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# GEOLOGY AND ENGINEERING CHARACTERISTICS OF SURFICIAL DEPOSITS, MONTREAL ISLAND AND VICINITY, QUEBEC

V.K. PREST
J. HODE-KEYSER

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# GEOLOGY AND ENGINEERING CHARACTERISTICS OF SURFICIAL DEPOSITS, MONTREAL ISLAND AND VICINITY, QUEBEC


## Abstract

This paper provides geological information on the origin, stratigraphy, and physical character of the surficial deposits of the Montreal area. Some notes are provided on bedrock geology and topography, but emphasis is placed on the history of glacial and postglacial events and on the resultant deposits. The inferred events in the Montreal area are compared with those of the Trois-Rivières, Sherbrooke, and Cornwall-Ogdensburg areas to the northeast, east, and southwest, respectively. The sequence and nature of the deposits in the latter area compare best with those on Montreal Island, but problems in interpretation are noted.

Two episodes of Wisconsinan Glaciation referred to as Malone and Fort Covington were responsible for the deposition of two till sheets. These tills generally are separated by a variable assortment of nonglacial, glaciolacustrine, glaciofluvial, and glacial deposits, collectively known as the Middle-till complex. The deposits are related to the waning of Malone ice and are considered Middle Wisconsinan in age. Only scant evidence exists of glacial lake or other deposits related to the retreat of the last or Fort Covington ice sheet; marine (Champlain Sea) sediments generally rest directly on the youngest till. The sea overlapped Mont Royal to a maximum elevation of about 565 feet (170 m) about 12 000 years ago. Isostatic rebound, following the recession of the last ice sheet, caused the withdrawal of the sea northeastward down St. Lawrence Valley. The transition from open sea to estuarine and then fluvial conditions began on Montreal Island about 10 000 years ago when the western flank of Mont Royal, at a present elevation of 170 feet (50 m), rose above the sea level of that time. Thus, erosional features on Mont Royal between elevations 565 and 170 feet (170 and 50 m) are marine-littoral, whereas lower ones over the entire island are estuarine-fluvial. By the time the estuary withdrew from the low northeastern tip of Montreal Island there had been 100 feet of downcutting by the early St. Lawrence River in the higher central and western parts of the island.

The engineering properties of different geological soil groups were determined by field and laboratory tests. Field tests included determination of in situ density, water content, and standard penetration of split-spoon sampler during borings. Laboratory tests included degree of stoniness, grading by sieve analysis and sedimentation, Atterberg limits, soaked and unsoaked California Bearing Ratio, unconfined compressive strength, and maximum density and optimum water content determinations.

Test results clearly indicate that, in regard to design and construction, each parent soil group has its particular engineering characteristics. Glacial tills are characterized by varying but generally high stone and boulder contents, in situ density higher than maximum laboratory density, relatively low water content and clay content, and great strength when the in situ water content is below or near the laboratory optimum water content. Glacial lake silts are characterized by relatively high unit weight and great strength and sensitivity to change in water content. Champlain Sea clay in the Montreal area is noted for its extremely high sensitivity, with the liquid limit depending directly on clay content. The strength of Champlain Sea clay, which varies widely, depends on its water content, density, and silt/clay ratio.

Some information is provided on the Champlain Sea fauna noted around Mont Royal.



## Résumé

Cet article donne des informations géologiques sur l'origine, la stratigraphie, et les caractéristiques physiques des dépôts meubles de la région de Montréal. L'article présente des données sur la géologie et la topographie de la roche en place, mais on insiste surtout sur l'histoire des événements glaciaires et postglaciaires et sur la mise en place des dépôts au cours de ces périodes. Les événements que l'on a déduits pour la région de Montréal sont comparés à ceux des régions de Trois-Rivières, de Sherbrooke, et de Cornwall-Ogdensburg, au nord-est, à l'est et au sud-ouest respectivement. La succession et la nature des dépôts de la région de Cornwall-Ogdensburg présentent de fortes ressemblances avec ceux de l'île de Montréal, mais il subsiste des problèmes d'interprétation.

La mise en place de deux couches de till est dûe à deux épisodes de la glaciation du Wisconsin appelés épisodes de Malone et de Fort Covington. Ces tills sont généralement séparés par un assortiment variable de dépôts non glaciaires, glacio-lacustres, fluvio-glaciaires, et glaciaires, qui ensemble constituent le complexe de till intermédiaire. Ces dépôts se sont formés au cours de la fonte de la masse de glace de Malone, et on les considère comme des dépôts du Wisconsinien moyen. Il n'existe que très peu d'évidences de l'existence de lacs glaciaires ou d'autres dépôts associés au retrait de la dernière calotte glaciaire, ou calotte de Fort Covington; les sédiments marins (mer de Champlain) reposant en général directement sur le till le plus récent. La mer a submergé le Mont-Royal jusqu'à une hauteur maximale d'environ 565 pieds (170 m), il y a environ 12 000 ans. Le relèvement isostatique postglaciaire a engendré

le retrait de la mer vers le nord-est, le long de la vallée du Saint-Laurent. C'est il y a environ 10 000 ans, sur l'île de Montréal, que la transition a commencé à se faire, d'un milieu marin à un milieu d'estuaire, et enfin à un milieu fluvial. A ce moment, la partie inférieure du versant ouest du Mont-Royal, dont l'altitude actuelle est de 170 pieds (50 m), a émergé. Ainsi, l'érosion qu'a subie le Mont-Royal entre les hauteurs de 565 et 170 pieds (170 et 50 m) est de nature marine et littorale, tandis qu'à des niveaux inférieures, l'île a été entièrement soumise à une érosion estuarienne et fluviale. Au moment où l'estuaire s'était retiré de l'extrémité nord-est de l'île de Montréal, le fleuve Saint-Laurent ancestral avait déjà entaillé les secteurs plus élevés du centre et de l'ouest de l'île jusqu'à environ 100 pieds de profondeur.

On a déterminé par des essais réalisés sur le terrain et en laboratoire les propriétés géotechniques des diverses unités géologiques. Les essais sur le terrain ont permis de déterminer le poids spécifique apparent humide "in situ", la teneur en eau, et, la résistance à la pénétration de la cuillère fendue au cours des sondages selon l'essai standard de pénétration. Les essais de laboratoire ont permis de déterminer le degré de pierrosité, la granulométrie (par tamisage et sédimentation), les limites d'Atterberg, l'indice portant C.B.R. (California Bearing Ratio) saturé et non saturé, la compression simple et la densité maximale pour le taux optimal d'humidité.

Les résultats des essais indiquent clairement que chaque groupe originel de sols possède des caractéristiques géotechniques particulières, dont il faut tenir compte dans la construction et la conception d'ouvrages. Les tills sont caractérisés par un contenu variable mais généralement élevé de pierres et de blocs, un poids spécifique apparent humide "in situ" plus élevé que la densité maximale relevée en laboratoire, une teneur en eau et un contenu en argile relativement faibles, et une grande résistance mécanique lorsque la teneur en eau "in situ" est au-dessous ou proche de la teneur en eau optimale telle que déterminée en laboratoire. Les silts glacio-lacustres sont caractérisés par un poids spécifique relativement élevé, une grande résistance mécanique et une forte susceptibilité aux variations de la teneur en eau. Dans la région de Montréal, l'argile de la mer de Champlain est caractérisée par une sensibilité élevée et sa limite de liquidité est directement proportionnelle à sa fraction argileuse. La résistance de l'argile de la mer de Champlain, qui varie fortement, dépend de la teneur en eau, du poids spécifique et du rapport silt/argile.

Des renseignements concernant la faune de la mer de Champlain, aux environs du Mont-Royal, sont fournis.

# GEOLOGY AND ENGINEERING CHARACTERISTICS OF SURFICIAL DEPOSITS, MONTREAL ISLAND AND VICINITY, QUEBEC

## INTRODUCTION

Field work was done mainly during 1951 and 1952 by V.K. Prest, although occasional observations were made in later years. Field work included detailed examination of construction sites and service excavations in urban areas and logging of soil borings made in former years by cities, municipalities, and engineering firms. In rural parts of the island traverses were made and holes were dug or hand augered to ascertain the nature of the soil; most holes were 2 to 5 feet deep, but in soft marine clay some reached 30 feet. The determination of engineering characteristics of the 'soils'[1] and the compilation of drift thickness (Map 1427A) are mainly the work of J. Hode-Keyser[2] since 1955. Keyser studied the soils while at École Polytechnique and later while he was Soils Engineer from 1955-1958, Materials and Research Engineer from 1958-1964, and Director from 1964-1973 of the Research and Control Division, Montreal Department of Public Works. All particle size analyses and engineering tests were carried out in the City of Montreal and École Polytechnique laboratories. The authors have co-operated in the study of the soils of Montreal Island since 1954. Except for some revisions made on the basis of extensive soil boring data from the eastern end of the island, the surficial geology map (Map 1426A) remains as it was at the end of the field program in 1952. In the western end of the island, where data were gathered mainly by field traverses, it will need revision as detailed information is gathered; this area has since been extensively urbanized, and little attempt has been made to integrate the surficial geology and the recent soils records for this region.


### Acknowledgments

The capable assistance of K.S. Knox in 1951 and W.R. Dunlop and P. Palij in 1952 during geological examination of the soils is gratefully acknowledged. Officials and other personnel of the Montreal Department of Public Works and of the Montreal Tramways Commission greatly facilitated the compilation of data in the urban areas. Also, officials of the many cities, towns, and municipalities around Montreal were extremely co-operative and provided plans and level surveys essential to the mapping program, for there was no suitable large scale map of the island available. Such data enabled the cartographic unit of the Geological Survey of Canada to compile a base map with 10-foot contours (Prest and Keyser, 1961a, b, 1962).

Information on soils also was provided by many consulting firms, engineers, and job foremen whose co-operation was essential in gathering adequate information on the urban areas. The authors gratefully acknowledge the contributions of all the engineering and consulting firms in the Montreal area that have contributed information from the inception of the field work through 1975.

Special thanks are extended to R.J. Mott for his palynological study of samples of stratified silty clay from the Montreal area.


## GENERAL GEOLOGY

The mantle of drift, debris, or soil that overlies the bedrock formations of Montreal Island is the result of glacial and related events of the last or Wisconsinan Glacial Stage of the Pleistocene Epoch or Quaternary Period, that is, the last 125 000 years of the earth's history. The deposits have been derived from much older local and distant bedrock formations of the region. Some knowledge of the bedrock and the topography over which the glaciers have passed is, therefore, pertinent prior to a fuller discussion of Pleistocene history and the soils themselves.

The rock types, stratigraphy, structure, and geological history of Montreal Island and the surrounding region are dealt with in comprehensive reports by Clark (1952, 1972). Precambrian or basement rocks outcrop in the Oka area west of Lac des Deux Montagnes, off the west end of Montreal Island, and 20 miles north of Montreal Island in the Laurentian Highlands. These rocks, which range in age from 3500 million or more years to less than 600 million years, include a variety of igneous and metamorphic rocks (**see** Table 1)[3]. On Montreal Island, these basement rocks are covered mainly by younger sedimentary rocks. Clark, however, observed small occurrences of anorthosite, a Precambrian ultramafic igneous rock, on the north side of Cartierville airport, west-northwest of Mont Royal. He presented evidence that this occurrence is a hilltop of the old basement surface which had a relief of over 3000 feet. During a period of crustal depression in the early Paleozoic Era, sandy, muddy, and limy sediments were deposited on this irregular surface until all parts were covered. The sediments became the sandstone, shale, limestone, and dolomite that now make up the main part of the island and the surrounding region — part of the St. Lawrence Lowland. The sedimentary rocks are mainly of Cambrian and Ordovician age, having been deposited between about 515 and 440 million years ago. Blocks of Devonian limestone comprise a unique breccia on Île Sainte-Hélène (Clark, 1972). The blocks are believed to be pieces of Devonian strata that were loosened and dropped into molten rock at the time of the Monteregian intrusions; they are now preserved well below their former stratigraphic position. These 'sunken' blocks provide the only evidence that a Devonian sea once covered this part of the St. Lawrence Lowland about 390 to 375 million years ago.

The Monteregian intrusions were emplaced 120 million years ago in middle Lower Cretaceous time.

[1] The term 'soils' is used in the engineering rather than the agricultural sense. It includes all deposits overlying the bedrock; these are commonly referred to as the surficial deposits or drift. The term 'drift thickness contours' is used for the lines that indicate the thickness of the soils overlying the bedrock.


[2] J. Hode-Keyser: Department of Civil Engineering, École Polytechnique, Montreal, Quebec.



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[3] Table 1 gives the names, order, and age of the geologic units referred to in the text.

TABLE 1

GEOLOGICAL TIME AND ROCK UNITS - MONTREAL AREA
(not to scale; see "years" column)

| EON | ERA | PERIOD | STAGE | SUBSTAGE | YEARS B.P.[1] | GEOLOGICAL UNIT |
|---|---|---|---|---|---|---|
| PHANEROZOIC | CENOZOIC | QUATERNARY | HOLOCENE (Recent) | (Present) Postglacial | 0<br>10 000 | Bog, pond, river deposits |
| | | | PLEISTOCENE | WISCONSINAN (Glacial) | 12 500 | Champlain Sea deposits |
| | | | | | 25 000 | Fort Covington Till |
| | | | | | 55 000 | Middle-till complex |
| | | | | | 70 000 | Malone Till |
| | | | | | 125 000 | |
| | | | | SANGAMON (Interglacial) | 250 000 | (deposits presumably removed by successive glaciations and erosion) |
| | | | | (Other glacials and interglacials) | 1.8 million | |
| | | TERTIARY | | | 6.5 million | |
| | MESOZOIC | CRETACEOUS | | | 135 million | Monteregian intrusives |
| | | JURASSIC | | | 195 million | |
| | | TRIASSIC | | | 225 million | |
| | PALEOZOIC | PERMIAN | | | 280 million | |
| | | PENNSYLVANIAN | | | 325 million | |
| | | MISSISSIPPIAN | | | 345 million | |
| | | DEVONIAN | | | 395 million | Limestone blocks in breccia |
| | | SILURIAN | | | 440 million | |
| | | ORDOVICIAN | | | 505 million | Trenton, Black River, Chazy, Beekmantown — Mainly limestone, dolomite and shale |
| | | CAMBRIAN | | | 570 million | Potsdam sandstone |
| (PRECAMBRIAN) | PROTEROZOIC | | | | 2500 million | Anorthosite - (in Cartierville) Granitic and other gneisses, schist, crystalline limestone, slate, etc. - (in Oka area and the Laurentians to the north) (Some of these rocks have been folded and metamorphosed several times) |
| | ARCHEAN[2] | | | | 3700 million | (oldest dated rocks in the world) |
| | | | | | 4500 million | (presumed age of the earth) |

[1] B.P.-"Before Present." The ages given are those generally accepted by the Geological Survey of Canada; they are based on a variety of radiometric-age determinations ($^{14}C$, K/Ar, Pb/Sr, U/Th/Pb) and partly on biochronological evidence.

[2] Subdivided by some authors into Pre-Archean and Archean, the latter being applied to the time of dated rocks only.

They form a chain of hills known as the Monteregian hills, which extend from Oka, west of Lac des Deux Montagnes, eastward to the Appalachian Highlands. Mont Royal is one of these hills; it is referred to as a stock of alkaline igneous rock and is described in great detail by Gélinas (1972). Smaller bodies of this igneous rock are scattered widely over the eastern part of Montreal Island, but they are now largely concealed by urban development.

## SURFICIAL GEOLOGY

### Geological Setting

There are some differences in the Quaternary stratigraphy of the Montreal area and of adjoining regions; the probable interrelations between these regions are shown in Table 2. All surficial deposits observed on Montreal Island are considered to be of Wisconsinan age. The oldest soil is a lodgment till believed deposited by the Laurentide part of combined Laurentide and Appalachian ice which moved southwestward up St. Lawrence River valley. Overlying this is a variable complex of thin till layers and lenses, rhythmically bedded and varved glacial lake sediments, and ice-contact deposits. The latter sequence indicates an ice margin that fluctuated in and near a glacial lake. Overlying this complex is another extensive till sheet which is generally finer textured and more clayey than the older tills. It was deposited by Laurentide ice that flowed southward across the St. Lawrence Lowland.

The sequence and character of these glacial deposits resemble closely those which were exposed along the St. Lawrence Seaway canal and lock excavations in the Cornwall-Ogdensburg region (MacClintock, 1958). For this reason the geological terminology used for the Seaway construction sites in New York State also was employed for the Montreal area by Prest and Keyser (1962). Thus the Montreal Island glacial deposits, from older to younger, were termed Malone Till, Middle-till complex, and Fort Covington Till. This terminology is retained here although the last glacier advance, responsible for the deposition of the uppermost till (Fort Covington) in the Seaway sections of the Cornwall-Ogdensburg region, is reported to have had its southern terminus on the north flank of the Adirondack Mountains and to have flowed down Champlain Valley and presumably into the Appalachian Mountains of northwestern Vermont (MacClintock and Terasmae, 1960; MacClintock and Stewart, 1965). McDonald and Shilts (1971), however, considered the uppermost till (Lennoxville) in the Eastern Townships, also deposited by southward-flowing ice, to represent the last major glaciation; if so, the southern terminus of the Champlain-Hudson Valley lobe of this ice sheet was, presumably, at the terminal moraine on or near Long Island, New York.

### Malone Glacial Episode

The glaciation responsible for the deposition of the basal Malone Till in the Seaway region was referred, with some reservations, to the last or younger part of the Wisconsinan Glacial Stage by MacClintock and Stewart (1965). McDonald and Shilts (1971) considered the Chaudière Till, the seemingly equivalent till in the Eastern Townships, to be Early Wisconsinan. In any case the glacier responsible for depositing the older tills and associated ice-contact deposits of the entire region, including Montreal Island, advanced southwestward up St. Lawrence Valley, passed into the lower Great Lakes basins, and reached its terminus south of the basins. This southwestward-flowing ice in the St. Lawrence Lowland was fed by ice from the north along its entire route, and by the end of this glacial period the direction of ice flow in the Eastern Townships shifted from the southwest to the southeast (McDonald and Shilts, 1971). The southwestward-flowing Malone ice deposited a dense lodgment till, which in the Montreal area is generally stony and has a variable silty to sandy matrix.

### Interstadial Episode

The Middle-till complex was deposited during the recession of the Malone ice as it fluctuated over the Montreal region. The complex was formed when the ice thinned to the point where Mont Royal protruded above its surface as a nunatak, whereas the surrounding lowlands remained covered. Meltwaters coursed from the debris-laden, thin ice into the 'notch' between the mountain and the ice and then found their way along crevasses in the ice, or beneath the ice, to the ice front to the south and southwest[1]. Thus sandy and gravelly sediments occur around Mont Royal, especially on its southwestern side, whereas sand and gravel occur intermixed with till and with varved lake sediments in the lowland areas.

Sand and gravel were deposited also in the Dorval area at this time. A partly buried gravel ridge trends southeast across the western end of Dorval airport and continues southward along Elmridge Street to near St. Lawrence River. Its intermittent exposures, seen in 1952 at elevations between 105 and 70 feet (32 and 21 m), comprise part of an esker, that is, they were laid down in

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[1] Although Stanfield (1915) mentioned the possibility of some nonfossiliferous deposits beneath 'Leda' clay being of glaciofluvial origin, as in the Glen section through the Upper Lachine Road (Turcot) scarp, it was Byers (1949) who first described the process of deposition around Mont Royal. Earlier, all the sand and gravel were regarded as washed from pre-existing till by normal erosion and by wave action in the Champlain Sea. Byers considered the 30 to 50 foot (9 to 15 m) thickness of 'Saxicava' sand and gravel at high elevations on Mont Royal (including that part in Westmount) as too great to have been washed from till during the rapid uplift of the land following retreat of the ice. He concluded that during thinning of the last ice sheet the hilltops appeared as nunataks, and sediment was deposited between the ice and these hills. Thick deposits of stratified sediments would then readily be redistributed by the Champlain Sea. In many places he observed fossiliferous sediments overlying nonfossiliferous sediments of slightly different character. Prest furthermore has observed that much of the nonfossiliferous sand and gravel around Mont Royal is overlain by a till (Fort Covington), and hence these glaciofluvial sediments stem from the recession of the earlier (Malone) ice sheet. It is probable that the massive nonfossiliferous sand and gravel beneath the variably fossiliferous sediments around Mont Saint-Hilaire and other Monteregian hills are similarly of ice-contact origin and Malone age.

TABLE 2

LATE QUATERNARY TIME — REGIONAL CORRELATION TABLE

| Geological Period and Epoch | Glacial and nonglacial subdivisions | Trois-Rivières, Quebec region (modified from Gadd, 1971) | Sherbrooke, Que.reg. (mod. from McDonald and Shilts, 1971) | Montreal, Quebec region (Prest and Keyser, 1962) | Cornwall-Massena, Ont.-New York (mod. from McClintock, 1958) | Age in Years Before Present (not to scale) | "Alternative" Age Relations, Montreal-Cornwall Region |
|---|---|---|---|---|---|---|---|
| QUATERNARY, HOLOCENE | Recent | Bog deposits<br>Windblown sand<br>Low terrace river sand<br>High terrace river sand | Bog deposits<br>Windblown sand<br>River sediments | Pond and bog deposits<br>Windblown sand<br>Early St. Lawrence R. and estuarine sediments | Bog deposits<br>Windblown sand<br>St. Lawrence River sediments | 0 – ca. 9500 | Postmarine |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Late, Champlain Sea Episode | Champlain Sea sediments (and St. Narcisse moraine deposits) | Champlain Sea sediments | Champlain Sea sediments (minor intercalated till) | Champlain Sea sediments | 10 000 – ca. 12 500 | Marine |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Late, Gentilly Stade | Glacial lake sediments | Glacial lake sediments | Glacial lake sediments | Glacial Lake Vermont sediments | ca. 13 000 | Glacial lake |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Late, Gentilly Stade | Gentilly Till | Lennoxville Till | Fort Covington Till | Fort Covington Till | ca. 23 000 | Readvance<br>Recession<br>Glaciation |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Middle, Gentilly Stade | Gentilly Till | Glacial Lake Gayhurst sediments | Glacial lake sediments<br>Middle-till complex (upland and lowland phases) | Glacial lake sediments<br>Middle-till complex | | (Bedrock) |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Middle, Gentilly Stade | Glacial Lake Deschaillons Sediments | Chaudière Till | Malone Till | Malone Till | 60 000 to 70 000 | |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Early, St. Pierre Interstade (Interval) | St. Pierre nonglacial sediments | Massawippi nonglacial sediments | (Bedrock) | (Bedrock) | 70 000 to 90 000 | |
| QUATERNARY, PLEISTOCENE | Wisconsinan, Early, Bécancour Stade | Glacial lake sediments<br>Bécancour Till<br>Glacial lake sediments | Johnville Till | | | ca. 125 000 | |
| QUATERNARY | Pre-Wisconsinan | | Pre-Johnville sediments | | | | |

a subglacial tunnel which carried meltwater from the Malone ice southward to a mid-Wisconsin ice front in a glacial lake[1].

The intricate relationships between glacial, glaciofluvial, and glaciolacustrine deposits on Montreal Island attest to the presence of glacier ice, glacial streams, and a glacial lake. The presence of a glacial lake on, and south of, Montreal Island at this time necessarily implies great thinning of the continental ice and consequent retreat of the ice margin; from its terminal position in the vicinity of New York City it must have receded up the Hudson-Champlain Valley and across the St. Lawrence Lowland. A somewhat similar situation has been described for the south side of the Lowland in the Sherbrooke – Thetford Mines region (McDonald and Shilts, 1971). Here, however, the ice occupied most of St. Lawrence River valley and still blocked the northern end of the Lake Champlain basin. It dammed a high-level glacial lake in the northern part of the Appalachian Mountains, for at least 4000 years. This lake (glacial Lake Gayhurst) drained eastward to Maine and New Brunswick (McDonald and Shilts, 1971). Prest herewith considers that, as the ice withdrew from the Lake Champlain basin and receded to the Montreal area, a lower, short-lived glacial lake occupied much of St. Lawrence River valley and discharged southward via the Lake Champlain-Hudson Valley. The ice front must have fluctuated in this glacial lake as several layers of till occur in the Montreal area, intercalated with rhythmically bedded and generally varved silty clays and with sandy sediments.

The amount of thinning and recession of Malone ice necessary for the deposition of the Middle-till complex in Montreal and Cornwall areas implies a major climatic change following the main Malone glaciation. This 'warm' interval between the Malone and Fort Covington glaciations is considered here to be a mid-Wisconsinan interstadial. In southwestern Ontario this event is known as the Port Talbot Interstadial, and its deposits, including vegetal and animal remains, indicate a cool temperate climate from about 55 000 to 25 000 years B.P.[2]. In the Toronto region the Thorncliffe sediments, with a sparse organic record, include some thin till lenses indicative of nearby glacier ice (Karrow, 1967, p. 34-36). The Thorncliffe Formation is believed to represent the nonglacial interval from about 50 000 to 30 000 years ago. In the Eastern Townships of Quebec, as mentioned above, a high-level glacial lake existed for at least 4000 years; limited vegetal remains extracted from its sediments (Gayhurst Formation) gave a radiocarbon age of more than 20 000 years B.P. (GSC-1137), and hence these sediments were inferred to be mid-Wisconsinan (McDonald and Shilts, 1971, p. 693). Farther east, in the Bécancour-Yamaska region south of St. Lawrence River and some 50 to 75 miles northeast of Montreal, the ice sheet which deposited the Gentilly Till did not recede from the Lowland during this interstadial interval (Gadd, 1971, p. 91)[3]. It is evident, furthermore, that the ice sheet blocked the St. Lawrence Lowland on the east, otherwise all the above-inferred glacial lakes would have drained to sea level and the sea would have invaded the St. Lawrence Lowland. The Laurentide mid-Wisconsinan ice margin, therefore, likely lay against the Appalachian Highlands at a point about 50 miles south of Quebec City. It probably extended southwestward to Drummondville, westward to north of Montreal Island, and southwestward to the Toronto area.

## Fort Covington Glacial Episode

Following the mid-Wisconsinan recession of the Laurentide Ice Sheet a climatic change took place that resulted in renewed glacierization. This glacial event and the till that was deposited at this time are named Fort Covington (but see possible alternative age-relations in Table 2). The last ice sheet presumably thickened and expanded, reoccupied the St. Lawrence Lowland including Lake Ontario and Erie basins, and reached its maximum point of advance in southern Ohio about 18 000 years ago. It also flowed southward into the Appalachian Mountains and down Champlain-Hudson Valley to New York City. Alternatively the Fort Covington ice only advanced onto the flank of the Adirondak Mountains and part way down the Lake Champlain basin.

## Late-glacial and Postglacial Events

The last Laurentide ice did not remain long at its maximum extent and receded rapidly as a warmer climate ensued. The Champlain and upper St. Lawrence valleys again were occupied by a succession of glacial lakes (Iroquois-Vermont), probably from about 13 500 to 12 500 years ago. Late and low phases of this succession of lakes are poorly represented in the deposits on Montreal Island. The lake clays are mapped only in Côte-Saint-Luc area, but varved clays and rhythmites are present southeast, south, and southwest of Montreal, and west to the Ottawa area (Gadd, 1963, p. 2; McDonald and Shilts, 1971, p. 692). The lake was probably short-lived in the Montreal area. When the ice front receded at Quebec City, the last low-level glacial lake in the lower St. Lawrence Lowland was drained to sea level. As deglaciation of St. Lawrence Valley was relatively rapid, the land surface had not yet recovered from its depressed position (caused by weight of the Laurentide and Appalachian ice on the area for several thousand years); hence the valley bottom was several hundred feet below the sea level of that time, which was about 150 feet (45 m) lower than present sea level (Shepard and Curray, 1967). Thus the sea occupied much of the former lake basin and a large area that had been ice covered during the lake phase. The sea at its greatest extent reached westward up St. Lawrence Valley to beyond Brockville, though not into Lake Ontario basin, and up Ottawa Valley to near Petawawa (**see** Prest **et al.**, 1968). This body of marine water west of Quebec City is

[1] The Dorval esker is thus older than the Sainte-Philomène ridge south of Montreal and the St. Lawrence River. This latter ridge is considered to be an esker related to the recession of Fort Covington ice. It has been reworked extensively by the sea and has been an important source of sand and gravel in the Montreal region for many years.

[2] B.P. – "Before present", refers to the year 1950. Ages have been determined by radiocarbon analyses of organic materials contained in the nonglacial sediments and are given in 'radiocarbon years', which may not correspond exactly to calendar years.

[3] Older nonglacial sediments, overlain by glacial lake sediments, however, are present in this area; these are referred to as the St. Pierre sediments and the Deschaillons sediments, and were formed 70 000 to 60 000 years ago, before the main early Wisconsinan ice had fully occupied the Lowland.

Figure 2

River-cut scarp, Boulevard St. Johns, Pointe Claire north of railway. The upper level surface is at elevation 150 feet (48 m), the lower terrace here is at 120 feet (35 m). View is to the west, 1952. (GSC-165130)

referred to as the Champlain Sea (Gadd, 1964, 1971), and its continuation farther east is termed the Goldthwait Sea (Elson, 1969).

Champlain Sea deposits relate to the close of the last glacial episode while ice was still present in the region. The retreating Laurentide and Appalachian glaciers calved into the sea in many places. A readvance of Laurentide ice constructed an end moraine system that to the north and northeast of Montreal Island was built in the sea. This system is known as the St. Faustin – St. Narcisse moraine (Parry and MacPherson, 1964). On Montreal Island, however, evidence of glacial ice during the marine episode is limited mostly to ice-rafted boulders and pods or pockets of till and till-like materials which were presumably emplaced in marine clay as debris-laden icebergs and shore ice melted in the sea. Only south of Metropolitan Boulevard (Highway 40) near Pie IX Boulevard are there extensive layers of till intercalated with unctuous or 'fatty' marine clay (Fig. 1). The till layers are regarded as 'flowtill', that is, glacial debris that has slid from the glacier at or near the ice front and has been transported as a slurry along the seabottom. The mixed layers or lenses of till and marine clay were seen both east and west of Pie IX Boulevard, but only to the east was it possible to study the intricate relationships. Several pink bands, common in sections of Champlain Sea clay, were noted here in the normally grey clay and associated flowtill. Marine shells were seen only in one place in this area of mixed lithologies.

Due to isostatic uplift of the land and to the tilting of the land surface northward in the direction of ice retreat, the shorelines and beaches of the Champlain Sea are found in elevated positions and rise northward. The highest marine strandline west of Lake Champlain, at Covey Hill, Quebec, is at an elevation of 523 feet (160 m) (Goldthwait, **in** Gadd, 1971, p. 128); on Mont Royal it is about 565 feet (170 m) (Prest, 1957, p. 470); and in the Laurentians north of Joliette, it is as high as 750 feet (230 m) (Prest, 1970, p. 726). At the time of its maximum extent the Champlain Sea was probably about 55 miles wide between the Laurentians and the Adirondaks along a north-south line through the western end of Montreal Island (Prest **et al.**, 1968). It was, of course, much wider both east and west of this constriction. As uplift of the St. Lawrence Lowland took place the Champlain Sea was increasingly restricted, and shorelines developed at successively lower elevations. On Montreal Island marine shells in shoreline sand and gravel deposits generally are restricted to elevations between the marine limit of 565 feet (171 m) on Mont Royal and a lower surface which slopes northeastward; this surface begins at elevation 170 feet (52 m) on the western side of Mont Royal in Hampstead and drops to elevation 135 feet (41 m) some 5 miles (8 km) off its northeastern side. Marine terraces and distinct shorelines were no doubt obvious on Mont Royal prior to extensive urbanization, but at present it is difficult to identify them. Terrace scarps and beaches may be recognized in a few places, however, such as on the north and west sides of Mont Royal, on the gentle west-sloping surface between Côte-des-Neiges Road and Décarie Boulevard, and in places near Côte-Sainte-Catherine Road in Outremont.

Continuing isostatic uplift of the land brought about a northeastward withdrawal of the sea and the consequent inception of estuarine conditions. The transition from open sea, through a brackish-water estuary with pronounced directional current, began when the land rose above sea level of that early time; this transition point on the island is now at about elevation 170 feet (52 m) in the town of Hampstead. The higher part of Montreal Island was then an island in the mouth of a 25-mile-wide (40 km) estuary. A terrace scarp and an intermittent strand of sand between Hampstead and Montreal West mark this nonmarine shoreline, the first evidence of the earliest St. Lawrence River on Montreal Island (**see** Map 1426A). Northeast of Mont Royal a strand of nonfossiliferous sand and a small scarp occur along the west side of the valley of the now defunct Molson Creek, east of Parc Maisonneuve and north of Sherbrooke Street, where it is about elevation 135 feet

Figure 3

Glacial boulders from excavations for housing development, Filion and Deguire Streets, Ville Saint-Laurent. The profusion of boulders provides a measure of the character of the till. View southward along Filion Street. (GSC-165052)

Figure 4

Sand lens in stony Malone Till, Tulip Avenue, Dorval. Several thin lenses were noted along the sewer line cut; this one was traced for about 30 feet (10 m); others were traced for 40 to 70 feet (12 to 21 m). (GSC-165065)

(41 m). This 35 foot (10.5 m) difference over a distance of about 10 miles (17 km) results from a combination of the early stream gradient and the amount of erosion that took place while the freshwater/saltwater interface migrated the 10 miles (17 km) northeastward. The same river-cut scarp may be identified on the southern flank of Mont Royal, as along St. James Street in the west and Sherbrooke Street in the east, but in large part it was truncated by a later stage of river erosion that was responsible for the main Turcot (CNR yards) scarp.

As the land continued its rise above sea level, the freshwater-saltwater interface migrated farther northeastward, and the width of the sea was greatly reduced. By the time the land surface, at present elevation 100 feet (30 m), reached sea level, most of Île-Jésus and Montreal Island were exposed and the sea (estuary) was separated into a number of arms. Narrow arms occupied the valleys of Rivière des Mille Îles and Rivière des Prairies, and the main sea arm, now only 15 miles (25 km) wide, lay to the southeast of Montreal Island. South of Gouin Boulevard in eastern Montreal North, river sand and fine gravel are interbedded with pink and grey marine clay at an elevation of 55 feet (17 m). This indicates that estuarine conditions prevailed prior to the downcutting that developed the Gouin Boulevard scarp between elevations 65 and 40 feet (20 and 12 m) in this locale. Estuarine conditions terminated when the northeastern tip of Montreal Island rose above sea level. Some 20 feet (6 m) of uplift has taken place since that time, and the estuary has migrated eastward to Quebec City.

Therefore, as noted above, all shore features above elevation 170 feet (52 m) on Montreal Island are marine-littoral (Champlain Sea), whereas below a northeastward sloping surface passing through this altitude in Hampstead, they are fluvial-channel in origin. Thus Prest considers all the erosional features between elevations 170 and 20 feet (52 and 6 m) on Montreal Island to be the work of rivers rather than the sea. This is the early St. Lawrence River episode. This interpretation contrasts with other reports that these scarps and bluffs are marine features related to "standstills" of the sea (Goldthwait *in* Gadd, 1971, p. 141; MacPherson, 1967).

Prominent river-cut scarps may be viewed on Île-Perrot, in Pointe-Claire (Fig. 2), Ville LaSalle, Montreal North, and also along Sherbrooke Street east of Mont Royal. The most prominent scarp on Montreal Island is that on the southeast side of St. James Street and

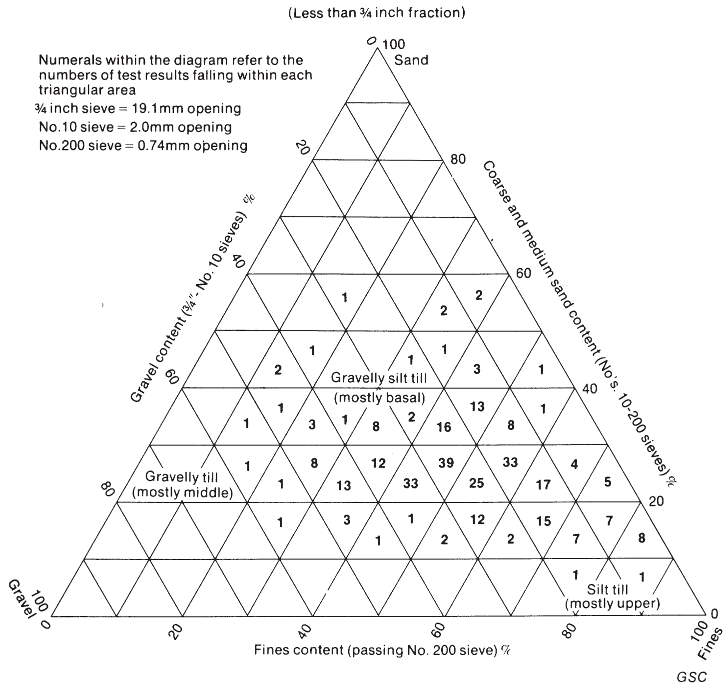


Figure 5. Sieve test results on 320 samples of Montreal area till.

referred to above as the Turcot scarp. It is a multiple scarp cut over an extended period of time from the inception of river erosion, about 10 000 years ago, until the river abandoned the Turcot flats at elevation 60 feet (18 m) and took up its present position farther south about 4000 years ago[1].

Following the river phase of deposition over what is now Montreal Island, numerous pond and bog areas remained in which pond clay, marl, sapropel and/or peat were deposited[2]. In some places the peat rests on bedrock, on glacial till, or on marine clay, but elsewhere it rests on intervening pond clay, marl, or sapropel.

The only deposits younger than the peat are the present-day river and stream sediments; these are too closely confined to their channels to be shown on Map 1426A. A major flooding of unknown antiquity, however, did deposit a layer of sand and minor gravel on top of peat in the Tulip Crescent area of Dorval, some 25 to 30 feet (7.5 to 9 m) above present river level. The flood deposits were washed from adjacent knobs of much older ice-contact deposits.

[1] Pollen studies of basal gyttja and peat in Lachine indicate that the organics began to accumulate 4000 to 5000 years ago according to J. Terasmae (unpublished GSC Palynological Report).

[2] The term marl is used here for whitish-grey calcareous clay, laden with freshwater shells. The term pond clay refers to a soft, light-weight, greenish grey, noncalcareous clay that generally contains remnants of algae and other pond plants. Sapropel is a jelly-like ooze composed of algae with some other plant materials and minor admixed mineral matter.

## SURFICIAL DEPOSITS (SOILS)

### Malone Till

The Malone Till is generally a dense, stony material with a silty to sandy matrix. The stones range in size from tiny pebbles to huge boulders; those with lengths of more than 3 feet are common and in places they are much larger. Generally the largest boulders are limestone or dolomite derived from the local lowland strata and not transported far from their source; but large boulders derived from Precambrian rocks of the Laurentian Highlands also are present (Fig. 3).

On Montreal Island the Malone Till rests on bedrock. The possibility of older deposits intervening between Malone Till and the bedrock, however, should be kept in mind during drilling or major construction operations. Older till and other sediments have been identified in the Sherbrooke – Lennoxville area (McDonald and Shilts, 1971). Alternatively, on Montreal Island, the till considered to be basal or lodgment Malone Till in places may be a till layer or lens within the Middle-till complex. It is less likely that the younger Fort Covington Till was mapped as Malone Till (where stratigraphic information was lacking) although in some places it is also very stony and has a silty to sandy matrix. Generally speaking, however, a stony, silty to sandy lodgment till, which is commonly 3 to 10 feet (1 to 3 m) thick, may be inferred to be Malone Till (Fig. 4).

Laboratory studies show that the basal Malone Till is generally well graded and consists of up to 40% stones greater than 3/4 inch (19 mm) size. In the fraction less than this size (see Fig. 5), 10 to 50% is pebbles and 15 to 40% is coarse and medium sand; the finer material rarely exceeds 70%. Although fines range between 30 and 60% the clay fraction (<0.002 mm) of the 136 samples tested ranges only from 1 to 12% with a mean value of 6%. The liquid limit[3] determined on samples of fines ranged from 13.2 to 22.4% with a mean of 15.4%. The plasticity index ranged from 1.8 to 4.8% with a mean of 3.2%.

The in situ properties of coarse grained lodgment till are shown in Figure 7. Histogram (b) shows that the density or unit weight generally ranges between 135 and 155 pcf (2.16 to 2.48 g/cm$^3$), which is about 110 to 130% of the laboratory density as determined by the AASHO's standard method. The in situ water content shown in histogram (c) generally ranges from 6 to 14% with an average of 9.6%. Owing to its high bearing capacity and high shear strength, the well compacted Malone Till commonly is termed "hardpan" by drillers and contractors. In places it is almost as resistant as bedrock when confined and not overly wet. Histogram (a) shows that the standard penetration value "N" is generally higher than 30 blows per foot of penetration of the standard split-spoon sampler. Numerous unconfined compressive tests performed on these tills yielded average strength values between 3 and 4 tons per square foot (approximately 320 to 430 kN/m$^2$)[4].

The influence of water content on the CBR strength values of samples of lower till are shown in Figures 8 and 9. It may be seen that (a) for unsoaked

[3] See Appendix for definition of engineering terms.

[4] kN/m$^2$ = kilonewtons per m$^2$; 1 newton – 1 kg force acting through 1 m per sec$^2$.

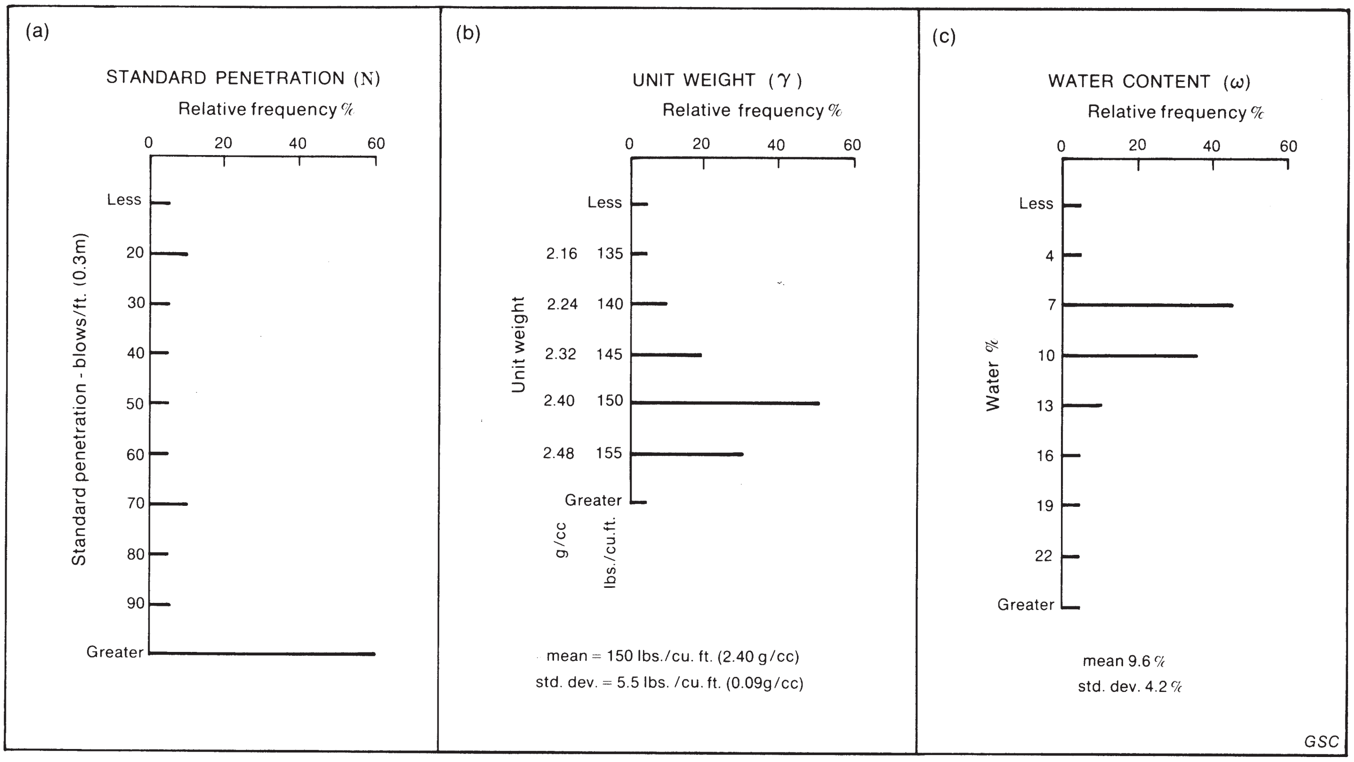


Figure 7. In situ properties of coarse grained till, Montreal area.

specimens the CBR is above 100% provided that the water content is kept below optimum and (b) there is a definite peak strength value for soaked specimens. This peak value is obtained when the till is compacted at or near its optimum water content; a slight increase or decrease in water content during the compaction can affect the soil strength drastically after a four day soaking period.

The high boulder content of the lodgment till makes it desirable, when compacting till embankment or backfill, to use heavy rollers (ca. 50 tons) and to employ 12 to 18 inch (30 to 46 cm) lifts where boulders range between 6 and 12 inches (15 to 30 cm). Experience shows that it is nearly impossible to compact the excavated till when the water content is above optimum, because of its low strength value and also because of the formation of spongy pockets in the almost impervious silty matrix.

## Middle-till Complex

This term applies to a highly variable mixture of stony, silty, and sandy tills commonly interlayered with well stratified gravelly to silty sediments and with massive structureless silt and fine sand lenses. The complex overlies basal (lodgment) Malone Till (Fig. 10). The Middle-till complex was well displayed in foundation sites and in excavations for services during the 1951 and 1952 urban development programs in Ville LaSalle and in Montreal North (Fig. 6). The complex probably was deposited at or close to the fluctuating margin of the Malone ice sheet during a short and late part of the mid-Wisconsinan interval. Thickness ranges from a few feet to many tens of feet. The complex may be conveniently divided into an upland and a lowland phase (Prest and Keyser, 1962). The upland phase predominantly is composed of well stratified silt, sand, and gravel (Fig. 11), whereas the lowland phase is made up mainly of

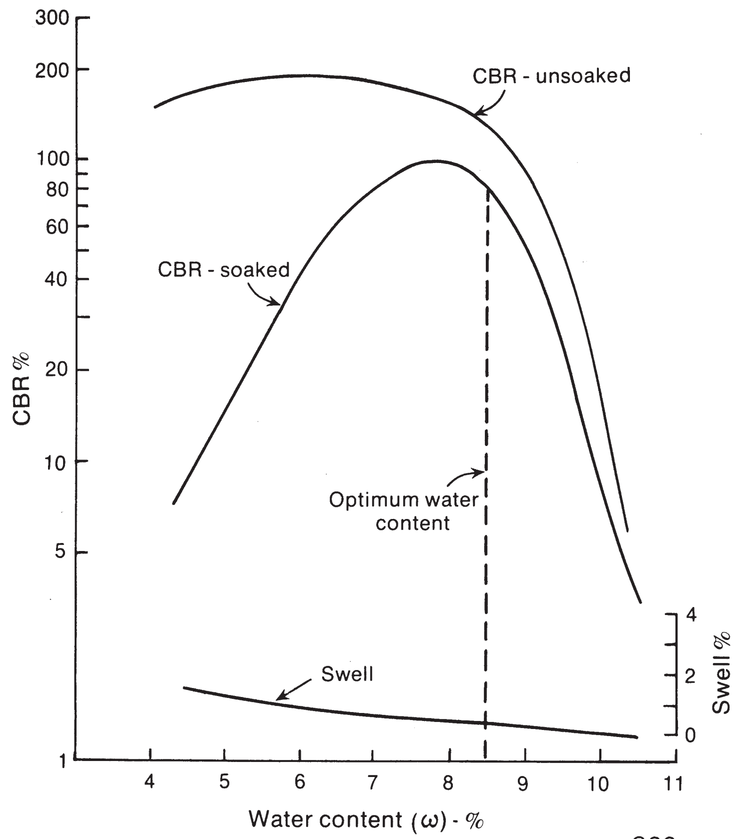


Figure 8. Relationship between water content, CBR, and swell for coarse grained till.

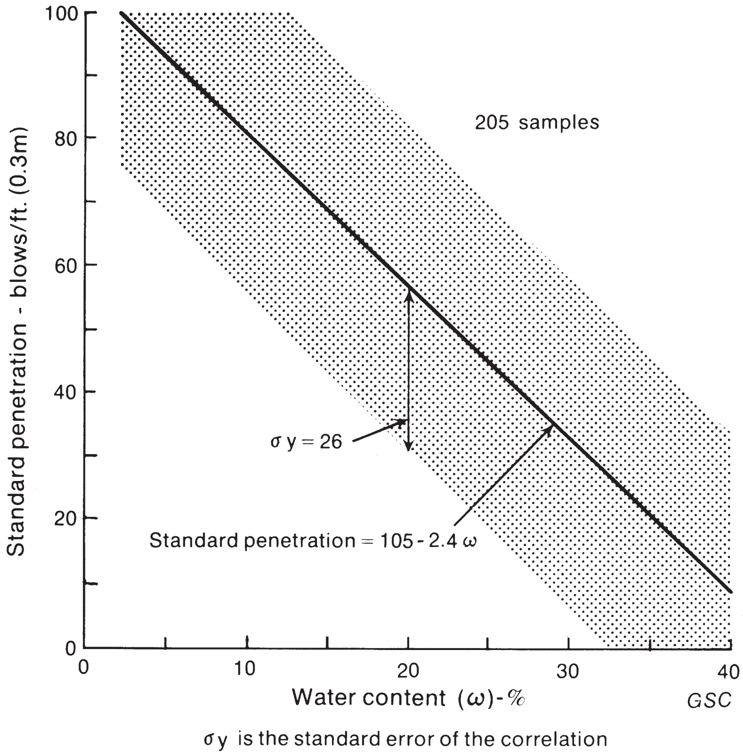


Figure 9. Influence of water content on standard penetration — coarse grained till.

Figure 10. Excavation for trunk sewer (1951) on Compte Street near Newman Street and Canadian Pacific Railway crossing, Ville LaSalle. The 35-foot deep trench reveals irregular lenses of massive silt up to 8 feet thick between stony tills. Only the lower part of the silt displays stratification; the beds overlie a concentration of angular stones at the contact with the lower till. The exposure is considered to be Middle-till complex over basal Malone Till. (GSC-165127).

rhythmically bedded finer sediments, massive silt, and fine sand (as lenses and pods), and interlayered till (Fig. 12). The upland phase sediments reach an elevation of about 175 feet (53 m) on the terrace surface at the top of the Turcot scarp and probably underlie younger marine deposits on Mont Royal to many tens of feet above this level. Their lower limit is not known; they probably merge into sediments of the lowland phase. The latter, which consist of rhythmically bedded and massive fine grained sediments with associated sand, gravel, and till layers, occur only below elevations of 125 feet (38 m) in both Montreal North and Ville LaSalle. Further information on the upland and lowland phases of the complex is given by Prest and Keyser (1962, p. 23-27).

Both the upland and lowland phases of the Middle-till complex contain thin beds of a rather soft, seemingly weathered, shale-rich gravel, which is, in places, interbedded with nonshaly gravels of fresher appearance. The weathered or 'old' appearance of the shale gravel may relate solely to its composition rather than, in part, to its age. The shale stones tend to be ovoid to discoid and seldom are more than 4 inches (10 cm) in size. The shale gravel is widespread in Montreal North. It was seen in many excavations west of Pie IX Boulevard within the quadrangle formed by Monselet, Martial, Plaza, and Coburg 'streets' (Fig. 14) between elevations of 100 and 125 feet (30 to 38 m) and in several places in Ville LaSalle at elevations below 120 feet (37 m). It was seen also within the upland phase of the complex, notably at the foot of Orchard Street on the top of the Turcot scarp at an elevation of 160 feet (49 m).

The thin till layers and lenses, commonly intercalated with rhythmically bedded sediments of the lowland phase of the Middle-till complex, closely resemble the basal (lodgment) Malone Till. In some places, however, the till layers show a substratification or grade laterally or vertically into stratified sediments. The individual till layers range from about 1 to 6 feet (0.3 to 2 m) in thickness. Generally the more massive units do not present problems during excavation work, but a streaky and sandy till-like unit beneath a more stony and massive capping of till in Ville Saint-Laurent did slump rapidly when encountered beneath the local water table (Fig. 15). The stratified and massive silt and sand units of the lower phase of the complex, however, frequently give trouble during excavation work below the water table for they become a 'quicksand'. Tunnelling operations for a 14-foot (inside diameter) collector sewer along Tolhurst Street in northern Montreal required 17 pounds air pressure (117 kPa)[1] to stabilize finely stratified silt and fine sand. Massive silt and fine sand units up to about 35 feet (10 m) thick were seen in Montreal North and in Ville LaSalle; these appear to have been rapidly dumped or slumped into standing bodies of water. The intertill rhythmically bedded clayey silt layers of the lowland phase of the complex are rarely more than about 6 feet (2 m) in Ville LaSalle and Montreal North. Generally the rhythmites are flat lying but locally are contorted due to

[1] kPa = kilopascal — a unit of pressure; 1 psi = 6.895 kilopascals.

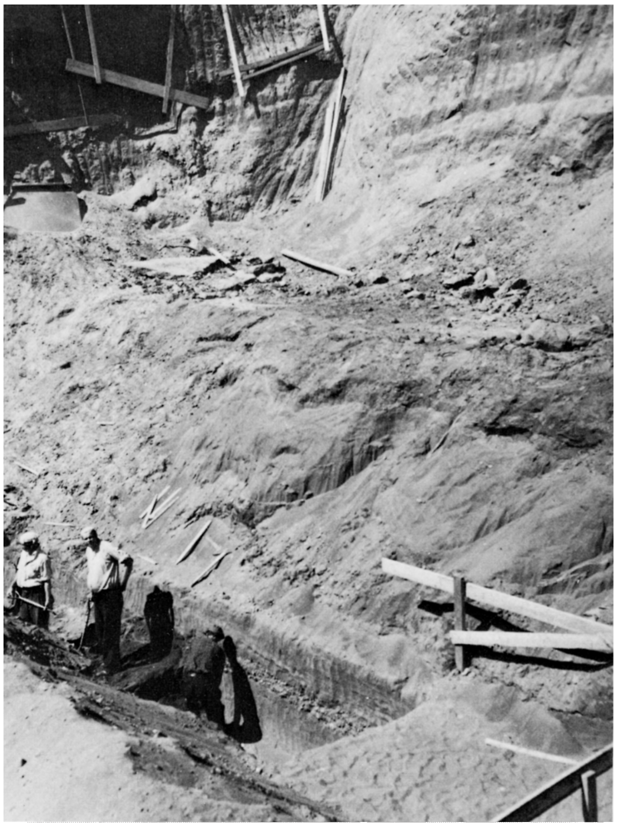

Figure 11. Cutbank in Turcot scarp; Glen Road, Westmount. The section reveals 30 feet of stratified silt, 4 feet of sand, 3 feet of silt, 3 feet of sand, 8 inches of pebble gravel, and 3 feet of sand. Cross-bedding dips to the southwest. All the materials are considered as the upland phase of the Middle-till complex. Marine clay overlies these materials nearby on top of the scarp. View to north. (GSC-165114)

slumping or, perhaps, to shove by glacier ice. Elsewhere they are truncated by layers of stony till. As might be expected under ice-marginal conditions, both the occurrence and the stratigraphic relations of the mixed lithologic units are very irregular over short distances.

The uppermost and youngest unit of the lowland phase of the Middle-till complex is a varved silt and clayey silt formed in a glacial lake at the time of the maximum retreat of Malone ice during the Mid-Wisconsinan interstadial interval and immediately prior to the readvance of the last or late Wisconsinan ice sheet. It was exposed in many excavations in Montreal North, where it was commonly 5 to 10 feet (1.5 to 3 m) thick and locally at least 15 feet (4.5 m) thick. The varves average 2 to 4 inches (5 to 10 cm) in thickness and consist of an uppermost 1/2 to 3/4 inch-thick clayey layer resting on a well laminated silt. The laminations show best as the material dries, but the repetition of clayey (winter) layers is apparent in fresh cuts. Varved clay-silt beds up to about 20 feet (6 m) thick also were seen in Ville LaSalle beneath an upper till unit, and thinner deposits were found westward as far as the Dorval area

The in situ properties of glacial lake silt deposits are illustrated in Figure 16: histogram (a) shows the standard penetration values which range from less than 10 to 80 with an average of 38 blows per foot; histogram (b) indicates the unit weight which ranges between 125 and 140 lb./cu. ft. with an average of 135 lb./cu. ft.; and histogram (c) indicates the range of water content values with a mean of 19.2%.

The influence of water content on standard penetration is shown on Figure 17. It is interesting to note that the slope of the line is similar to that for lodgment till.

## Fort Covington Till

The Fort Covington Till or 'upper till' on Montreal Island is a variably clayey silt till that is seldom stony (Fig. 18). It includes some substratified drift related to the advance of the last ice sheet to cover the region. For example, an excavation in a river-cut scarp south of St. Patrick Street and east of Dollard Avenue exposed the basal-type (lodgment) till overlying 18 feet of

Figure 12

Services excavation along Smith Street, 835 feet east of Lafleur Avenue, Ville LaSalle. Photo shows a concentration of angular stones between two 'middle' tills. (GSC-165159)

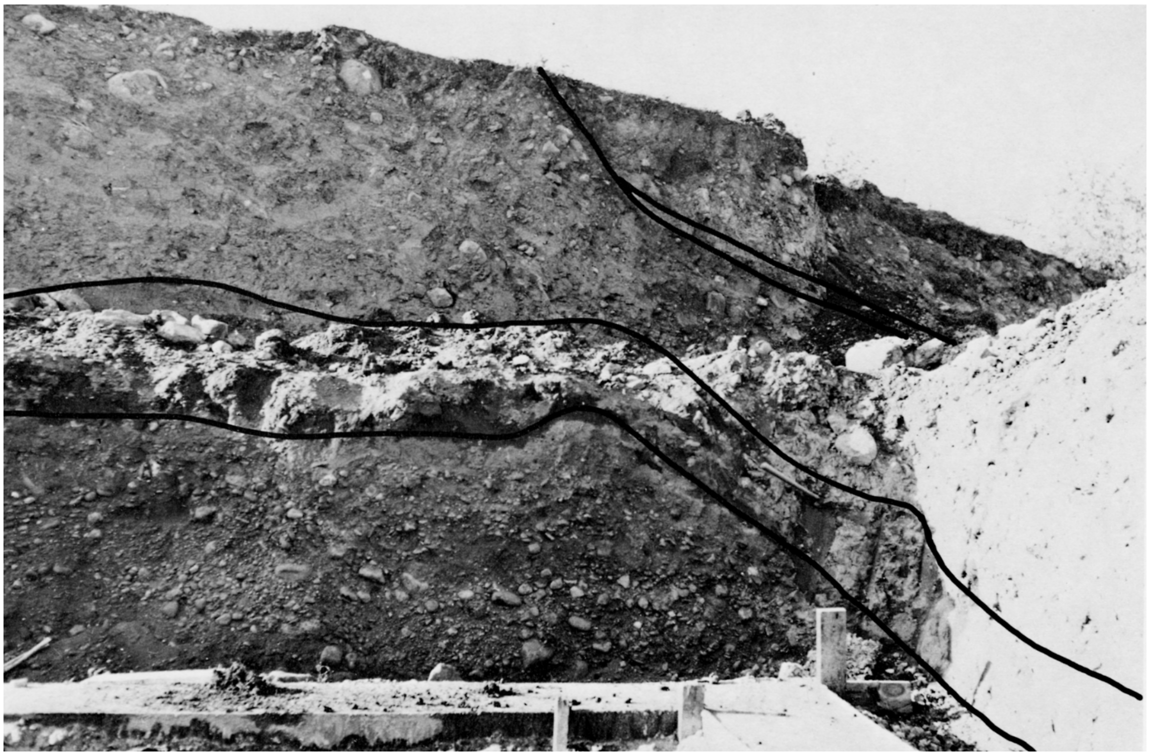

Figure 14. Stratigraphic section exposed in excavation in knoll (not indicated by elevation contours on existing Maps) on west side Avenue Laurentides between Martial and Monselet Streets, Montreal North. Alluvial gravel overlies marine clay over till over stratified silt over shale gravel; the units represent the early St. Lawrence River, Champlain Sea, Fort Covington, and Middle-till complex events.

Figure 15

Services excavation on Clément Street west of Filion Street, Ville Saint-Laurent. Photo shows 2.5 feet of stony till resting on substratified sandy material with scattered stones. At the 8 to 9 foot depth this material behaved as a 'quicksand'. The entire section is probably Middle-till complex. (GSC-165097)

substratified but similar drift (Fig. 19). A nearby cut exposed this same substratified drift overlying 6 feet (2 m) of well bedded (varved) clayey silt. It is evident that Fort Covington ice advanced into a glacial lake and deposited the substratified drift before overriding the area and depositing the upper lodgment till. Near Boulevard Henri Bourassa in the north end of Montreal, however, the upper till is relatively stony and directly overlies more than 10 feet (3 m) of varved clayey silt (Fig. 20).

In general the stones in the upper lodgment till are small pebble to cobble size, but locally where the Fort Covington ice scoured Malone Till or bedrock, rather than fine grained sediments the till is remarkably bouldery and may be mistaken for a Malone till. Based on stratigraphic evidence at any specific site, it may be mapped for some distance from this site or even recognized in excavations where it rests on an older till or on bedrock. Some of these occurrences are indicated on the surficial geology map (Map 1426A).

Grain size analyses (Fig. 5) of a large number of upper till samples suggest that (a) the till is generally fine grained; (b) it has few stones or particles greater

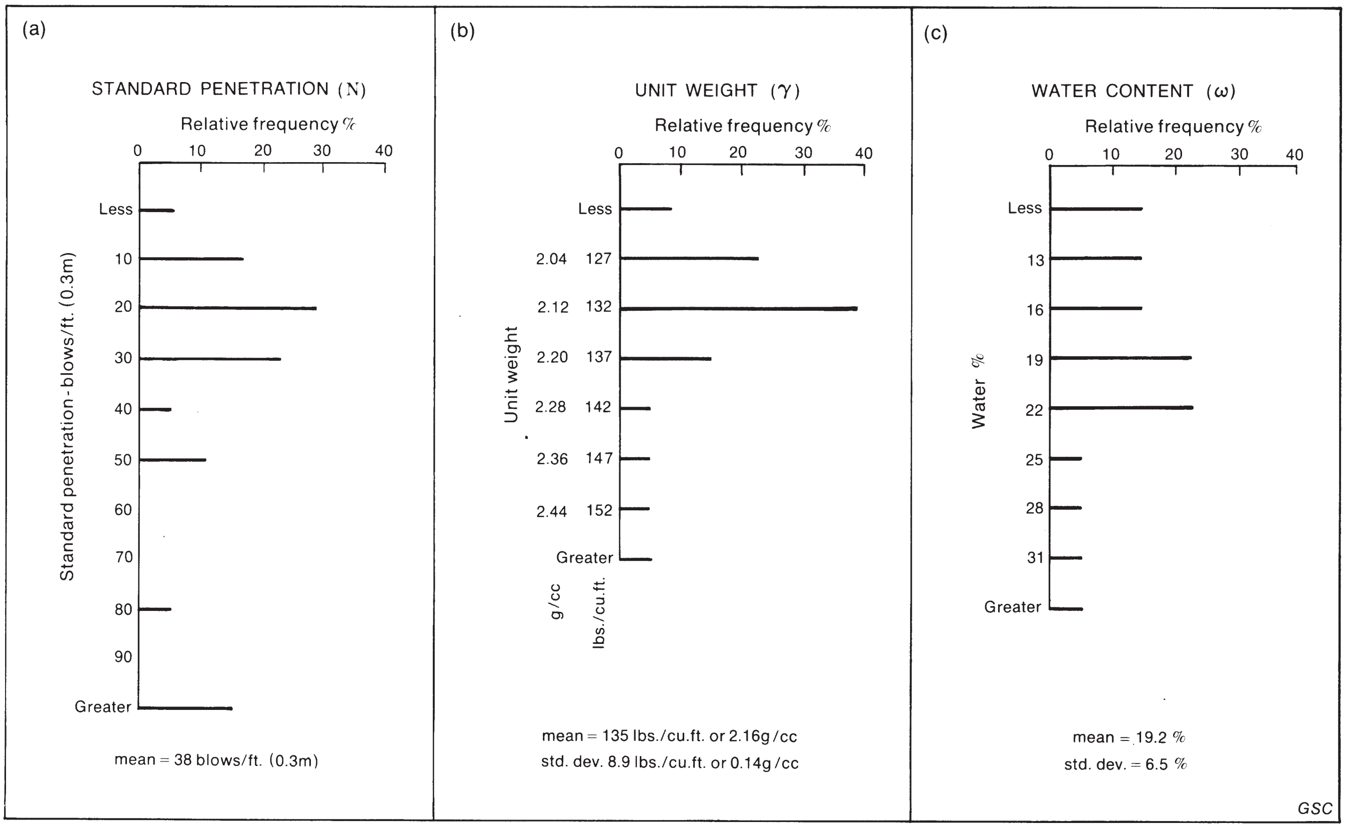


Figure 16. In situ properties of dense glacial lake silt, Montreal area.

than 3/4 inch (19.1 mm) size; (c) the fraction less than 3/4 inch size contains rarely more than 20% particles retained on the No. 10 sieve (2 mm opening); and (d) it has more than 60% fines or particles passing the No. 200 sieve (0.074 mm opening). Hydrometer analysis of 12 samples yielded a clay fraction which ranged from 4 to 14% with a mean value of 7%. Atterberg limits on fine grained till yielded liquid limit values ranging from 24 to 38% and plasticity index values ranging from 6 to 18% with corresponding mean values of 32 and 12%.

The in situ properties of the upper till are shown on Figure 21: histogram (a) shows that the standard penetration ranges from less than 10 to more than 100 blows per foot; histogram (b) indicates that the in situ unit weight of upper till generally ranges between 120 and 155 pcf (1.92 to 2.48 g/cm$^3$) with an average of 141 pcf (2.26 g/cm$^3$) (about 110 to 130% of the laboratory maximum density); histogram (c) shows that the water content is generally above the optimum content and ranges between 7 and 25% with a mean of 14.4%. The influence of water content on standard penetration is shown in Figure 22; the slope of the median line is almost identical to that for dense glacial lake silt (cf. Fig. 17).

The Fort Covington lodgment till is usually structureless but locally, in shallow cuts, it displays a rough, horizontal fissility. This discontinuous flaky structure probably is caused by ice segregation during the winter. Local investigations of frost action in the till indicate that both ice segregation and frost heave often occur (Prest and Keyser, 1962, Fig. 5 and Plate 5). Over a full winter, pavement laid on the upper till heaved from 0.7 to nearly 2 inches. It also was noted that both heaving and rate of settlement varied from place to place.

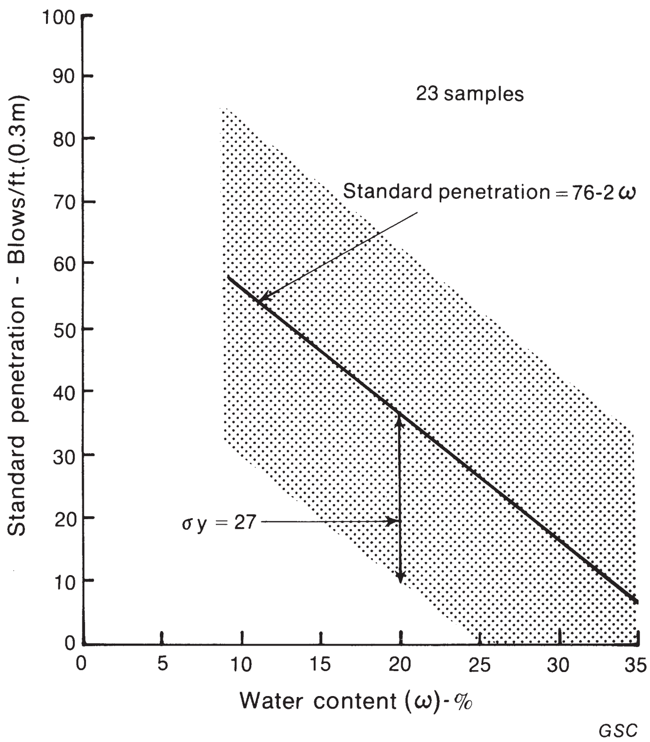


Figure 17. Influence of water content on standard penetration — glacial lake silt.

The CBR swell, and moisture content of samples of typical upper till are shown in Figure 23. Examination of the figure reveals that (a) in contrast to the lower till (cf. Fig. 8) practically no peak value is provided by the variation in water content before the soaking period, even if the water content in the sample during the compaction is beyond the optimum value; and (b) a relatively high swell value is obtained. As can be expected, high CBR values are obtained with unsoaked specimens because the upper till is generally well graded.

The relationship between standard penetration (N) and the unit weight of upper and lower tills and of silt is shown in Figure 24. It indicates that the standard penetration of coarse grained till is influenced most by unit weight, whereas the standard penetration value of dense glacial lake silt is practically unaffected by the unit weight. This shows that the standard penetration increases with stone content (silt 0%; upper till 5 to 25%; lower till 45 to 70%).

Figure 18

Services excavation along Smith Street, 500 feet east of Lafleur Avenue, Ville LaSalle. Photo shows Fort Covington Till overlying a stony middle till. (GSC-165158)

Figure 19. Cutbank in St. Patrick Street scarp, near railway spur-line east of Dollard Avenue, Ville LaSalle. Section reveals thin alluvium over 7 feet of till, overlying 18 feet of substratified drift, which in turn rests on varved clayey silt at 'ground' level. Both the till and the substratified drift are considered Fort Covington age. (GSC-165141)

Figure 20. Till overlying varved clayey silt in Meilleur Street collector sewer cut (1953) at Dazé Street, north end of Montreal. Fifteen feet of variably stony Fort Covington Till overlies more than 6 feet of glaciolacustrine clayey silt beds. View to the north. (GSC-165173)

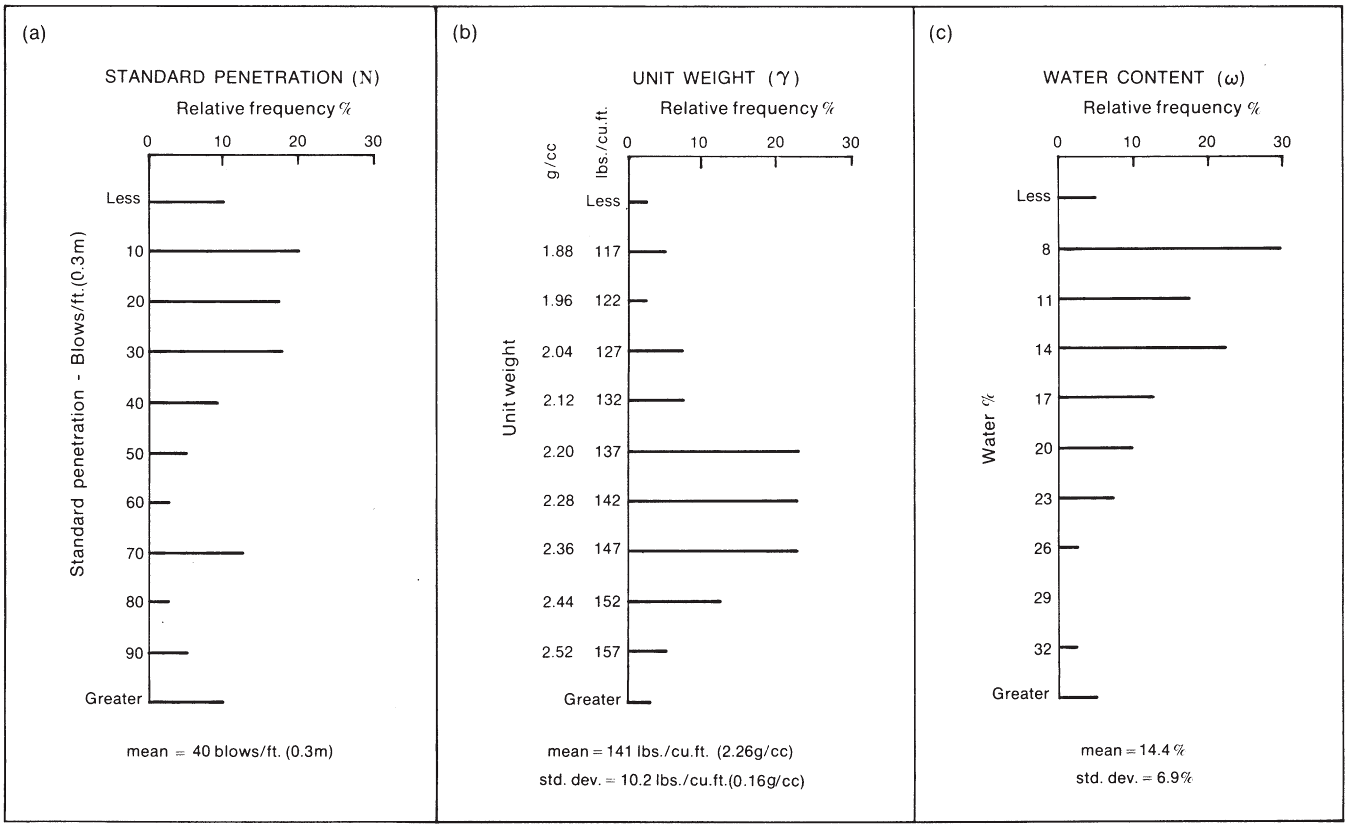


Figure 21. In situ properties of fine grained till, Montreal area.

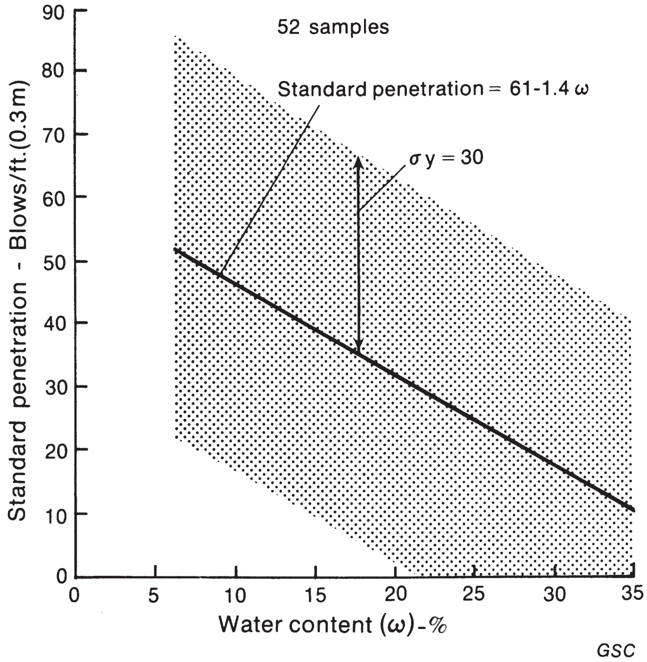


Figure 22. Influence of water content on standard penetration — fine grained till.

## Younger Glacial Lake Deposits

Apart from the varved silty clay deposits of the Middle-till complex, glacial lake deposits are scarce on Montreal Island. In other words, there is scant evidence of a glacial lake during retreat of the Fort Covington ice sheet. Stratified silt and clay, believed to have been deposited in a lake immediately prior to the invasion of the St. Lawrence Lowland by the Champlain Sea, have been mapped only in the Côte-Saint-Luc area although they also are present in Ville LaSalle and south of the International Airport at Dorval. In Côte-Saint-Luc there are several feet of horizontal or slightly contorted, well bedded, light grey silt and clay. Nowhere is the deposit distinctly varved although well bedded silt layers up to a foot or more thick are separated by 0.1 to 0.3 inch pale grey clay beds. The beds do not resemble the drab, dark grey rhythmites and varved sediments of the Middle-till complex and do not appear to be as well compacted. They are unlike also in that they contain some pollen of spruce, pine, and birch. R.J. Mott (pers. comm.) considers this pollen to result from long-distance transport, but its presence nevertheless suggests that this deposit is unrelated to the Malone sediments on Montreal Island which are nearly devoid of pollen. The known distribution of lake deposits in Côte-Saint-Luc is indicated on Map 1426A, but in large part they are concealed by marine clay.

The flat-lying and contorted silt and clay beds in Cote-Saint-Luc are considered post-Fort Covington in age because there was no overlying Fort Covington Till — only marine clay. Perhaps the contorted beds were deposited prior to the Fort Covington Till, and only the horizontal beds are younger than the till; but certainly neither resembles the Malone sediments seen elsewhere in the region, and both contain pollen. On the other hand, sparse organic matter is present in the mid-Wisconsinan lake deposits of southeastern Quebec (McDonald and Shilts, 1971). The mapping of the largely concealed, bedded sediments in the Côte-Saint-Luc area was complicated by the presence of Fort Covington Till nearby, which overlies other bedded silt and sand deposits of Malone age (see Fig. 13), but nowhere could the complete stratigraphic sequence be established. The Côte-Saint-Luc bedded sediments, directly beneath the marine clay, may give trouble during excavation work as they are locally water bearing and tend to flow, but where they are dry vertical cuts may be made.

Well stratified silt in an eroded and excavated part of the St. Patrick Street scarp, west of Dollard Avenue in Ville LaSalle, also is believed to be a glacial lake deposit (Fig. 25). It overlies an irregular surface of Fort Covington Till and is overlain by early St. Lawrence River gravel. The irregularity of the silt-till contact indicates burial of the till without any erosion of its surface. The general appearance of the silt unit and the absence of marine fossils suggest that it is a freshwater deposit; presumably the marine clays that must have overlain the silts were removed by river erosion. Clasts of marine clay and a few marine shell fragments were found in the gravelly river sediments.

In the Dorval area horizontal to contorted rhythmites also are present which may relate to a post-Fort Covington glacial lake, rather than to a Malone-age lake. The rhythmites in many places are overlain directly by a sticky, unctuous, marine clay. The most contorted rhythmites were seen along the side of the Dorval esker south of the Dorval International Airport but are not shown on Map 1426A.

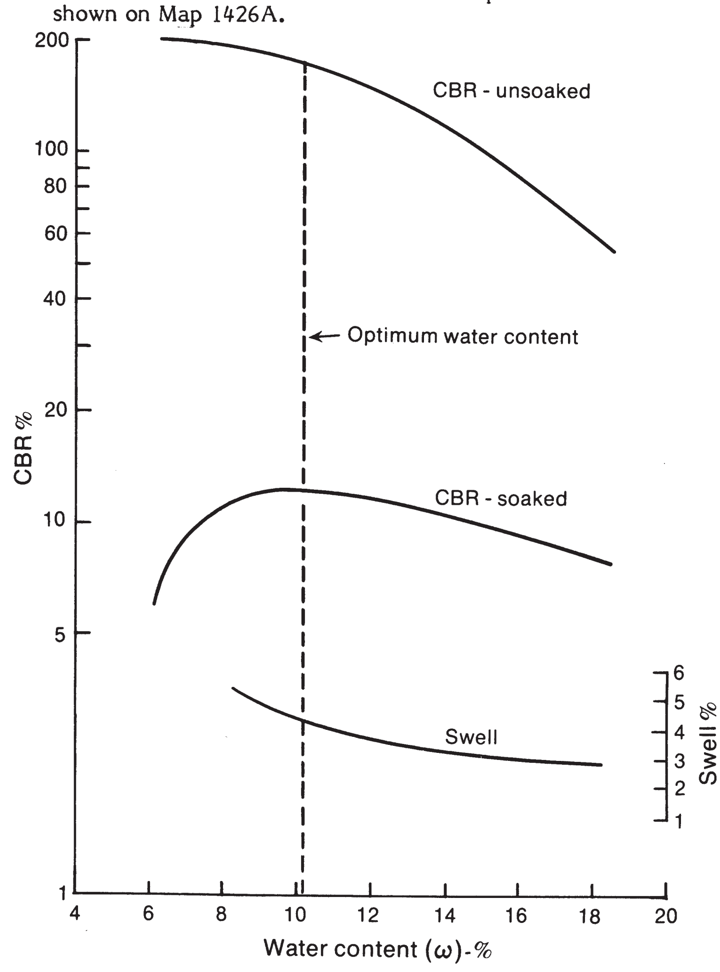


Figure 23. Relationship between water content, CBR, and swell for fine graine till.

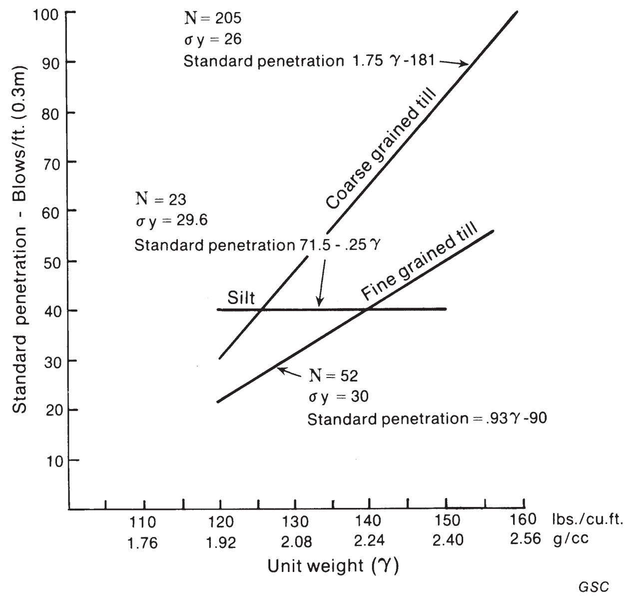


Figure 24. Influence of unit weight on standard penetration.

## Champlain Sea Deposits

Two contrasting types of sediments were deposited in the Champlain Sea: (1) nearshore, wave sorted, gravelly to sandy deposits and (2) offshore, quiet-water, silty to clayey deposits. The former are found around Mont Royal from the marine limit at about elevation 565 feet (170 m) down to a northeastward-sloping lower limit of marine sand and gravel at about elevation 170 feet (52 m) on the western side of the mountain, and at about 135 feet (40 m) off the northeastern side of the mountain Marine gravels below these elevations, as on Pie IX Boulevard north of Metropolitan Boulevard (Highway 40) at elevation 130 to 120 feet (39 to 26 m) and also in a small area immediately southeast of the corner of Sherbrooke and Dickson Streets (east of the Botanical Gardens) at elevation 105 feet (31 m), appear to be remnants of offshore shallow-water deposits, although perhaps they were formed onshore somewhat later as the sea continued its recession from the island The offshore, quiet-water, unctuous, clayey deposits have been observed from a maximum elevation of 370 feet (111 m) on Mont Royal down to present river levels all around the island Marine clay also has been recognized from borings at the eastern end of the island to about 100 feet (30 m) below river level or 80 feet (24 m) below sea level.

### Marine Sand and Gravel (Saxicava Sand)

Marine sand and gravel, commonly termed Saxicava sand[1], is present on the flanks of Mont Royal, although it is now generally concealed by urban development. Many

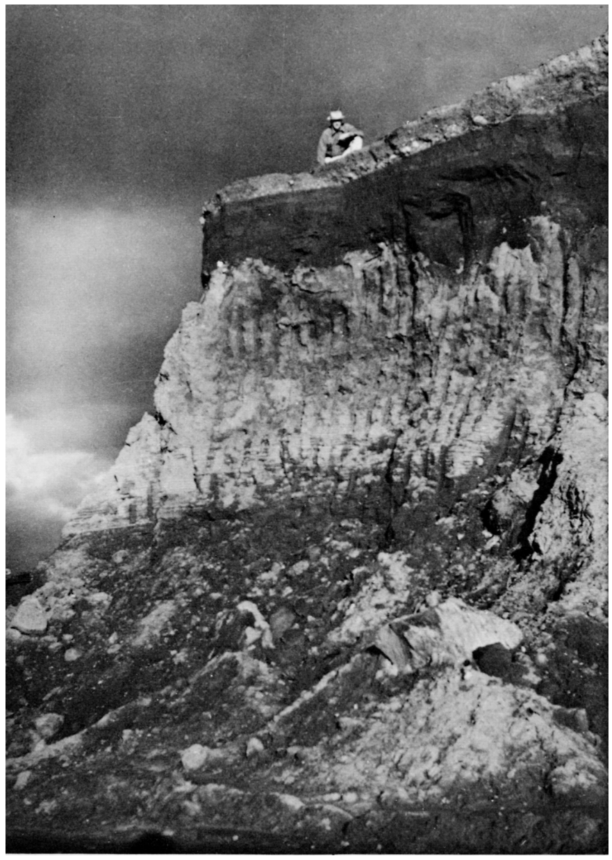

Figure 25. Cutbank south of St. Patrick Street and west of Dollard Avenue, Ville LaSalle. Photo shows early St. Lawrence River gravel over glacial lake clayey-silt, over Fort Covington Till, over Malone varved clay-silt. Two feet of sandy alluvium have been removed from the surface here. The upper silt unit and some of the till appear dark due to a prolonged wet period. The lower varved clay-silt passes downward into stratified sand. Some clasts of Leda clay and a few marine shell fragments were noted in the river gravels. The marine clay presumably has been stripped off the upper silt surface. Elevation of top of natural slope nearby is 153 feet (GSC-165073).

good exposures were observed during the building boom of 1951-52. Marine shells, mainly pelecypods, gastropods, and barnacles, were seen in many places and locally were so abundant as to constitute a coquina as on the northwestern side of Mont Royal and also at D'Iberville and Masson Streets, northeast of Mont Royal. Some shell occurrences are noted on the surficial deposits map (Map 1426A).

Specimens of all the species illustrated in Plates I and II, except for **Balanus hameri** (Pl. II, fig. 20), have been found in Champlain Sea deposits on Montreal Island[2].

[1] The term Saxicava sand, widely used in engineering circles, was applied to these marine deposits after a common elongate pelecypod shell formerly known as **Saxicava rugosa**; this fossil is now correctly named **Hiatella arctica** (see Pl. I, figs. 16, 17).

[2] All identifications were made by F.J.E. Wagner.

Figure 26. Excavation in offshore clayey sand believed formed during recession of the Champlain Sea. The clayey sand beds are rich in shells in contrast to the 1.5 foot-thick bed of pink (red) clay which only locally contains sparse shells; vicinity of Jean Talon and de Lanaudière Streets, Montreal. (Photo J. Hode-Keyser)

Figure 27. Excavation in unctuous (fatty) marine clay of the Sherbrooke Street terrace scarp at the Olympic site, Montreal; view is to the north and shows the upper part of the reinforced retaining wall along Sherbrooke Street. The anchor bolts are 60 feet long and extend into bedrock. This wall is bolted at 20-foot vertical intervals. (Photo J. Hode-Keyser)

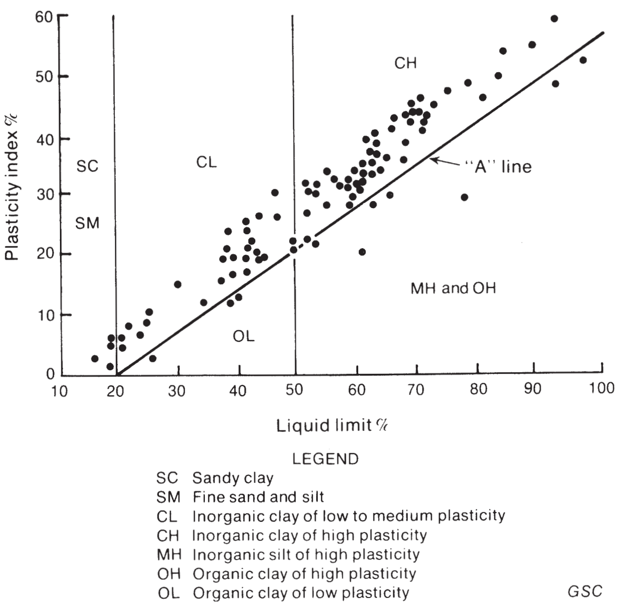


Figure 28. Relationship between liquid limit and plasticity index for Champlain Sea clay of Metropolitan Montreal.

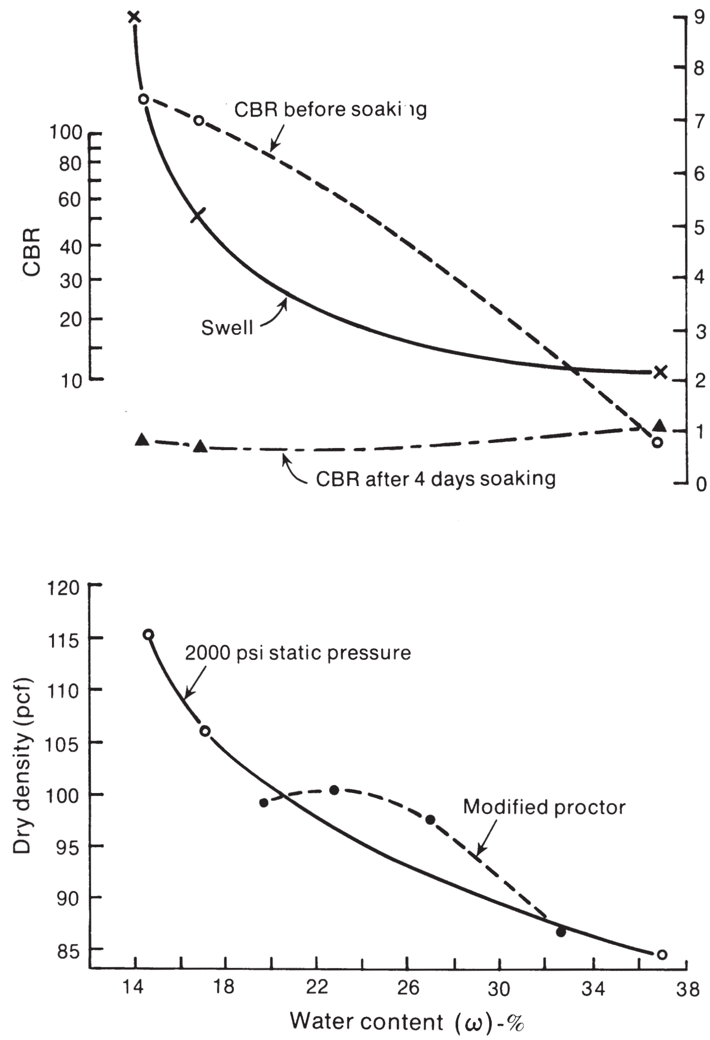


Figure 29. Relationship between density, CBR, swell, and water content for Champlain Sea clay, Montreal area.

In a few places where clayey sands were deposited near the close of the marine episode, clumps of "furry looking" material were noted with the shells; these were identified as sponge spicules (**Tethya logani** Dawson). They also were found in excavations on the north side of Mont Royal in the vicinity of Des Ecores and Villeray Streets and on 1st Avenue a few hundred feet north of the site reported by (Sir) Wm. Dawson as between Allan and Lacoste Streets (**see** Wagner, 1970, p 27), and since renamed L-O David (also Vaquelin) and Villeray Streets respectively. The common oyster **Crassostrea virginica**, a very rare species in the Champlain Sea was found in place at only two sites, both on the northwest side of Mont Royal: one at elevation 310 feet (93 m) on Côte-Sainte Catherine Road west of Descelles Avenue, and the other (in clay) at elevation 171 feet (51.3 m) on Westbury Avenue near Mackenzie Street.

Elson (1969) refers to the time of greatest submergence by the Champlain Sea as the **Hiatella arctica** phase, after a common pelecypod This pelecypod constitutes 85 to 90% of the shells from the uppermost beaches on Mont Royal. At a site in the Roman Catholic cemetery at elevation 545 feet (163.5 m), it was accompanied in order of abundance by **Macoma balthica Balanus crenatus, Mya truncata uddevallensis**, and **Mytilus edulis** (Plates I and II)[1]. For the time of the shallower, warmer, and less saline sea during isostatic uplift of the St. Lawrence Lowland following retreat of the ice, Elson employed the term **Mya arenaria** phase after another common pelecypod. From examination of innumerable shell sites on Mont Royal, Prest has concluded that the early, cold water forms generally persisted throughout the life of the sea, but that there was an increase in the abundance of other forms of animal life, including foraminifers and ostracodes (**see** Plate II) at lower elevations. For example, **Mya arenaria** (Pl. I, figs. 13-15) was not noted in deposits above elevation 250 feet (75 m) but was common below this elevation. Gastropod fragments were not noted in collections above elevation 232 feet (70 m), whereas many species of pelecypods (Pl. I) and some gastropods (Pl. II, figs. 21-24) were common below 200 feet (60 m). The sponge **Tethya logani** was noted only between elevation 165 and 175 feet (50 and 53 m). In clayey and in some sandy materials at lower elevations, which were deposited offshore in deeper water, the number of species of pelecypods, gastropods, foraminifers, and ostracodes was even more varied, although the abundance of some species locally appeared to exclude others.

Marine sand and gravel deposits on Mont Royal are generally less than 10 feet (3 m) but locally are as much as 50 feet (15 m) thick. They may be poor foundation materials due to uniform grading, high water content lack of compaction, and interbedded layers of clay in some localities. Slumping of cutbanks is to be expected. In some localities the sand may include beds or lenses of

[1] A radiocarbon dating on **Macoma** and **Hiatella (Saxicava)** shells from this site gave an age of 11 370 ± 360 years B.P. (Y-233).

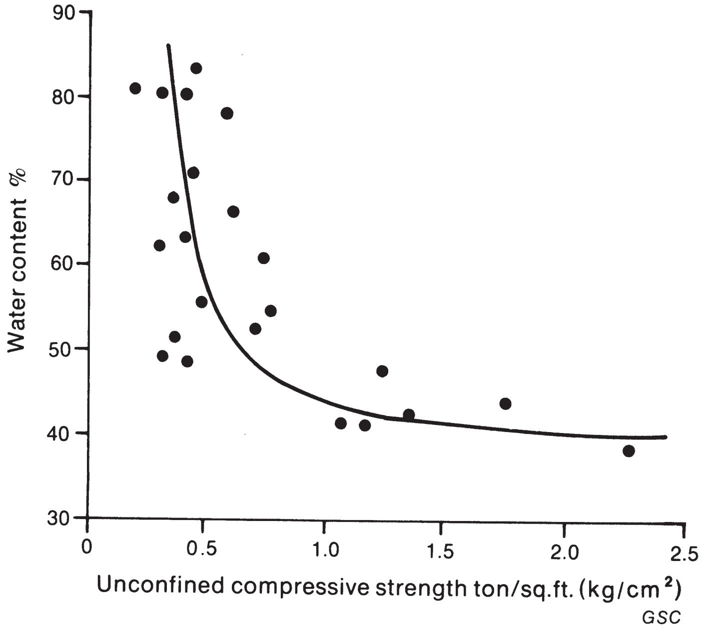


Figure 30. Relationship between unconfined compressive strength and water content for 'fatty' Champlain Sea clay.

silt or may be interbedded with clay including pink or red clay (Fig. 26); such materials are especially troublesome when wet. Where the sand and gravel are dry, however, they provide good foundation materials for houses and other small buildings

Marine Clay and Silt (Leda Clay)

Champlain Sea clay is widely known as "Leda clay" named after a small, boat-shaped pelecypod shell found in the clay in many places where no other fossils were evident. The original fossil **Leda**, however, was renamed **Yoldia (Portlandia) glacialis** and is now properly identified as **Portlandia arctica** (Pl. I, figs. 3-4). In addition some boat-shaped shells that have been casually reported as "**Leda**" do not belong to this genus but rather to other species of **Yoldia** or to species of **Nuculana**; hence the term "Leda clay" is not scientifically appropriate. The name, however, by common usage has become synonymous with the Champlain Sea clay unit and thus is retained as a convenient general term Marine shells may occur in clay at any elevation below the observed maximum, at 370 feet (112 m) on the southwestern side of Mont Royal, to below sea level as noted in borings at the northeastern end of the island. Localities where plentiful marine shells have been observed in the finer sediments also are shown on the surficial geology map (Map 1426A).

In the Montreal area the marine clay varies considerably in character; where it was deposited in deep water off the 'mountain' it is a massive, fatty', or unctuous clay (Fig. 27), but where deposited in shallow water it may be well laminated and silty. The unweathered marine clay is usually dark bluish grey depending on the relative amount of clay and silt. In a few places thin beds of the fresh clay have a pink hue and are referred to as 'red clay'; such clay was observed in several stratigraphic horizons and at elevations between 37 and 175 feet (11 and 53 m), but boring records show that it also occurs at much lower elevations. It is usually a few inches to about 3 feet (1 m) thick and seldom contains marine shells. The pink colour is considered to be due to: (a) an influx of 'red' mud from sources such as the Queenston shales, (b) oxidation in local, shallow water embayments of the Champlain Sea during deposition of the clay, or (c) an influx of partly oxidized clay, either from land or from shallow water embayments, into deeper water. The red Queenston shale, however, is the most likely source of the red materials.

Liquid limit and plasticity index determinations on more than 90 samples of marine clay taken from different sites are shown in Figure 28. The values vary widely but most are concentrated in a narrow band. Hydrometer grain-size analyses of Champlain Sea clay show great variation in silt and clay content. The clay content of highly plastic clays, however, generally ranges between 60 and 75%.

Champlain Sea clay is noted for its high to extremely high sensitivity. Its natural unit weight generally varies between 95 and 120 pcf (1.52 and 1.92 g/cm$^3$) where water content ranges from 30 to 80%. Specific gravity tests on solid constituents show values ranging from 2.60 to 2.74.

The swell and strength properties of the local marine clay are given in Figure 29, which shows the influence of water content and density on CBR values of a typical disturbed Champlain Sea clay. Examination of the test results shows: (a) the high bearing value of the clay when the water content is below optimum value; (b) the excessively low CBR value after four days of soaking; (c) the increase in strength with increasing density; and (d) the high swell value of the clay when the water content is below the optimum, and the low swell value when the water content is above the optimum.

Figure 30 shows the relationship between water content and unconfined compressive strength of practically undisturbed, highly plastic Champlain Sea clay. It is interesting to note the abrupt increase in strength when

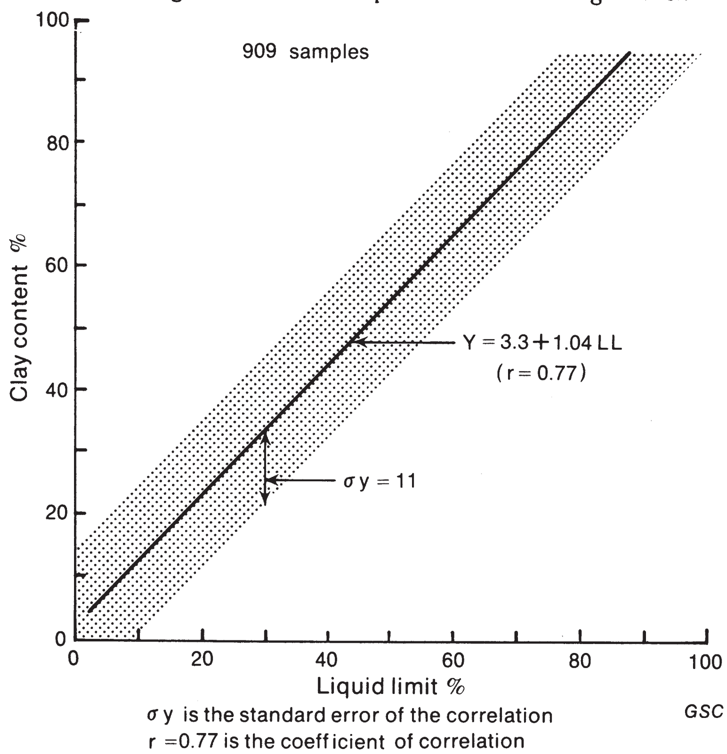


Figure 31. Relationship between clay content and liquid limit for Champlain Sea clay.

the water content falls below 50% which is approximately the plastic limit. Figure 31 shows the direct relationship between clay content and the liquid limit of 909 samples of Champlain Sea clay.

## River and Stream Deposits

Fluvial sand and gravel deposits occur widely over Montreal Island and on Île-Perrot. The main deposits occur only below an elevation of about 170 feet on the western flank of Mont Royal. The highest deposit, as mentioned above, is the long strand of fine to medium sand with scattered pebbles which extends intermittently from near Boulevard Decarie and the Canadian Pacific Railway tracks, southward through Hampstead to Montreal West. This deposit has a maximum thickness of about 5 feet (**see** Fig. 13). It represents an early washing of the higher altitude marine gravels as the land emerged from the sea The equivalent sand deposit is preserved intermittently, eastward around the southeastern side of Mont Royal and eastward along the crest of the Sherbrooke Street scarp to Molson Creek valley. Along the western side of this former creek the nonfossiliferous sand is at an elevation of about 135 feet (41 m). This sand deposit is rarely more than a few feet thick. At the southwest corner of the McGill University campus (elevation 145 feet or 44 m) the sand displayed trough cross-bedding in a section nearly normal to stream flow. These structures and the disconformable sand/clay contact attest to the alluvial origin of the sand (Figs. 32a, b).

In the far western end of Montreal Island and on Île-Perrot deposits of similar fine to medium grained sand occupy large, slightly elongate areas (**see** Map 1426A) and overlie marine clay, till, and bedrock. The sandy deposits lie mainly between elevation 170 and 130 feet (51 and 40 m). As Lac des Deux Montagnes, at the western end of the map-area has an elevation of 72 feet (22 m), there obviously has been a downcutting of about 100 feet (30 m) by the early and present St. Lawrence rivers. These deposits are up to 20 feet (6 m) thick and represent bars of the overloaded early St. Lawrence River. The sand probably was deposited in the lee of knolls of bedrock and till. This is obvious on Île-Perrot, but is less evident on the Morgan Arboretum north of Highway 40 at the west end of Montreal Island, and in Baie d'Urfé where the sand occurs as discrete 'islands' capping marine clay. Even there, however, low outcrops of rock or till do occur at their 'upstream' ends

Figure 32a

Excavation for McGill University library building, McTavish Street near Sherbrooke Street. Section shows fill over alluvial sand which rests, with an erosional contact, on marine clay. Both the sand and clay thin westward as the underlying stony till rises towards the mountain. At the centre of the photo the bedrock is 21 feet below base of excavation. (GSC-165058)

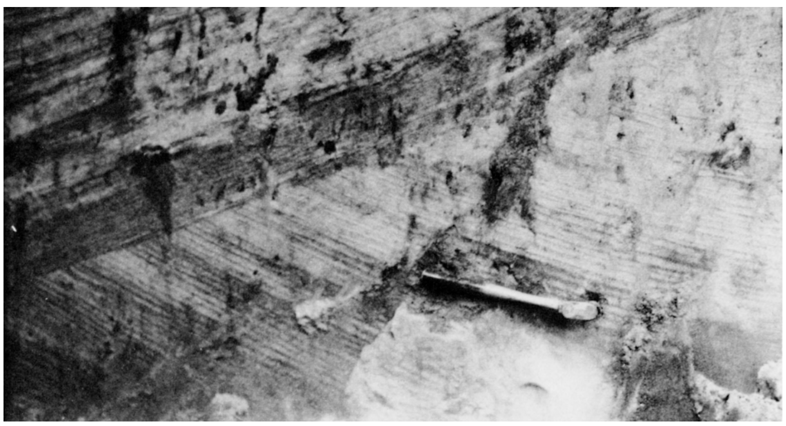

Figure 32b

Trough-type cross-bedding in the alluvial sand exposed in a nearby trench south of the McGill University library building. View is to the north-northwest, approximately at right angles to the channels. (GSC-165061) and may have deflected the river currents and thus preserved the bars. At lower elevations in the western end of the map-area the sand deposit is a patchy mantle, rarely more than 2 to 3 feet (0.5 to 1 m) thick.

Irregular patches of river sand in the Dorval area owe their existence to winnowing from a premarine glaciofluvial deposit – an esker-outwash system of the receding Malone ice sheet. The early St. Lawrence River redistributed these older materials so that sand may now be found overlying both Fort Covington Till and Champlain Sea clay. The sand deposits range in thickness from less than a foot to about 10 feet (3 m) near the esker.

River sand and gravel are important sediments in Montreal North where they occur as river bank deposits mainly derived from nearby Malone glaciofluvial and perhaps fluvial deposits. The younger river deposits rest directly on the Malone sediments in many places but also on Fort Covington Till and marine clay. The river deposits are commonly 5 to 10 feet (1.5 to 3 m) thick and were deposited when the early St. Lawrence River washed the land surface between about 110 feet (33 m) elevation and the present river level at about 60 feet (18 m).

Extensive areas of fine sand, up to 20 feet (6 m) or more thick, occur in the northeast end of Montreal Island between elevations 50 and 30 feet (15 m and 9 m). These represent slack-water deposits of clayey sand formed in the lee of a prominent area of bedrock in Pointe-aux-Trembles during isostatic uplift of the island The present St. Lawrence River is cutting through this sandy mantle and the underlying marine clay. At the northeast end of Montreal Island the river is at elevation 17 ± 2 feet (5 ± 0.6 m).

The river sand and gravel deposits seldom give trouble during construction work because they are generally thin, but where the deposits are many feet thick and saturated they may pose problems.

Local elongate areas of clay and silt, mapped west of Dorval, are considered to be slack-water river deposits. These are at about elevation 100 feet (30 m) and lie in former channels in the central part of Montreal Island, which were abandoned as the river was diverted to either side of the island. The deposits are noncalcareous and are a darker grey and less unctuous than the marine clay. They may relate to the Lampsilis Lake phase of Elson (1969), but the freshwater clam **Lampsilis** sp. was not found in these clays. In any case this and other 'lake phases' are considered here as part of the river erosion period, i.e., such lakes were but widenings of the main river system, as occur today.

Freshwater shells are rare in the river deposits They were noted in river gravels overlying marine gravelly sands directly southeast of the corner of Sherbrooke and Dickson Streets, on Pie IX Boulevard north of Metropolitan Boulevard, and in Montreal North. In a few places fragments of marine shells were found in the gravels, along with the freshwater shells; the latter no doubt were washed in from higher marine beds and redeposited in the river sediments

### Pond and Bog Deposits

The numerous ponds that remained on Montreal Island as the flow of the main river was directed to the edge of the island soon developed a rich vegetal and animal culture, and hence in addition to pond clay, deposits of algae and freshwater shells accumulated in them. The algal deposits produced sapropel or gyttja, and the shell-rich ones formed marl. Any of these materials may give place upward into sphagnum moss which forms the widely distributed peat deposits of the island. They are generally only a few feet thick, but in the Turcot flats north of Lachine Canal more than 20 feet (6 m) of peat has been recorded from test borings. This has been successfully compacted by heavy fill to serve as the 'base' of much of the Canadian National (Turcot) rail yards. The thinner deposits, in the early years of farming on the island, frequently were used for vegetable crops – especially celery. Many bog areas mapped in 1951-52 now are covered by urban development. The general thinness of pond and bog deposits precluded any notable construction problems.

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## APPENDIX

### Definition of Engineering Terms

The engineering terms referred to in this paper are taken, in most part, from the Earth Manual (1960), United States Department of the Interior, Bureau of Reclamation.

Geotechnical studies have shown that the amount of water present in fine grained soils has a marked effect on soil properties. Thus in determining the water content of soils, only the fraction passing the No. 40 sieve (0.0165 inch opening) is employed. Three main states of soil consistency are recognized; liquid, plastic, and solid. The amount of water, in percentage of the dry weight of the soil, at which the soil passes from the liquid state into the plastic state is called the **Liquid Limit**, LL. Conversely, liquid limit is the maximum amount of water a soil will hold without 'flow' or liquefaction. Similarly, the water content of a soil at the boundary between plastic state and the solid (or semisolid) state is called the **Plastic Limit**, PL. These limits of soil consistency are known as the **Atterberg limits.**

The range in water content over which a soil remains plastic or is capable of being molded is referred to as the **Plasticity Index**, PI, hence PI = LL - PL. Highly plastic soils have high PI values whereas for nonplastic soils PI = 0. A plasticity chart is a plot of liquid limit versus plasticity index, on which is imposed a diagonal line termed the "A" line. Inorganic clays normally plot above the "A" line whereas silts and organic soils plot below it. An inorganic soil is said to have a low plasticity (CL) where the liquid limit is less than 50% and high plasticity (CH) where more than 50%.

**Standard penetration** value "N" refers to the number of blows of a 230 lb. hammer required to drive a standard split-spoon sampler 1 foot through a soil.

**Unconfined compression** test refers to a load test on a prepared cylinder of soil (with length twice the diameter) to measure its resistance to shear.

**Sensitivity** is the ratio of the undisturbed strength of a soil to its remolded strength at the same water content.

**The California Bearing Ratio**, CBR, is an empirical method of expressing the resistance of a compacted sample of soil to penetration by a plunger of specific size, in other words, a measure of the resistance of soils to penetration.

The term **Modified Proctor (see** Fig. 29) refers to a standardized test to measure the denisty achieved by a soil, over a range of water contents, for a given compactive effort.

AASHO – American Association of State Highway Officials.

## PLATE I

### FOSSILS FROM CHAMPLAIN SEA DEPOSITS

(all figures x 1)

### PELECYPODA (CLAMS)

| | |
|---|---|
| Figures 1, 2 | **Astarte montagui warhami** Hancock<br>Interior and exterior views of a right valve; corner of Wiseman Avenue and Jean Talon Street, Montreal; hypotype, GSC No. 20152. |
| Figures 3, 4 | **Portlandia arctica** (Gray) var. **siliqua** Reeve<br>Exterior and interior views of two right valves; west bank of Batiscan River, 2 miles east-southeast of Sainte-Geneviève, Quebec; hypotypes, GSC Nos. 20148, 20147. |
| Figures 5, 6 | **Astarte montagui striata** (Leach)<br>Exterior and interior views of a left valve; ditch draining into Rivière du Cedre, 0.3 mile southeast of Saint-Janvier-de-Joly, Quebec; hypotype, GSC No. 20151 |
| Figures 7, 8 | **Nuculana pernula** (Müller)<br>Interior and exterior views of a right valve; same locality as figures 3 and 4; hypotype GSC No. 20145 |
| Figures 9, 10 | **Macoma balthica** (Linné)<br>Exterior and interior views of a right valve; pit about 2 miles northwest of Saint-Joseph-du-Lac, Quebec; hypotype GSC No. 20157. |
| Figures 11, 12 | **Macoma balthica** (Linné)<br>Interior and exterior views of a left valve; Wilson Avenue, 100 feet north of Notre-Dame-de-Grace Avenue Montreal; hypotype, GSC No. 20159. |
| Figures 13-15 | **Mya (Arenomya) arenaria** Linné<br>Interior and exterior views of a right valve and dorsal view of a left valve; ditch on north side of highway 36, 0 4 mile east of railway crossing in Saint-Rémi, Quebec; hypotype, GSC No. 20160 |
| Figures 16, 17 | **Hiatella arctica** (Linné)<br>Interior and exterior views of a left valve; 1 mile south-southeast of Chevalier, on west side of road to Beauport, Quebec; hypotype, GSC No. 20164. |
| Figure 18 | **Macoma calcarea** (Gmelin)<br>Interior view of a left valve; slide scar 1 mile northeast of Saint-Maurice, Quebec; hypotype, GSC No. 20158 |
| Figures 19, 20 | **Mytilus edulis** Linné<br>Exterior and interior views of a valve; same locality as figures 9, 10; hypotype, GSC No. 20149 |
| Figure 21 | **Mya (Mya) truncata** Linné<br>Interior view of right valve; east bank of Grande Rivière du Chêne, Quebec just south of highway 9; hypotype GSC No. 20161. |
| Figures 22, 23 | **Mya (Mya) truncata uddevallensis** Forbes<br>Interior and exterior views of a left valve; corner of Masson and D'Iberville Streets, Montreal; hypotype GSC No. 20162. |
| Figures 24, 25 | **Crassostrea virginica** (Gmelin)<br>Interior and exterior views of a valve; Westbury Avenue near Mackenzie Street, Montreal; hypotype, GSC No. 20150. |

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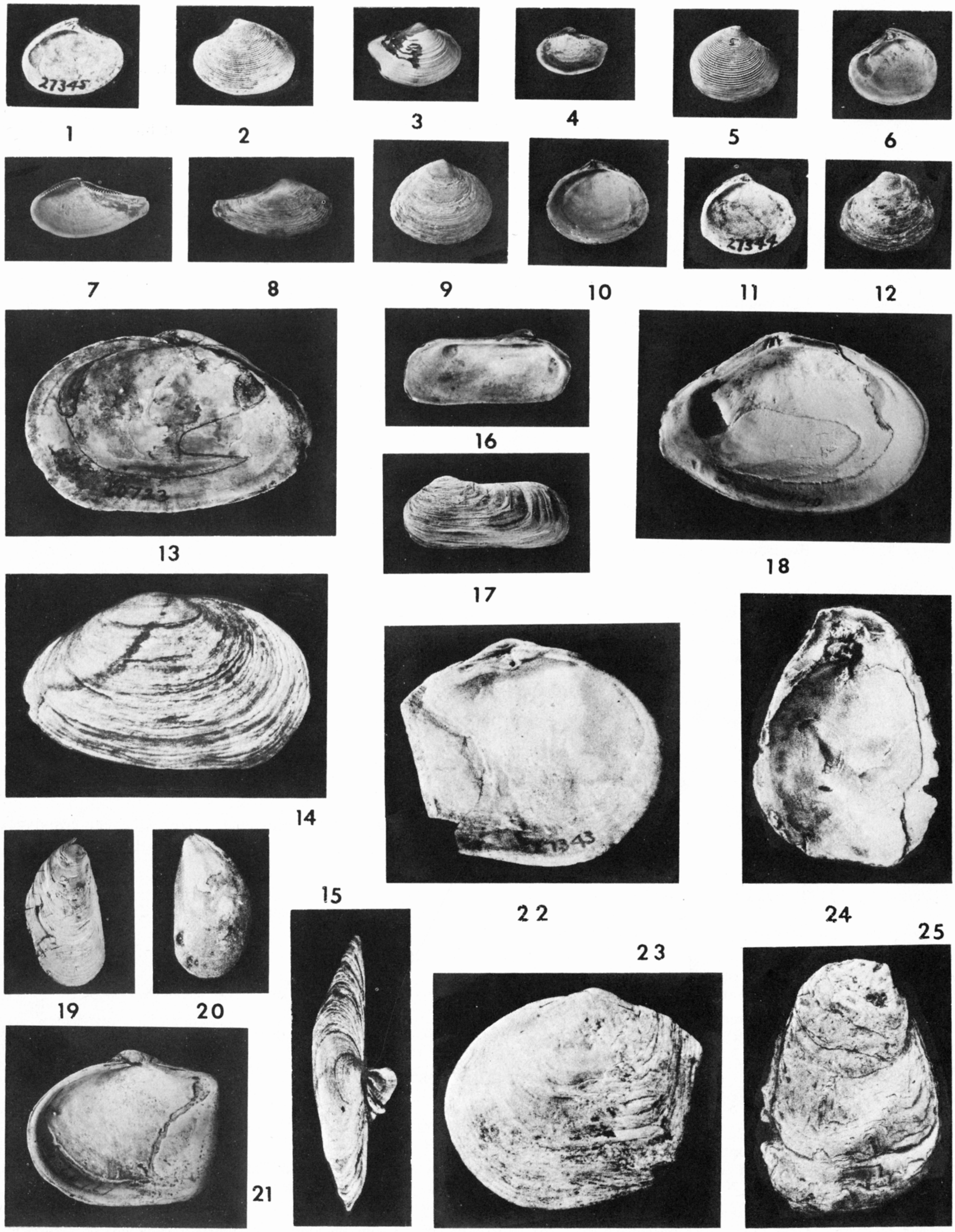
Plates I and II were prepared by M.J. Copeland and T.E. Bolton from information supplied by F.J.E. Wagner.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## PLATE II

## FOSSILS FROM CHAMPLAIN SEA DEPOSITS

### OSTRACODA

Figure 1. Ostracode indet.
Lateral view of a right valve, x 40; corner of Masson and D'Iberville Streets, Montreal; hypotype, GSC No 20189.

Figure 2. **Leptocythere macchesneyi** (Brady and Crosskey)?
Lateral view of a left valve, x 45; same locality as figure 1; hypotype, GSC No. 20178.

Figure 3. **Heterocyprideis sorbyana** (Jones)
Lateral view of a right valve x 25; Sherbrooke and Mansfield Streets, southwest corner of McGill University campus Montreal; hypotype, GSC No. 20170

### FORAMINIFERA

Figures 4, 9. **Elphidium excavatum** (Terquem) forma **clavata** Cushman
Side views, x 55; Honoré Beaugrand Street, 100 feet south of Avenue Souligny, Montreal; hypotypes, GSC Nos. 20119, 20120

Figures 5, 10. **Elphidium excavatum** (Terquem) forma **alba** Feyling-Hansen
Side views, x 50 and x 35; southwest corner of Isabella and Décarie Streets, Montreal and 1 mile east-northeast of Glen Robertson, lot 4, con I, Lochiel tp , Glengarry co., Ontario; hypotypes, GSC Nos. 20121, 20122.

Figure 6. **Elphidium bartletti** Cushman
Side view, x 75; Cornwall dyke, near Hydro-Electric Power Commission of Ontario office, Cornwall, Ontario; hypotype, GSC No. 20117

Figure 7. **Protelphidium orbiculare** (Brady)
Side view, x 60; same locality as figure 3; hypotype, GSC No. 20126.

Figure 8. **Pseudopolymorphina novangliae** (Cushman)
Side view, x 50; Westbury Avenue near Mackenzie Street, Montreal; hypotype, GSC No. 20105.

Figures 11, 14 **Elphidiella arctica** (Parker and Jones)
Side views, x 35; same locality as figure 3; hypotypes, GSC Nos 20125, 20124.

Figure 12. **Islandiella teretis** (Tappan)
Side view, x 45; 2.5 miles south-southwest of Alexandria, lot 6, con. I, Kenyon tp., Glengarry co., Ontario; hypotype, GSC No. 20112.

Figure 13. **Elphidium frigidum** Cushman
Side view, x 45; same locality as figure 1; hypotype GSC No. 20118

Figure 15. **Lagena apiopleura** Loeblich and Tappan
Side view, x 40; southwest corner of Isabella Avenue and Décarie Boulevard, Montreal; hypotype, GSC No. 20100.

Figure 16. **Elphidium subarcticum** Cushman
Side view, x 45; second pit from southern end of Sainte-Philomène ridge, Quebec; hypotype, GSC No. 20123.

### PORIFERA (SPONGES)

Figure 17. **Tethya logani** Dawson
View from above, x 2; First Avenue between Allan and Lacoste (now L-O. David and Villeray Streets), Montreal, hypotype, GSC No. 20130

### CIRRIPEDIA (BARNACLES)

Figures 18, 19. **Balanus crenatus** Bruguière
Top and side views of three individuals, x 1; Recent, Atlantic coast; hypotype, GSC No. 20191.

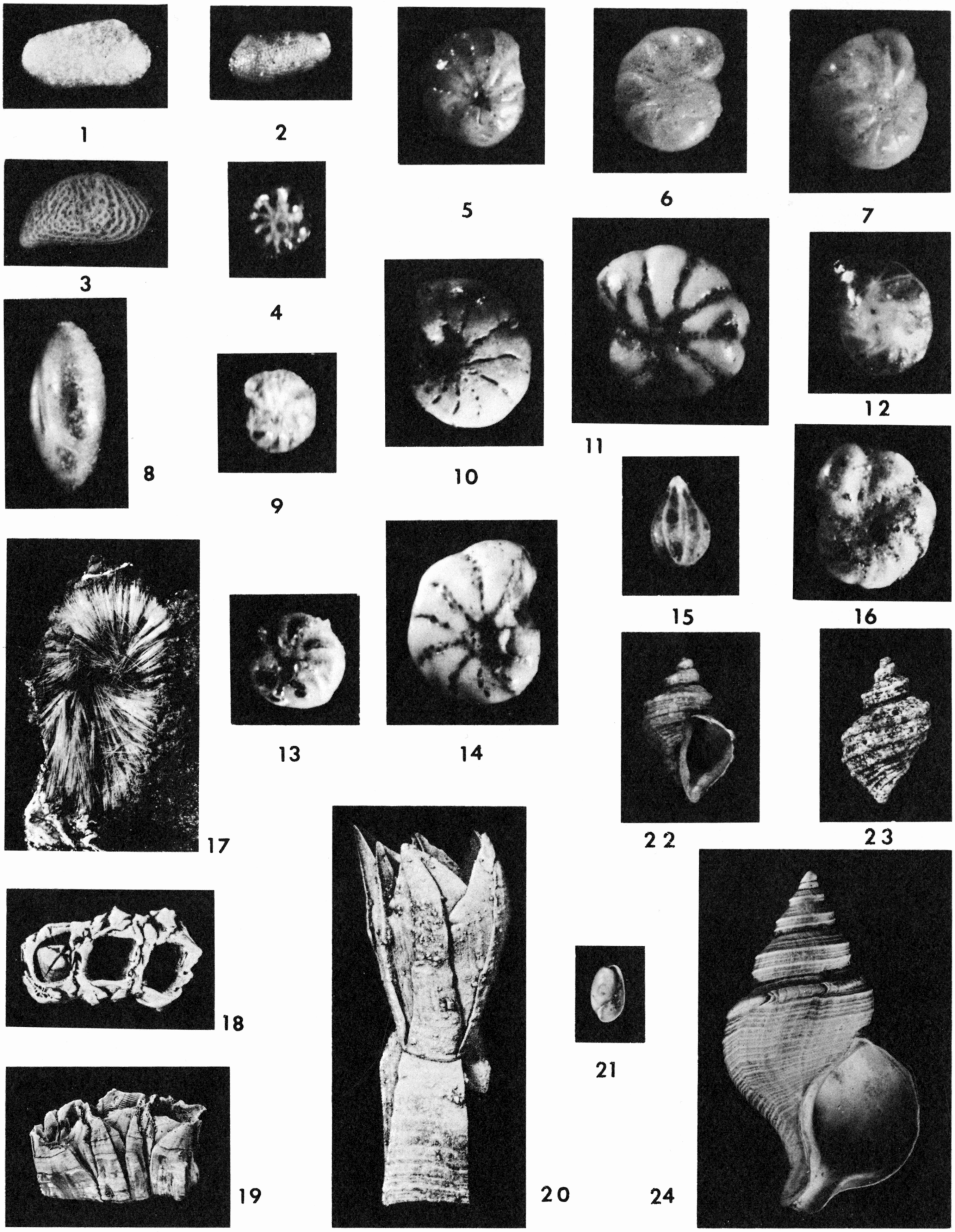
Figure 20. **Balanus hameri** (Ascanius)
Side view, x 1; southern part of pit 1.4 miles southeast of Sainte-Philomene, Quebec; hypotype, GSC No. 20192.

### GASTROPODA (SNAILS)

Figure 21. **Cylichna occulata** (Mighels and Adams)
Oral view, x 2; same locality as figure 3; hypotype, GSC No. 20143.

Figures 22, 23. **Trichotropis borealis** Broderip and Sowerby
Oral and aboral views, x 2; corner of Wiseman Avenue and Jean Talon Street, Montreal; hypotype GSC No. 20134

Figure 24. **Neptunea despecta tornata** (Gould)
Oral view, x 1; east bank of Grande Rivière du Chene, Québec, just south of highway 9; hypotype, GSC No. 20140.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