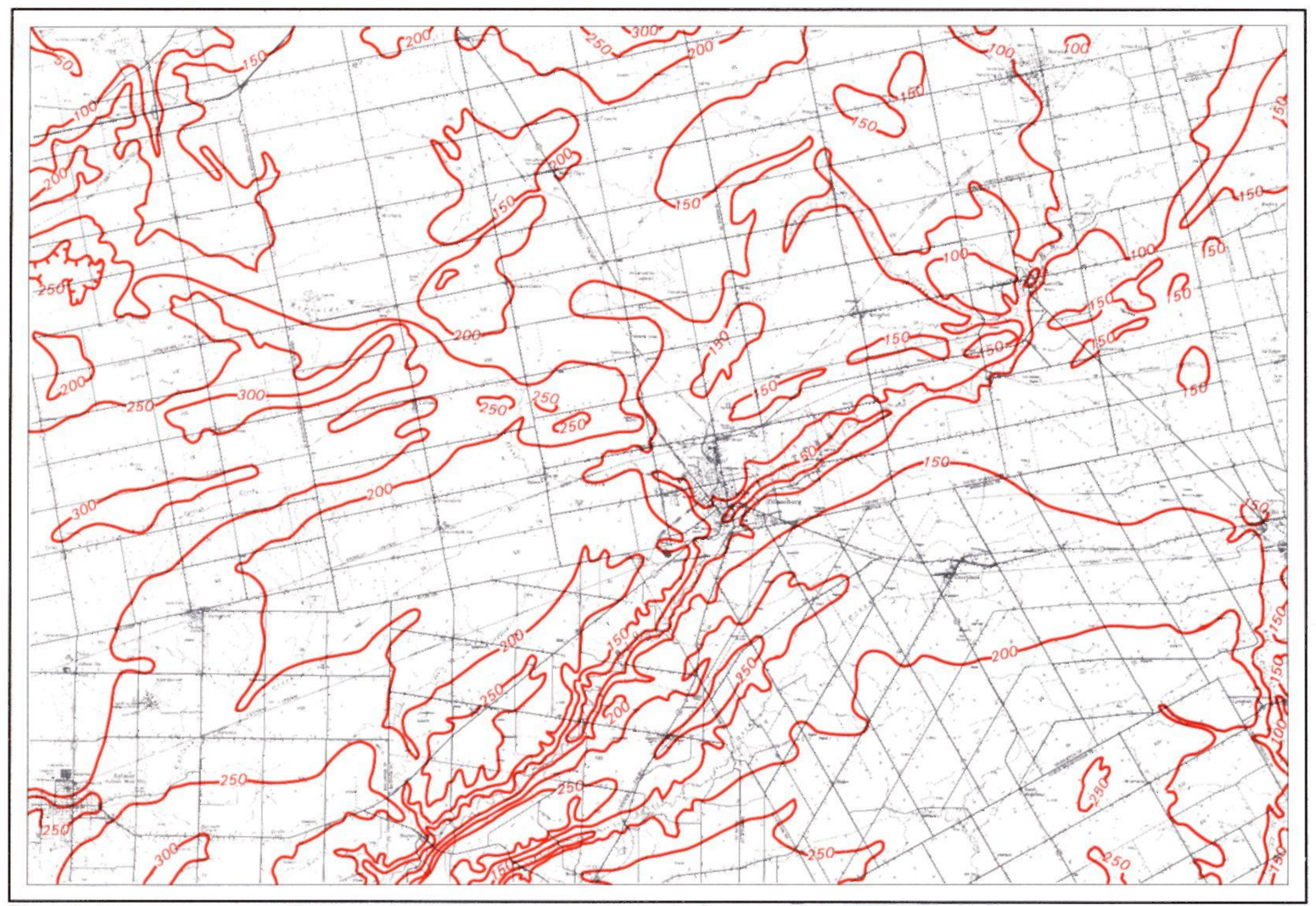


Fig. 4 Drift thickness of the Tillsonburg Map-area (after Barnett and Starkoski 1978b). SMC14955

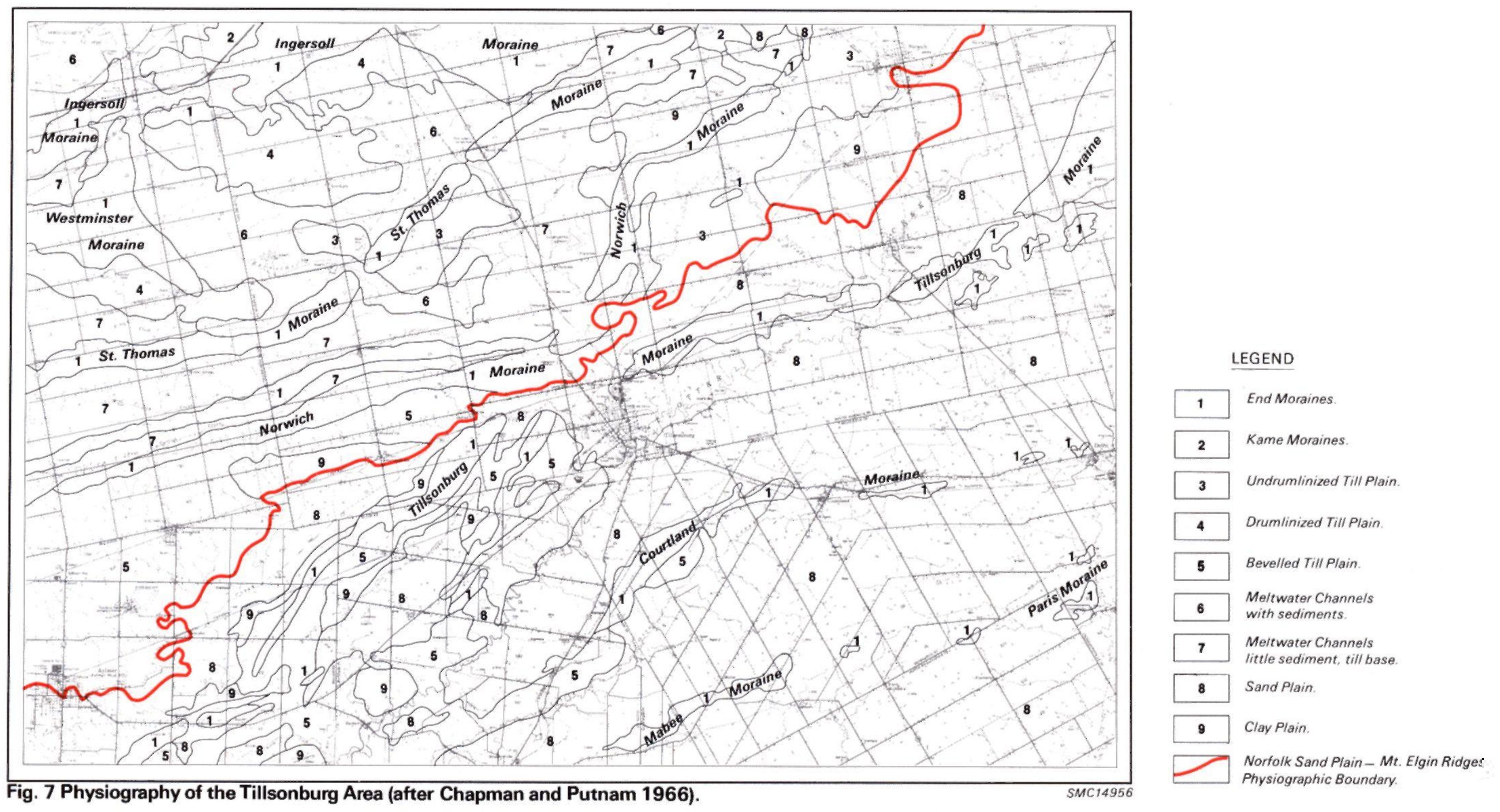
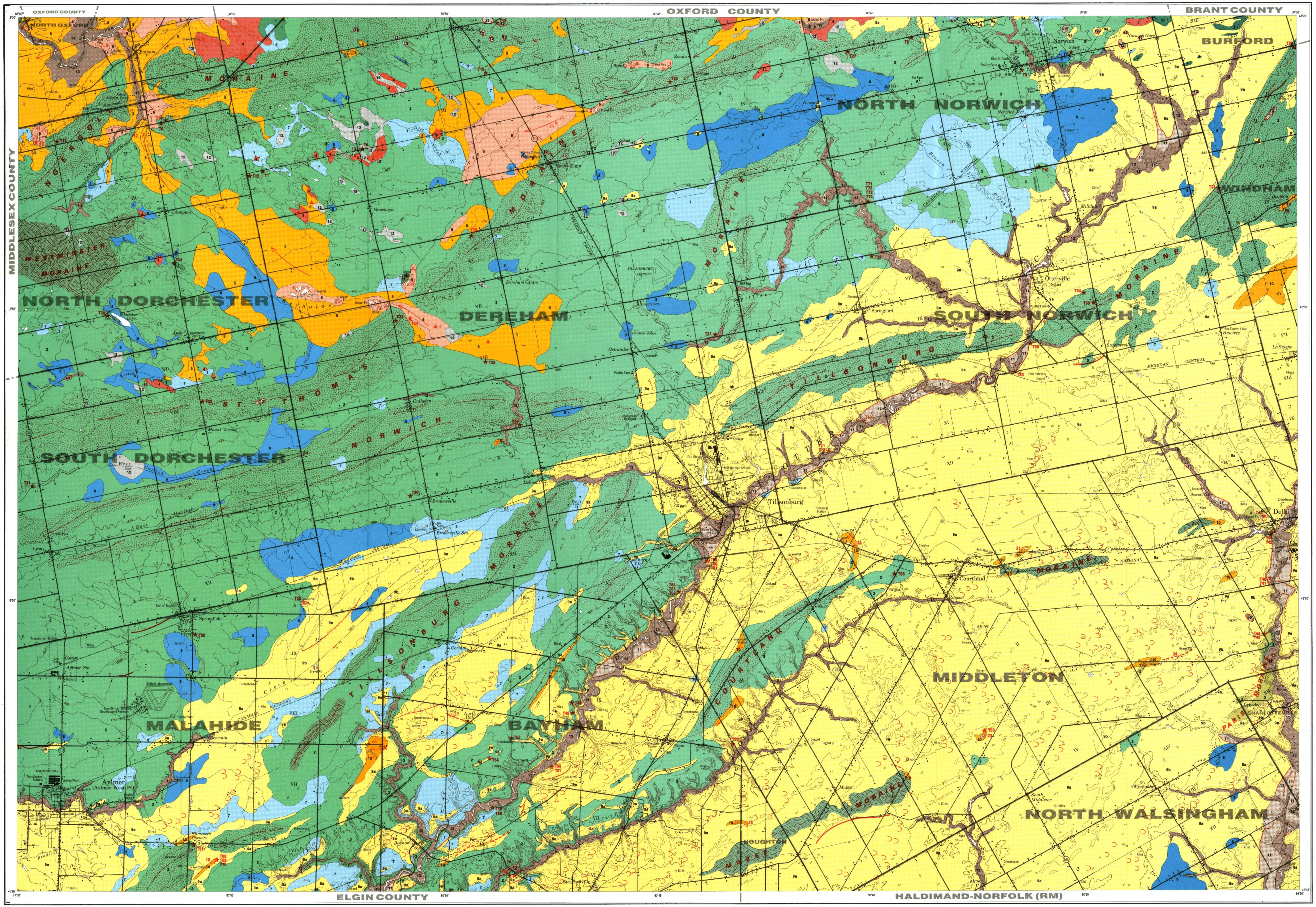


Fig. 7 Physiography of the Tillsonburg Area (after Chapman and Putnam 1966). SMC14956



Ontario

Ministry of
Natural
Resources

Ontario Geological Survey

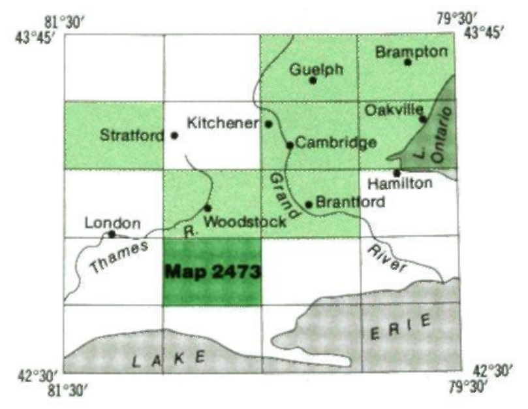
Map 2473

TILLSONBURG

Southern Ontario

Quaternary Geology

NTS 40 I/15 Scale 1:50 000



MAP COVERAGE: INDUSTRIAL MINERALS, QUATERNARY OR PLEISTOCENE GEOLOGY SERIES (EXCLUDING PRELIMINARY MAPS)

LEGEND

PHANEROZOIC

CENOZOIC

QUATERNARY

RECENT

14	*14 Cultural features deposits: earth fill.*
13	*13 Modern alluvium: clay, silt, sand, muck.*
12	*12 Bog deposits: muck, peat or marl.*

PLEISTOCENE

LATE WISCONSINAN

11	*11 Older alluvium in terrace remnants: fine to medium sand with occasional pebbles.*
10	*10 Glaciolacustrine beach or bar deposits: gravel to gravelly coarse sand.*
9	*9 Glaciolacustrine shallow water and deltaic deposits slightly modified by wind.* *9a Fine to medium sand.* *9b Sand containing occasional pebbles.*
8	*8 Glaciolacustrine deepwater deposits: massive to laminated silt, minor clay.*
7	*7 Glaciolacustrine deepwater deposits: massive to laminated clay, minor silt.*
6	*6 Glaciofluvial outwash and deltaic deposits: gravel and gravelly sand.*
5	*5 Glaciofluvial outwash and deltaic deposits: sand.*
4	*4 Glaciofluvial ice-contact stratified drift: morainic or kame sand and gravelly sand.*
3	*3 WENTWORTH TILL: silt till.*
2	*2 PORT STANLEY TILL: silt to silty clay till.*
1	*1 CATFISH CREEK TILL: stony sandy silt till.*

Deposits on this sheet are mapped only where they reach three feet or more in thickness. Thinner deposits are not shown.

SYMBOLS

	Drumlin.		*Glacial fluting.*
	Meltwater channel; (direction of flow inferred).		*Kame.*
	Area of several small dunes.		*Kettle hole.*
	Sand or gravel pit.		*Terrace escarpment.*
○	*Clay pit.*	★ T64	*Till sample locality, see report.*
▲	*Peat pit.*		*Geological boundary; (approximate).*
	Abandoned shore bluff.		*Topographic contours.*
	Abandoned beach bar.		*Regional Municipality or County boundary.*
	End moraine crest.		*Geographic Township boundary.*
	End moraine, hummocky topography.		
	End moraine without hummocky topography.		*For other conventional signs refer to 1:50 000 National Topographic System maps.*

SOURCES OF INFORMATION

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Aerial photography: Ministry of Natural Resources, Toronto.

Preliminary map P 1214 Quaternary Geology of the Tillsonburg Area, scale 1:50 000, issued 1976.

Cartography by D.G. James and assistants, Surveys and Mapping Branch, 1981.

Topography from map 40 I/15 of the National Topographic System.

Magnetic declination in the area was approximately 6° West, 1975.

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

Barnett, P.J. and Girard, C.K.
1982 Quaternary Geology of the Tillsonburg Area; Ontario Geological Survey, Map 2473, Quaternary Geology Series, scale 1:50 000, Geology 1976.

Published 1982

Scale 1:50 000