Geology and Geotechnical Properties of Glacial Soils in Windsor

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Abstract

The City of Windsor is located on the Detroit River, a link in the Great Lakes system between Lake St. Clair and Lake Erie. The city is underlain by Devonian shale and carbonate bedrock with a bedrock surface and ground surface of low relief. The latter is part of the St. Clair Clay Plain. Quaternary deposits are 15 m to 50 m thick and from top down consist of brown, weathered and desiccated lacustrine clay, normally consolidated lacustrine clay, silty Tavistock Till, glaciolacustrine clay and coarse Catfish Creek Till. Hydraulic permeabilities for the brown clay average 2.2 x 10 $^{-9}$ *m·s* $^{-1}$ *and for the grey, 6.8 x 10* $^{-10}$ *m·s*$^{-1}$*. Fine-to-coarse lacustrine sand overlies the clay in the western part of the city. Geotechnically, the part east of Huron Church Road is less troublesome than the western part. In the eastern part, normal foundation design is practised for bearing loads of 200 kPa to 330 kPa. In the west, where a high water table in the sand makes excavation difficult, the range of bearing loads is 60 kPa to 100 kPa. The 1972 Geological Survey of Canada geotechnical data bank, supplied by the Ontario Geological Survey, has been transformed into a modern data base format. Comprising 1560 borehole logs, it provides Atterberg limits, water levels and penetration test results. Other sources of information are local geotechnical consulting engineers and the City of Windsor engineering office.*

Résumé

La ville de Windsor est située sur le bord de la rivière Detroit, cours d'eau qui relie le lac St. Clair et le lac Érié. La ville est construite sur des unités de schistes argileux et de carbonates dévoniens au relief peu accentué. Les parties basses du relief font partie de la Plaine de St. Clair. Les dépôts quaternaires dont l'épaisseur varie de 15 à 50 m, et sont composés, de haut en bas, d'une unité d'argile lacustre desséchée altérée de couleur brune, d'une unité d'argile lacustre grise et en général consolidée, de la moraine limoneuse grise de Tavistock Hill, d'argiles glaciolacustres, et de la moraine à grains grossiers de Catfish. La perméabilité hydraulique moyenne des argiles brunes est de 2,2 x 10 $^{-9}$ *ms*$^{-1}$ *et celle des argiles grises est de 6.8 x 10* $^{-10}$ *ms*$^{-1}$*. Des sables lacustres fins à grossiers recouvrent les argiles dans la partie ouest de la ville. D'un point de vue géotechnique, la partie à l'est de la route Huron Church pose moins de problème que la partie à l'ouest. Dans la partie est, les pratiques de construction sont normales et les fondations mise en place peuvent porter des charges de 200 à 330 kPa. Dans l'ouest, là où le niveau de la nappe phréatique est élevé, l'excavation des sables pose problème et les charges tolérables sont plutôt de l'ordre de 60 à 100 kPa. La banque de données de 1972 de la Commission géologique du Canada et fournie par la Commission géologique de l'Ontario a été transformée en une banque de données moderne en format D-base. Incluant des données sur 1560 trous de forage, elle fournit les limites d'Atterberg, les niveaux des nappes d'eau et les résultats d'essais de pénétration. Les firmes locales de géotechnique-conseil ainsi que des services de génie de la ville de Windsor sont d'autres sources d'information.*

INTRODUCTION

Windsor, located in the southwest tip of Ontario, is the southernmost city in Canada. Its latitude is near that of the California-Oregon border (42°N). The region forms part of the border area between southwestern Ontario in Canada and southeastern Michigan in the United States. The city is on the south bank of the Detroit River, which is the connecting channel between Lake Huron and Lake Erie *via* Lake St. Clair (Fig. 1).

Climate

The mid-latitude and mid-continent position of the area results in seasonal weather changes which are tempered by the moderating influence of the Great Lakes (Niedringhaus, 1966). Windsor lies within "tornado alley", the result of frequent meeting of the cold dry Arctic air from the north and the warm, moist air from the Gulf of Mexico (Sanderson, 1980).

The mean annual temperature is 8.3°C (Environment Canada, 1982). Precipitation annual means range from 101.7 cm·a^{-1} in Monroe County in the west (Michigan Department of Agriculture Weather Service, 1981) to 76.2 cm·a^{-1} in Kent County in the east (Brown *et al.*, 1980). The prevailing wind direction is from the southwest.

Topography

The surface topography of the Windsor area is, to some, distressingly flat, a legacy of former glacial lakes. The lake plain in Essex County slopes primarily northward and westward from a topographic high of 210 m near Leamington. The surface topographic highs correspond with underlying bedrock highs.

ANTHROPOLOGIC HISTORY OF WINDSOR

The region of southwestern Ontario was occupied by mostly nomadic Indian tribes known as the Neutral nation, principally because of their non-alignment with either the English or French colonists in the eastern parts of the country. The presence of these "heathen" souls kindled the zeal of the Jesuits, and in the fall of 1640 Fathers Brebeuf and Chaumonot left the country of the Hurons to preach the Gospel to the Neutrals. There is some evidence that the Jesuit missionaries may have reached the Detroit River region overland and briefly established the Mission of St. Michael on the present site of the City of Windsor (Lajeunesse, 1960).

Fur traders and overland expeditions under the French explorer La Salle also travelled to this area. However, La Salle was the first to sail Lake Erie on the barque Griffon and reached the mouth of the De-

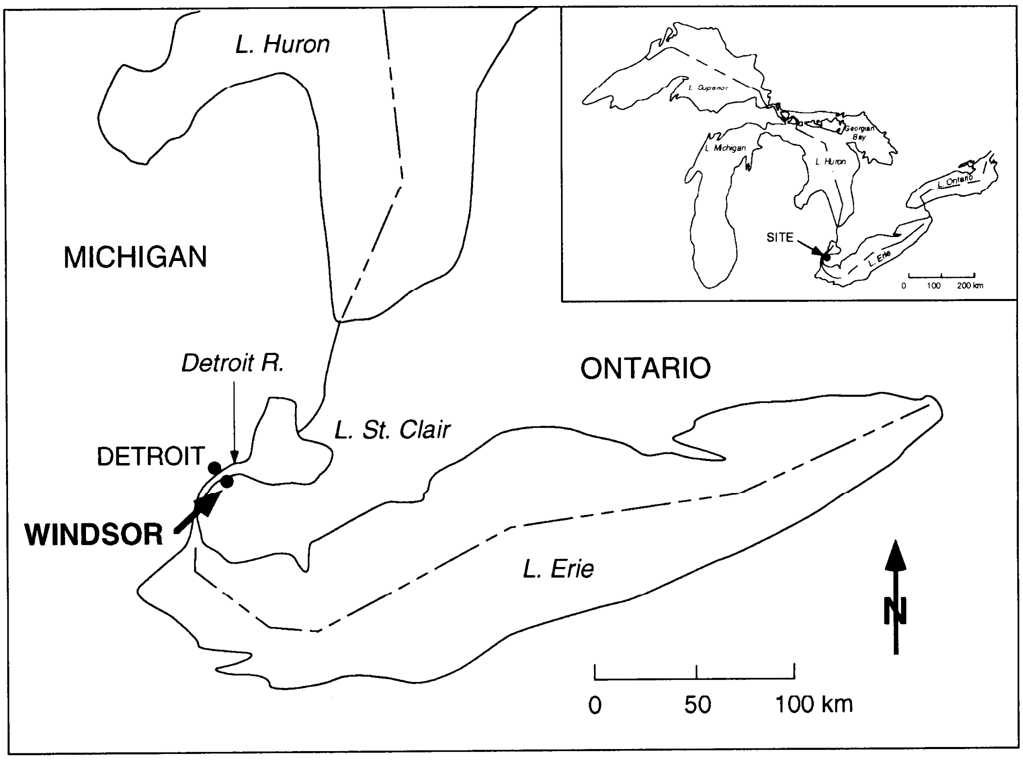

Figure 1. *Location map for the Windsor area.*

troit River on 10 August 1679. Two days later, on the feast day of Sainte Claire, he reached Lake St. Clair, naming it in honour of the saint. In 1701, a permanent settlement was established at Detroit under Cadillac, principally to control the French fur trade. The Detroit River was part of the main line of communications along the Great Lakes, and was therefore militarily important as well. Dominion of the area was frequently in dispute.

About the middle of the 18th century, French settlement began on the Canadian side across from Detroit. This was the first non-military settlement in southern Ontario. By about 1780, all the arable lands from a few miles below Sandwich (now part of Windsor) to the foot of Lake St. Clair were occupied. Fort Malden in Amherstburg was built in 1796 and, along with the rest of the area, saw much action in the war of 1812-1814. By 1854 the Great Western Railway stretched from Niagara to Windsor. The area has seen continued growth since then. With the establishment of auto manufacturing by Henry Ford in Detroit, both Detroit and Windsor have become the automotive capitals of their respective countries. Windsor's venture into casino gambling signals renewed economic growth for the region, and considerable new construction. It is therefore timely that the engineering geology and geotechnical properties of Windsor soils are reviewed.

REGIONAL GEOLOGY

Windsor is located on the southeastern margin of the Michigan Basin. The Algonquin Arch and the Findlay Arch form a structural flexure which separates the Michigan Basin to the northwest and the Appalachian Basin to the southeast. The position of the region on the rim of the Michigan Basin produces a slight dip to the northwest at a rate of 6-9 $m \cdot km^{-1}$. Locally, the dip varies due to the dissolution of salt beds in the deeper Silurian strata, creating collapse structures.

Paleozoic sedimentary rock sequences composed of shale, limestone, dolomite and sandstone underlie unconsolidated Quaternary deposits. The Quaternary deposits consist primarily of glacial drift varying in thickness from a few metres to more than 50 m. Localized alluvium deposits of Recent age overlie the glacial deposits. Regional information on the bedrock and surficial geology of southwestern Ontario and southeastern Michigan can be found in the following sources: Beards (1967), Dorr and Eschman (1970), Brigham (1971), Winder and Sanford (1972) and Lilienthal (1978). More detailed studies of the Quaternary geology are provided by: Mozola (1953, 1969, 1970), Dreimanis (1961), Quigley and Ogunbedejo (1976) and Morris (1988, 1994).

Local Bedrock Geology

The Windsor region is underlain by an evaporite-carbonate sequence which includes the Silurian Salina Formation, the Devonian Bass Islands dolomite, the Detroit River Group and the Dundee Formation. This sequence is overlain by the Hamilton Group shale. Only the last three units occur at the bedrock surface in the Windsor area. Table 1 is a partial stratigraphic column of formations which subcrop beneath the glacial drift under Windsor. The subsurface distribution of the bedrock units is shown in Figure 2.

The bedrock topography under Windsor (Fig. 3) is relatively flat, with the exception of a significant depression in the vicinity of the Windsor airport. The depression may represent a dissolution collapse of either the underlying carbonates or the lower Salina salt beds (Morris, 1994).

Table 1

Sub-cropping formations in Windsor.

Period	Formation	Description
Middle Devonian	Hamilton	Grey, soft shales interbedded with brown argillaceaous coarse-grained, crinoidal and bioclastic limestone.
	Dundee	Brown, medium to thick-bedded fossiliferous limestone with bituminous partings and chert nodules.
	Lucas	Anderdon Member: Light to dark grey-brown, fine-grained (micritic) high calcium limestone, alternating with coarse-grained bioclastic limestone. Bottom: tan sandy limestone.
	Amherstburg	Tan to grey-brown to dark brown, fine- to coarse-grained, bioclastic cherty, massive-bedded, laminated, bituminous dolostone with oolitic, bioclastic and coral-algal zones.

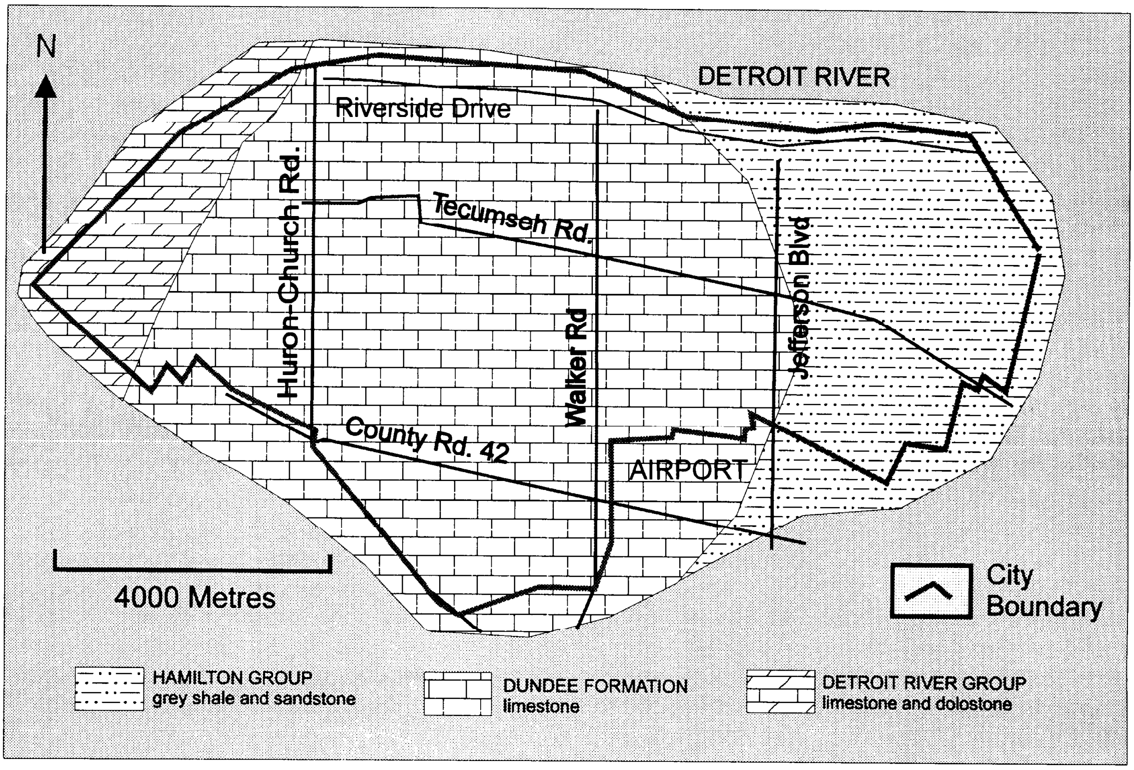

Figure 2. *Subsurface bedrock geology under Windsor (after Sanford, 1969).*

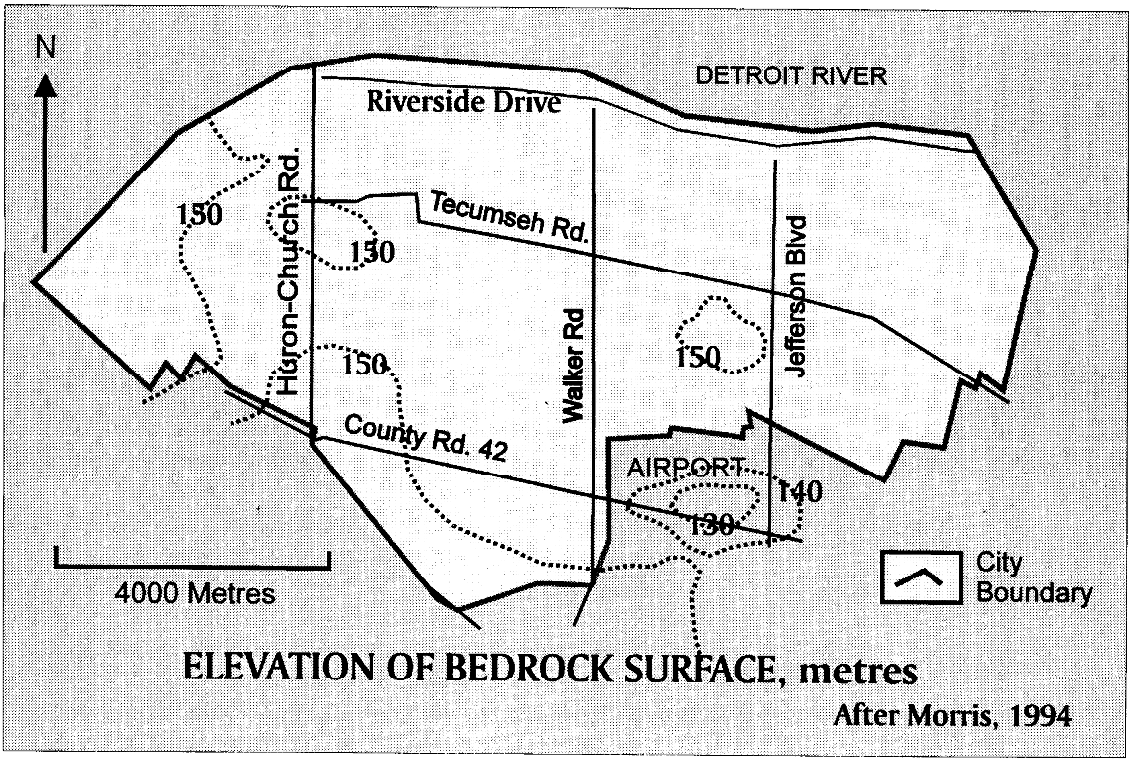

Figure 3. *Bedrock topography under Windsor (after Morris, 1994).*

Quaternary Geology

The unconsolidated sediments which overlie the bedrock were deposited during the late Wisconsinan stage of glaciation (Dreimanis and Karrow, 1972). In the Windsor area, a clay and till plain of little relief, known as the St. Clair Clay Plain, covers the bedrock. In the western part of the city, extensive, but relatively thin sand with some gravel blankets the clay. These are interpreted as lacustrine beach, bar and near-shore deposits (Morris, 1994). Though the clay plain is essentially flat, the glacial overburden is not uniform in thickness. The drift thickness strongly reflects the topography of the underlying bedrock surface. In the western part of Essex County the drift thickness increases from west to east from 5 m to more than 50 m (Morris, 1994). The thickness of the unconsolidated glacial deposits in Windsor is shown in Figure 4.

The overburden in the St. Clair Clay Plain has variously been described as a clayey silt till (Vagners, 1972a, b), silty clay till (Desaulniers *et al.*, 1981) and glaciolacustrine clay (Chapman and Putnam, 1984). Agricultural soil surveys denote the prevailing soil type as the Brookston clay loam, a dark-surfaced gleysolic soil developed under a swamp forest of moisture-loving trees (Chapman and Putman, 1984).

The exact nature of the surficial fine-grained sediments underlying the Essex County Clay Plain has long been puzzling. Morris (1994), however, has identified weathered (brown) massive clay overlying unweathered laminated grey clay as a glaciolacustrine sequence, with gritty clayey silt Tavistock Till below. The till contains carbonate and shale fragments from underlying bedrock as well as Precambrian rock fragments (Dreimanis, 1961). Morris (1994) interprets the till as forming, in part, from debris flows off the ice margin into standing bodies of water. He identifies several subdued moraines associated with the former still-stands of the ice margin.

At the surface, 2 m to 4 m of brown, weathered, desiccated and fractured lacustrine clay and till are underlain by visually unweathered and unfractured grey clay and till. The upper few metres of the grey till are also fissured (Soderman and Kim, 1970; Brathwaite, 1988; Ruland *et al.*, 1991). The colour boundary is often not sharp and its depth varies throughout the region.

Local deposits of discontinuous sand and gravel lenses have been intersected in boreholes at various depths throughout the clay plain. Morris (1994) finds these to be associated with morainic deposits. They often occur in varying thicknesses of interbeds of silty sand with clay and minor amounts of gravel. This zone has been termed "the interbedded zone" by consultants conducting subsurface investigations at the Essex County Landfill No. 3 (Puce). M.M. Dillon Lim-

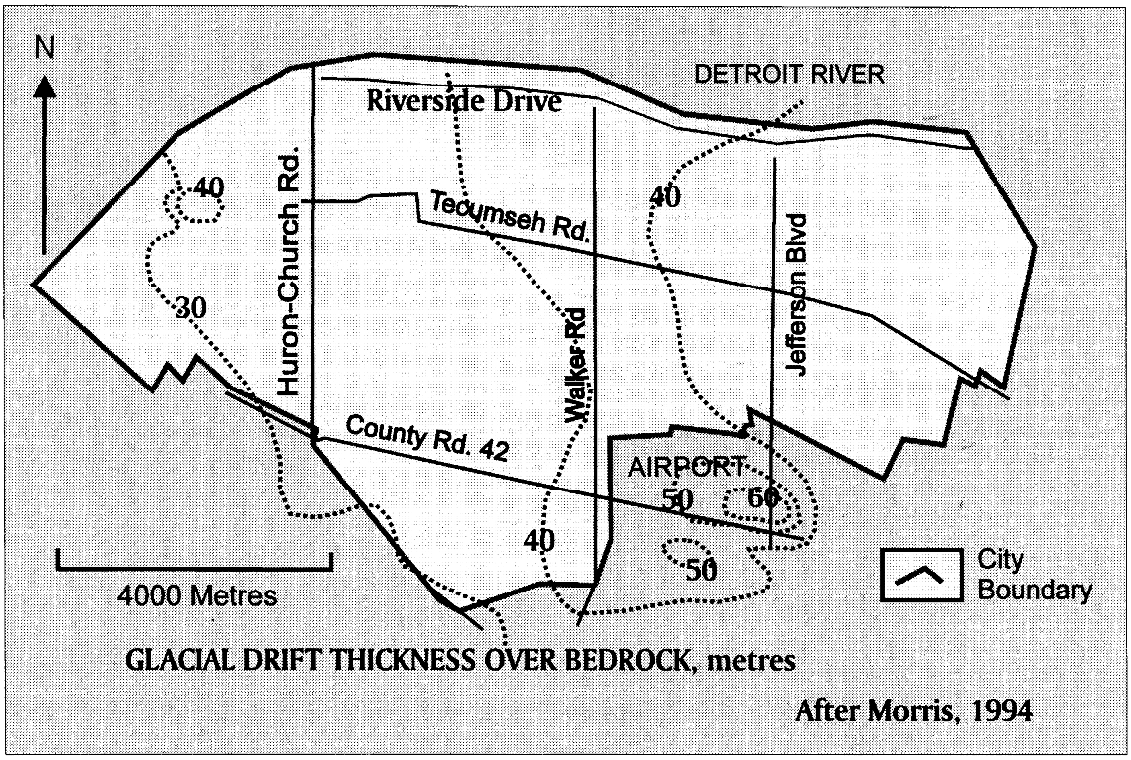

Figure 4. *Thickness of glacial deposits underlying Windsor (after Morris, 1994).*

ited (1988) was unable to trace the zone for any considerable distance; however, Morris (1994) has traced a moraine through the site.

A map of Quaternary deposits underlying Windsor is shown in Figure 5. An idealized east-west cross-section (Fig. 6) shows the bedrock and Quaternary sequence. A fairly continuous layer of coarse material occurs beneath the grey Tavistock Till at the bedrock contact. This has been identified as Catfish Creek Till (Morris, 1994) and varies in thickness from zero to several metres.

HYDROGEOLOGY

Since most of Essex County and the City of Windsor are flat and surrounded by water, the groundwater table is close to the surface. The groundwater levels have not been constant; the existence of the weathered brown lacustrine deposits and till which extend below the current river and lake levels is quoted as evidence that lower groundwater levels existed in the past. The lowered groundwater levels have affected the geotechnical properties of the near-surface sediments of the St. Clair Clay Plain, as will be shown later. The regional groundwater flow is generally to the north from a groundwater high in the southern part of Essex County (Crnokrak, 1991). The age of the ground water and the implied vertical movement of water and pollutants has been the study of graduate students at the University of Windsor (Chiasson,1992; Crnokrak, 1991) and the University of Waterloo (Desaulniers *et al.,* 1981). The results of the studies suggest that in zones deeper than 4 m or 5 m (the weathered zone), water moves by molecular diffusion rather than by Darcian flow.

Four hydrostratigraphic units can be recognized throughout the overburden in the St. Clair Clay Plain (modified after Chiasson, 1992):

- Brown weathered, fractured glaciolacustrine silt and clay
- Blue/grey unweathered glaciolacustrine silt and clay and Tavistock Till
- Sporadic interbedded zones of sand, gravel and clay (morainic deposits) and
- Basal sand-bedrock aquifer (Catfish Creek Till).

M.M. Dillon Limited (1988) has compiled hydraulic conductivity values for the brown unit, the grey unit and the interbedded sand unit (Table 2). The brown fractured unit is the zone of most active groundwater flow with hydraulic conductivities of at least one order of magnitude higher than the underlying grey unit at each location throughout the St. Clair Clay Plain. The interbedded sand unit, which possesses hydraulic conductivities approximately two orders of magnitude higher than the brown fractured unit, provides a local conduit for groundwater movement. Profiles drawn across the glacial lake plain show that most of the individual sand and gravel zones cannot be correlated between test holes (Mozola, 1953). This suggests that these confined aquifers, which are probably buried moraines, are discrete, discontinuous, of small areal extent and with limited storage capacity and recharge capability (WMU, 1981a, 1981b; OWRC, 1970, 1971). The discontinuity of these small buried aquifers is of major importance in landfill siting and approval within Essex County. Most areas are suitable for waste disposal; the siting of fills is therefore more a political than a geotechnical problem.

The main water-bearing formation throughout the St. Clair Clay Plain is the basal sand-bedrock aquifer. The unit is described as a nearly continuous, thin and uneven layer of sand, gravel, and fractured bedrock (Gillespie and Dumouchelle, 1989; Intera Technologies Ltd., 1989; URM, 1984). It is usually 1.5 m to 6 m thick (Gillespie and Dumouchelle, 1989) and confined when found between shaly bedrock and overburden composed of clayey Tavistock till.

In some areas, carbonate rocks form a bedrock aquifer. The well yields from the bedrock aquifer are good, especially where some solution has taken place (GLBC, 1975). Deep rock wells in areas where the Detroit River Group subcrops (as it does under Windsor) are common. (OWRC, 1971). Since there is no physical barrier to flow between the basal sand and bedrock zones, they probably act as a single aquifer (M.M. Dillon Limited, 1988). This aquifer has been shown to have a probable yield of 0.15-0.75 $L{\cdot}s^{-1}$ (OWRC, 1971). In the Essex Clay Plain, 69% of the Ontario Ministry of the Environment (MOE) (1977) well records report water found in the bedrock and 25% report water found in the basal sand unit. Of these, the groundwater use is 43% domestic, 13% agricultural, 41% combined domestic and agricultural and 3% commercial and public. Natural gas has been reported from the bedrock-soil interface aquifer in established wells and from drilling into this horizon. Other than posing a risk of an explosion, it does not affect water quality.

In Windsor and surrounding municipalities, water for domestic use is obtained largely from a municipal water distribution network drawing its water from Lake St. Clair. However, in Essex County, ground water is extensively used as evidenced by the abundance of wells listed in the MOE well records (1977).

There are several localized areas, mostly in the western part of the Windsor metropolitan area, composed of glaciofluvial-glaciolacustrine sands and gravels at or near the surface, which form unconfined shallow aquifers. These are interpreted as small lacustrine fans related to an early Lake Erie (Morris, 1994) or Lake Rouge (Vagners, 1972b). None of these are currently used as sources of potable water because of

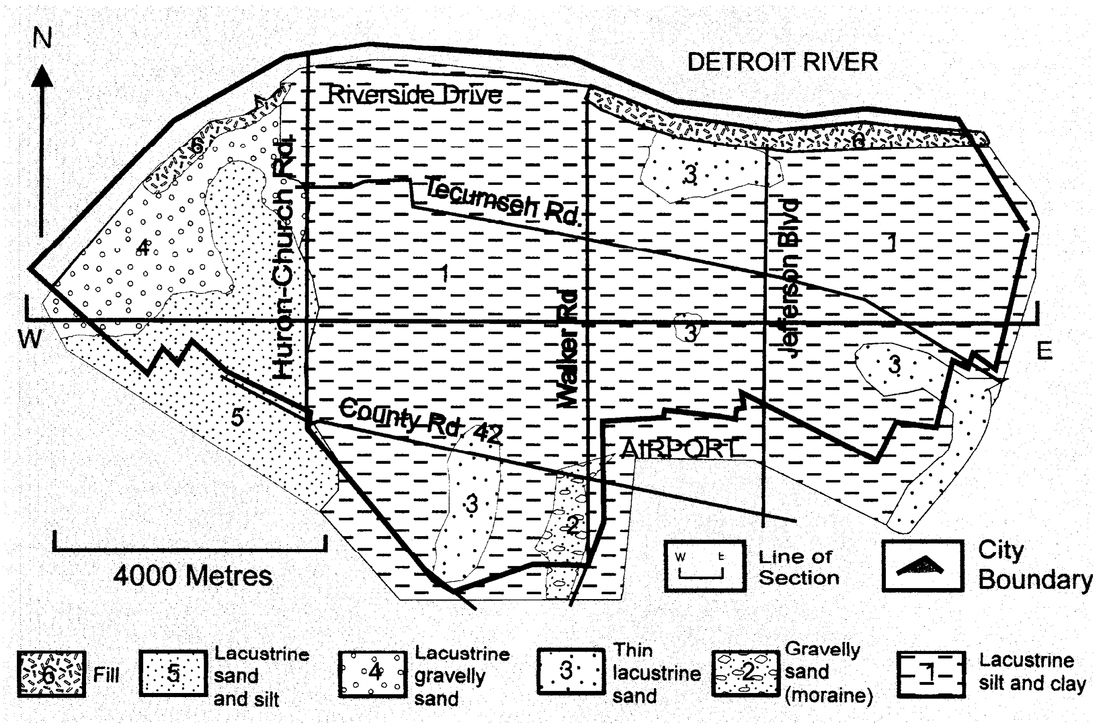

Figure 5. *Glacial deposits underlying Windsor (after Chapman and Putnam, 1984; Morris, 1994).*

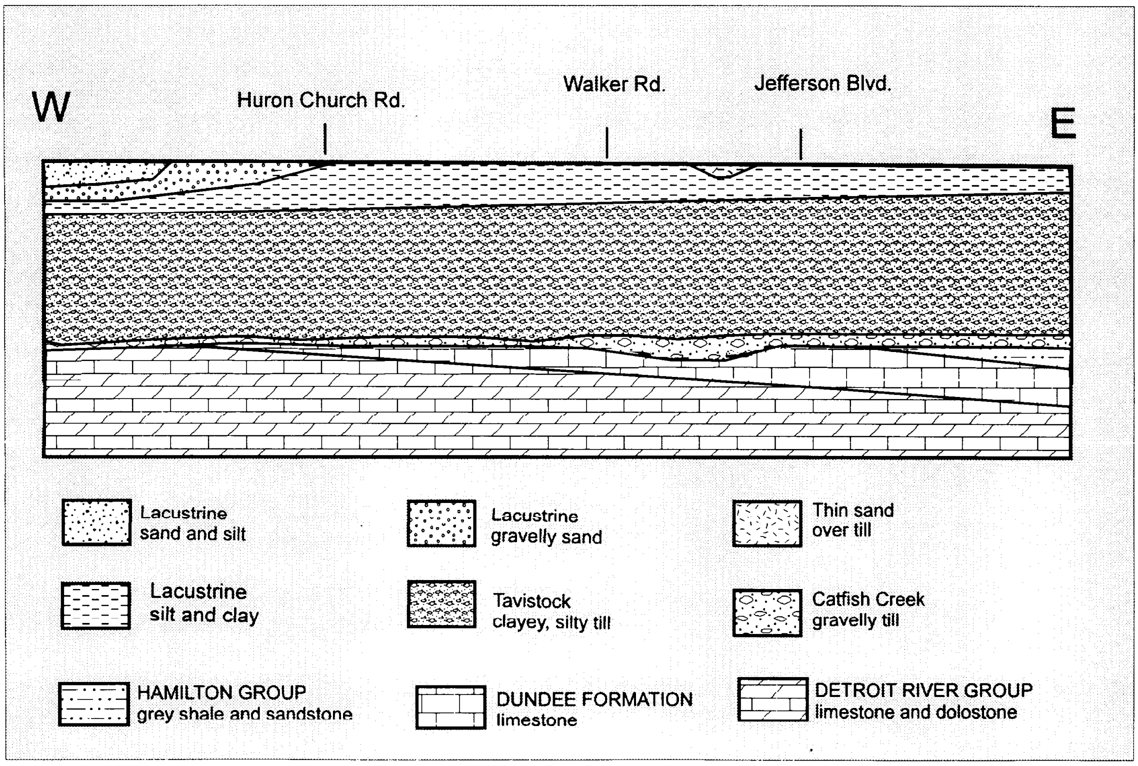

Figure 6. *Idealized east-west cross-section based on Figures 2 and 4.*

surface contamination potential; however, they present geotechnical problems in excavation, as will be discussed later.

GEOTECHNICAL CONDITIONS IN WINDSOR

The Windsor area can be divided as geotechnically "benign" east of the Huron Church Road (a major artery connecting Highway 401 with the Ambassador Bridge to the United States), and "problematic" west of this line. The major difference between these two areas is the presence of thin silt, sand and occasionally gravel cover in the western part and the general lack of it in the eastern portion. The broad areas of geotechnical similarity are shown in Figure 7. The specific geotechnical problems are discussed below.

East Windsor

The eastern part of Windsor is underlain generally by normally consolidated glaciolacustrine silts and clays. A weathered layer about 2 m to 2.5 m thick is found below approximately 0.3 m of topsoil. It consists of stiff, sandy-to-silty weathered clay. It is underlain by a "crust" 4 m to 5 m thick of hard brown till, or stiff, lacustrine clay-silt, somewhat overconsolidated, and of higher bearing and shear strength than lacustrine clay underlying grey Tavistock Till. It is well fissured (desiccated). The brown layer changes gradually to grey, silty clay with embedded sand and fine gravel. The shear strength of the grey clay generally decreases with depth. Both brown and grey layers are composed of about 50% clay, 30% silt and 20% sand with minor fine gravel. The upper, brown lake sediments and till are thought to be the result of ground water lowering in the past, resulting in exposure to air, desiccation, and oxidation. The water table in most places is now found close to the interface between the two layers, but is well above the interface in some areas. Two instances of smectite presence in the brown clay (J. Rogers, Golder Associates Ltd., personal communication) also suggest a more active weathering environment than at present.

A relatively small area in the vicinity of Devonshire Mall contains buried swamp (peat) deposits in the near surface. The areas north of the Airport have frequent sand lenses, leading to potential differential settlement for structures. The sand lenses are associated with the Bryndale Moraine in east Windsor and the Elmstead Moraine in the south-central area near the airport. More detailed soil investigations are often required.

Foundations and Excavations

Staff at the local consulting engineering firms (J. Rogers, Golder Associates Ltd. and N. Sitar, Dominion Soil Investigation Ltd., personal communications, 1993) report that in general, spread footing foundations for allowable soil bearing pressures of 200 kPa to 330 kPa are used for structures in this area of the city. Heavier structures and overpasses of the E.C. Row Expressway are founded on piles to bedrock. There are no friction piles. A major high-rise hotel/office complex across the river in Detroit is founded on large caissons seated in the lower till just above the aquifer zone overlying bedrock. Water pressures precluded excavating to bedrock. In the downtown Windsor area, buildings employ mostly raft foundations to minimize settlement in the underlying soft clay. Excavations must be shored, cross-braced, or tied back. Dewatering of excavations is usually no major problem (N. Sitar, Dominion Soil Investigation Ltd., personal communication, 1994). Because of the highly variable soil conditions, the University of Windsor structures employ a variety of foundations, from raft to spread footings to piles. The Energy Conversion Centre at the University is founded on expanded base

Table 2

Hydraulic conductivity for brown and grey till in Essex and Windsor (M.M. Dillon, 1988).

Material	Location	Range $m\,s^{-1}$	Mean $m\,s^{-1}$	Tests
BROWN TILL	Essex County	1.5×10^{-10} to 1.4×10^{-4}	5.8×10^{-9}	15
	Maidstone	1.1×10^{-10} to 2.7×10^{-9}	4.6×10^{-10}	13
	Windsor	1.5×10^{-10} to 2.0×10^{-7}	2.2×10^{-9}	14
GREY TILL	Essex County	5.8×10^{-11} to 4.5×10^{-9}	2.3×10^{-10}	37
	Maidstone	4.2×10^{-11} to 8.8×10^{-8}	5.5×10^{-10}	35
	Windsor	1.3×10^{-10} to 1.2×10^{-8}	6.8×10^{-10}	28
INTERBEDDED SAND UNIT	Maidstone	1.1×10^{-9} to 1.0×10^{-4}	1.8×10^{-7}	27

caissons (Franki piles), the only such foundations used in Windsor. The Franki piles were used because changing ground conditions required a broader bearing base for a heavy, vibrating structure.

West Windsor

Going westward from approximately the north-south Ouelette Avenue, the brown crust decreases in thickness, and disappears entirely beneath the granular cover in the west end of the city. The granular cover over the till in the west end has protected the till from oxidation and inhibited the formation of the desiccated crust. This, coupled with constantly high water levels in the permeable sands, accounts for many excavation and foundation problems to be found in the western part of the city. The granular cover represents deltaic channel deposits found near the Windsor race track.

The land adjacent to the Detroit River has some relatively recent flood deposits of silt and clay. Small areas along Riverside Drive and along the river's edge are reclaimed land and thus contain a variety of materials.

Foundations and Excavations

The western part of the city is generally more problematic. The sand-silt layer over clay is invariably saturated. Excavations require de-watering and shoring. The clays have a bearing capacity of only 60 kPa to 100 kPa, and more substantial structures are founded on end-bearing piles (N. Sitar, Dominion Soil Investigations Ltd., personal communication, 1994). Excavations are difficult, especially during wet periods. Portions of a recently installed sewer line along Prince Road were placed using tunnelling rather than surface excavation because of poor ground conditions both in the upper sands and the lower soft clays (J. Rogers, Golder Associates Ltd., personal communication, 1994).

Ground Subsidence

In 1954, a large surface subsidence in the form of a crater developed at the site of the solution mining operation of the Windsor Salt mine. The subsidence was rapid, swallowing a locomotive and a service building. The possible cause of the subsidence was an undetected, directional dissolution of the underground salt, found some 430 m below the surface at this location. The caverns, rather than roughly circular in plan, formed elongated, step-like patterns when viewed in vertical sections. The directional dissolution may have been aided by the regional tectonic pattern. The subsidence was investigated by Karl Terzaghi, assisted

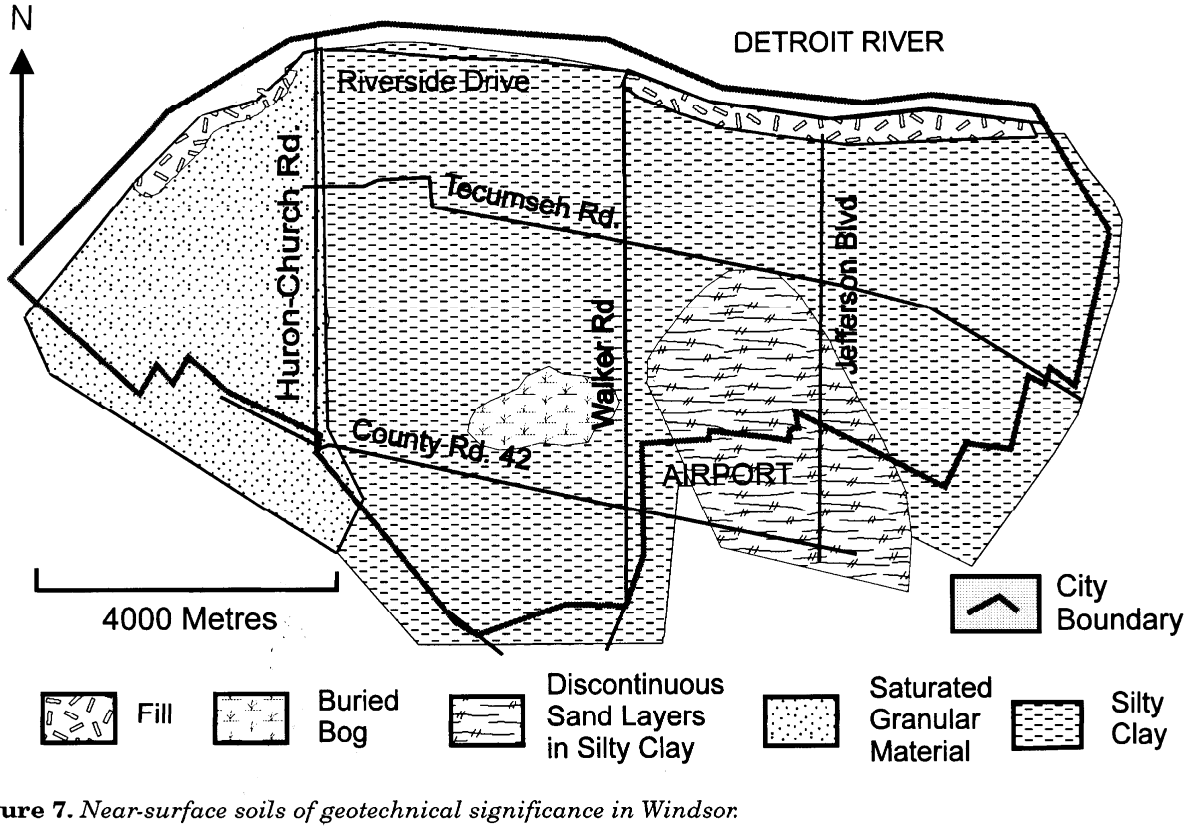

Figure 7. *Near-surface soils of geotechnical significance in Windsor.*

by Ralph Peck. Over the past two decades some worked-out salt caverns have been utilized for underground storage of LPG (liquefied petroleum gas) by Dome Petroleum and are now owned by AMOCO. A bedrock depression under the airport may represent a karst or solution collapse (Morris, 1994).

The west end of Windsor, although ideally situated for industrial development, is still mainly rural. A major Carolinian forest preserve, Ojibway Park, exists here primarily because developers were discouraged by difficult ground conditions.

Until recently, large parts of the south and west ends of the city were still on septic systems. Most systems were in a state of failure: in the east because of impermeable clays, and in the west due to a high water table within the sands. In the last few years, most or all of the city and the surrounding municipalities have been connected to the sanitary sewer system.

Groundwater Pollution / Waste Disposal

There are no currently operating landfills within the city boundaries, although one, in the western part of the city, just recently ceased accepting inert (structural) waste. Waste from the city and the surrounding areas was, until recently, trucked to Maidstone landfill to the east of Windsor. The landfill closed in the summer of 1997 and the waste is now trucked to a new, large-capacity regional landfill in Colchester North Township. The Maidstone landfill has been the subject of extensive geotechnical investigations in the last several years to investigate the possibility of the leachate leaking though the thin sand lenses found interspersed within the lower grey (Tavistock) till. The sand lenses were found to be isolated from each other. No significant leachate migration was detected.

The current search for a new landfill site has concentrated on sites in the central part of Essex County, where there is a relatively low population density. The same clay till environment, that has proven to be relatively successful in former landfills, is also present.

Recent research headed by Mike Sklash and his students in the Department of Earth Sciences, University of Windsor, has concentrated on the origin and significance of the vertical cracks observed both in the upper brown weathered zone, and to some extent, in the grey zone below. The conventional methods of estimating groundwater flow velocity using the Darcy equation is questionable in low permeability media with vertical cracks (Chiasson, 1992). The current techniques used to measure hydraulic conductivities by drilling and inserting sampling tools are suspect, since the act of creating a hole smears and plugs the vertical fractures (Hudec, 1994). Hydraulic conductivities were shown to be underestimated by a factor of 10^2. Isotopic studies by Chiasson (1992) of ground water in a buried esker trending roughly from south of Puce to Leamington (Morris, 1994) suggest vertical recharge of the esker through the fractures in the till.

SOURCES OF GEOTECHNICAL INFORMATION

Most of the geotechnical information on the soils of Windsor and Essex County is found in the files of the consulting engineering firms in the city. The city engineer's office also maintains records of geotechnical investigations contracted by the city. Some of the older records, however, reside with municipalities, the townships, and Essex County for lands that have been annexed by the city.

A fairly comprehensive data bank of geotechnical soil properties based on 1560 investigative borings put down in Windsor before 1972 can be found in the Geological Survey of Canada-Ontario Geological Survey computerized data base compiled for Windsor and other metropolitan areas across the province. The Windsor portion of the data base has been resurrected and partially transformed by the author from a Cobol tape format to a modern database diskette-based format. Because of its previous format, the old data base was virtually unusable, and was, indeed, totally unused; however, in its present form, it can be used by any DOS or WINDOWS data base program. Although much more additional information exists in the files of the local consulting firms, there are currently no plans and no funds available to update the old data base. Perhaps another project similar to the one over 22 years ago could be mounted with the cooperation of the federal, provincial and local governments and industry.

Boutette (1979) has used the geotechnical data bank to correlate the standard penetration test results at the 25- and 50-foot levels to differentiate the glacial till and glaciolacustrine origin of the soil at these levels. The identification of the material at these horizons was based on drillers' logs.

SUMMARY AND CONCLUSIONS

The flat terrain of Windsor, and its proximity to the Great Lakes and the Detroit River system, present special geotechnical problems that are unique in Ontario. Geotechnically, the soil above the bedrock is divided into upper brown, oxidized glaciolacustrine silt and clay and some weathered Tavistock Till. The upper crust is desiccated, fractured and somewhat overconsolidated and generally provides good foundation material. It predominates in the eastern part of Windsor. The sand unit in western Windsor has protected the till from weathering, and provides conditions of high saturation. The combination has resulted in geotechnically poor soils, requiring end-bearing piles to bedrock for all major structures.

The generally low hydraulic conductivity of the Tavistock Till, and the location of the main aquifer at the till–bedrock contact has precluded any significant groundwater pollution in the area. The sand lenses within the till are thin, discontinuous, and not hydraulically connected. There is some question about the reliability of the hydraulic conductivity determinations in fractured tills, since the fractures tend to get plugged during the testing process, thus underestimating the hydraulic conductivity. The fractured till is vertically permeable, as shown by recent meteoric water found in a buried esker.

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