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SURFICIAL GEOLOGY OF THE LAC MÉGANTIC AREA, QUÉBEC

W.W. SHILTS

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Critical Reader

R.J. Fulton

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Preface

The surficial geology of upper Chaudière River valley has been of interest since the late 19th century because of the classic occurrences of placer gold in the unconsolidated deposits of the region. Because of this interest and because of numerous exposures created by gold mining, many observations on the glacial stratigraphy of the Appalachians were made by early scientists of the Geological Survey trying to uncover principles that would aid in the search for gold.

The present paper continues the quest of the early geologists for definitive data on the relationship of drift composition to the composition of bedrock. The modern data, which consist of chemical, mineralogical, and fabric measurements, have been used to develop a model for predicting drift composition and for properly correlating various glacial sediments exposed in sections or intersected in drillholes throughout the region. In addition, the accompanying map presents an inventory of surficial deposits and indicates areas where evidence of widespread slumping suggests potential instability in the event of any alteration of the landscape.

Finally, this report presents an up-to-date discussion of the glacial events that have affected this portion of the Appalachians. It is, perhaps, the last of a series of major investigations, begun in the 1950's by the Geological Survey, of the Quaternary geology of the area from St. Lawrence River southward to the United States border.

D.J. McLaren
Director General
Geological Survey of Canada

OTTAWA, October 1978

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Frontispiece. *Lac-Mégantic and surrounding region. Note outline of glacial dispersal train of nickel extending southeastward from the Thetford Mines area. The vegetation/settlement pattern of the northern and western edges of this train seems to be related to the configuration of the train. LANDSAT image E-1096-15060, MSS Band 7, October 27, 1972.*

SURFICIAL GEOLOGY OF THE LAC-MÉGANTIC AREA, QUEBEC

Abstract

Till and related deposits from three glaciations are exposed in the Lac-Mégantic area; indirect evidence indicates at least one earlier glaciation. Nonglacial fluvial sediments bearing far-travelled erratics at Grande Coulée River are the oldest Pleistocene sediments in the area. They are overlain by Johnville Till with fabric indicating ice flow from west or northwest. Johnville Till is overlain by fluvial sand containing organic debris more than 40 000 radiocarbon years old. This sand tentatively is correlated with sediments of the St. Pierre Interstade and is called the Massawippi Formation.

Chaudière Till overlies the Massawippi Formation or varves associated with retreat of the Johnville glacier. Fabric and composition suggest that it was deposited by a glacier flowing first southwest from an Appalachian ice cap and then shifting to flow southeast when the Appalachian ice cap was overwhelmed by ice from a Laurentide source.

The glacier that deposited Chaudière Till retreated towards the northwest only as far as the northwest-facing slopes of the Appalachians, blocking northward drainage and impounding glacial Lake Gayhurst in Chaudière Valley and in adjacent valleys to the west.

The Gayhurst Formation, consisting of a low member of about 3400 well graded silt-clay laminae, a middle member of deltaic sand and gravel, and an upper member of about 600 well graded silt-clay laminae, was deposited in a 370 to 380 m outlet phase (lower and middle members) and a 430 m outlet phase (upper member) of glacial Lake Gayhurst. The 370 to 380 m outlet carried overflow east into Saint John River; the 430 m outlet carried overflow southeast through Coburn Gore, Maine and operated whenever ice stood far enough south of the Appalachians to block the 370 to 380 m outlet. It is suggested that the Gayhurst Formation was deposited during the entire time interval separating deposition of Chaudière Till and overlying Lennoxville Till; 4000 couplets of laminated silt-clay may represent at least 4000 years of deposition.

Lennoxville Till was deposited during a major re-advance of the glacier that deposited Chaudière Till. The Lennoxville glacier is inferred to have covered all of southeastern Quebec and New England. Striae, fabric, and indicator dispersal patterns support east-southeast movement of the Lennoxville glacier at its maximum. The Drolet lentil, derived from the clayey sediments of Gayhurst Formation, is a facies of Lennoxville Till deposited during early south-southwest advance of the Lennoxville glacier up Chaudière Valley.

Lennoxville glacier retreated from the Lac-Mégantic area by backwasting of actively flowing ice. During halts or re-advance the glacier built till and gravel moraines and impounded proglacial lakes in Chaudière Valley and its tributaries.

Although no evidence was found to support the concept of late-glacial ice flow into Quebec from highland centres in Maine or New Hampshire, areas north and west of the study area were subjected to a reversal of ice flow; this reversal probably was caused by drawdown into St. Lawrence Valley where a deep re-entrant was formed in the ice sheet as the result of the development of a calving bay as sea level rose. Eventually a separate ice cap developed, with its divide through the northwest corner of the map area, as a result of a cutoff of ice south of St. Lawrence River from the main Laurentide Ice Sheet.

After deglaciation streams incised deep channels in thick deposits of unconsolidated sediments, and large scale rotational slumping and flow slides occurred on the sides of the channels. The area of greatest slumping is in the Drolet Depression, a closed bedrock depression filled with more than 100 m of glacial sediments (largely varves of the Gayhurst Formation) in the vicinity of the confluences of Drolet and Eugénie rivers with Chaudière River.

Résumé

Dans la région du lac Mégantic, sont exposés des tills et dépôts connexes laissés par trois glaciations; il existe des indices indirects d'au moins une glaciation antérieure. Sur le site de la rivière Grande Coulée, on rencontre les sédiments pléistocènes les plus anciens de la région, représentés par des sédiments fluviatiles non glaciaires, contenant des blocs erratiques qui ont été transportés sur de grandes distances. Ceux-ci sont recouverts par le till de Johnville, dont la texture indique un écoulement des glaces à partir de l'ouest ou du nord-ouest. Un sable fluviatile contenant des débris organiques datés par la méthode du radiocarbone à plus de 40 000 ans recouvre ce till. On a provisoirement établi une corrélation entre les sédiments de l'interstade de St-Pierre et ce sable fluviatile nommé formation de Massiwippi.

Le till de Chaudière recouvre la formation de Massawippi, ou les varves associées au recul du glacier Johnville. La texture et la composition de ce till suggèrent qu'il a été déposé par un glacier qui s'écoulait initialement vers le sud-ouest à partir d'une calotte glaciaire appalachienne, puis s'est dirigé vers le sud-est lorsque cette calotte a été envahie par les glaces issues d'une nappe glaciaire laurentidienne.

Le glacier qui a déposé le till de Chaudière n'a reculé vers le nord-ouest que jusqu'aux versants nord-ouest des Appalaches, bloquant ainsi l'écoulement des eaux vers le nord et retenant les eaux du lac glaciaire Gayhurst dans la vallée de la rivière Chaudière et les vallées adjacentes plus à l'ouest.

La formation de Gayhurst, comprenant un membre inférieur composé d'environ 3400 m de laminations bien granoclassées de silts et d'argiles, d'un membre moyen composé de sables deltaïques et de graviers, et d'un membre supérieur composé d'environ 600 laminations bien granoclassées de silts et d'argiles, s'est constituée pendant une phase où existait un déversoir entre 370 et 380 m (membres inférieur et moyen) et une autre phase, où existait un déversoir situé à 430 m (membre supérieur) dans le lac glaciaire Gayhurst. Le déversoir situé entre 370 m et 380 m permettait l'écoulement des eaux dans la rivière St-Jean; celui de 430 m l'écoulement vers le sud-est à travers le site actuel de Coburn Gore dans le Maine; il remplissait sa fonction toutes les fois que les glaces arrivaient suffisamment au sud des Appalaches pour endiguer le premier déversoir. On suggère que la formation de Gayhurst s'est constituée pendant tout l'intervalle de temps écoulé entre le dépôt du till de Chaudière et celui du till sus-jacent, appelé till de Lennoxville; 4000 couples de laminations alternativement argileuses et silteuses pourraient représenter au moins 4000 ans de sédimentation.

Le till de Lennoxville s'est déposé pendant une importante réavancée du glacier qui avait laissé le till de Chaudière. On suppose que le glacier de Lennoxville avait recouvert tout le sud-est du Québec et la Nouvelle-Angleterre. La présence de stries, les types de texture, et les marques laissées par la dispersion des glaces semblent confirmer le déplacement est-sud-est du glacier Lennoxville pendant l'extension maximum de celui-ci. La lentille de Drolet, dérivée des sédiments argileux de la formation de Gayhurst, représente un faciès du till de Lennoxville, déposé pendant les premières phases de l'avancée sud-sud-ouest du glacier Lennoxville, celui-ci remontant la vallée de la rivière Chaudière.

Le glacier Lennoxville s'est retiré de la région du lac Mégantic, par recul progressif du front de ce glacier encore actif. Pendant les phases de stationnement ou de réavancée, le glacier a édifié des moraines de till et de graviers, et endigué les lacs proglaciaires dans la vallée de la rivière Chaudière et les vallées tributaires.

Bien que l'on n'ait pu trouver de preuves d'un écoulement glaciaire tardif à l'intérieur du Québec à partir de zones montagneuses situées dans le Maine ou le New Hampshire, il est évident que des secteurs situés au nord et à l'ouest de la région étudiée ont vu une inversion de l'écoulement glaciaire: celle-ci résultait probablement d'un rabattement provoqué par l'écoulement des eaux dans la vallée du Saint-Laurent; dans celle-ci, il est apparu une profonde échancrure de la nappe glaciaire, par suite de la formation d'une baie, devenue site de vêlage des glaciers, au fur et à mesure de la montée du niveau de la mer. Il s'est finalement formé une calotte glaciaire distincte, dont la ligne de partage passait par le coin nord-ouest du secteur cartographié, les glaces situées au sud du Saint-Laurent s'étant scindées de la partie principale de la nappe glaciaire laurentidienne.

Après la déglaciation, les cours d'eau ont creusé de profonds chenaux dans les épais dépôts de sédiments non consolidés; de part et d'autre de ces chenaux, ont eu lieu d'importants glissements rotatoires et coulées de solifluxion. La zone qui a subi les plus forts glissements est la dépression de Drolet, bassin fermé ayant comme matériau de base la roche en place et rempli de plus de 100 m de sédiments glaciaires (en grande partie des varves de la formation de Gayhurst) à proximité de la confluence des rivières Drolet et Eugéni avec la rivière Chaudière.

INTRODUCTION

This report describes Quaternary deposits in the Woburn – Lac-Mégantic – Saint-Martin region of southeastern Quebec, an area of 2100 km^2, bounded by 46°N, 71°W and the Canada-United States border (Fig. 1). Field work was carried out during 1967, 1968, and 1969. The study area includes Quebec portions of NTS National Topographic System map areas (1:50 000) 21 E/15 (St. Evariste), 21 E/16 (St. Théophile, formerly Armstrong), 21 E/10 (Mégantic), 21 E/7 (Woburn), and 21 E/9 (Lac Émilie).

Geography

The map area comprises the easternmost portion of the Eastern Townships and a portion of the southern part of the culturally distinctive Beauce County region. Lac-Mégantic (population 7108) is the major population and commercial centre of the area, which has about 20 000 inhabitants overall.

The climate is characterized by short, cool, wet summers and long, cold winters. It is notable that the mean annual temperature (0.8°C) of Lac-Mégantic (45°35'N, 70°53'W) is more than 1°C cooler than Quebec City (46°50'N, 71°15'W) and 2°C cooler than Sherbrooke (45°24'N, 71°54'W); precipitation at Lac-Mégantic (652.5 mm) averages 175 mm less than Quebec and 90 mm less than Sherbrooke (data converted from Wernstedt, 1972).

The economy of the region is based largely on harvesting and processing of forest products. Most wood is shipped to Windsor or East Angus (near Sherbrooke) for pulp, but semi-finished wood products are produced in Lac-Mégantic. Tourism is a small but growing industry in the region, and studies are underway to develop Mont Mégantic into a major ski area.

Mining of copper and gold has proceeded on a limited basis for the past 100 years. Gold was mined from placer deposits in Chaudière River and its tributaries in Beauce County, and McGerrigle (1936) has reported traces of placer gold in modern alluvium in many streams of the region. Gold was mined from a porphyritic felsic dyke at Mines Saint-Robert (45°46'N, 70°31.4'W) until the middle 1960's, and occurrences of scheelite and argentiferous galena were reported from this deposit by Faessler (1939). Copper and molybdenum mineralization is common along the eastern contact zone of the granodiorite forming the Little Mégantic Mountains, and a molybdenum mine was operated on the east side of Mont Saint-Sébastien until the early 1960's. Base metal deposits in the volcanic member of Frontenac Formation received much attention from exploration geologists in the Mont Scotch area from 1967 to 1970 and have since been the site of mining activity.

Objectives

The main objectives of the project were: (1) to produce a map of surficial deposits; (2) to investigate the possibility of late-glacial ice flow into Quebec from New England; (3) to define Pleistocene stratigraphy and develop petrologic methods for correlating ice-laid units; and (4) to study the glacial dispersal of rocks, minerals, and trace elements in till sheets. Brief summaries of objectives (2) and (3) (McDonald and Shilts, 1971) and (4) (Shilts, 1973a, b) have already been published.

Methods of Investigation

Field Methods

Mapping of surficial deposits was accomplished by vehicle traverses along provincial, county, city, private farm, and logging roads and by foot traverses across critical areas and along streams inaccessible to a jeep. Field information was supplemented by study of aerial photographs at scales of 1:15 000 and 1:40 000.

Till fabric was measured at critical sites to determine strike of ice flow direction during till deposition. Azimuths of 30 to 100 elongate stones with major to intermediate axial ratios of at least 2:1 were measured at each site. Stones with long axes more than 20° from a horizontal position were not included.

To test the objectivity and reproducibility of fabric measurements, till fabric measurements were repeated at several sites by different individuals. The results of these comparative studies generally showed acceptable fabric reproducibility (Appendix 1).

From most fabric sites at least 100 pebbles (1 to 5 cm minimum diameter) and a bulk till sample of approximately 500 g were collected. Pebble and bulk samples also were collected from several sites where fabric was not measured. The majority of bulk samples were of unoxidized, unleached till.

Percentages of rock types lying on the till surface were determined by counting 100 to 200 clasts from boulder piles on farms. Counts were made at more than 200 sites from Woburn to Saint-Martin.

At least two sets of striae are present on almost every striated outcrop observed in the study area. Care was taken to record the strike of every prominent direction preserved. Where hard bedrock inclusions such as vein quartz and pyrite cubes were present in fine grained rock, "tails" of uneroded bedrock commonly made it possible to determine the direction of ice flow.

Hammer seismic traverses were carried out at several locations by the Resource Geophysics and Geochemistry Division. Bedrock depths as great as 60 m were determined with acceptable precision (Appendix 3).

Three deep boreholes were drilled by the Canada Department of Public Works for the purpose of sampling Pleistocene sediments. Both split-tube and Shelby tube samples of till and lacustrine sediment were recovered from boreholes 1 and 2. Pebble samples were recovered from borehole 3.

Laboratory Methods

Complete sieve and pipette size analysis of particles from 2 to 0.002 mm (2 μm) was performed on 71 samples of till and one sample of varves by the sedimentology laboratory of Terrain Sciences Division. Cumulative weight percentages of ϕ5%, ϕ16%, ϕ25%, ϕ50%, ϕ75%, ϕ84%, and ϕ95% were read from cumulative frequency curves. Where extrapolation was necessary beyond 2 μm, the method described by Folk (1965, p. 39) was used. The statistical parameters of M_Z (graphic mean grain size), σ_I (inclusive graphic standard deviation), K_G (graphic kurtosis), and Sk_I (inclusive graphic skewness) were calculated from formulas in Folk and Ward (1957).

X-ray diffraction analysis of the <4 μm fraction of till was performed with a General Electric XRD-5 diffractometer using Ni-filtered, CuK_α radiation. Oriented slides were prepared by sedimenting the <4 μm size fraction (obtained by centrifugation) onto glass slides. Enough sediment was added to make the resultant film opaque on drying.

Integrated peak intensities were obtained for 7Å and 10Å* peaks by multiplying half-peak height above background by half-peak width. From these values, D.I. (diffraction intensity) ratios (Frye et al., 1962) consisting of the integrated intensity of the 001 reflection of 10Å mica divided by the integrated intensity of the 002 reflection of chlorite (7Å) were calculated. Selected samples were heated, treated with boiling HCl, glycolated, and X-rayed under humidity of 0% and 100% to test for the presence of expansible phyllosilicates and kaolinite (Appendix 2).

Heavy minerals were separated from the 2ϕ to 3ϕ size fractions of till with bromoform (s.g. ≈2.85), and weight percentages were calculated for the heavy mineral fraction. Magnetite was removed by hand magnet, and its weight per cent of the heavy fraction was calculated. Light minerals were mounted on glass slides and ground to a thickness of about 0.05 mm. Each slide was systematically stained with sodium cobaltinitrite and amaranth solution to ease identification of potassium feldspar and plagioclase grains, respectively. The staining method of Boone and Weaver (1968) was followed, but the procedure was modified by using an initial HF etch of 27 seconds and by reducing amaranth immersion time to 4 seconds. Amaranth stained about 25% of the serpentine grains to a deep purple colour. Even heavily kaolinized and sericitized feldspar grains were stained and classified using this method.

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* 1Å = 0.1 nm.

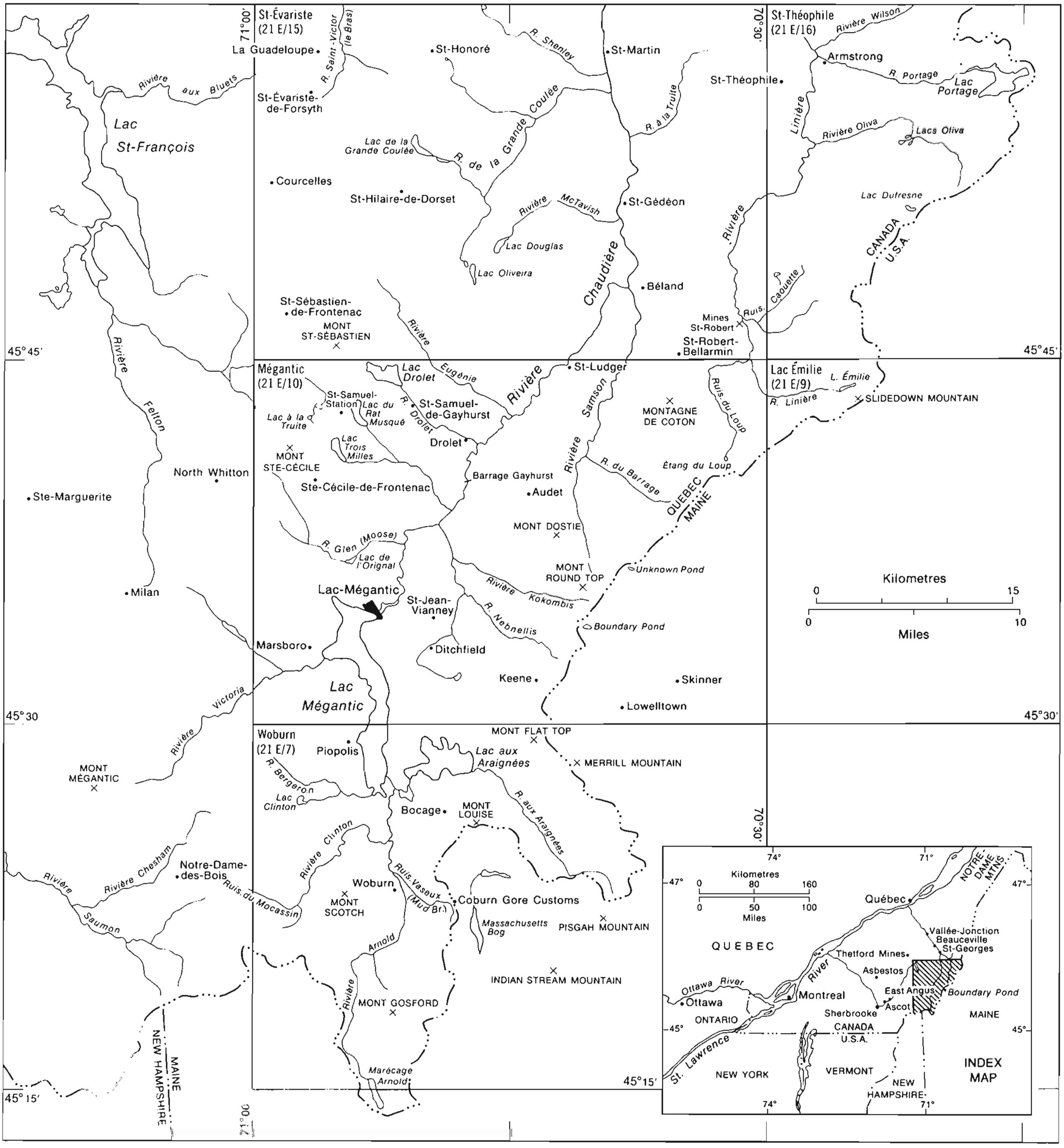


Figure 1. *Study area and adjacent areas with place names.*

Five hundred to one thousand grains were identified on each slide. Feldspar and quartz percentages were calculated exclusive of rock fragments and serpentine grains, which also occur in the "light" fraction. Calcite commonly constitutes less than 3% of the light minerals and only its presence or absence was noted. Polycrystalline quartz and rock-fragment frequencies were calculated together as percentages of the whole grain count for any one slide.

Concentrations of Al, Fe, Mg, Ca, Mn, Ba, Co, Sr, Ti, Zr, Cu, Ni, Cr, and V in the <64 µm fraction of till were determined by the Analytical Chemistry Section of the Central Laboratories and Technical Services Division with an emission spectrograph. Zn, Pb, and Ag were determined by hot $HCl-HNO_3$ leach and atomic absorption on the samples that were analyzed spectrographically.

Five lakes situated in high-altitude bedrock basins were cored using a modified Livingstone corer. The base of the organic-rich portion of each core was dated as well as some higher, palynologically distinct zones. Finely divided plant remains were concentrated, using sieves and decantation, from two samples recovered from stratigraphic positions below the Lennoxville Till.

All organic samples were dated by the radiocarbon laboratory of Terrain Sciences Division. Palynological examination of the cores and samples was done by personnel of the Paleoecology and Geochronology Section of Terrain Sciences Division (see Appendix 4).

Previous Work

Chalmers (1898) was the first geologist to make systematic observations of glacial features in the Lac-Mégantic area. Chalmers recorded striae at several sites and grouped them into four categories that he felt represented formation during four distinct glacial events. Each measurement was assigned to a category on the basis of one or more of the following criteria: (1) degree of weathering of the striated surface; (2) "strength" of striae; (3) superposition of striae; and (4) determination of stoss or lee side of the outcrop with respect to ice flow. Thus, although more than 90% of the striae he measured strike between 90 and 180°, he considered them to be of four ages, based on criteria cited above.

Largely from interpretation based on striae, Chalmers considered that southern Quebec first was glaciated by "mountain" glaciers that emanated from ice caps located in highlands in New Hampshire and in the Eastern Townships of Quebec. This "Appalachian" glaciation, with ice flow radiating in all directions from centres of accumulation, was succeeded by a glacier that flowed first from the Laurentian Highlands approximately to the International Boundary (older Laurentide glacier), retreated, and readvanced into the St. Lawrence Lowland (late Laurentide glacier). Chalmers described the final glacial episode "local" glaciation in the vicinity of highlands in the Eastern Township – presumably by outlet glaciers from small ice caps centred on the highlands.

Chalmers examined several sections in Chaudière Valley and observed two tills ("boulder clay") separated by stratified silty clay. He described these as deposits of the "Appalachian glacier" (lower till) and of the "early Laurentide glacier" (upper till). Correlation with specific glaciations was based on the reported lack of Precambrian Shield erratics in the lower till and their presence in the upper till.

Since publication of Chalmers' report, several authors have suggested that southeastern Quebec was invaded in late Wisconsinan time by glaciers that flowed northward and northwestward from highland ice caps in Vermont, New Hampshire, and Maine. Cooke (1937), Duquette (1960), and Thornes (1965), among others, have cited erratics displaced north of their presumed source areas as evidence of northward movement from New England. Clark (1937) and Lamarch (1971, 1974), among others, inferred local northward movement from crag-and-tail features associated with striae. Borns and Hagar (1965) inferred the existence of highland ice centres in Maine (but not flow into Quebec) on the basis of outwash overlying marine sediments. Flint (1951, 1957), suggested that active, late-glacial ice caps may have existed in the New England highlands.

Mackay (1921, p. 34-36, p. 51-56), on the other hand, concluded from detailed study of striae and erratics in the Beauceville area, several kilometres north of the study area, that all local ice flow was from the north or northwest. He could find no striae that clearly indicated northward flow and, although acknowledging the presence of erratics north of their apparent sources, felt that they could have been transported by ice rafting.

Gadd (1960, 1964a, b, 1965a, b, 1967, 1971) has done the bulk of modern research on the Quaternary history of southeastern Quebec. Among his many important contributions have been defining and dating the "Highland Front" moraine – described as a major recessional position of the last glacier – and describing the two-till stratigraphy of the St. Lawrence Lowland. Gadd described sections near Bécancour, Pierreville, Les Vieilles-Forges, and St-Pierre-les-Becquets where he could demonstrate that a surface till (Gentilly Till) is separated from an older till (Bécancour Till) by fluvial or organic sediments of the St. Pierre Interval – an interstadial (or interglacial) episode of early or pre-Wisconsinan age (Gadd, 1960, 1971).

McDonald (1966a, b, c, 1967a, b, c, 1968, 1969) mapped the Sherbrooke-La Patrie area west of the present study area. He described moraine systems older than the "Highland Front", concluded that ice did not flow northward into Quebec from late-glacial highland ice caps in Vermont, provided new data on the age and altitudes of the highest shorelines of the Champlain Sea, and demonstrated that two tills overlie sediments of St. Pierre age in the Appalachian region.

McDonald (1971) and McDonald and Shilts (1971) have summarized the Pleistocene stratigraphy of the Sherbrooke-La Patrie-Lac-Mégantic area. In Vermont, Stewart and MacClintock (1964, 1969) have described stratigraphic sections that superficially resemble the stratigraphic succession proposed by McDonald and Shilts (1971). Although their sequence for northern Vermont may be correlative with Quebec, objections have been raised to their regional interpretations (for further discussion, see Behling, 1965; Shilts and Behling, 1967; Schafer and Hartshorn, 1965; and McDonald and Shilts, 1971).

Acknowledgments

The author was capably assisted in the field by André Lemay (1967), Jean-Jacques Bouillon and Marcel Ouellet (1968), and Robert Bélanger (1969). Much of this paper is abstracted from a Ph.D. thesis (Shilts, 1970) presented to Syracuse University. I am indebted to my thesis advisor, Professor E.H. Muller of Syracuse, and to B.C. McDonald and R.J. Fulton, who provided critical discussions of the material presented here. In addition, I thank G.M. Boone, C. Bernard, H.W. Borns, Jr., P. Calkin, R. Denis, J-C. Dionne, J.C. Dubé, J.G. Fyles, P. MacClintock (deceased), and W. Newman for stimulating field discussions in the Lac-Mégantic area.

PHYSIOGRAPHY

Physiography and Bedrock Geology

Bostock (1969) includes most of the study area in the Mégantic Hills physiographic province. I have subdivided the region into six distinct physiographic sections (Fig. 2) which are described below.

Boundary Mountains

The Boundary Mountains (Fig. 3) are a northeastern extension of the White Mountains of New Hampshire. The highest peak in this range is Mont Gosford (1220 m); several peaks stand at altitudes near or above 900 m. The crest of the range forms the International Boundary as well as the St. Lawrence River-Kennebec River drainage divide.

The Boundary Mountains owe their high altitudes largely to erosion-resistant metasandstone of the Arnold Formation (Marleau, 1968) southwest of Boundary Pond, and to a high proportion of resistant basic metavolcanic and meta-igneous rocks within the Frontenac Formation (Fig. 4) northeast of Boundary Pond.

Portage Uplands

The Portage Uplands section (Fig. 2) is a high, relatively level upland, largely underlain by steeply dipping, interbedded sandstone and slate of the Frontenac Formation. Altitudes range between 525 and 640 m. The north and northwest-facing edge of the uplands is a prominent escarpment, underlain by basic metavolcanic rocks in its southwestern portion. The Portage Uplands are thinly veneered by till, and their surface is typically corrugated by prominent 6 to 20 m-high strike ridges formed on sandstone interbeds of

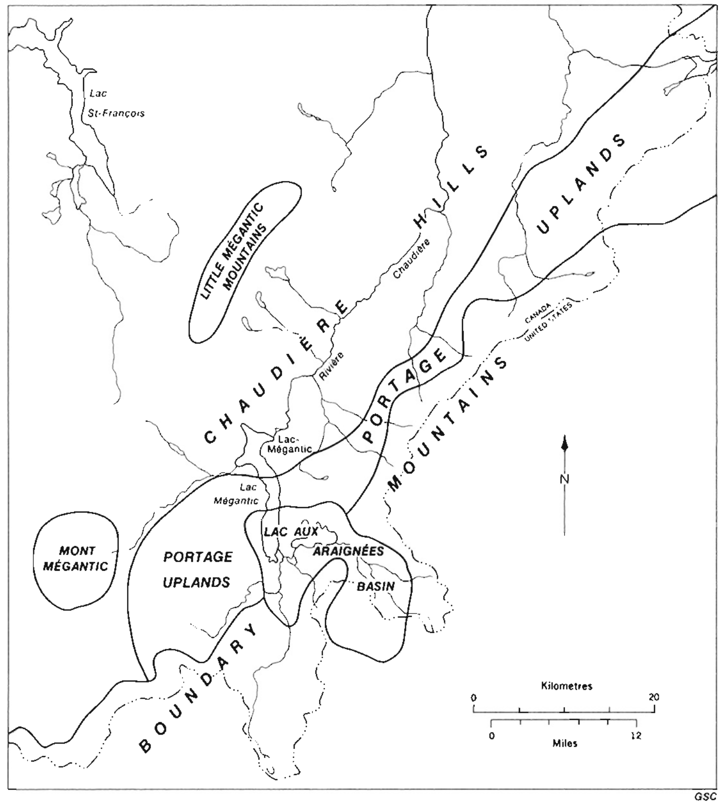


Figure 2. Physiographic sections, Lac-Mégantic region.

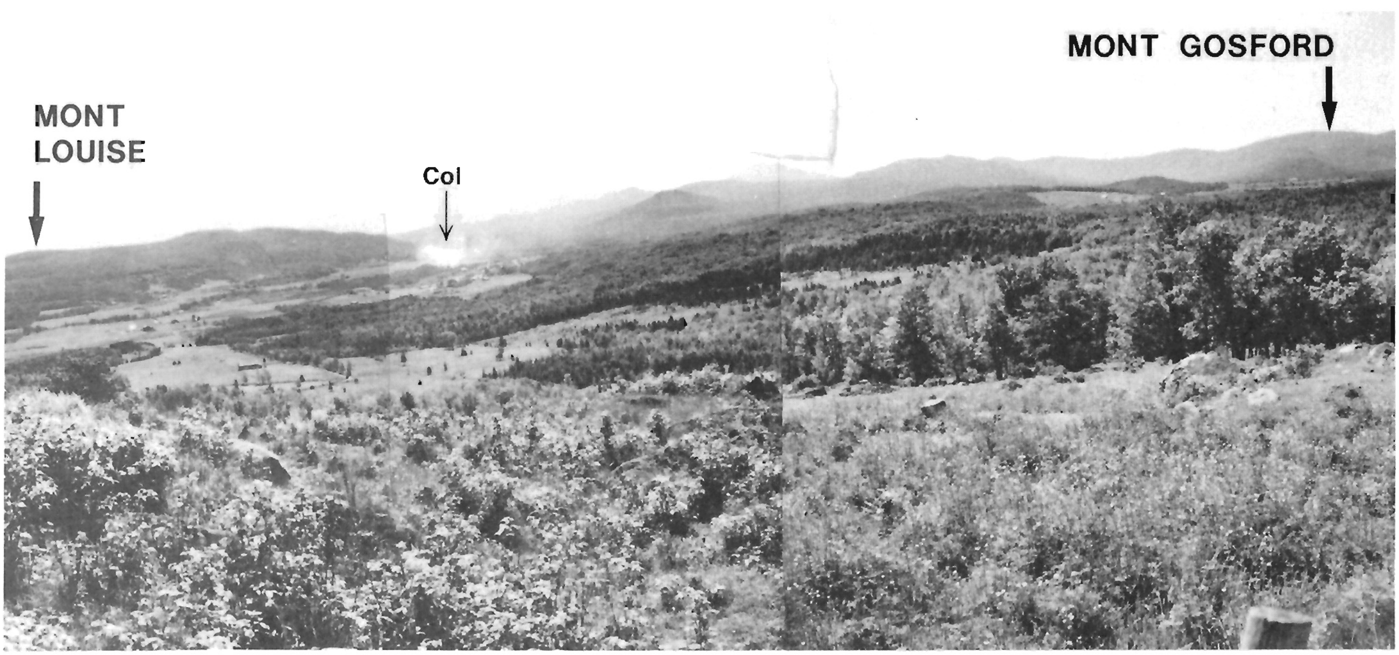


Figure 3. Boundary Mountains, panoramic view east and southeast from east-facing flank of Mont Scotch. Town in region of smoke is Woburn. Depression at and north of Woburn is Lac aux Araignées basin. The col east of (behind) the smoke is one of the important 430 m outlets through the mountains into the Dead River drainage system in Maine. (GSC 148119, 148118, 148117 in mosaic)

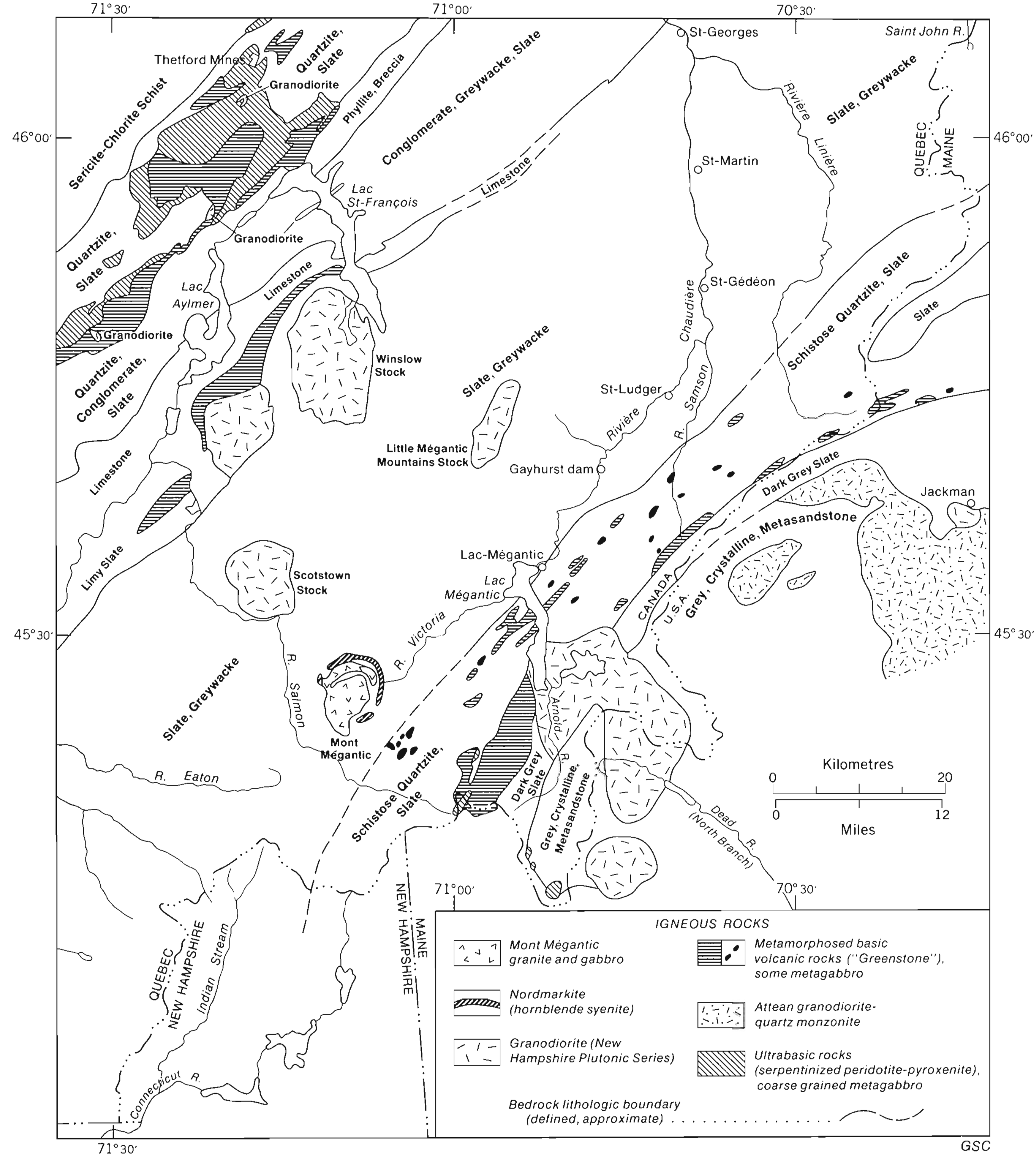


Figure 4. *Generalized bedrock geology of study area and adjacent areas. See text for sources of information.*

the Frontenac Formation (Fig. 5). Intervening valleys are formed in slate. The strike ridges trend from 50 to 70°, and differential glacial erosion of the slate interbeds during an early (northeast) phase of the penultimate glaciation may have enhanced relief.

Lac aux Araignées Basin

The Lac aux Araignées Basin (Fig. 3) is formed over an intrusion of granodiorite of the New Hampshire Plutonic Series (Doyle et al., 1967), which elsewhere forms topographic highs. The Lac aux Araignées Basin is similar to the Yellow Bogs depression (Myers, 1964) developed on the Nulhegan quartz monzonite of northeastern Vermont. Lord (1938) described the Lac aux Araignées pluton as a "barely unroofed" stock, and Myers felt that this interpretation also best explained the Yellow Bogs depression.

A "barely unroofed" stock first would expose its easily weathered contact zone to weathering and erosion. Fluvial and/or glacial erosion preferentially would remove the cover of contact-metamorphic rocks leaving surrounding, low-grade metasediments to stand temporarily in relief above the uncovered igneous body. Since granodiorite is relatively more resistant to weathering and erosion than slate, metasediments eventually would be reduced in altitude relative to the intrusion, and the granodiorite would ultimately stand as a topographic high similar to the Little Mégantic Mountains (see below).

Chaudière Hills

The Chaudière Hills section (Fig. 6) is a region of low hills with gentle slopes developed over isoclinally folded slate and sandstone of the Compton Formation (Devonian). Glacial deposits are relatively thick over this region, and glaciers have effected a significant levelling of the ancestral terrain by filling in hollows and planing off topographic prominences. The Chaudière Hills generally range from about 490 to 270 m elevation.

Little Mégantic Mountains

The Little Mégantic Mountains (Fig. 7) form a north-northeast-trending ridge, largely underlain by granodiorite of the New Hampshire Plutonic Series. They are mantled by thick glacial deposits on their northwest flank but are largely devoid of glacial cover elsewhere. Several granodiorite peaks have the appearance of giant rôches moutonées, being rounded on their northwest-facing sides and steepened by plucking on their southeast-facing sides (Fig. 8). A depression, averaging 1 km in width, commonly occurs over the zone of contact metamorphism on the east-facing side of the ridge and is underlain by andalusite (chiastolite)-bearing slates and sandstones.

Mont Mégantic

Mont Mégantic is the most easterly of the distinctive Monteregian Hills. It consists of a conical, central, granite-gabbro peak rising to 1150 m surrounded by a ridge (ring dyke) of syenite that stands 500 to 600 m above the surrounding Chaudière Hills (Reid, 1960). It is heavily drift-covered on its northern side to a point about halfway up its slopes, but the rim and central peak have thin till cover elsewhere.

"Preglacial" Bedrock Surface

At least one and probably several glaciations may have preceded the Johnville, Chaudière, and Lennoxville glaciations, which are responsible for deposition of nearly all the unconsolidated sediments that presently cover the Lac-Mégantic area. Because so little is known about possible early glacial events, it is not reasonable to speculate on the nature of the true preglacial bedrock surface. Thus the term "preglacial", as used in this report, refers to the bedrock surface as it is thought to have existed just prior to the onset of Johnville glaciation.

The preglacial surface is visualized as being similar to the modern surface in most respects. Mont Mégantic and the Boundary and Little Mégantic mountains probably have been reduced a few tens of metres in altitude, their relief being "softened" as slopes and valleys were rounded by glacial erosion of prominences and glacial deposition in depressions. The relief of the northeast-southwest-trending sandstone ridges of the Portage Uplands probably was enhanced by preferential glacial erosion of intervening slate during the southwestward flow phase of the Chaudière glacier.

The most severe changes in the preglacial landscape have occurred in the Chaudière Hills section where the low relief of the upland portions of the original bedrock surface has been modified further by glacial erosion and deposition. Many small streams in the Chaudière Hills follow or are diverted by glacial features, such as end moraine deposits or meltwater channels.

Figure 5

Ground, end-on view of bedrock hill (strike ridge) near Lac Portage, Portage Uplands. See Figure 44 for aerial view of this region. (GSC 154405)

Figure 6. *Typical rolling Chaudière Hills topography between Saint-Martin and Saint-Théophile. (GSC 148124)*

Figure 7. *Little Mégantic Mountains ridge (Mont Sainte-Cécile on left, Mont Saint-Sébastien on right) standing over Chaudière Hills; view from altitude of ca. 400 m over Lac Mégantic. Town of Lac-Mégantic at right centre; view towards northwest. (GSC 201696-C)*

Figure 8. *North end of Mont Sainte-Cécile. Note gentle slopes on up-ice (right or northwest-facing) side and steep slopes on southeast side, an example of glacial smoothing. Part of the slope on the right may be constructional, i.e., comprising an unknown amount of till fill. (GSC 148200, 148202)*

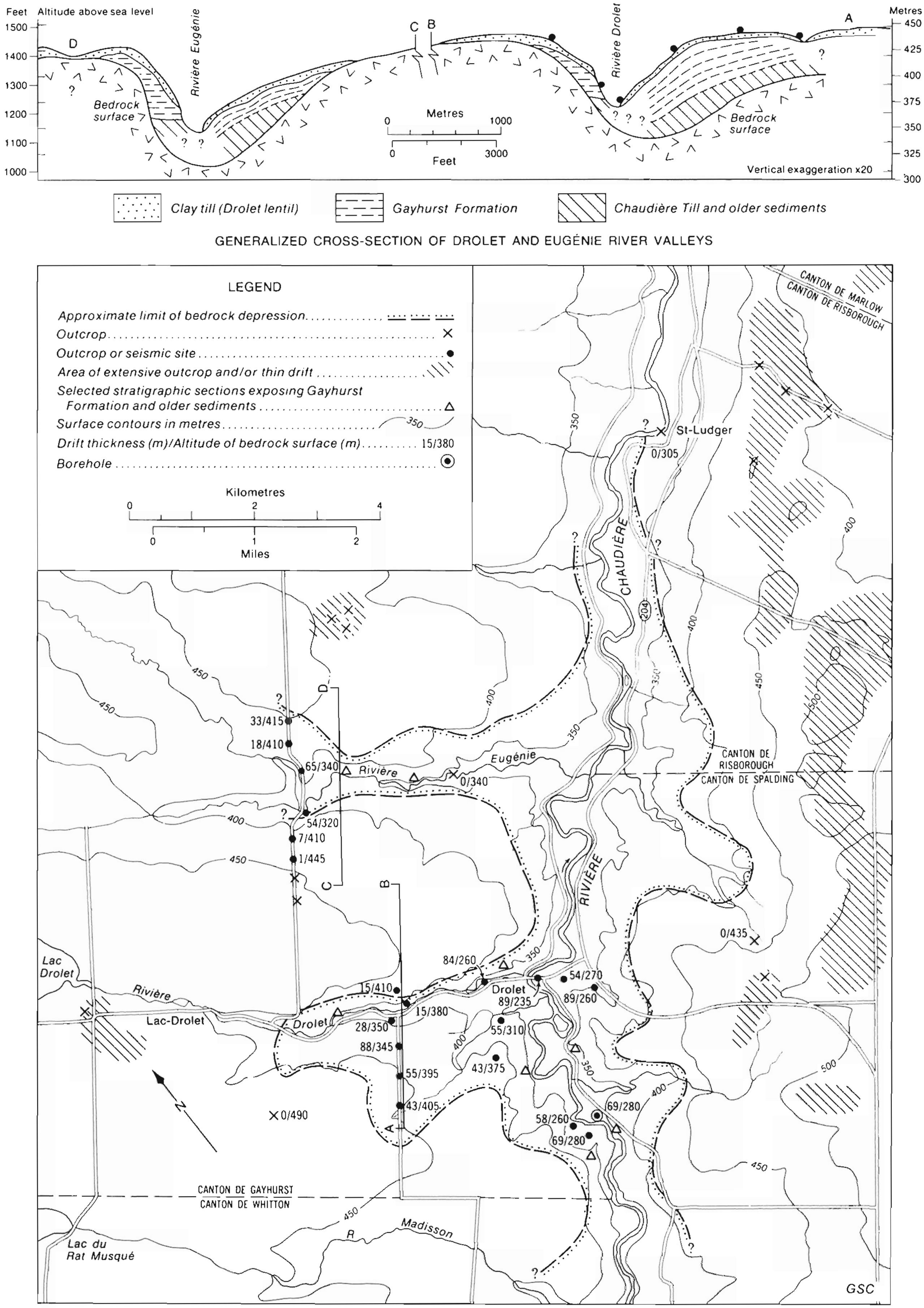


Figure 9. *Map of Drolet Depression including generalized cross-sections based on seismic profiles across Eugénie and Drolet river valleys.*

Figure 10

Vicinity of Drolet Depression, view up Drolet Valley towards west-northwest. Chaudière River in foreground; the hills on the horizon are Little Mégantic Mountains. Note the steep, right, south-facing side of Drolet Valley and the gentler north-facing side. (GSC 201696-K)

Major preglacial drainage in the Chaudière Hills followed bedrock troughs that were incised deeply into the gently rolling surface of the Chaudière Hills. Most of these troughs were sites of glacial or lacustrine deposition throughout the middle to late Wisconsinan, starting with the Chaudière and ending with the Lennoxville glaciations. The accumulation of massive amounts of till and lacustrine sediment of two glacial events with no interstadial fluvial erosion below 430 m filled most of these troughs almost to the level of the adjacent bedrock surface. Postglacial rivers have been able to excavate no more than 30 to 50 per cent of the fill. Substantial amounts of glacial fill are found in portions of the Arnold, Bergeron, Victoria, Chaudière, Drolet, Nebnellis, Kokombis, Eugénie, Samson, Grande Coulée, la Truite, Linière, and Wilson river valleys.

Drolet Depression and Associated Asymmetric Valleys

The Drolet Depression is a significant but presently unexplained feature that occurs on the preglacial bedrock surface in the vicinity of the confluence of Drolet and Chaudière rivers (Fig. 9). Information from sections, a borehole, and seismic records (Appendixes 1, 2) indicates that glacial fill in this vicinity exceeded 160 m before postglacial erosion and that the bedrock surface lies at 260 to 280 m a.s.l. near the axis of the valley. Deep lateral depressions extend westward under the valleys now occupied by Drolet and Eugénie rivers. Approximately 12 km downstream from Drolet, in the town of Saint-Ludger, the Chaudière River is flowing over bedrock at an altitude of 305 m a.s.l.

The fact that the bedrock surface slopes up to Saint-Ludger suggests that a deep preglacial channel could lie beneath the west side of the river, bypassing the Saint-Ludger outcrop. No such channel has been found, leading to the possible conclusion that Saint-Ludger is located near a preglacial drainage divide between the St. Lawrence and Kennebee-Dead River (Maine) drainage basins. Seismic profiles across the south end of Lac Mégantic and mountainous topography east of the Chaudière-Arnold river basin, however, indicate the lowest bedrock surface to be of the order of 315 m a.s.l., more than 50 m above the lowest part of the Drolet Depression. For drainage to escape southwestward into the Saint-François River basin via Victoria River, about 300 m of glacial fill would be required at the head of Victoria River on the east side of Mont Mégantic. Mapping near the headwaters of Victoria River gives no indication of such massive glacial fill.

After considering seismic and drilling information and studying the map of surficial deposits (Map 1494A), it is possible to speculate that the Drolet Depression may not be a preglacial erosional feature but either 1) some sort of structural depression with closure of, perhaps, several tens of metres or 2) a closed depression, excavated by glacial erosion, that at one time could have held a nonglacial lake similar to modern Lac Mégantic or Lac aux Araignées, both of which appear to occupy glacially overdeepened depressions in the bedrock surface. However, if the few metres of oxidized rubble lying beneath lake sediment at the base of borehole 1 is weathered bedrock, it is probably preglacial or interglacial in age and does not support glacial overdeepening during the Wisconsinan.

Drolet and Eugénie rivers follow westward extensions of the Drolet Depression. Both valleys are asymmetric with steep south-facing sides that expose pre-Lennoxville sediments or thin colluvium over bedrock. North-facing sides are much less steep and are composed of Drolet lentil. The north-facing sides have the aspect of a till plain that was once horizontal but that has been dropped and rotated (Fig. 9). Neither Drolet nor Eugénie rivers have excavated their present valleys but flow along the lowest edge of the "rotated" surface, against the steep south-facing slope (Fig. 10). The bedrock valleys beneath both rivers are considerably larger and deeper than the present valleys, and the profiles of the bedrock surface appear to match roughly the asymmetry of the modern valleys. Without more complete seismic and/or drilling data, the asymmetry may be explained by one of the following hypotheses:

1. The deeply filled south sides of the valleys have been downthrown by some sort of soft-sediment slumping under glacial loading or in postglacial times; this would require substantial displacement and deformation of the thick underlying lacustrine sequence.
2. "Neotectonic" activity, such as that postulated by Oliver et al. (1970), may have caused bedrock displacements along pre-existing fault systems during or after glaciation; this hypothesis also would explain a "closed" Drolet Depression.
3. The asymmetry of the surface of glacial fill merely may be the reflection of either glacial or fluvial erosional asymmetry of the bedrock depressions.

PLEISTOCENE SEDIMENTS

Introduction

Table 1 lists the major stratigraphic units encountered in the map area; Figure 11 is a schematic cross-section showing relationships of stratigraphic units across St. Lawrence Valley from the Canadian Shield to the Boundary Mountains.

In this paper, emphasis is placed on defining the petrologic properties of till sheets, because only by developing a set of unique petrologic criteria for each till can the various sheets be separated in section or traced laterally with any degree of confidence. Till sheets are examined closely, not only because they are volumetrically the most important unconsolidated sediments, but also because they are the only widespread sediments that always require glacier cover for their deposition. The number of major till sheets that can be identified represents the minimum number of glacial events that have affected the area.

Because each till sheet varies areally according to variations in its source rocks, the youngest (Lennoxville) till sheet is described in terms of its compositional and textural variation 1) so that older tills may be compared to it and 2) to provide a data base for any future investigations of variations of geochemical, agricultural, or engineering properties of Lennoxville Till and associated soils and sediments.

During each glaciation a variety of water-laid sediments was deposited during the advance and retreat of ice fronts throughout the map area. Between glaciations and after the last glaciation, fluvial and mass wasting processes produced sediments that can be related to the general stratigraphic sequence.

The most widespread water-laid sediments are clayey silty lake sediments that were deposited in the proglacial lakes formed by the blockage of northward or westward drainage whenever an ice front stood south of the St. Lawrence Lowland (McDonald and Shilts, 1971, p. 683). Although each till sheet may be underlain and overlain by lake sediments, the thick pile of clayey sediments of the Gayhurst Formation, which forms the sides of Chaudière Valley between Lac-Mégantic and Saint-Ludger, represents the most massive accumulation of lacustrine deposits in southeastern Quebec. These sediments locally had a profound effect on the character of Lennoxville Till and on the stability of valleysides during postglacial erosion.

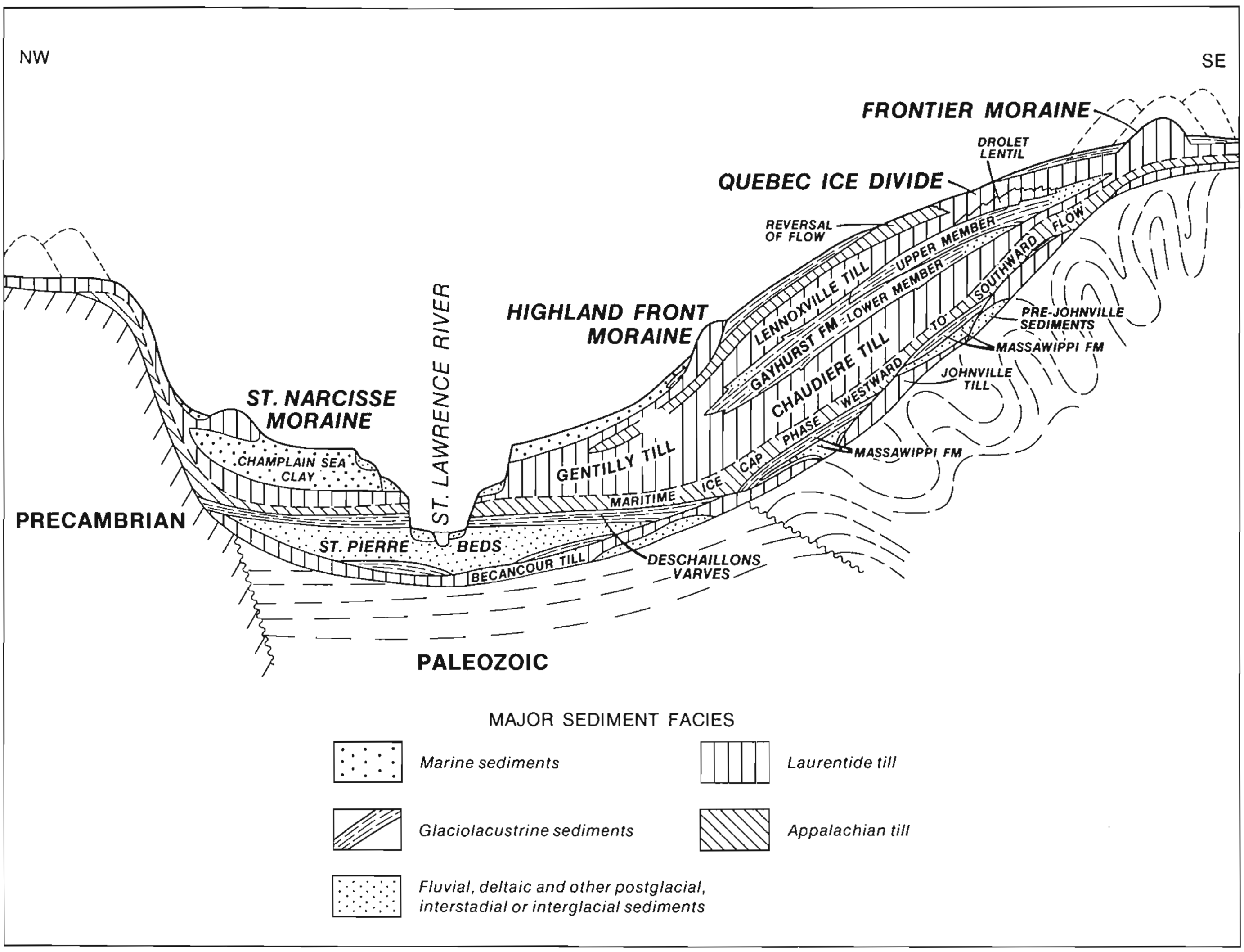


Figure 11. *Schematic cross-section showing generalized Quaternary stratigraphy from the Laurentian Hills north of Trois-Rivières to the Boundary Mountains in the study area. This figure is modified from an original conceived by J.A. Elson, McGill University.*

Table 1. Generalized stratigraphic column for Quaternary sediments of the Lac-Mégantic region

TIME STRATIGRAPHIC				EVENT OR SEDIMENT	ROCK STRATIGRAPHIC
ERA	EPOCH	STAGE	SUBSTAGE		
	RECENT			Lake-bog sediment Fluvial sediment Downcutting Proglacial lakes	Postglacial sediments
CENOZOIC	QUATERNARY	WISCONSINAN	LATE	(Reversal of flow – Quebec Ice Divide) Lennoxville glaciation (Southeastward flow – deflection by highlands during advance)	Lennoxville Till Drolet lentil
			MIDDLE	Glacial Lake Gayhurst (Ice fills St. Lawrence Lowland)	Gayhurst Formation Upper Member Lower Member
				(Southeastward glacial flow – Laurentide Ice Cap) Chaudière glaciation (westward-southwestward glacial flow – Maritime Ice Cap)	Chaudière Till
			EARLY	Fluvial sediment; free drainage preceded by proglacial lakes	Massawippi Formation
				Johnville glaciation (southeastward glacier flow)	Johnville Till
		PRE-WISCONSINAN	?	Fluvial gravel Varves Fluvial gravel Fluvial sand	Pre-Johnville sediments
PALEOZOIC	ORDOVICIAN – DEVONIAN				Bedrock

Coarse, water-laid sediments deposited as deltas, eskers, or ice front fluvial gravels are important in interpreting glacial lake levels and the configuration of the ice front during deglaciation. Although such deposits also accompanied earlier glaciations, they rarely are encountered in stratigraphic sections in this area, either because they were removed by later glacial erosion or because they were not very extensive.

Nonglacial fluvial sediments, deposited during periods of free drainage of Chaudière River to the St. Lawrence, rarely are seen in stratigraphic section. Where identified, they are important to the interpretation of glacial history – particularly to the interpretation of drainage conditions in interstadial or interglacial times. Postglacial fluvial and colluvial deposits are important because of their relationship to slope stability and their value as agricultural land or aggregate sources.

Because each glacial event is associated with sediments that can be broken down into 1) till (ice deposited), 2) laminated silty clay (deposited in glacial lakes), 3) sand and gravel (deposited by subglacial or proglacial rivers), or 4) postglacial river, lake, and mass wasting deposits, the sediments will be discussed group by group and not in historical sequence. Although each glacial event differs from its predecessors in detail, the same depositional sequences may be expected before, during, and after each glaciation.

An attempt has been made in this paper to emphasize the depositional environments of the sediments and their petrology, resource potential, and influence on human activity.

Complications in Interpreting Stratigraphy

In southern Quebec, as in many glaciated areas, the interpretation of stratigraphic data is complicated by the effects of certain glacial processes as well as by the effects of postglacial events. Some of the complexities that are particularly troublesome in the map area will be pointed out so that the reader, when evaluating the interpretations given here, might be aware of the range of interpretations possible.

As noted previously, till sheets have been considered to be key stratigraphic units. When a till can be identified accurately and related to other glacial and nonglacial units in a section or can be traced through several sections, a history of ice cover and ice-free periods can be reconstructed. When till-like deposits (i.e., colluvium) are misidentified as till or unusual facies (ablation till, clay till) are misidentified as being deposited during different glaciations, serious problems in interpretation can arise. Superimposed on these basic problems is the apparent presence, in several sections in the map area, of many more tills or till-like units than can be accommodated within the regional stratigraphic framework. These "extra" units usually are not related to separate glaciations but may develop as a result of shear stacking, turbidity currents or mudflows (and/or flow tills), or slumping of coherent sediment blocks along rotational faults. In parts of the study area the advancing Lennoxville glacier oscillated slightly, producing two true till members, particularly in Samson River valley.

Shear stacking is thought to be a common phenomenon and is probably the most difficult glacial process to identify. Shear stresses transmitted by the glacier to the glacial bed or freezing of the upper parts of the bed to the base of the glacier (Boulton, 1970) cause thin plates of sediments that have been deposited already (or bedrock in areas of flat-lying rocks) to be sheared from the bed, transported down-ice, and redeposited on top of each other or on other glacial sediments. These plates in many cases are transported with minimal deformation and are stacked up against bedrock or glacial sediment protuberances or in depressions (such as valleys) on the glacial bed. Several of these plates may be stacked, one on top of the other, in one location so that an abnormally thick pile of drift results. When the plates are composed of till alone, the stacking is almost impossible to detect, except where running water has etched out the silty zones that commonly separate the plates (Fig. 12). Where the thrust plane has penetrated underlying sediments, cross-bedded sand, for example (Fig. 13), the shear stacking can be seen as a section comprising several identical till or lacustrine units separated by deformed lacustrine deposits; thus, one 3 m-thick till and lake sediment couple may give rise to a "multiple till" section several tens of metres high. In such sections interpretation of stratigraphy is very difficult.

Several sections in the map area are complicated by shear stacking of till/lacustrine sediment couples. Section 7 (see Map 1494A and Table 4, Appendix 1 for locations and descriptions of numbered sections) along Linière River consists mostly of thin thrust plates of sandy or clayey lake sediment and clay till; at least 13 m of the 23 m-high section is involved in stacking. Thrust planes also have been

Figure 12

Shear planes in Lennoxville Till, Samson River. Note that the till is apparently massive above the dashed line but is seen to have numerous shear planes below the line where stream flow has etched them out. (GSC 154380)

Figure 13. *Sand bed forming base of one till plate sheared onto another, section 7, Linière River. Note highly contorted bedding. (GSC 154472)*

Figure 14. *Massive, stony turbidite beds interbedded with laminated silty clay of Gayhurst Formation, section 10, Samson River. Note flow rolls and other contortions in the lowest stony bed, just to the left of the end of the shovel handle. Arrows point to a massive, stone-free silty clay bed typical of turbidites higher in the section. (GSC 154481)*

identified in portions of sections 1, 1a, 2, 3, 10, 12, 13, and 14, and at several other minor exposures both within and outside the map area.

Another glacial process that gives rise to multiple, till-like units is deposition of till-like material by subaqueous mudflow or turbidity currents. In most valleys of the map area, each glacier advanced and retreated in contact with a proglacial lake. Slumping of till from the sides of these basins and from debris bands melting out of the ice front caused dense slurries of "till" to flow out over normal laminated lacustrine sediment. In sections 10 and 11, thick lacustrine sediments are interbedded with massive stony or silty beds, which at casual glance have the aspect of structureless till (Fig. 14). The lacustrine sediments are flat-lying and undisturbed above and below each till-like bed but are strongly deformed where they are in contact with Lennoxville Till at the top of the section. Where these bands were excavated by a high-discharge water hose, abundant flow rolls and contorted structures typical of a turbidite deposit were seen. At section 10 the beds are stony and till-like at the base of the lacustrine section but give way to beds of massive, structureless clayey silt near the top, indicating that the source of the turbidites, probably the glacier front, was moving away from the site (retreating) during deposition of the lake sediment.

Postglacial rotational slumping of large blocks of unconsolidated sediment is common in the map area and causes serious problems in stratigraphic interpretations in Chaudière, Samson, and Eugénie river valleys. The slump blocks may contain several stratigraphic units, can be up to 2 km in length, and may be displaced as much as 50 m below their original position. Individual blocks can be difficult to recognize because erosion and revegetation have destroyed their original form. Because stratigraphic information usually is derived from scattered exposures along valleysides and in river channels, the vertical displacement of unrecognized slump blocks may cause young units to appear low in a valley or to be apparently repeated up the valleyside (Fig. 15). Thus young units may be misinterpreted as occurring lower in the stratigraphic sequence if altitude alone is used as a criterion for their stratigraphic position.

This problem is particularly acute in Chaudière, Eugénie, and Drolet river valleys where extensive rotational slump occurs and where critical type sections of the Gayhurst Formation and Drolet lentil clay till exist. It is thought that the configurations of the slumped portions and individual displaced blocks are known well enough that the critical stratigraphic implications of the sections in this region are accurate. Figure 16 shows a small slump block that occupies the middle portion of section 10 on Samson River. After this section is eventually stabilized and revegetated, future interpretations of the stratigraphy will be difficult, due to the 12 to 13 m displacement of the upper Lennoxville Till into a stratigraphic position coincident with the middle of the underlying Gayhurst Formation.

One last complication in stratigraphic interpretation is the rare occurrence of two members of Lennoxville Till, separated by a thin layer of lake sediments. This sequence is thought to have been deposited by slight backward and forward oscillations of the glacier front during advance or retreat while in contact with a glacial lake. At Gayhurst dam a similar bipartite division of the Chaudière Till is

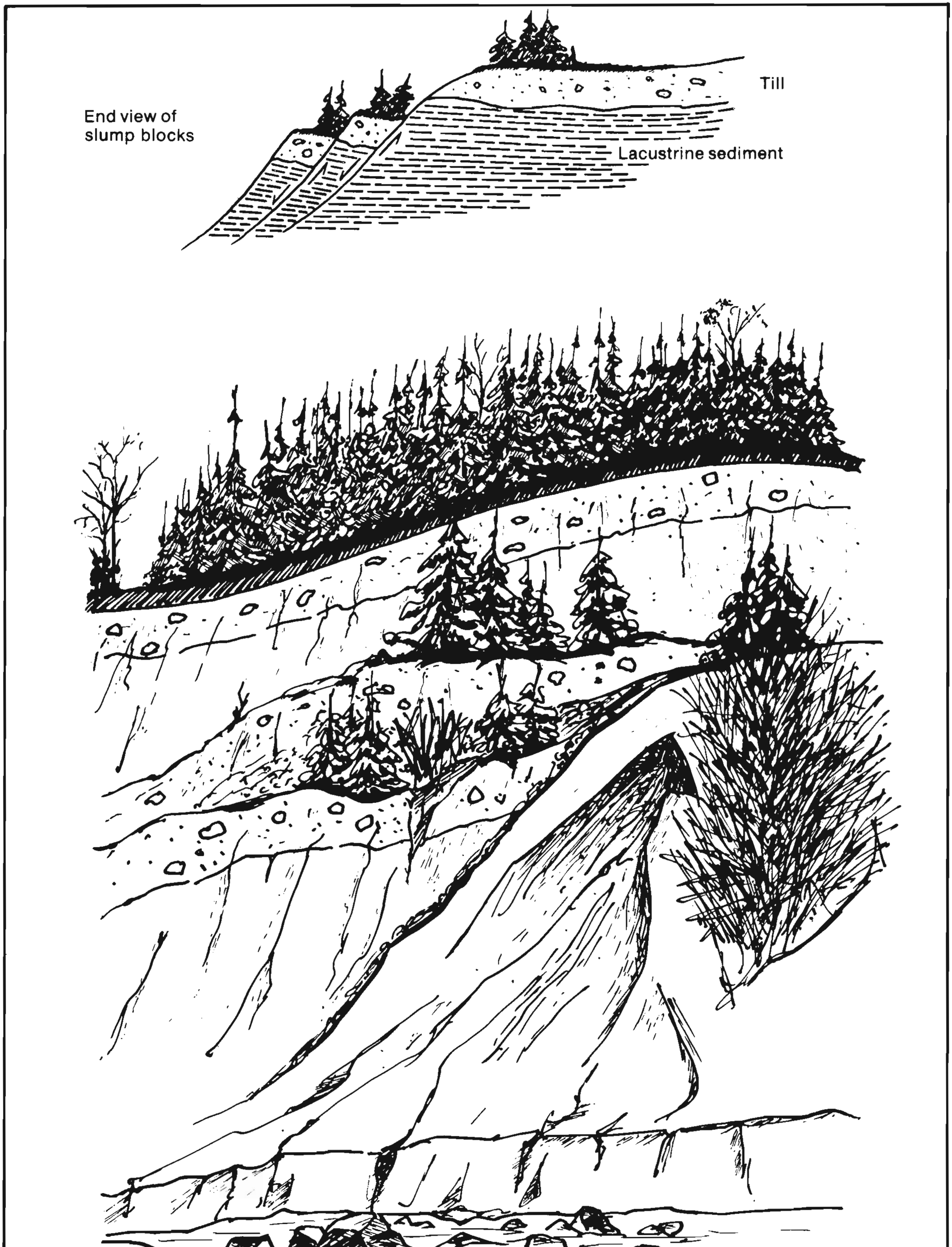


Figure 15. *Diagrammatic sketch showing typical displacement of slump blocks in study area. Erosion and redeposition on this section after slumping can create an exposure in which the upper till appears to be three separate tills. (Original drawing by D. Campbell)*

GSC

inferred. Where such bipartite units occur, it is difficult to decide to which glacial event the lower of the two units relates. The distinction usually has been made on the basis of comparisons of composition and fabric, presence of lower (older) petrologically distinct tills in the same or nearby sections, and the amount of lake sediment separating the units.

Subsequent discussions here of glacial history and of tills of different ages should be studied bearing in mind the problems in interpretation outlined in this section. Although the general stratigraphic framework developed for the Lac-Mégantic area is valid and fits well with regional stratigraphic models from the St. Lawrence Lowland (Gadd, 1971), the Sherbrooke-La Patrie area (McDonald, 1967a, b, c, 1969), and from Vermont (Stewart and MacClintock, 1969; Behling, 1965), details of the stratigraphy at any site could be reinterpreted in light of new exposures or new stratigraphic techniques.

Bedrock Sources and Provenance Regions

The major factor that controls the physical and mineralogical characteristics of tills of the Lac-Mégantic area is the monotonous pyritiferous, slate-sandstone, limy mudstone lithology that comprises most of the bedrock terrain of this portion of the Appalachians (see Fig. 4). "Normal" tills in this region are composed principally of a crushed mélange of these rocks. The isolated granodioritic, syenitic, volcanic, gabbroic, and ultrabasic outcrops that occur here and there throughout the region have added distinctive mineral components that are superimposed on the mineralogy of the slate-sandstone-mudstone mélange. Distinct dispersal bands of these "exotic" components trend southeastward from their sources, in places giving rise to distinctive changes in physical and chemical properties of Lennoxville Till, the normal surface till of the area, and of soils developed on it (Shilts, 1973a, b, 1975).

Three lithologically distinct dispersal bands, formed during Lennoxville glaciation, cross the map area; these, in addition to a fourth area of "normal" slate-sandstone-mudstone till, comprise four provenance regions, each of which has distinctive mineralogical, chemical, or physical properties (Fig. 17).

Each of the four generalized provenance regions is characterized by a cover of Lennoxville Till with a composition reflecting total or partial derivation from slate-sandstone-limy mudstone (I); serpentinized peridotite, pyroxenite, metagabbro (II); granodiorite (III); or syenite and associated rocks, high grade metamorphic rocks, and basic volcanic rocks (IV). Water-laid sediments deposited at or near the ice front during deglaciation and postglacial fluvial and lacustrine sediments closely follow the compositions of tills of their provenance regions. Generally, the major difference between the coarse-fraction lithologies of till and glaciofluvial sediments is lower percentages of soluble (carbonate) and easily abraided (slate) clasts in water-laid sediments. However, ice front gravel deposited on granodiorite-poor Drolet lentil is rich in granodiorite (see section on Glaciofluvial Deposits).

Each provenance region outlined for Lennoxville Till provides 1) convenient reference compositions with which compositions of the older Chaudière and Johnville tills may be compared; 2) reference compositions that permit determination, by comparison, of whether older tills were deposited by ice flowing in the same direction as or in different directions from the Lennoxville glacier; and 3) general patterns of chemical and mineralogical composition that may influence the characteristics of aggregate resources, clay deposits, soils, vegetation, etc. in the region (see Frontispiece).

Figure 16. *Slump block on face of section 10, Samson River. A rotational slump block comprising the upper till units separated by lake sediment has dropped vertically more than 10 m to its present position. Figure 15 is modelled after this photograph. (GSC 154545)*

Provenance Region I

In general, all unoxidized tills of provenance region I are olive-black to medium grey, compact, stony sediments with abundant, sand-sized pyrite fragments. Their clasts and surface boulders are predominantly black and grey pyritiferous slates, metagreywackes, and impure carbonate rocks. Up to 10% vein quartz fragments and 1% or less each of chloritic schist, volcanic breccia, Laurentian (Precambrian) gneiss, and garnet-bearing gneiss of unknown origin comprise the remainder of the clasts. The latter erratic type is common only in the region north of 45°45'N and east of Samson-Chaudière rivers. Heavy mineral content, magnetic mineral content, and trace element concentrations vary little among all till samples from the region (see Fig. 17).

Lennoxville Till of provenance region I shows little evidence of derivation from igneous sources, although some ultrabasic rocks outcrop to the northwest and north. Lennoxville Till and water-laid sediments associated with or derived from it are considered to be background sediments for the study area – sediments derived largely from sandstone, slate, and impure limestone beds. Igneous suites that affect the composition of drift in provenance regions II, III, and IV have added mineral, rock, and trace element components to background concentrations typical of provenance region I (see Table 2).

Lennoxville Till in provenance region I has less total fine sand-sized feldspar than either Chaudière or Johnville tills (Fig. 18). The only samples of Johnville Till examined have more feldspar than Chaudière Till and, in fact, have a feldspar composition typical of Lennoxville Till derived from

Table 2. Summary of petrologic characteristics of Lac-Mégantic tills

	Textural Parameters (<2mm fraction)						Pebble Composition (%)							
	$\overline{M_z}$	$\overline{\sigma_I}$	$\overline{K_G}$	% Sand	% Silt	% Clay	Ultrabasic (1)*	Ultrabasic (3)	Granodiorite (2)	Granodiorite (4)	Vein Quartz	Carbonate	Lauren-tian	Sandstone Slate
Lennoxville Till	6.04φ σ=0.87φ N=40	3.74φ σ=0.36φ N=40	0.99 σ=0.10 N=40	13-50 N=40	32-53 N=40	16-52 N=40	0-4 $\bar{x}$≈2 N=28	4-39 $\bar{x}$≈5 N=23	0-1 N=20	4-43 $\bar{x}$≈19% N=14	2-13 $\bar{x}$≈6 N=29	0-31 $\bar{x}$≈14 N=29	0%-2% N=29	48-89 $\bar{x}$≈68 N=29
Drolet Lentil	8.77φ σ=0.74φ N=11	2.97φ σ=0.50φ N=11	0.93 σ=0.07 N=11	2-10 N=11	30-45 N=11	45-68 N=11	0 N=5	--	--	0-5 N=5	5-10 N=5	14-22 N=5	0-1 N=5	65-75 N=5
Chaudière Till	6.31φ σ=0.8[illegible]φ N=11	3.58φ σ=0.37φ N=11	1.07 σ=0.25 N=11	14-37 N=11	29-63 N=11	20-51 N=11	0 N=4	0-1 N=7	0-Trace N=6	0(18 on Arnold R.) N=4	2-10 $\bar{x}$≈5	9-33 $\bar{x}$≈15	0-2 N=9	51-85 $\bar{x}$≈74
Johnville Till	6.31φ N=1	3.84φ N=1	0.98 N=1	30 N=1	41 N=1	29 N=1	0 N=1	--	0 N=1	--	6 N=1	0 N=1	0 N=1	84 N=1

	Fine Sand Petrology (%)											X-Ray Data
	% Quartz (2)	% Quartz (4)	% Plagioclase (2)	% Plagioclase (4)	Heavy Mineral Wt. % (2)	Heavy Mineral Wt. % (4)	Magnetic Minerals % (1)	Magnetic Minerals % (3)	Rock Fragments	Serpentine	Calcite	10Å/7Å (<4µm fraction)
Lennoxville Till	76-83 $\bar{x}$≈79 N=16	61-74 $\bar{x}$≈67 N=11	8-17 $\bar{x}$≈12 N=17	16-29 $\bar{x}$≈22 N=11	1.3-3.1 $\bar{x}$≈2.2 N=25	1.9-7.5 $\bar{x}$≈4.3 N=27	3-13 $\bar{x}$≈7 N=24	6-22 $\bar{x}$≈11 N=45	22-65 $\bar{x}$≈35 N=32	0-6 $\bar{x}$≈1	1-3	1.105-1.605 $\bar{x}$≈1.358 N=13
Drolet Lentil	--	--	--	--	1.6-2.9 $\bar{x}$≈2.0 N=9	--	5-14 $\bar{x}$≈8 N=11	--	--	--	--	1.314-1.757 $\bar{x}$≈1.621 N=5
Chaudière Till	68-77 $\bar{x}$≈72 N=6	77-85 $\bar{x}$≈81 N=4	13-19 $\bar{x}$≈15 N=6	8-15 $\bar{x}$≈11 N=4	1.3-3.9 $\bar{x}$≈2.1 N=7	2.3%-4.7% $\bar{x}$≈3.4% N=4	5-13 $\bar{x}$≈7 N=9	3-6 $\bar{x}$≈4 N=4	22-48 $\bar{x}$≈36 N=13	present in all samples (1)	1-3	1.092-1.341 $\bar{x}$≈1.201 N=10
Johnville Till	60 N=1	--	21 N=1	--	2.6 N=1	--	7 N=1	--	38 N=1	1	present	1.545 N=1

	Trace Element Concentration Ranges (ppm)								Munsell Colour	
	Cr (1)	Cr (3)	Ni (1)	Ni (3)	Cu	V	Ti	Zr	Unoxidized	Oxidized
Lennoxville Till	57-150 $\bar{x}$≈100 N=35	60-280 $\bar{x}$≈148 N=42	25-100 $\bar{x}$≈40 N=35	25-180 $\bar{x}$≈77 N=42	14-75 $\bar{x}$≈27 N=93	40-120 $\bar{x}$≈86 N=96	3200-7000 $\bar{x}$≈4773 N=96	160-800 $\bar{x}$≈362 N=96	5GY4.5/1 5Y4.5/1 5Y4/1	5Y4.5/2 5Y4.5/3 5Y5/3
Drolet Lentil	64-100 $\bar{x}$≈81 N=13	--	30-46 $\bar{x}$≈37 N=13	--	23-43 $\bar{x}$≈30 N=12	78-100 $\bar{x}$≈99 N=12	4200-5200 $\bar{x}$≈4900 N=12	160-530 $\bar{x}$≈238 N=12	N4	5Y4.5/2
Chaudière Till	84-130 $\bar{x}$≈98 N=6	57-84 $\bar{x}$≈71 N=4	20-40 $\bar{x}$≈31 N=6	20-32 $\bar{x}$≈24 N=4	17-35 $\bar{x}$≈26 N=12	57-110 $\bar{x}$≈83 N=12	4300-5600 $\bar{x}$≈4792 N=12	270-480 $\bar{x}$≈357 N=12	5Y4/1 N4 N5	--
Johnville Till	56 N=1	--	30 N=1	--	24 N=1	90 N=1	5200 N=1	520 N=1	light olive grey 5Y5/2	-- --

* (1) Samples outside ultrabasic dispersal region (Provenance regions I, III)
(2) Samples outside granodiorite dispersal region (Provenance regions I, II)
(3) Samples from ultrabasic and gabbro dispersal region (Provenance regions II, II/III)
(4) Samples from granodiorite dispersal region (Provenance regions III, IV)

$\bar{x}$ = sample mean
N = number of samples

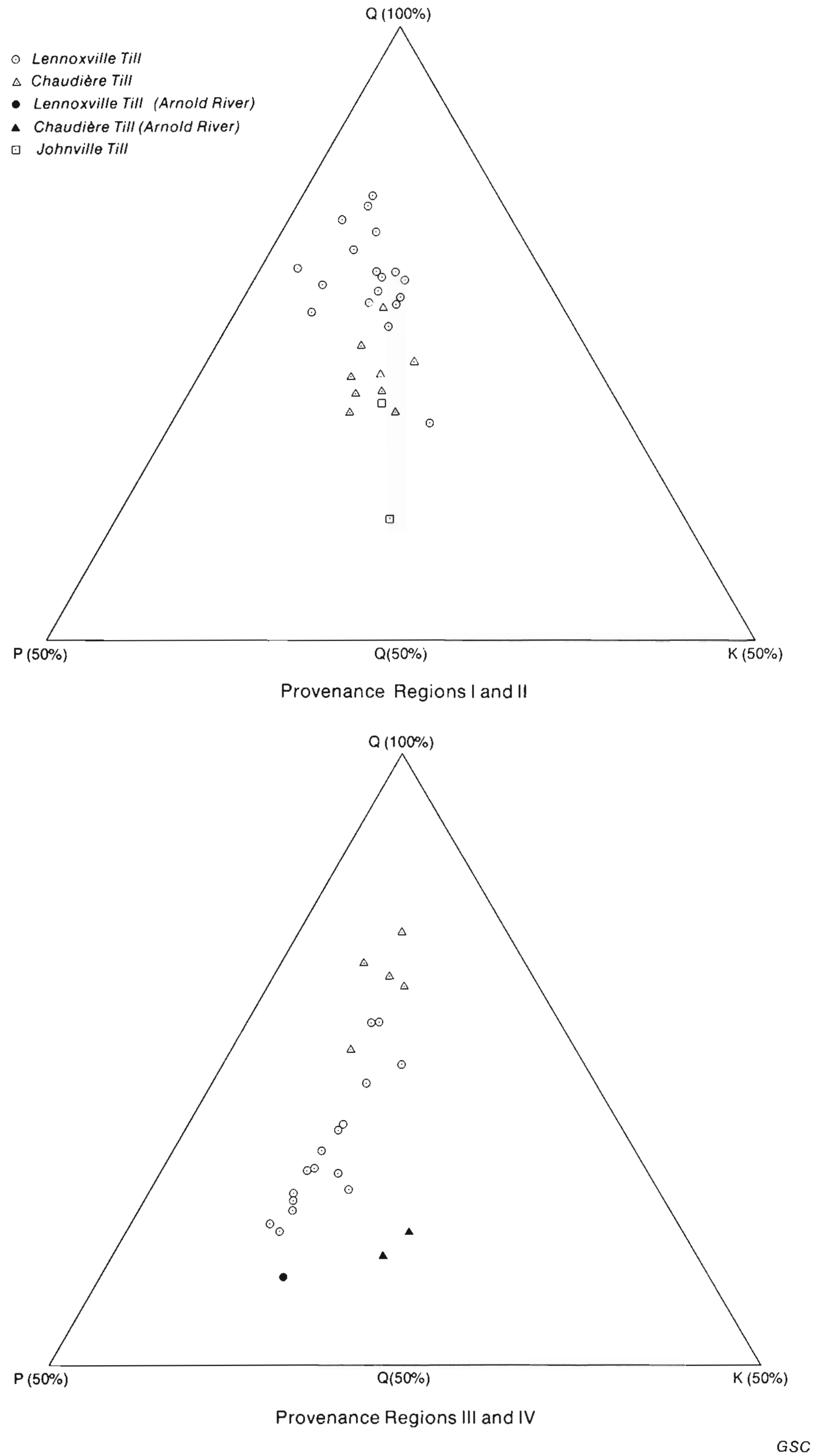


Figure 18. *Triangular plot of quartz (Q), plagioclase (P), and potassium feldspar (K) percentages in the fine sand (0.125-0.250 mm) fractions of Chaudière and Lennoxville Till samples (see also Appendix 1 for locations of and more specific stratigraphic information on samples).*

granodiorite in provenance region III. No reasonable explanation has been found for feldspar enrichment in older tills of provenance region I. As in the other provenance regions the unoxidized, <4 μm fraction of Chaudière Till has relatively lower diffraction intensity ratios (relatively more chlorite) than similar fractions of Lennoxville Till or Johnville Till (Fig. 19).

Provenance Region II

Lennoxville Till of provenance region II is rich in ultrabasic erratics and in minerals and trace elements eroded primarily from the large area of ultrabasic outcrop about 60 km away near Thetford Mines (see Fig. 4, 17, Table 2). Chaudière Till from provenance region II is almost devoid of ultrabasic erratics and, except for feldspar contents, has an overall composition comparable to the "background" compositions cited for Lennoxville Till of provenance region I. As in provenance region I, Chaudière Till is richer in feldspar than Lennoxville Till (Fig. 18).

In general, Lennoxville and Chaudière tills of provenance region II are physically similar to outcrops of these units in provenance region I. Chemically, however, Lennoxville Till and soils developed on it are relatively rich in chromium and nickel. Lennoxville Till contains 10 to 15% magnetic minerals in fine sand-sized heavy minerals as opposed to 2 to 5% in Chaudière Till.

Chromium and nickel enrichment for Lennoxville Till corresponds with a distinctive vegetation pattern (see Frontispiece) that appears to coincide with the boundary of the Ni-Cr dispersal train on which the northern part of provenance region II is based. The pattern does not correspond wholly to patterns of tree cover but rather appears to represent some subtle contrast in the overall composition of the vegetative cover or in the general soil conditions between provenance region II and the rest of the Lac-Mégantic area.

Provenance Region III

Provenance region III is a zone of granodiorite dispersal which results in Lennoxville Till being rich in feldspar and granodioritic erratics (Fig. 17, 18). In the central portion of region III, ultrabasic and gabbroic erratics and associated high concentrations of magnetic minerals, chromium, and nickel from a 10 km-wide, southeast-trending band superimposed upon the granodiorite-rich till.

Amphibole, mica, and andalusite, derived from granodioritic stocks and their contact-metamorphic zones, are common in Lennoxville Till of provenance regions III and IV but are rare in regions I and II. The addition of these minerals causes weight percentages of heavy minerals for tills partially derived from granodioritic sources to be 1 to 3% higher than for tills of regions I and II (Fig. 17).

Chaudière Till generally has low feldspar content compared to Lennoxville Till, but its upper portions, deposited by southeastward-moving ice (see McDonald and Shilts, 1971, p. 689-690), could be enriched in feldspar and granodiorite, although such enrichment was not observed in any of the samples collected.

The Drolet lentil clay till (a compositional phase of Lennoxville Till) lies wholly within provenance region III and replaces Lennoxville Till in Chaudière Valley (see Map 1494A). Drolet lentil is devoid of or impoverished in granodioritic clasts, its mineralogical and trace element composition is similar to that of Lennoxville Till of provenance region I, and its texture and composition contrast strikingly with Lennoxville Till that flanks it on all sides. The Drolet lentil clay till is, however, characteristically covered by a dense mantle of cobbles and boulders with a high granodioritic component. Ice-front gravels, deposited on the Drolet lentil during deglaciation, also have high percentages of granodioritic clasts.

Provenance Region IV

Lennoxville Till in provenance region IV is composed of detritus eroded from granodiorite stocks, coarsely crystalline, high-grade metasediments of the Boundary Mountains, basic metavolcanic rocks of the Portage Uplands, and syenite, gabbro, and granite intrusions at Mont Mégantic. Metagreywacke, impure carbonate rocks, and slate, which usually form the bulk of the larger clasts in provenance regions I, II, and III, are minor components of till in region IV.

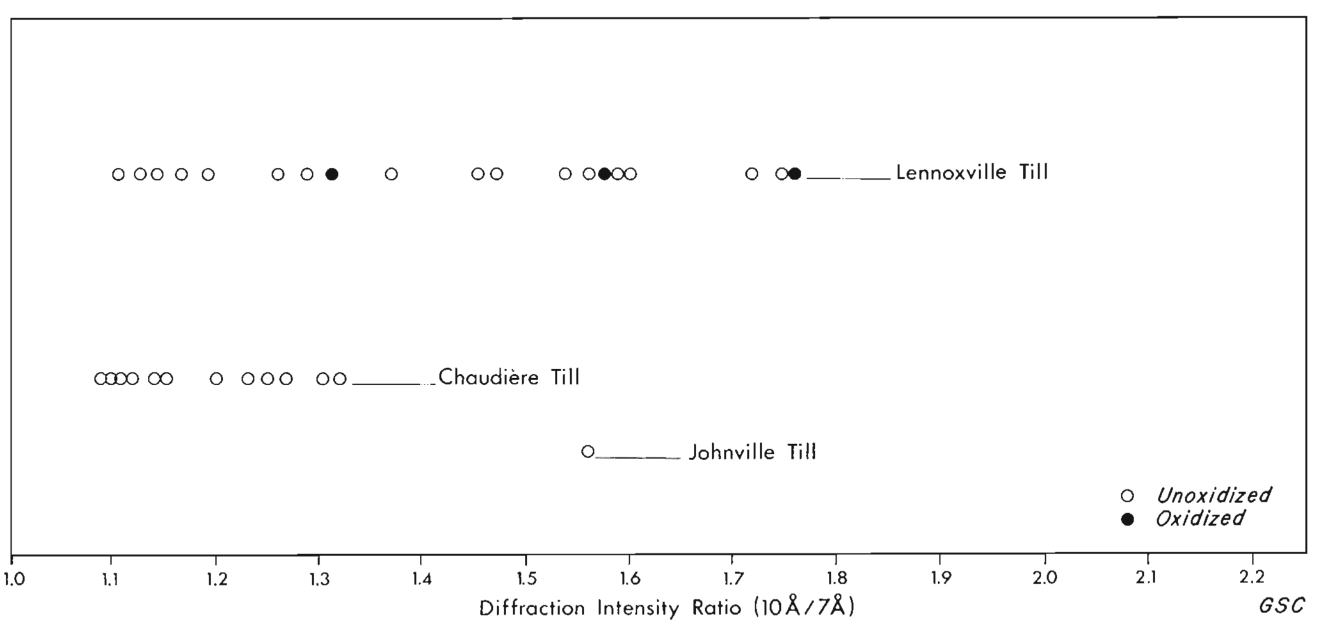


Figure 19. *Diffraction intensity (Frye et al., 1962) ratios for <4 μm fractions of Lennoxville, Chaudière, and Johnville tills. Note that Lennoxville and Johnville tills appear to be relatively enriched in "mica" (10 Å) but that overlap is considerable.*

Chaudière Till exposed along Arnold River has less magnetic minerals, fewer heavy minerals, and less plagioclase than overlying Lennoxville Till.

Generally, Lennoxville Till in provenance region IV is sandy and loose, particularly in mountainous areas. It may consist of a lower, compact lodgment facies overlain by a loose, sandy, ablation facies. Lennoxville Till of provenance region IV contains twice as many heavy minerals (by weight) as, and more titanium, zirconium, and vanadium than, Lennoxville Till of regions I, II, and III (Fig. 17).

Johnville Till

Johnville Till was identified at only two exposures in the map area, in section 3 along the north bank of Grande Coulée River and section 7 on Linière River (see Appendix 1). A till that may be correlative with Johnville Till was encountered at the base of borehole 1 at Gayhurst dam, but no sample was recovered from this unit.

At section 3, the upper part of Johnville Till is covered by colluvium, and the till itself, although grey, appears to be weathered. It contains no detectable carbonate, and sulphides, prominent components of unoxidized Chaudière and Lennoxville tills, are not present in its heavy mineral suite. It is grey and very compact and has a northwest-southeast fabric. Texturally, it is similar to the lodgment facies of Lennoxville Till that occurs higher in the section, and it has a diffraction intensity index typical of Lennoxville Till. Mineralogically, it is rich in total feldspar relative to Lennoxville Till, but this composition may be a local phenomenon related to felsic intrusive rocks seen along the river (one sample of the ablation facies at this section is also rich in feldspar).

Near the base of section 7 a pod of dense, grey till, physically dissimilar to overlying Lennoxville and Chaudière(?) tills, tentatively is correlated with Johnville Till. The pod has been emplaced by shearing, and its base lies along a shear plane in the surrounding lake sediment. The till is rich in total feldspar compared to younger till in this region, and it is calcareous and unoxidized. Because of complications caused by the extensive shear stacking in this section, the assignment of this transported pod to the Johnville glaciation is tenuous.

Chaudière Till

Chaudière Till has been identified tentatively at twelve locations in the map area, but it is probably common in the subsurface of many of the bedrock depressions that were filled with glacial sediments and subsequently partially excavated by major postglacial rivers. It largely was removed from upland areas by the later Lennoxville glaciation. If the extensive slump and fluvial terrace deposits that mantle the steep sides of deeply excavated portions of valleys (such as the Samson, Eugénie, Chaudière, Grande Coulée, and Linière) could be removed, Chaudière Till probably would outcrop in many places in the lowest portions of the valleys where it was protected from later glacial erosion by overlying thick, laminated silty clay of the Gayhurst Formation.

General Characteristics

Because Chaudière Till is generally physically similar to Lennoxville Till, in many cases it is difficult to identify it positively. Usually Chaudière Till was identified on the basis of two or more of the following criteria: 1) in the presence of Lennoxville Till, stratigraphic position below the surface till; 2) in the absence of Lennoxville Till, stratigraphic position beneath one or more metres of laminated silty clay; this criterion does not preclude its confusion with older tills but usually separates it from Lennoxville Till, which is rarely overlain by significant thicknesses of lake sediment in the upper part of the Chaudière drainage basin. 3) Compactness – again this criterion does not preclude confusion with older tills, but Chaudière Till is generally much more compact and is less likely to be easily eroded by running water than Lennoxville Tills. 4) Fabric – the fabric of Chaudière Till is northeast-southwest at the base shifting to northwest-southeast at the top where it was first described by McDonald (1967b; see also McDonald and Shilts, 1971); in Chaudière Valley, only the upper part of the Chaudière Till usually is exposed so that most fabrics measured are similar to the northwest-southeast fabrics of Lennoxville Till or have north-south or slightly east of north maxima – positions intermediate between the early and late directions cited by McDonald (1967b) for the thick section of Chaudière Till (Till II) located on Ascot River, about 48 km west of the map area. 5) Position in valley – isolated exposures of till that occur near the bottom of deep, postglacial valleys are likely to be Chaudière Till, unless Lennoxville Till is abnormally thick or major rotational slumping has taken place. 6) Weathering – the upper surface of Lennoxville Till is oxidized and leached to depths of 3 m or more, and Johnville Till is oxidized and leached at two of the four sites where it has been identified in southeastern Quebec; Chaudière Till has never been observed in a weathered state although it may show evidence of slight oxidation at sections 17 and 18 on Arnold River. 7) Colour – in some places Chaudière Till is slightly different in colour from overlying Lennoxville Till. Whereas the younger till is usually grey or dark grey where unoxidized, Chaudière Till may be slightly reddish in Samson River valley (due to incorporation of older laminated silt-clay with a reddish clay component). In Arnold River valley, Chaudière Till has a yellow-brown colour compared to the overlying grey Lennoxville Till. The colour difference is probably rare but where noticeable can be a valuable criterion. In Arnold River valley, this difference is particularly useful because the two tills are in direct contact. The valley is above the level of glacial Lake Gayhurst so that Gayhurst sediments do not conveniently separate the tills as they do in lower valleys to the north. 8) Composition – the trace element, mineralogical, and lithological composition of Chaudière Till is commonly distinct from older and younger tills, largely because of the northeast-southwest transportation direction of the glacier that influenced at least the early stages of its deposition. Determining compositional differences is the most time consuming, but most definitive way of identifying Chaudière Till. To use the compositional criteria effectively, regional variation of Lennoxville Till composition must be known. This requirement has led to the definition of the provenance regions described earlier (Fig. 17). In most cases Chaudière Till has compositions that vary distinctly from those of overlying Lennoxville Till.

Table 2 summarizes the characteristics of Chaudière and younger and older tills (Tables 4, 5, 6, in Appendix 1 give values for various textural, mineralogical, lithological, and chemical parameters measured). Except for its common occurrence beneath Lennoxville Till in stratigraphic sections, no generalizations can be made to characterize Chaudière Till uniquely with respect to older and younger tills. Texture, fabric, and composition vary according to local conditions, just as they do for Lennoxville Till, so that multiple tills in section often must be differentiated using site-specific data.

In all exposures Chaudière Till is calcareous, unoxidized, rich in pyrite, has few, if any, Precambrian "shield-type" erratics, and has diffraction intensity ratios that are the same as or slightly lower than Lennoxville Till. At most sites where Chaudière Till was identified, it is slightly sandier and much more compact than overlying Lennoxville Till; at sections 1 and 13, it is so hard (compacted) that it forms rapids where it outcrops in the stream bed.

Site-specific Characteristics

At section 10 on Samson River, Chaudière Till is overlain by delicately laminated silts of the Gayhurst Formation. Several square metres of the till surface were stripped hydraulically, revealing it to be heavily striated and fluted (Fig. 20). The striae and flutes trend 110° (S70°E), southeastward movement being indicated by crag-and-tail features. Lennoxville Till at the top of the section was deposited by ice flowing in a similar direction and is rich in ultrabasic components, being located near the axis of the Thetford Mines ultrabasic dispersal train (Shilts, 1973a, p. 214). Chaudière Till, however, has no obvious ultrabasic component, supporting the hypothesis that it was deposited largely by a glacier entering the area from east of north (McDonald and Shilts, 1971, p. 688-689), with a shift to southwestward flow by the end of the Chaudière glacial phase. The late, southeastward flow phase was apparently not of sufficient duration to transport ultrabasic components from Thetford Mines to Samson River, a distance of some 60 km.

In the large area covered by clay till of the Drolet lentil, Chaudière Till is relatively sandy, suggesting that its associated glacier did not advance over a thick accumulation of proglacial lake sediments as did the later Lennoxville glacier. At sections 17 and 18 on Arnold River, Lennoxville Till rests directly on Chaudière Till, the contact being marked by small springs and a subtle colour difference between the units. Unlike other sections examined, the altitude of Chaudière Till at these sections is above the highest water plane of glacial Lake Gayhurst, so that the thick lake sediment deposited in that lake does not separate these tills in upper Arnold River valley.

Lennoxville Till

Till of the Lennoxville glaciation (map unit 2) is areally and volumetrically the most extensive surficial sediment in southeastern Quebec. Even in areas designated as bedrock on Map 1494A, thin deposits of till or thick pockets of till are common.

General Characteristics

Lennoxville Till characteristically has a fabric with maxima oriented at one or more of the following directions: 110°, 130°, and 140°. The correspondence between the frequency of clast orientations in Lennoxville Till and the frequency of bedrock striation azimuths (Fig. 21) is very close. Lennoxville Till in places is a bipartite unit with lake

Figure 20. *Striae on Chaudière Till, Samson River, section 10. Overlying Gayhurst Formation varves have helped to preserve the surface. View is vertically downward on the surface of the till; knife is 25 cm long. (GSC 171673)*

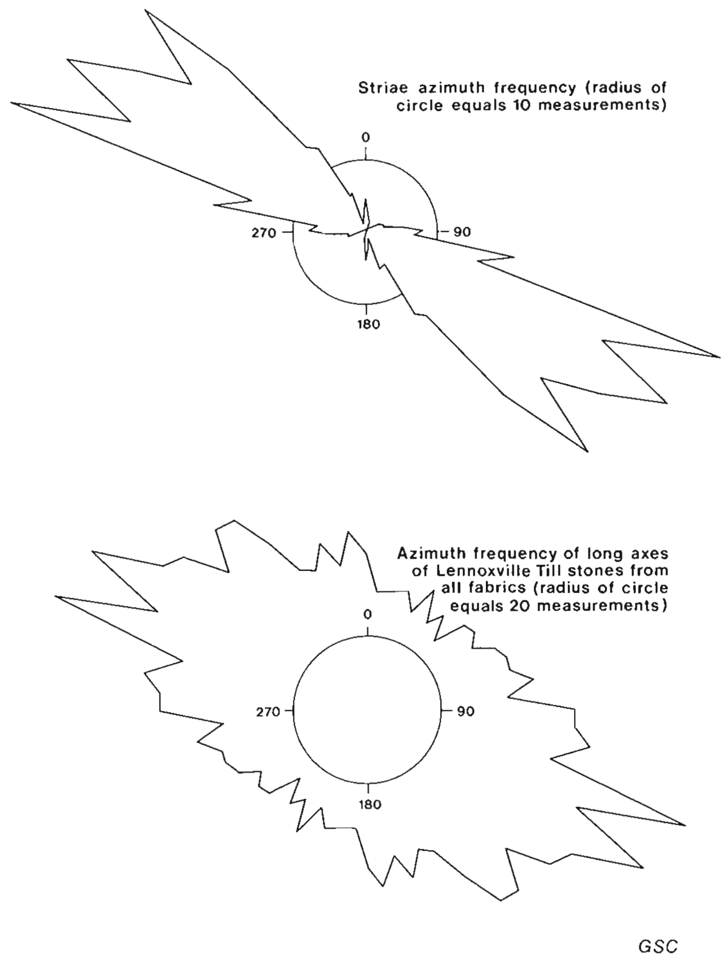


Figure 21. *Comparison of azimuth frequencies of striae to orientations of till stones measured in Lennoxville Till. Note the presence of three corresponding maxima in each set of data. The diagrams are compiled from all striation and surface till fabric measurements in the Lac-Mégantic region.*

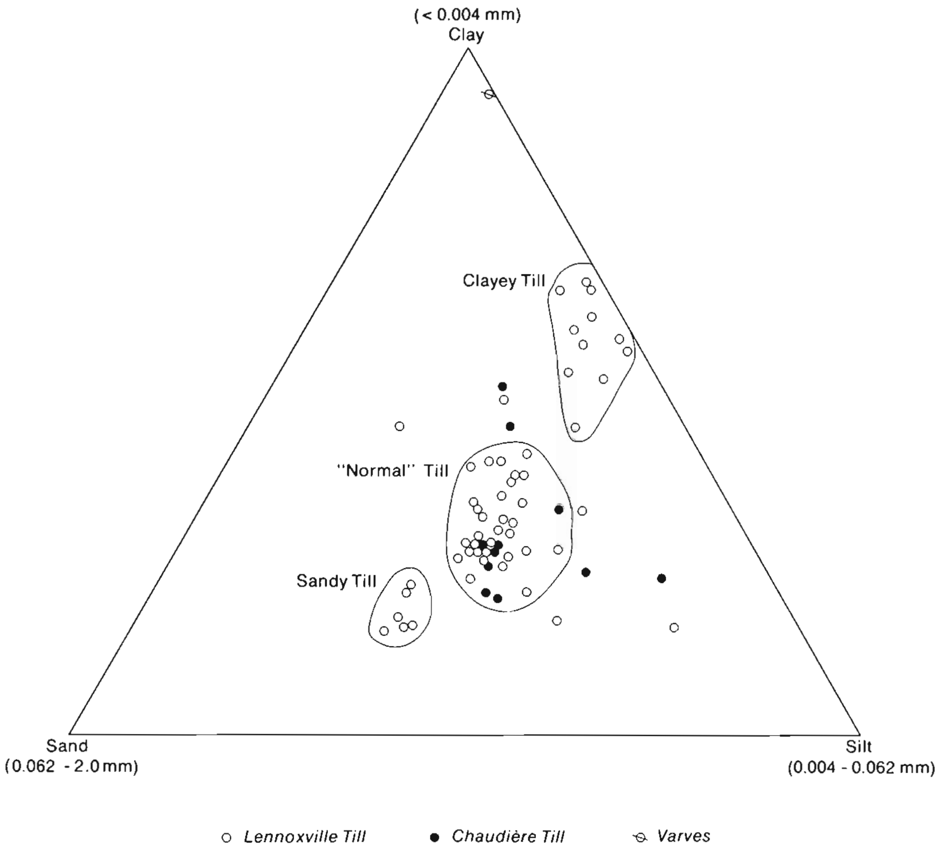


Figure 22

Sand-silt-clay ratios for Lennoxville and Chaudière tills, Lac-Mégantic region. Sandy till is generally an ablation facies found in the southern mountainous areas. Clayey till is typical of the Drolet lentil but can occur elsewhere.

sediments separating its upper and lower parts. Where this separation is identified, the lower unit may have a more northerly fabric than the upper.

Textural parameters of the bulk of Lennoxville Till are scattered within a narrow range (Table 2, Fig. 22, 23). In general, the coarser the till, the better (the lower) its sorting coefficient (Fig. 23). Sandy facies represented in Figure 22 are rare and are thought to represent 1) flow till, related to ice-front deposition during retreat or 2) ablation till that is common in the Boundary Mountains where sandy facies are extensive due to the widespread occurrence of coarsely crystalline source rocks and the high relief; ablation till characteristically forms a thick mantle over lodgment till in adjacent mountainous areas of New England.

Unweathered Lennoxville Till can be characterized as a slightly calcareous, grey to dark grey, stony till with stones larger than cobble size generally occurring only as a dense cover (ablation mantle, Shilts, 1973b, p. 206) on or near its surface. In its 'normal' facies it usually contains subequal amounts of sand, silt, and clay (Fig. 22); sulphides (largely pyrite) are conspicuous components of the sand fraction. The older Chaudière and Johnville tills are physically similar to Lennoxville Till but are usually highly compacted, probably as a result of dewatering caused by loading by later glaciers.

Lennoxville Till is weathered (oxidized and leached) to an average depth of 4 m. In sandy facies weathering may extend as deeply as 6 or 8 m. Within the weathering zone, four major changes may be observed: (1) Carbonates and calcareous erratics are leached, leaving 0.5 to 0.6% carbonate (of an original content of 2 to 5%) in the matrix, and punky 'ghosts' of calcareous erratics. (2) Within 2 or 3 m of the ground surface, chlorite is broken down so that the strength of its even-numbered basal reflections decreases and the 001 (14Å) reflection is enhanced; occasionally expansible 14Å mineral phases are observed (Fig. 24). (3) Pyrite crystals and pyritiferous erratics, ubiquitous in Lennoxville Till, are oxidized, and the iron oxide that is released stains the normally dark grey till yellow-brown; at section 1 at Saint-Martin euhedral selenite crystals were observed in this zone – possibly formed by the reaction between H_2SO_4, formed during pyrite oxidation, and $CaCO_3$ in the till; other sulphides, also present in the till, break down, releasing their cations (Zn, Ni, Pb, Cu, Cd, etc.) into the ground and surface waters. Some of these cations are adsorbed by phyllosilicates and hydrous Mn-Fe oxides in the till, but some escape into drainage systems (Shilts, 1975). (4) Granodioritic and ultrabasic erratics are decomposed, ultrabasic clasts become pockets of orange powder, and granodioritic clasts become loose pockets of quartz and feldspar crystals because of decomposition of biotite; erratics lying on the surface, however, are decomposed only where in contact with the ground.

Ablation Till

Ablation till is a sandy, bouldery facies of Lennoxville Till that probably forms a persistent cover in the mountains south and east of Lac Mégantic. This type of till is usually oxidized, loose, and may contain discontinuous lenses of stratified sediments. It has not been mapped as a separate unit because of lack of exposures, but significant thicknesses of it have been observed along Arnold River (section 17, Appendix 1) and in the vicinity of Mont Gosford. It is a common, thick deposit in the mountains of New England, south of the map area (Drake, 1971).

Ideally, ablation till is derived from englacial or supraglacial debris that is let down onto basal till deposits as the glacier melted. In mountainous terrain, the high relief of the glacier bed causes relatively high concentrations of debris throughout the significant thickness of a continental glacier,

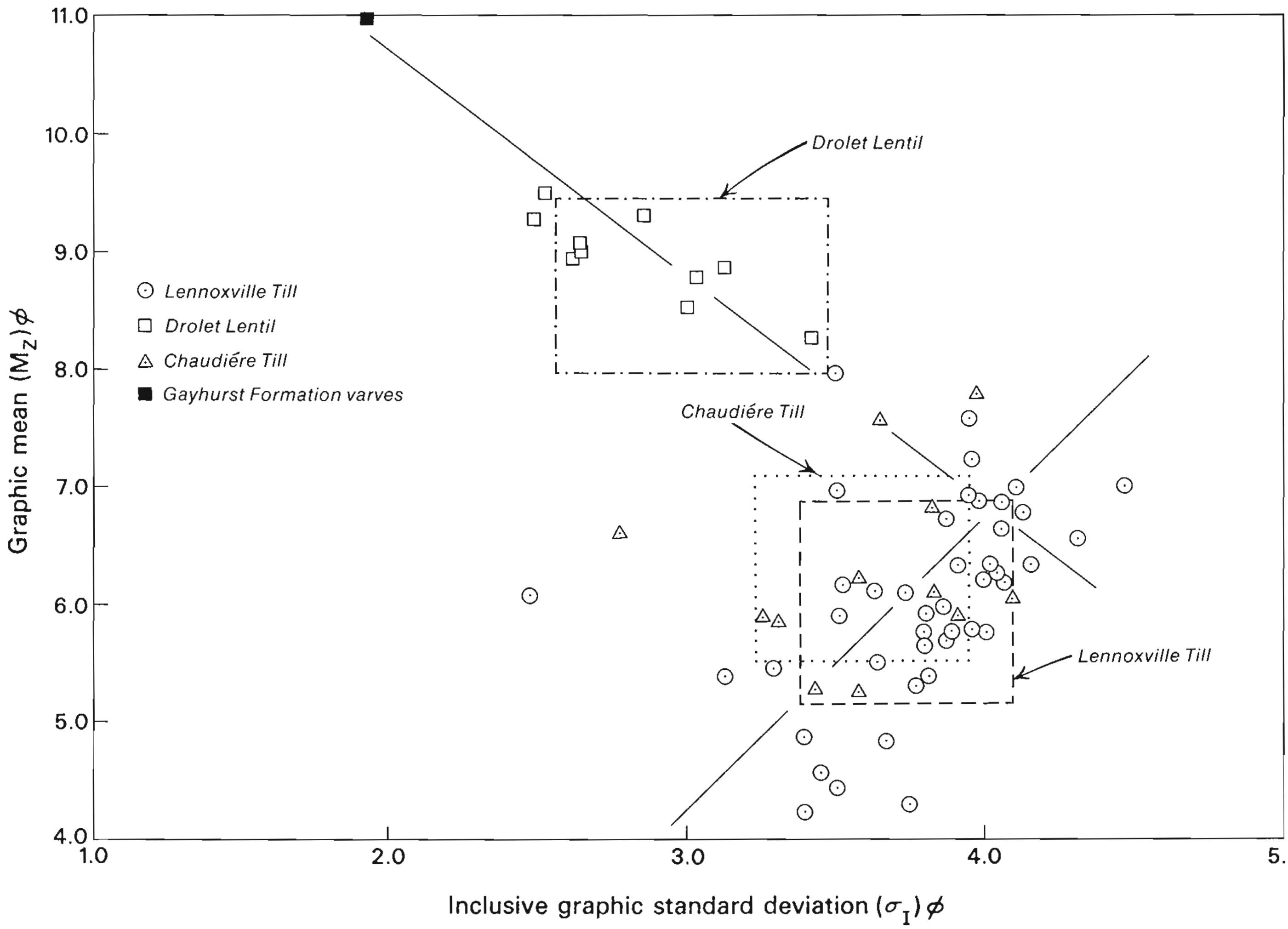


Figure 23. *Plot of graphic mean grain size (M_Z) (Folk and Ward, 1957) against inclusive graphic standard deviation (σ_I, sorting). The rectangular boxes enclose an area equal to one standard deviation in ϕ units from the mean M_Z and σ_I of each type of till. Note that the 'normal' till (see Fig. 22) becomes more poorly sorted with decreasing grain size, but that the incorporation of varves, represented by the Drolet lentil samples, causes the till to assume the reverse trend.*

so that the ablation facies is most common in rough terrain, where it may completely replace the lodgment facies, except in valleys.

The boulder mantle (ablation mantle, Shilts, 1973b, p. 206) that covers lodgment till surfaces over most of the map area (Fig. 25) is also thought to be an ablation deposit largely derived from isolated hills and incorporated into the englacial load of the Lennoxville glacier. The lithologic composition of this mantle of boulders is different from that of the underlying lodgment till in some places and reflects the lithologies of hills that stand above the surrounding countryside by virtue of their superior resistance to long-term erosion or weathering.

Drolet Lentil Clay Till

A second distinctive type of Lennoxville Till is a very clayey facies that resulted when a glacier advanced over thick, unconsolidated lacustrine clays, reworking them into a massive clay till. The Drolet lentil (map unit 2a) and a "clay-silt" till that occurs near East Angus (McDonald, 1969, p. 4) are major examples of this type of deposit. In both cases the clay till replaces the normal Lennoxville Till facies completely.

Scattered outcrops of Lennoxville-age clay till were observed in the Kokombis-Nebnellis River valley, in Saint-Ludger (Dionne and Shilts, 1974) in Samson Valley, and in Linière Valley south of Saint-Théophile. Some exposures of Chaudière Till in Samson Valley also show clay till with varved inclusions at the base grading upward into 'normal' till.

Drolet lentil has a fabric (measured only at section 16) that strikes 180° to 210°; east of Drolet it lies directly on bedrock with striae at similar azimuths, reflecting deposition by a Lennoxville glacier lobe that advanced up Chaudière Valley. The <4 µm fraction is similar in composition to 'normal' Lennoxville Till and its weathering characteristics are similar, except that depth of weathering is generally only 1 to 1.5 m. The Drolet lentil has a conspicuous ablation mantle of cobbles and boulders, deposited in the same way as that on Lennoxville Till.

The most distinctive properties of Drolet lentil are its very clayey texture (see Table 2, Fig. 22, 23) and the paucity of pebble-sized and larger clasts within its matrix. The contact between the underlying Gayhurst Formation and Drolet lentil is usually indistinct; Gayhurst laminae become progressively more deformed towards the contact until their structures are obliterated completely (Fig. 26). The distinction between clay till and deformed, nearly structureless lake sediment is made on the basis of the noticeably higher content of sand and pebbles in the former. At the type section of Drolet lentil (section 16, Appendix 1), the Gayhurst varves contain almost no pebbles and less than 0.5% sand whereas the overlying Drolet lentil contains sparse pebbles and 5 to 10% sand.

As mean grain size of Drolet lentil diminishes, sorting coefficients decrease (becomes better sorted), a trend opposite to that noted for Lennoxville Till (Fig. 23). This trend suggests that if 100% of a Drolet lentil sample were composed of Gayhurst Formation silt-clay laminae, it would have an M_Z/σ_I ratio that would plot where the single, composite sample of Gayhurst 'varves' occurs in Figure 23.

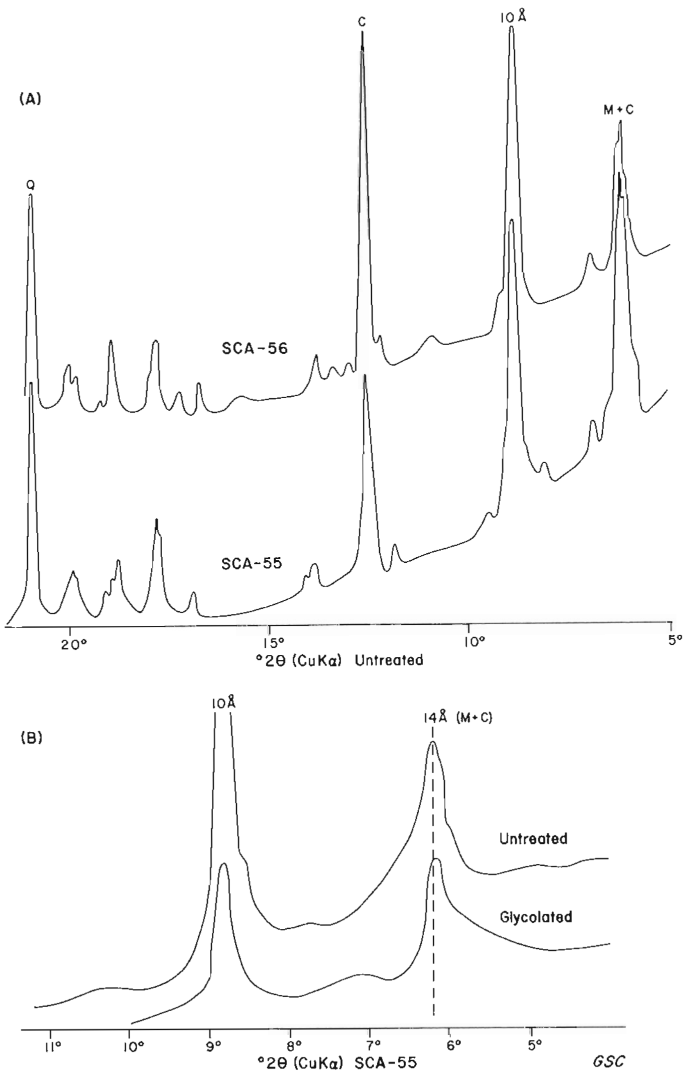


Figure 24. *Diffractograms illustrating the nature of chlorite alteration in weathered Lennoxville Till, Oliva Lakes area. Q = quartz, C = chlorite, 10 Å = mica, M = expansible 14 Å mineral. A) Untreated mount of silt-clay; SCA-56 is relatively unaltered; SCA-55 is highly oxidized; note reduction of 7 Å peak and growth of 14 Å peak in SCA-55. B) Glycolated and untreated mounts of SCA-55; note expansion of the 14 Å peak in the glycolated trace.*

As greater proportions of sandy debris, derived from bedrock or pre-existing, sandier till, were added to the silt-clay mixture, mean grain size, as well as the sorting coefficient, would increase. Thus, the M_Z/σ_I trend of the Drolet lentil is thought to be typical of till derived from unconsolidated, fine grained sediments as opposed to that of till derived from consolidated, fine grained sediments (slate, shale, limestone, etc.) that break down not only to silt and clay particles as do unconsolidated varves, but also to sand-sized silt-clay aggregates that cannot be dispersed in water.

Postglacial Modification

Lennoxville Till in and adjacent to the map area has relatively low liquid and plastic limits, and these properties, combined with the gently to steeply rolling Appalachian terrain, give rise to much mass movement on slopes. In nearly all of the several hundred exposures of lodgment till examined, a thin, 0.3 to 1.5 m-thick disturbed zone of colluviated till overlies undisturbed lodgment till (Fig. 27). These slope deposits exhibit crude horizontal bedding, are thoroughly oxidized, and may be complexly interstratified with buried soil horizons or water-laid deposits. Colluviated till or till mixed with older and younger sediments forms a persistent and thick cover on the sides of valleys whose streams have cut through thick Quaternary deposits. If this thin cover of slumped material is removed by undercutting or excavations, it commonly can be seen to have covered complex stratigraphic sequences capped by Lennoxville Till. The possibility should not be ruled out that at least some of these slope deposits are relict periglacial features, that is, represent disturbance in a former active (seasonally thawed) layer on permafrost.

Landforms Composed of Lennoxville Till

In most of the map area the Lennoxville Till surface corresponds closely to the bedrock surface, and till thicknesses seldom exceed 5 to 10 m. In the Chaudière Hills physiographic section, till has filled in many minor depressions and bedrock valleys, and this fill, combined with the general reduction of bedrock surfaces by repeated glaciations, has formed a gently rolling to flat surface. A flat till plain with scattered low outcrops exists in the region north of Grande Coulée River, between Saint-Martin and La Guadeloupe.

In major bedrock depressions, such as Chaudière (between Lac-Mégantic and Saint-Ludger), Samson, Eugénie, Grande Coulée, and Linière valleys, Lennoxville glaciation was the last of a series of glacial and nonglacial events that filled the bedrock depressions with unconsolidated sediment to such an extent that the bedrock topography has been almost completely masked. The bulk of the fill in these valleys, however, is largely lake sediment capped by a relatively thin sheet of Lennoxville Till that formed a continuous plain before partial excavation by postglacial streams.

In some bedrock depressions Lennoxville Till is thick and completely obliterates the former topography. Examples of exceptionally thick till occur in borehole 2 (Lac-Mégantic) and borehole 3 (south of Lac Mégantic) where bedrock depressions are filled with 40 m and more than 25 m of Lennoxville Till, respectively. More than 20 m of till is found near Chaudière River in sections north of Saint-Martin and is indicated in several seismic profiles (Appendixes 1, 3).

Thick aprons of till rest against the north- and northwest-facing sides of major prominences such as the Little Mégantic Mountains, portions of the Boundary Mountains, and Mont Mégantic. Such aprons cause these slopes to be gentler than those on the south- or southeast-facing sides (Fig. 8).

Figure 25. *Ablation mantle largely composed of granodiorite clasts from Winslow Stock (see Fig. 4) on a field about 1.5 km southwest of Mont Sainte-Cécile (peak in background). This cover is typical of untilled fields at all altitudes throughout the study area. Clasts this size rarely are found within 'normal' till facies but are restricted to till surfaces. (GSC 203214-F)*

North of Audet, several east-west-trending drumlinoid hills have been formed partly by till deposition against the west faces of bedrock prominences and partly by glacial erosion of the bedrock surface to a streamline form. A single, drumlin-like till prominence occurs about 3 km north-northwest of borehole 3.

End moraines composed of till are rare but are present in the area. One large area of hummocky till moraine exists on the Drolet lentil till plain west of the Gayhurst dam site, but at least some of this moraine is composed of irregular bodies of ice-contact stratified drift. Associated with this feature are subparallel, low ridges composed of clay till. These may be the upturned edges of shear plates or the surface expression of drag folds formed by the movement of the southwestward-flowing ice lobe that existed in this area at the onset of glaciation and/or during deglaciation.

The most common form of till end moraine is single or nested, usually smooth-surfaced ridges from 4 to 40 m high and 100 to 500 m wide at the base (Fig. 28). Such ridges rarely can be traced for more than 2 km. Little is known about the nature of the sediment composing these ridges, but their composition is apparently variable, some being composed in part of stratified gravels. Whether they originate solely as ice-front constructional features (push moraines?) or whether they represent high areas between subparallel ice-front meltwater channels is often in doubt. In some cases (particularly in the Frontier moraine system) each ridge consists of multiple or minor ridges with many kettles, suggesting a constructional origin; in other cases (for example, Mégantic moraine system) the ridges appear to be part of a lodgment till or outwash surface dissected by subparallel, subglacial, or proglacial channels. In either case their trends probably approximate the configuration of a former ice front. At present there is no way to interpret the internal composition of these ridges from aerial photographs, and in places it is difficult to differentiate them from eskers.

Glaciofluvial Deposits

Glaciofluvial deposits are stratified sand and gravel deposited in close proximity to the ice front of a retreating or advancing glacier. The gravel commonly displays overall poor sorting or strongly polymodal grain size distribution with large blocks, 1 m or more in diameter, dispersed through a medium or fine gravel matrix (Fig. 29). Internal structures consist of various types of fluvial and deltaic crossbedding (Fig. 30) typically cut by high-angle reverse and normal faults (Fig. 31). It is not uncommon to fine crossbedding that indicates current flow away from the ice front and in a direction reversed from that of modern drainage. This occurred any time that glaciers advanced southward out of the St. Lawrence Lowland, as broad lobes flowing up Chaudière Valley blocked normal northward drainage as well as the drainage of tributaries.

Internal faulting (McDonald and Shilts, 1975) is present in fluvial gravels that were deposited against or on glacier ice. Collapse caused by melting of buried ice blocks results in the formation of high-angle reverse faults (Fig. 31) whereas melting of a confining ice wall causes slumping with attendant formation of gravity (normal) faults.

Composition of the sand and larger clasts in glaciofluvial gravels closely approximates the composition of the till with which they were deposited. The markedly granodiorite-rich gravels lying on areas underlain by granodiorite-poor Drolet lentil, however, more closely match the lithology of the bouldery ablation mantle that also covers the Drolet lentil surface. This fact is interpreted to mean that most of these gravels were derived largely from englacial debris and not from reworking of already deposited lodgment till. A similar conclusion was reached by Shilts and McDonald (1975) regarding the ice-contact gravel of the Windsor Esker north of Sherbrooke, Quebec. Thus, it is probable that much of the ice-contact gravel of the Lac-Mégantic region is of englacial or supraglacial origin and more closely corresponds to the lithologic composition of the surface boulders or ablation till facies than to underlying lodgment till.

Pre-Lennoxville Outwash

Two types of pre-Lennoxville outwash have been recognized. The first is a coarse sand to fine gravel deposit that occurs at the base of glaciolacustrine sequences or beneath tills deposited by glaciers advancing into proglacial lakes. Such beds are usually flat lying and may be partially reworked into overlying till. At the base of the Gayhurst Formation at Gayhurst dam, 10 to 11 m of coarse sand rests on Chaudière Till. The sand grades upward into laminated silt clay. Similar sand underlies Lennoxville Till and overlies Gayhurst Formation varves at section 1a near Saint-Martin and underlies the Drolet lentil at sections 13 and 14 (Fig. 32). In all cases these sandy units occur at the base or at the top of the lacustrine sequence in topographic positions that require the presence of a deep lake in front of a glacier that is advancing from east, west, or north. From these relationships it is inferred that the sandy deposits represent subaqueous outwash, deposited by density underflows (Gustavson, 1975) from an advancing (top of lacustrine sequence) or retreating (base of lacustrine sequence) glacier.

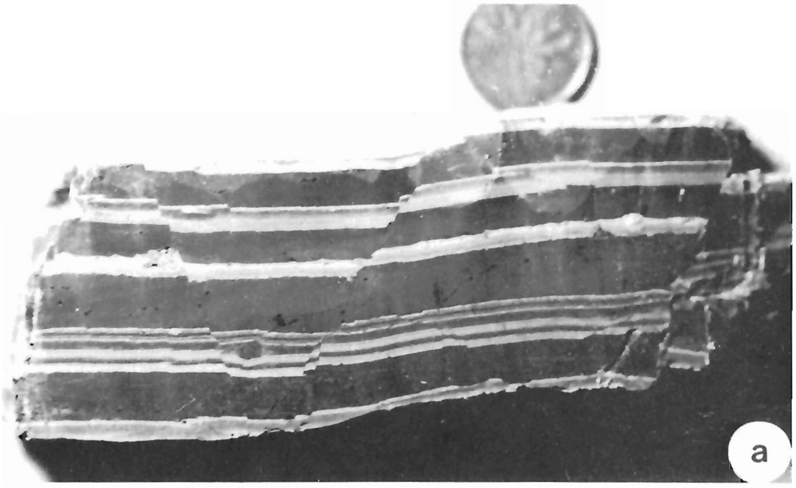
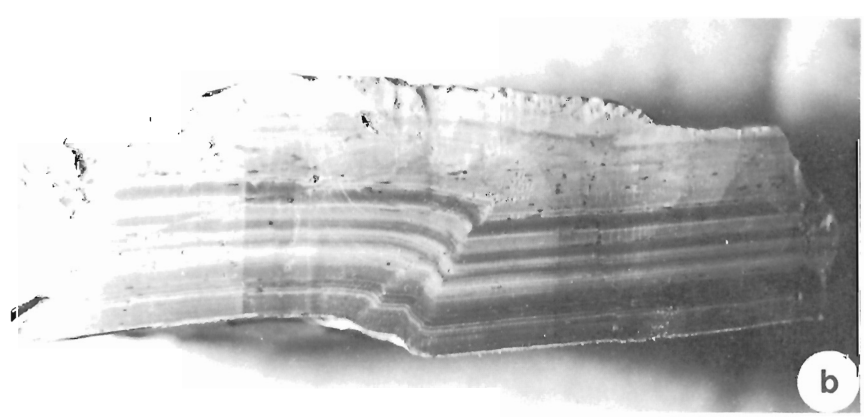


Figure 26

Progressive stages of glacial deformation of Gayhurst Formation varves beneath Drolet lentil near the confluence of Drolet and Chaudière rivers: (a) simple (normal) faulting with little deformation; note multiple layers in the coarse (light) bands, thought to result from periodic turbidity flows; (b) thrusting and folding, décollement; note that bedding in part of the sample is severely disrupted (sample measures ~12 by 4 cm); (c) severe disruption of bedding. With increasing disruption, traces of bedding disappear altogether, and sand content increases as Gayhurst varves are mixed with debris from outside the lake basin to form a true till.



A second type of pre-Lennoxville outwash comprises sands and gravels whose overall poor sorting and internal structures suggest a subaerial or shallow water, ice-contact origin. Three such deposits have been found, one beneath the till plain along the east branch of le Bras River east of La Guadeloupe (Fig. 33), beneath the Drolet lentil plain about 6.4 km west of Saint-Ludger, and a group of several exposures beneath Drolet lentil about 2 km west of the confluence of Drolet and Chaudière rivers. These deposits may be ice-front deposits formed during retreat of the Chaudière glacier, during the advance of the Lennoxville glacier, during minor readvances during general retreat of the Lennoxville glacier, or by glacial activity associated with remnant ice near the ice divide described by Gadd et al. (1972; see also Lamarche, 1971, 1974; Shilts, 1976).

Glaciofluvial Sediments Formed During Final Glacial Retreat

Sedimentary Environments

The retreat of the Lennoxville glacier or of the southern edge of a remnant ice mass from the Lac-Mégantic area was characterized by several pauses or oscillations.

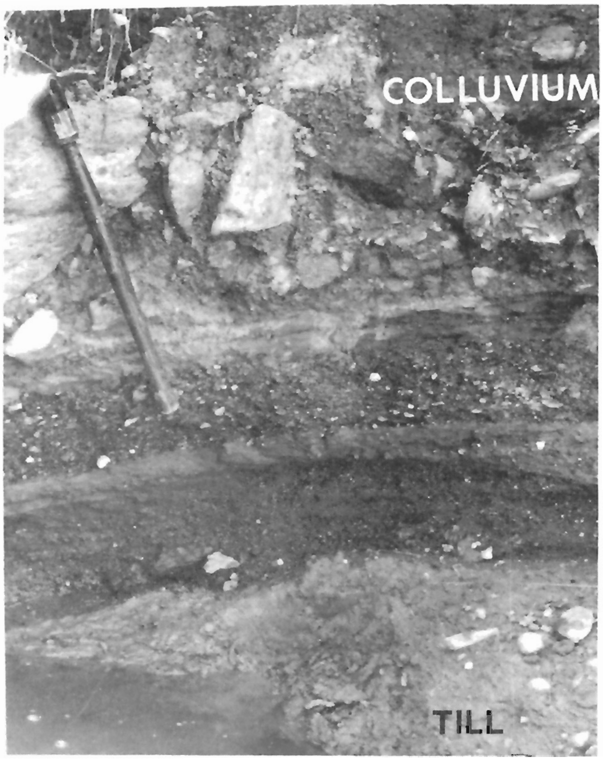


Figure 27a

Colluvium and fluvial gravel over till, Lac-Mégantic area. Such materials commonly overlie till on most slopes, but usually the two do not occur together. (GSC 171634)

Figure 27b

Crudely stratified colluvium overlying lodgment till. This material contains some sorted pockets and is typical of the cover produced by mass movement processes over till on slopes. The prominent contact between colluvium and till can be seen at the shovel blade. An alternative explanation for some of these deposits may be that they originated under periglacial conditions. (GSC 171648)

Figure 28

Till ridge south of Mont Sainte-Cécile. This is one of several nested end moraine ridges that outline an ice lobe that projected eastward around the south end of Little Mégantic Mountains. (GSC 154387)

Figure 29

Ice-contact fluvial gravel containing large blocks of granite in Moose (Glen) River valley, 8.8 km northwest of the bridge over Chaudière River in the town of Lac-Mégantic. (GSC 201696-L)

Figure 30. *Crossbedding and planar bedding in ice-contact fluvial gravel in end moraine of Mégantic moraine complex, 2.9 km west-southwest of Audet church. Crossbedding dips eastward, opposite to present drainage. Height of face is approximately 4 m. (GSC 148172)*

Figure 31. *High-angle reverse faults in ice-contact gravel on east side of Arnold River, Woburn, Quebec. Face is about 10 m high. (GSC 148121)*

Figure 32

Medium grained outwash sand deposited in a proglacial lake that was more than 110 m deep when the advancing Lennoxville glacier passed over this site (Saint-Ludger) (altitude based on height of lowest col in upper Chaudière drainage basin). The site is the same as that described in detail by Dionne and Shilts (1974). Sand is overlain by mixture of clay till (Drolet lentil), varves, and 'normal' till in alternating shear plates. In the centre of the photograph note the till wedge extending downward into sand. (GSC 154488)

During these pauses, discontinuous bands of stratified and unstratified sediments were deposited at or near the ice front (map units 2b, 3, 3a, 3b). The configuration of the retreating ice front has been approximated by relating these deposits to each other and to associated erosional forms. At any one time during a halt or oscillatory phase, several facies of sediment were deposited and channels were eroded at the ice front (Fig. 34). Deltaic sediments were deposited where the ice stood in a proglacial lake. Fluvial sedimentation occurred where debris-laden meltwater was supplied to the ice front, and drainage was free in the "crease" between the ice front and ice-free slopes. In areas where the fluvial phase was predominantly erosional, channels were cut into bedrock or glacial deposits. The channels parallel the former ice front where flow was confined between the ice front and a slope, but where water could not flow freely along the margin, it was ponded and escaped over drainage divides, cutting channels trending away from the glacier.

Ridges (push moraines?) composed largely of till are interspersed among the fluvial and deltaic deposits. They commonly are developed or preserved where fluvial action was not strong and above proglacial lake levels.

Ice-contact Fluvial and Lacustrine Sediments

Two facies of outwash sand and gravel can be distinguished in the Lac-Mégantic area: (1) subaerial deposits, usually occurring above 430 m altitude (map unit 3); and (2) deltaic deposits (map unit 3a) occurring at or near 430 m altitude in Chaudière Valley and at higher altitudes in west or north flowing Chaudière tributaries.

Ice-contact stratified sediments occurring at or below 430 m altitude were deposited into the glacial lake at 430 m altitude that occupied Chaudière Valley and its tributaries until lower outlets were free of ice in lower Chaudière Valley. Ice-contact sediments deposited in the lake consist mostly of fine sand to pebble gravel. In some deposits, such as the delta 6 to 8 km south of the town of Lac-Mégantic, on the east side of the lake, large-scale foreset bedding dips southward, away from the former ice front.

Subaerial deposits commonly have hummocky surfaces and may form benches or ridges perched on hillsides, suggesting that at the time of deposition a hillside served as one wall of a fluvial channel and the ice edge as the other. Good examples of such benches occur at Ditchfield, between St-Evariste-de-Forsyth and La Guadeloupe, between Audet and Chaudière River, and on the southwest side of Samson River valley (southeast of Audet).

Isolated mounds of gravel (kames) that have the sedimentological and structural characteristics of outwash benches are rare, but are present in the Lac-Mégantic region. They are found generally in the upper reaches of the eastern tributaries of Chaudière River and are particularly common in the upper portions of Samson River valley and in the low terrain east and north of Lac aux Araignées.

Figure 33. *Ice-contact gravels underlying a portion of a till plain east of La Guadeloupe. The deposit is deformed and displays overall poor sorting. It is capped by about 2 m of lodgment till. (GSC 148185)*

Subaerial ice-contact deposits commonly are composed of granule to cobble gravel with stratification typical of fluvial deposits. Clasts larger than cobble size commonly are distributed randomly throughout the deposits.

Eskers

Eskers (map unit 3b) are straight to sinuous ridges deposited in ice channels or tunnels. Most eskers in the Lac-Mégantic region are relatively short compared to those occurring across the border in the Maine highlands. Esker ridges are sharper than the till and gravel moraine ridges, which they resemble. Some eskers that appear to be continuous can be seen, on close examination, to have been built in several stages with succeeding segments being built over or against older segments. Eskers along Moose River[1] and near Woburn (Fig. 35) are examples of eskers built in segments.

Current directions in eskers are generally south to east. The esker along Moose River, however, is located west of the axis of the major glacial lobe that occupied Chaudière Valley during Lennoxville deglaciation. Imbrication of cobbles and boulders in that esker indicates a westward current, opposite the direction of current in Moose River.

Eskers occur for the most part in the hilly areas south of Lac-Mégantic. They are commonly located on valley bottoms (Woburn area, Victoria River, and Moose River complexes), but also may lie on slopes where no present major drainage occurs (Ditchfield esker complex).

Eskers usually are composed of crossbedded sand to cobble gravel. Portions of the esker along Victoria River were observed to have a cobble-boulder core with a mantle of crossbedded sand and granule gravel. The Victoria River esker is mantled by about 1 m of poorly sorted silt, sand, and cobbles (Fig. 36), which may be classified either as till that melted out of ice that formed the 'roof' of its ice tunnel or as a layer of material reworked by lacustrine processes.

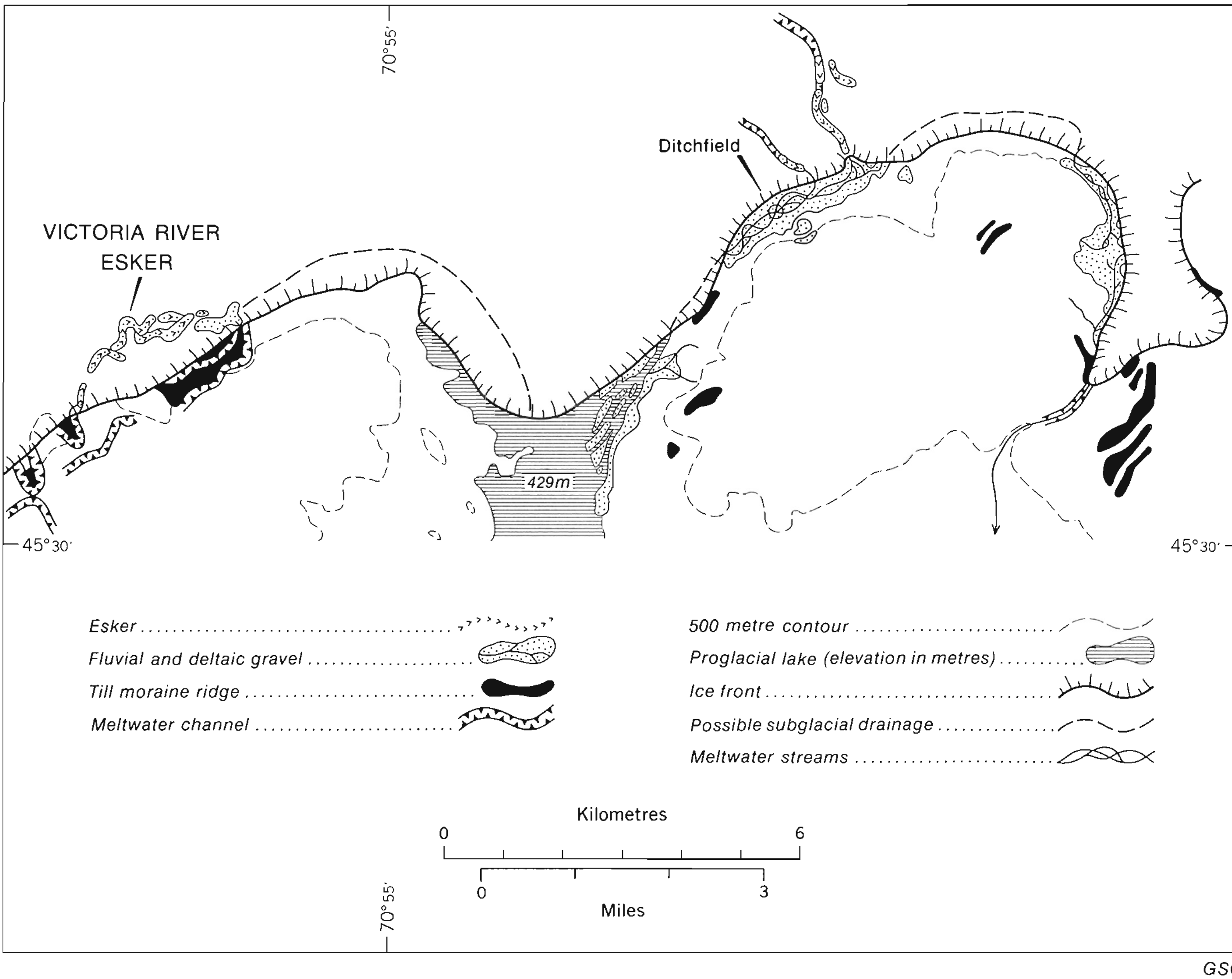


Figure 34. *Depositional and erosional features along a portion of the ice front at the time of formation of the Ditchfield moraine complex across the Lac Mégantic basin (cf. Fig. 51). Eskers to the east terminate in the hummocky gravels at Ditchfield; those to the west lie in the valley of Victoria River, just west of where it enters modern Lac Mégantic. Ice front positions have been reconstructed by correlating such diverse markers of a former ice front.*

[1] Now named Glen River on recently published National Topographic System maps

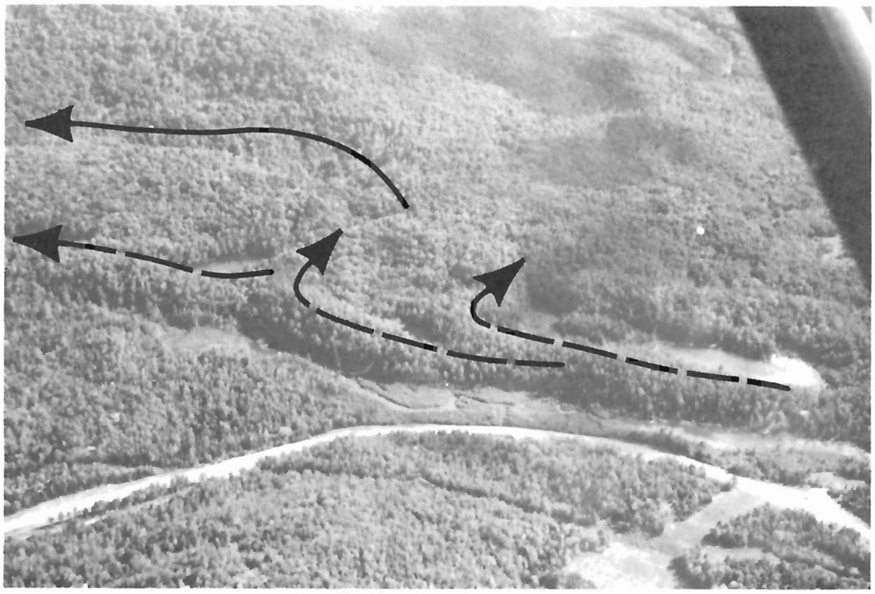


Figure 35

Woburn esker complex between Woburn and the Canada-United States border; view south with Ruisseau Vaseux in foreground. Note that three segments (indicated by dashed arrows) are shown, the westernmost two being built on top of the segment in front (to east or left). Eskers parallel the former ice front, which stood against the hill in the background, except at the ends of their segments where they turn abruptly south, terminating at the edge of an ice-marginal meltwater channel (indicated by a solid arrow). (GSC 148242)

Figure 36. *One metre-thick capping of poorly sorted silty gravel in test pit at crest of the esker along Victoria River. This material may be an ablation deposit or wave-reworked layer. It was observed in several other nearby pits. (GSC 148111)*

The flanks of esker near Ditchfield are composed of crudely bedded, poorly sorted cobble gravel (Fig. 37), apparently slumped from the crest of the esker. This slumping is best explained as a form of slope adjustment and probably occurred after confining ice melted away, leaving a deposit with sides standing at an angle greater than the angle of repose; adjustment to a stable angle was accomplished by slumping.

Landforms Composed of Ice-contact Stratified Sediments

Areas underlain by ice-contact stratified drift are usually hummocky with closed depressions (kettles). In the Lac-Mégantic area such terrain usually occurs in discontinuous strips that parallel ice-marginal positions of the retreating Lennoxville glacier. Sinuous to straight esker ridges may lead into the hummocky areas, joining them at right angles (Ditchfield area, Fig. 34) or may parallel the strips, following depressions against whose sides the hummocky gravels were deposited (Woburn area, Victoria Valley). Some esker ridges are interrupted by bulbous masses ('beads', Banerjee and McDonald, 1975) of hummocky stratified sand and gravel (Moose River valley).

Strips of ice-contact gravels commonly form crude benches (probably equivalent to 'kame terraces' of some authors) against valleysides. The surface of the benches varies from completely hummocky with few flat areas to flat surfaced with isolated closed depressions. Hummocky terrain on the east side of Saint-Victor River, north of La Guadeloupe, is similar to these benches but is actually a limestone surface that appears to have undergone severe solution pitting.

In some areas, ice-contact stratified drift occurs in end moraine ridges indistinguishable from end moraine ridges composed of till (Fig. 38). It is suspected that both till and stratified sediment occur together in some ridges and that some ridges are composed wholly of till while others are composed wholly of gravel.

Glaciolacustrine Deposits

Lake sediments are largely older than the Lennoxville glaciation, and, therefore, outcrops are restricted mainly to valleysides where modern rivers have dissected valley fill. Except for scattered occurrences of thin, post-Lennoxville lake sediments and pre- and post-Lennoxville deltas, lake sediments tend to be composed of calcareous silt and clay in rhythmic, parallel laminations. The composition of lacustrine sediment is generally similar to that of underlying till and the <4 μm fraction is made up of chlorite and 10Å mica.

Pre-Chaudière Lake Sediment

The oldest lake sediment observed is in a 1.6 m-thick bed that separates two fluvial gravel units that underlie the Massawippi Formation at section 3 on Grande Coulée River (Fig. 39). It comprises about 150 laminae of silt and clay, is noncalcareous, and is oxidized to a light brown colour in its upper 1.3 m.

Calcareous, interlaminated silt and clay also occur beneath Chaudière Till at sections 10 and 11 along Samson River. These beds outcrop at many places near river level from the mouth of Samson River to a point about 9 km upstream. The clayey laminae are generally dark brown to maroon, probably due to incorporation of clay-sized hematite glacially transported from Ordovician redbeds in the St. Lawrence Lowland. These beds are commonly deformed and presently are being extruded into the river channel by the weight of the thick overlying Quaternary sediments at section 10. They also occur as diapiric structures into younger sediments of glacial and postglacial age (Fig. 40).

An unknown thickness, probably in excess of 10 m, of grey, interlaminated, calcareous, deformed silt and clay underlies Chaudière Till at section 7 on Linière River. In a borehole at Gayhurst dam, 2.4 m of grey, calcareous, deformed, interlaminated silt and clay underlie Chaudière Till.

Gayhurst Formation

The Gayhurst Formation is generally a thick silt-clay unit that lies between Chaudière Till and Lennoxville Till at altitudes below 430 m a.s.l. It was deposited in glacial Lake Gayhurst (Shilts, 1970; McDonald and Shilts, 1971), a large lake that existed in the Appalachian region for an estimated 3000 to 4000 years between the Chaudière and Lennoxville glaciations. The thickest Gayhurst sediments are found below 380 m, and most Gayhurst sediments occur below 430 m.

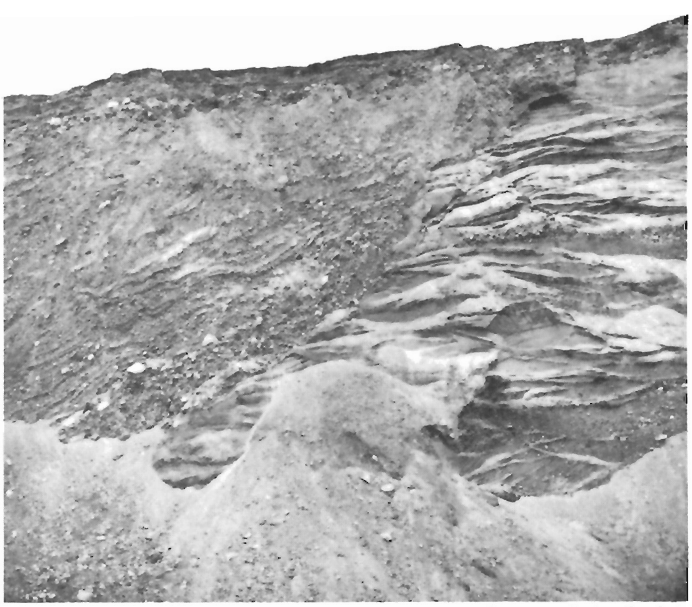


Figure 37. *Poorly sorted, crudely stratified debris (left) thought to be formed by slumping at the sides of the esker at Ditchfield. These deposits form the basal part of the flanks of the esker. (GSC 148214)*

Three facies of Gayhurst Formation have been observed: (1) Silt-clay facies: This facies includes jointed, graded, calcareous, grey, laminated silt or sand and clay sequences (Fig. 41, 42) that reach a maximum observed thickness of 53 m at the Gayhurst dam site. This facies usually contains sparse, microscopic plant and microfaunal remains and circular to amoeboid calcareous concretions. It contains less than 1% sand and rare ice-rafted pebbles. The <4 μm fraction is mostly chlorite and 10Å mica. (2) Deltaic facies: Where major streams entered glacial Lake Gayhurst at altitudes of 370 m to 380 m and at about 430 m, sand and fine gravel of foreset and bottomset deltaic facies were deposited over or intercalated with the silt-clay facies. At Gayhurst dam the upper 6 m of the 53 m thickness of silt-clay is separated from the lower 47 m by 22 m of sand and fine gravel of a delta built into the 380 m-phase of the lake (Fig. 43). The 380 m deltaic facies has been recognized at several exposures in Chaudière Valley for 5 km downstream from the Gayhurst dam. It also has been recognized near 370 m altitude in Eugénie River valley. (3) Turbidite facies: In most sections exposing the Gayhurst Formation, isolated beds occur that are thought to have been deposited by subaqueous slumping or turbidity flow. These beds are found in all facies of the Gayhurst Formation and are characterized by poor sorting, convolute bedding, flame structures, and flow rolls. Turbidity-current structures are common in the Gayhurst region, and the coarse layers of silt-clay laminae are commonly complex sequences of two or more graded beds which suggest periodic turbidity flows (Fig. 26a, 42).

At section 10, several 20 cm- to 1 m-thick beds of massive silt-clay are interbedded with parallel-laminated, undisturbed silt and clay. In most of the units, no structure is apparent but several stony beds near the base and near the top of the sequence have well developed convolute bedding. The stony units are graded, with concentrations of cobbles occurring near the base of the units (see Fig. 14).

Post-Lennoxville Lake Sediment

As the ice front stood against the Boundary Mountains and Portage Uplands, lakes were dammed in the upper reaches of streams that presently flow westward or northward into Chaudière River. All these basins are heavily wooded and relatively inaccessible at present so that no clear picture of their lake histories has been worked out. Small outcrops of laminated silt and clay have been noted at an altitude of about 550 m in Arnold Valley. Sandy lacustrine sediment is exposed at about 540 m in a borrow pit where the Woburn – Notre-Dame-des-Bois road crosses Mocassin Brook, and similar sediment is present in the headwater region of Samson River. A normal fluvial delta was mapped at an altitude of about 515 m near Lac Émilie.

In the Lac-Mégantic area several deltas with altitudes at or near 430 m confirm the presence of a major, proglacial lake in the Chaudière Valley – Lac Mégantic – Lac aux Araignées basin. The probable outlet for this lake was through the col on the border at the Coburn Gore (Maine) customs houses, at the source of Vaseux River.

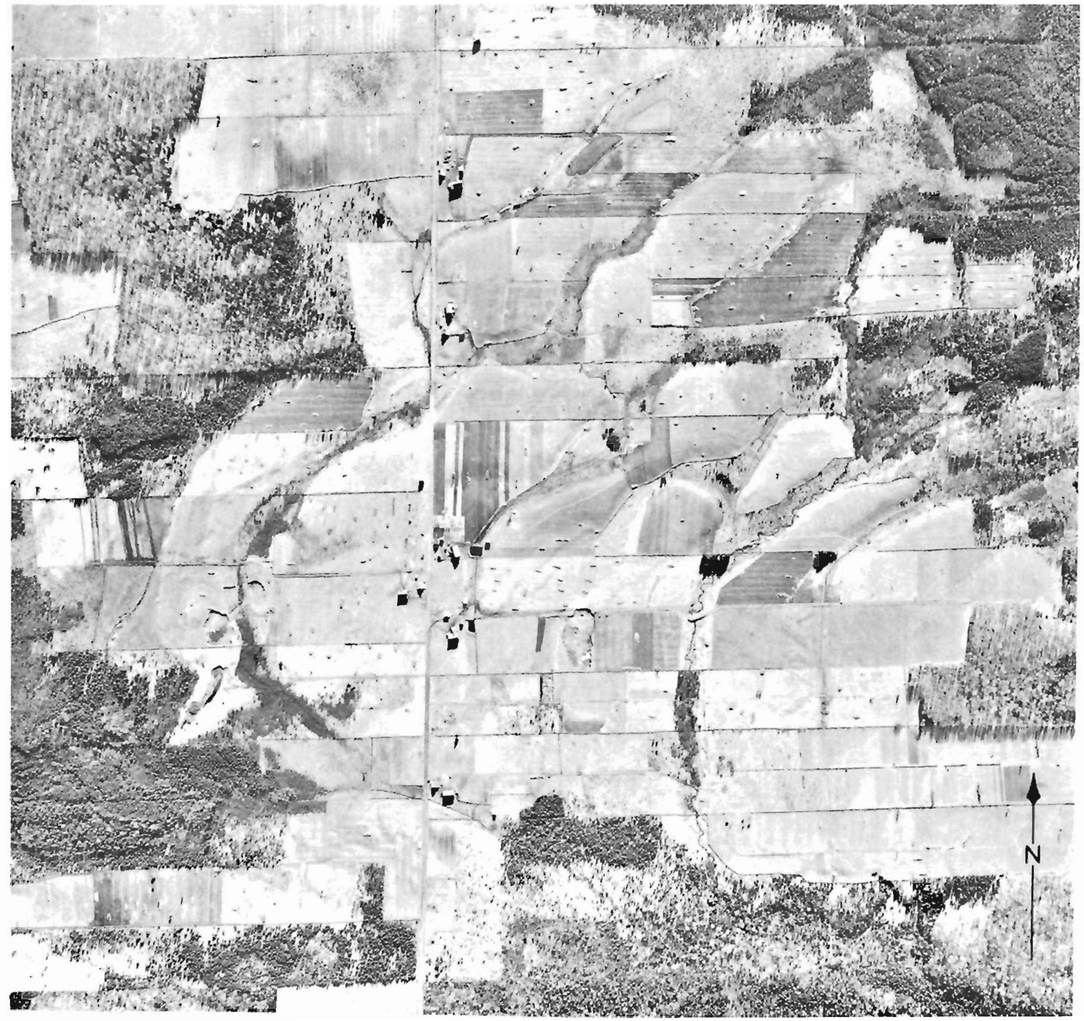
Very little post-Lennoxville lake sediment is shown on Map 1494A. Most deposits are thin, fine to medium grained sand lying in slight depressions on the till surface. The only occurrences of rhythmically banded, fine grained sediments were found where Route 161 crosses Arnold River (north of Woburn); in an artificial bank on the east side of the bypass road at Saint-Gédéon; and at the top of section 8 north of Saint-Gédéon. It is probably reasonable to assume that 1 or 2 m of sand, reworked till, or varves, formed during this lake phase, are more common below 430 m altitude than is indicated on Map 1494A, and that beach and deltaic features may be found in heavily forested parts of the lake basin.

Figure 38

Examples of moraine-like ridges composed of sand and gravel.

a. Moraine-like ridge composed of ice-contact lacustrine sands, northwest Lac Mégantic (southwest side of Baie au Sable). In shape and scale, these ridges are indistinguishable from till ridges. (GSC 154356)

b. Crescent-shaped ridge composed of ice-contact lacustrine sand and gravel in the valley of the stream flowing into the northwest end of Baie au Sable. (GSC 154359)



c. Nested ridges, composed of gravel (note pits) and separated by meltwater channels, 5 km southeast of la Guadeloupe (Ministère des terres et forêts, 1126A-56).

Figure 39. *Lake sediment predating Massawippi Formation and Johnville Till, section 3, Grande Coulée River. Nonglacial, fluvial gravel overlies and underlies approximately 150 noncalcareous laminae at this site. (GSC 148165)*

Laminated silty clay also has been found beneath a 1 to 2 m-thick capping of fluvial gravels that form prominent terraces adjacent to Chaudière River north and south of Saint-Martin. These deposits are of uncertain origin and likely were deposited in a lake dammed by ice that formed the massive ice-contact deltaic deposits at Vallée-Jonction, 50 km northwest of Saint-Martin. The deposits at St-Gédéon-de-Beauce also may be related to the damming at or near Vallée-Jonction. No surface lacustrine sediment has been noted in numerous exposures along roads and in valleys between Saint-Ludger and Saint-Gédéon.

Postglacial Sedimentation

Immediately after the retreat of the Lennoxville glacier and the draining of associated proglacial lakes, the landscape of the Lac-Mégantic area was much as it is today. It probably had a tundra vegetation for a few hundred years (see Appendix 4), and major river valleys such as the Chaudière, Samson, Linière, la Truite, and Grande Coulée were filled with glacial sediment so that drainage followed broad depressions whose surfaces before fluvial excavation were, in places, 10 to 50 m above the present courses of these rivers. Lakes were probably about twice as numerous as they are now, but those that have since disappeared were mostly small and/or shallow.

Bog and Lake Deposits

Bog deposits (map unit 5) occur in bedrock and drift depressions that were, for the most part, former lake basins. In shallow lakes where organic production was high, vegetation gradually grew from the shores towards the middle of the lake, eventually filling the lake basin with decaying plant remains on which typical bog vegetation now grows. The time required for this organic infilling was dependent on the area of the lake, its depth, and the rate of organic accumulation (autochthonous and allochthonous). Lakes that still persist in the Lac-Mègantic area are in various stages of infilling; large, deep lakes such as Lac aux Araignées, Lac Mégantic, and Lac Portage show little or no effect from organic accumulation; but small lakes, such as Étang du Castor (east of Lac Mégantic), have increasingly restricted open water areas (Fig. 44).

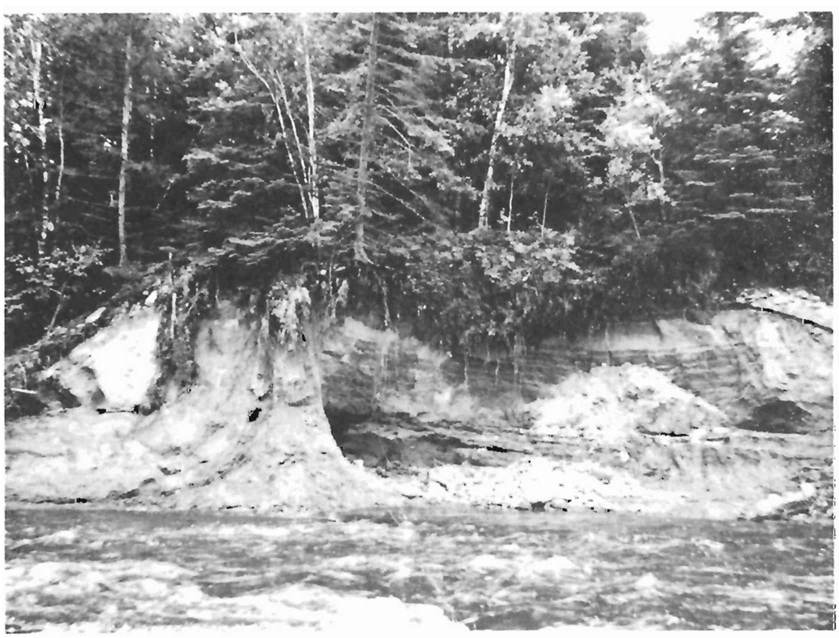


Figure 40. *Diapir of pre-Chaudière laminated silty clay in fluvial terrace between sections 10 and 11, Samson River. The diapir pierces fluvial sands of the Massawippi Formation and penetrates the overlying modern fluvial cobble gravel. (GSC 202929-ZZ)*

Most areas mapped as bog deposits are filled with 1 to 4 m of finely divided organic fragments, peat, and some macroscopic pieces of shrubs and trees. Bottom sediments in lakes comprise finely divided organic matter (gyttja) which may have considerable admixtures of mineral sediment. Sediment fill in the deepest parts of Lac aux Araignées, for example, comprises more than 13 m of a laminated mixture of organic and mineral sediment.

At the base of organic bog and lake sediments, there is generally a sharp break separating the organic phase of deposition from a preceding phase of mineral-sediment deposition. In Unknown Pond (Maine), a zone of moss fragments set in a few centimetres of marl was observed at the base of the organic sediment. The underlying mineral sediment is generally a grey, sandy silt with few or no stones. It contains scattered plant fragments and traces of iron phosphates or sulphides such as vivianite or hydrotroilite. Pollen profiles derived from cores collected from Unknown Pond and Boundary Pond are shown in Appendix 4.

In the northern part of the area the bog partially filling Lac de la Grande Coulée and a bog 13 km to the east-northeast have a ribbed pattern on the surface (Fig. 45). These are similar to the string bogs common north of St. Lawrence River in the boreal forest and may be the most southerly examples yet reported.

Fluvial Erosion and Deposition

Streams flowing over thick glacial fill have eroded channels that range from a few metres to more than 50 m in depth. The depth and rate of erosion was controlled by the physical nature of the glacial sediments, by the levels of higher order streams or lakes into which the stream was flowing, and by the altitude of obstructions, such as bedrock, uncovered in the channel in the course of fluvial excavation. Temporary periods of channel stability during the down-cutting phase are marked by terraces, which now stand a few to several tens of metres above the modern floodplains; each terrace approximates the level of a portion of a former floodplain formed during a temporary decrease in the rate or halt of downcutting. Such halts were caused by establishment of temporary base levels related to the uncovering of obstructions somewhere along the stream channel. Many modern streams have not cut entirely through their unconsolidated deposits to bedrock, indicating that obstructions that create temporary base levels are present in the Chaudière drainage system today. Because it is necessary to recognize the base level controls in order to prevent severe erosion that would accompany renewed downcutting if these obstructions were modified or destroyed, some of the more important ones will be described.

In the upper portions of the Chaudière drainage system, the level of downcutting is controlled by bedrock outcrops in the modern channels above Woburn. Below Woburn, the level of Arnold River is controlled by the level of Lac Mégantic. If the level of Lac Mégantic should drop significantly, only the portion of the Arnold downstream from Woburn would suffer extensive erosion. Terraces that flank the Arnold and other streams flowing directly into Lac Mégantic or Lac aux Araignées are probably remnants of floodplains that were graded to the level of the 430 m proglacial lake that filled the Chaudière basin during deglaciation and to higher level phases of modern Lac Mégantic, which existed while Chaudière River (its outlet stream) was cutting through the thick glacial fill between the town sites of Lac-Mégantic and Saint-Ludger.

Figure 41. *Jointed laminated silt and clay facies of the Gayhurst Formation exposed in the west bank of Chaudière River a few hundred metres south of Drolet. Joint systems strike at 90° (parallel to shore) and 30 to 50°. (GSC 148092)*

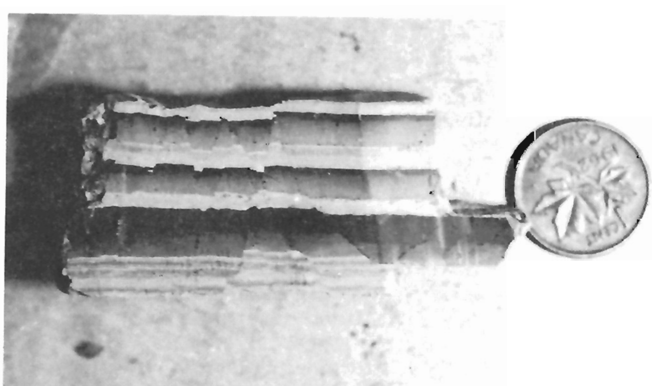


Figure 42. *Typical glacially overridden, graded silty clay laminae of Gayhurst Formation from near Drolet. Laminae show multiple 'summer' layers (light coloured) thought to be related to turbidite events. (GSC 203214-J)*

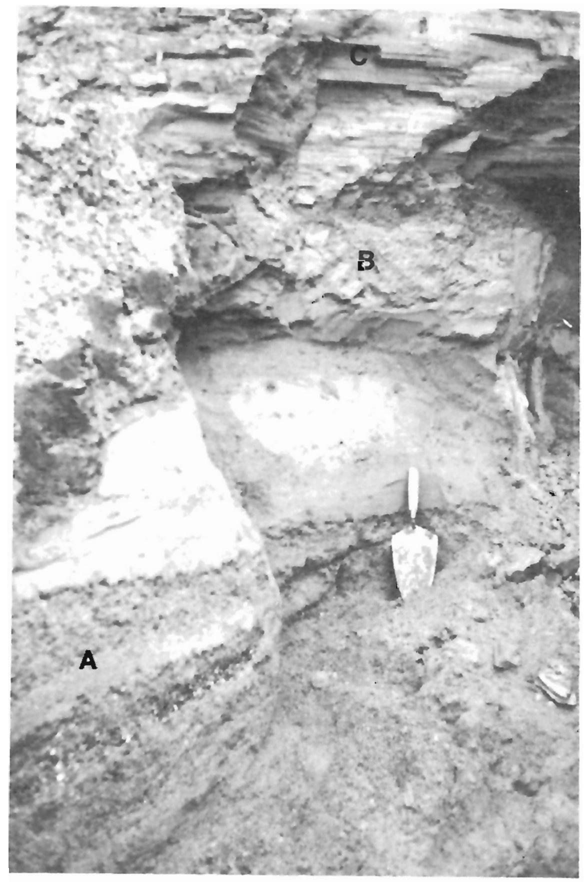


Figure 43. *Exposure in borrow pit for Gayhurst dam, section 16. Large-scale, pebbly sand crossbeds (A) of deltaic facies of Gayhurst Formation underlie laminated clayey silt (C) of upper member of Gayhurst Formation; the deltaic sediments were deposited in the 370-380 m phase. Zone (B) is a disrupted clayey silt bed, probably representing slumping caused by initial instability of fine grained sediment deposited on an irregular deltaic surface. (GSC 154459)*

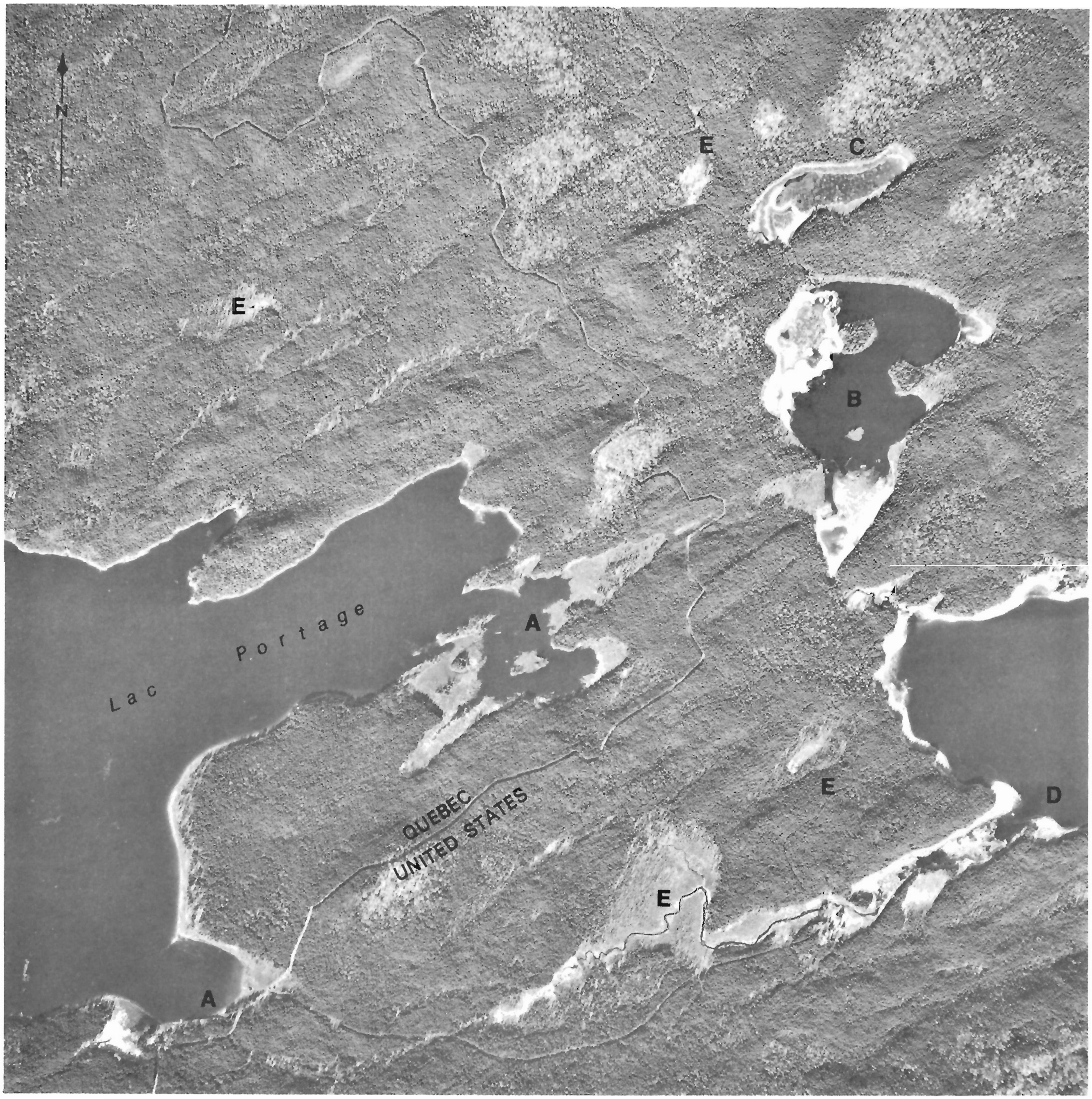


Figure 44. *Lakes in various stages of infilling by organic deposits, Lac Portage area of the Portage Uplands (see also Fig. 5); irregular line that bisects the aerial photograph is the Canada-United States border. A. Infilling in bays of a large lake (Lac Portage); B. Shallow lake with advanced infilling; C. Small, shallow lake that is almost a bog; D. Infilling by combination of deltaic sedimentation and autochthonous organic growth; E. Areas of bog development in sites of completely filled in lakes. (Ministère des terres et forêts, 1126A-88)*

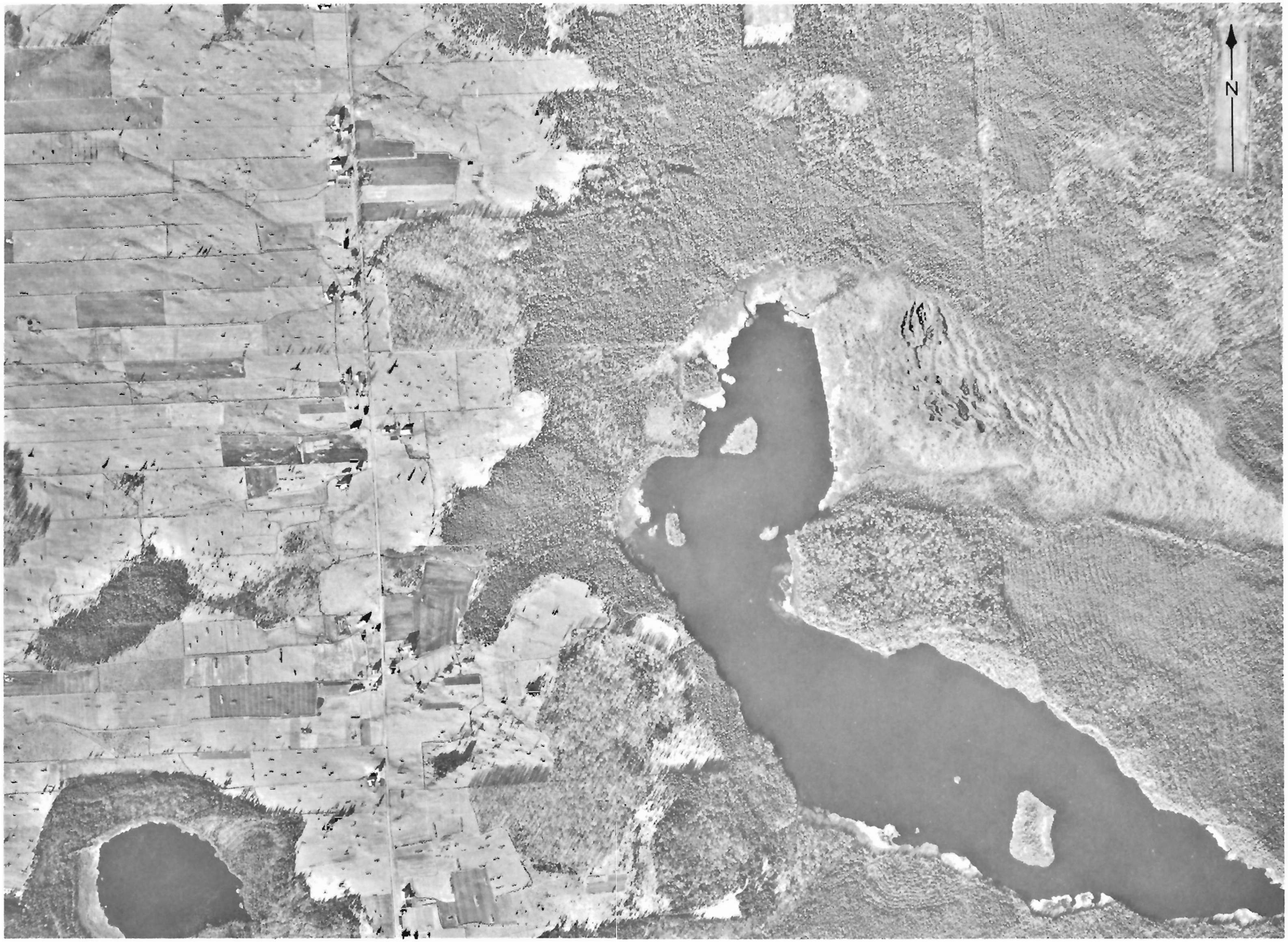


Figure 45. *String bog infilling an area of Lac de la Grande Coulée (45°54'N) southeast of La Guadeloup. Two other bogs with 'strings' in some parts occur a few kilometres east and west of this site, but string bogs are rare south of St. Lawrence River. Note also glacial grooving (southeast) of northeast-striking bedrock and stone piles on fields. (Ministère des terres et forêts, 1138-74)*

Lac Mégantic itself is dammed by thick, normally easily eroded glacial sediments at its outlet (see log of borehole 4, Appendix 1). At the outlet the finer parts of Lennoxville Till largely have been removed, leaving a thin cover of boulders that has armoured the underlying varved clay (Gayhurst Formation), preventing further downcutting of the outlet.

Between Lac-Mégantic and Saint-Ludger, Chaudière River flows over thick, unconsolidated deposits that reach more than 60 m in depth in the Drolet Depression. The base level control that prevents further downcutting through these soft sediments is bedrock outcrop in the Chaudière River channel at Saint-Ludger. This outcrop may affect the channel profile as far upstream as Lac-Mégantic so that removal of the boulder armour at the outlet might lead to downcutting of only a few metres before re-establishment of an equilibrium profile. The terraces that flank the Chaudière floodplain are not particularly well developed and may be partially related to low-level proglacial lakes that occupied lower Chaudière Valley during deglaciation.

In its lower reaches Samson River has cut through more than 50 m of glacial fill comprising several stratigraphic units, and it now flows in a channel cut into a varved unit predating Chaudière Till. Chaudière River forms the local base level preventing further downcutting through these unconsolidated deposits. Fluvial terraces are well developed along the lower half of Samson Valley, flights of three or more being common at some localities. Fluvial terrace gravels have been noted at elevations of more than 50 m above the present river level near section 10. The reason for the relatively well developed terraces in this valley is not known, but they may be related to erosional adjustments in the stream profile as glacial units of varying resistance to erosion were encountered during downcutting in the lower part of the valley (see stratigraphic descriptions of sections 10 and 11, Appendix 1).

Fluvial Terrace Gravels

Fluvial terrace gravels (map unit 6) comprise 2 to 6 m of coarse sand to boulder gravel, usually with some large scale cross-stratification that forms a capping on terraces. The compositions of the gravels correspond roughly to compositions of till clasts from the provenance region in which the gravel occurs. The highest terraces in Samson River valley in the vicinity of section 10 are composed of sand and gravel that is finer grained than gravel that caps terraces at lower levels; the gravel in the present channel is the coarsest of all fluvial deposits in this vicinity. The coarser texture in lower terraces is thought to be the result of preferential erosion and transportation of sand, silt, and clay with concommitant concentration of coarser clasts derived during downcutting through till beds that make up a significant part of valley fill. The finer components were flushed downstream into the Chaudière drainage system, leaving behind a progressively coarser lag deposit of clasts not easily moved by the Samson under its normal range of flow conditions.

Modern Alluvium

Modern alluvium (map unit 8) includes gravel, sand, and sandy silt underlying floodplains and active channels. A thin cover of woody peat is common on the floodplains over sandy silt deposited during overbank flooding; coarser sediments are confined to active channels and to ancient channels buried beneath the floodplain. Included within this map unit are the varied sediments of deltaic complexes deposited where rivers enter modern lakes.

River and delta distributary channels contain sorted sediments with mean grain sizes ranging from sand to boulders. The texture of the channel deposits in many places is related closely to the average texture of the glacial sediment(s) into which the channel is cut. Channel deposits are not thicker than the maximum depth of the river that deposited them. Because rivers meander across their valleys and distributaries shift courses on delta surfaces, channel deposits may be found at many places beneath the floodplain or deltaic plain, buried beneath silt, sand, or organic deposits.

Floodplains are mantled by sand or sandy silt, deposited during overbank flooding, and are generally poorly drained, covered by less than 1 m of woody peat, and furrowed by old meander scars. Some meander scars, such as the one 5.5 km southwest of Saint-Ludger, hold ephemeral (oxbow) lakes that fill in the spring and dry up during the summer. Deltaic plains are similar in composition to floodplains but are scarred by abandoned distributary channels that also may be the sites of ephemeral lakes.

The subaqueous foreslopes of modern deltas built into Lac Mégantic and Lac aux Araignées are composed of fine to medium grained sand with few or no pebbles. Large quantities of such sediment form extensive, shallow subaqueous flats where Arnold River, Victoria River, and Baie au Sable deltas occur in Lac Mégantic and at the Araignées River delta at the east end of Lac aux Araignées. The shallow sandy plain of the Arnold River delta extends for almost 1 km out into Lac Mégantic in a water depth of less than 1 m.

Colluvium

Colluvium is divided into two units, one a poorly sorted, in places weakly laminated, oxidized stony, silty clay (map unit 7) and the other a bouldery deposit (map unit 7a). The first type is similar in texture to till and occurs on virtually all slopes of the region to a thickness of less than 1 m (see Fig. 27). It is composed of mixtures of till, lake sediment, gravel, organic material, etc. that have been mixed together by frost action, downslope creep under wet

Figure 46. *Rounded boulders that cover a valley bottom near the mouth of Madisson River, just south of Gayhurst dam. The valley is excavated in Drolet lentil clay till and in Gayhurst Formation varves. The origin of the boulder lag is unknown. (GSC 148089)*

conditions, or large and small scale slumping. In many places where rivers have deeply excavated their valleys, it forms a persistent cover over the various stratigraphic units that intersect the valley wall, obscuring them. This unit is mapped only where it occurs in significant thicknesses along the sides of deeply excavated portions of Chaudière and Samson valleys.

Bouldery colluvium is relatively rare but may be more common than is indicated on the map in the heavily forested mountainous regions east and south of the map area. This type of bouldery deposit is coarse bedrock talus formed by postglacial slumping or sliding from steep slopes. A particularly prominent talus of this type is found at the base of Slidedown Mountain on the Quebec-Maine border.

A second and unusual type of bouldery deposit was found in two stream valleys, one just south of the Gayhurst dam in a western tributary (Madisson River) of the Chaudière and one in a meltwater channel on the volcanic ridge south of Victoria River. In both cases exceptionally large, rounded, erratic boulders cover the valley bottoms from side to side (Fig. 46). Their origin and localized occurrence in these particular valleys is unexplained at present, but they may be lag deposits left behind when till in the valleys was excavated by meltwater or postglacial streams.

QUATERNARY HISTORY

Pre-Johnville Events – Evidence for Older Glacial and Nonglacial Sedimentation

The oldest sediments identified in the Lac-Mégantic area lie beneath Johnville Till at section 3 on Grande Coulée River. They comprise two fluvial units separated by about 150 graded, silt-clay laminae interpreted as a glacial lake deposit (Fig. 39). This evidence of glacial ponding, combined with the presence, in the fluvial gravels, of rare fragments of granite gneiss, probably derived from the Canadian Shield, strongly suggests that the region was glaciated at least once before the Johnville glaciation. The pebbles of the upper gravel, which lies beneath Johnville Till, are heavily coated with iron oxide as are the pebbles of a similar fluvial(?) gravel that underlies Johnville Till at its type section on Ascot River (McDonald and Shilts, 1971). The heavily oxidized, so-called 'Tertiary' gold-bearing gravels of the Beauceville area may well be correlative with the gravel at the Grande Coulée section, but no evidence of gold has been found in heavy-mineral separates from the latter location.

Except for the suggestion of pre-Johnville glaciation, very little historical interpretation can be made of these gravel and varved units. The gravels suggest nonglacial (free drainage) conditions in Chaudière Valley, and it is reasonable to assume similar conditions in the St. Lawrence Lowland. The high degree of weathering of the upper gravel may have been developed during the Sangamonian interglacial, an interpretation that McDonald (1967a) has suggested for a similar gravel at Ascot River. This interpretation hinges on the assignment of overlying Johnville Till to the early Wisconsinan, an interpretation that traditionally has been made because the Massawippi Formation (St. Pierre beds) has been relegated to an early Wisconsinan interstadial, based on palynological evidence (Gadd, 1971, p. 83).

Johnville Glaciation – Period of Major Southeasterly Glacial Flow from the Canadian Shield

Very few unequivocal exposures of Johnville Till are known in the Lac-Mégantic area and in the Appalachians as a whole. Johnville Till is correlated with Bécancour Till (Gadd, 1971), which is well exposed below St. Pierre interstadial beds at several sections in the St. Lawrence Lowland.

Where identified, Johnville Till appears to be thoroughly oxidized and leached, but no soil profiles have been found on it (see section on Pleistocene Sediments for a description of Johnville Till). In the Sherbrooke area and in the Lac-Mégantic area, fabric and clast lithologies indicate that the till in those exposures examined was deposited by a glacier that was flowing southeastwardly from the Canadian Shield. The form of those exposures of Johnville Till that have been found suggests that they are erosional remnants and that Johnville Till may not be common in the subsurface due to later glacial erosion on the uplands and to glacial and fluvial erosion in valleys.

Massawippi Formation – An Interstadial Deposit

Sandy, plant-bearing sediments of probable fluvial origin lie on colluvium that overlies both the oxidized fluvial gravel and Johnville Till at Grande Coulée River. The palynology of these sediments indicates a climate cooler than present (R.J. Mott, personal communication, 1969); finely divided plant detritus from the sediments yielded an age of >40 000 radiocarbon years (GSC-1084). On the basis of their apparent antiquity, palynology, and stratigraphic position, they are correlated with the Massawippi beds of the Sherbrooke area (McDonald and Shilts, 1971). On the basis of similar criteria, the Massawippi Formation is correlated with the St. Pierre beds of the St. Lawrence Lowland (McDonald and Shilts, 1971; McDonald, 1971). At present, these units are interpreted to record an early Wisconsinan interstadial event which was characterized by a climate cooler than that at present (Terasmae, 1958) and free drainage throughout the Appalachians and St. Lawrence Valley. Recent discoveries of arctic moss species (LaSalle et al., 1977) in beds that are apparently correlative with the Massawippi Formation at Vallée-Jonction, downriver from Saint-Martin, support an interstadial rank for the Massawippi Formation.

Chaudière Glaciation – Glaciers from a Maritime Source

Chaudière Till first was described by McDonald (1967b) at its type section on Ascot River, and he correlated it with a till unit in northern Vermont described by Stewart and MacClintock (1964). The main criteria for correlation were the indications from fabric and lithological data that these tills were deposited, in part, by glaciers that were flowing regionally westward and southwestward. McDonald showed further that in the 25 m of Chaudière Till at Ascot River, fabric shifted gradually from southwestward at the base to southeastward at the top, a shift that was confirmed on lithological grounds. Many more exposures of this till have been discovered in the Lac-Mégantic area during the course of this study, and the unit ultimately was named for its numerous exposures and definitive properties in the upper Chaudière Valley (McDonald and Shilts, 1971).

In the Lac-Mégantic area, the Chaudière Till has fabric that varies from slightly west of south to slightly east of south, but no detailed vertical fabric measurements, such as those done at Ascot River, were made, and most fabric was measured near the middle or top of the unit, the base rarely being well exposed. At section 10 on Samson River, the surface of the Chaudière Till is marked with crag-and-tail striae (McDonald, 1969, p. vi) that indicate southeastward flow (see Fig. 20), a direction that agrees well with a fabric measured just below the surface on which the striae are formed (see Appendix 1).

Despite evidence of late southeastward movement of the Chaudière glacier, Chaudière Till is usually dissimilar in lithology to overlying Lennoxville Till that was deposited largely by a southeastward-moving glacier. This dissimilarity is seen best in provenance regions characterized by Lennoxville Till rich in ultrabasic debris, where Chaudière

Till contains few of the chemical or mineralogical indicators typical of till derived from the ultrabasic areas to the northwest. Exposures of Chaudière Till along lower Samson River show this contrast well, although some sand-sized serpentine grains, presumably derived from reworking of earlier Johnville Till and related sediments, were observed in light-mineral separates.

Other lithological differences between Chaudière Till of the Lac-Mégantic area and overlying Lennoxville Till are: 1) markedly higher feldspar content of Chaudière Till in provenance regions I and II (Fig. 18) which is presently unexplained; 2) its lower feldspar content than Lennoxville Till in provenance region III, due to the large amounts of plagioclase in Lennoxville Till derived from granodiorite in the Little Mégantic Mountains; and 3) the general lack of Precambrian lithologies in the Chaudière Till throughout the region.

All of the lithological, geochemical, mineralogical, and fabric data indicate that Chaudière Till was deposited by a glacier that originally entered the Lac-Mégantic – Sherbrooke – Vermont region from the east, probably from a major centre of ice dispersal formed by coalescing local ice caps in Maine and the Maritime Provinces. The shift in ice flow from southwestward to southeastward is attributed to the later arrival of a Laurentide glacier that displaced or merged with the Maritime ice. The period of southeastward flow may not have been long since this event only produced a structural (fabric) imprint on the till and did not cause any significant southeastward transport.

The encroachment of a Maritime ice cap this far westward is a new concept at present, and it is not known whether this event is unique or was repeated in earlier Pleistocene time. Certainly, there seems to be no such event associated with either the earlier Johnville or later Lennoxville glaciations. Another question that remains to be answered is just how far west and south the Chaudière event can be traced. Numerous sections in northern Vermont, within 80 km of the Quebec border, seem to contain Chaudière Till, and sections comprising two tills separated by lake sediments on the St. Lawrence Seaway (MacClintock and Stewart, 1965) and in the Montreal area (Prest and Hode-Keyser, 1977) superficially resemble those of the Lac-Mégantic area. In the latter cases, however, the lower tills may be correlated better with Bécancour Till of the St. Lawrence Lowland.

In the Lac-Mégantic area, the Chaudière glacier seems to have advanced in such a fashion that no significant blockage of drainage occurred, so that in many places Chaudière Till lies directly on bedrock or on fluvial sediments bearing mineralogical components transported from the northwest during Johnville glaciation. The Gentilly Till of the St. Lawrence Lowland, with which both the Chaudière Till and younger Lennoxville Till are correlated, however, rests on a thick sequence of varved clay (Deschaillons varves, Gadd, 1971), which in turn overlies fluvial sediments. Thus, it appears that during the initial phases of Chaudière glaciation, ice advanced into the area of the southern tributaries of St. Lawrence River (Appalachians) before the St. Lawrence estuary was completely cut off from the sea either by northward flowing Maritime-Gaspé ice or by southward-flowing Laurentide ice. It further appears that a considerable period of lacustrine deposition occurred before either Maritime or Laurentide ice of the Chaudière event invaded central St. Lawrence Valley.

Gayhurst Formation – Deposition During a Prolonged Period of Glacier Equilibrium

The Gayhurst Formation comprises lacustrine sediments deposited in a large lake that existed in the Appalachians during the time interval separating Chaudière and Lennoxville glaciations. It is defined in a series of borrow pits, gullies, and borings in the vicinity of Gayhurst dam (sections 16, 16a, 16b, BH-1, Appendix 1), the site of a hydroelectric project of the late 1950's. The sediments exposed in this vicinity provide the critical key for interpreting the relationship of Chaudière Till to Lennoxville Till in the Appalachians and to Gentilly Till in the St. Lawrence Lowland. In fact, they provide, along with the St. Pierre beds, the "peg" on which all modern interpretations of the Quaternary history of southern Quebec are hung.

The Chaudière glacier front apparently retreated across the Lac-Mégantic region from south or southeast to north or northwest. As long as it stood in or against the Appalachians it blocked northward drainage, ponding lakes in the southern tributaries of the St. Lawrence. When the ice front eventually retreated to the Appalachian front, these lakes coalesced into a single large body of water, informally named glacial Lake Gayhurst (McDonald and Shilts, 1971) (Fig. 47).

The type section of the Gayhurst Formation is fortuitously located where an ancestral river carrying drainage from upper Chaudière Valley entered glacial Lake Gayhurst at its lowest stage. Thus, the delta built into the lake by this river is preserved in the section; the delta was protected from erosion by the later Lennoxville glacier by a thick sequence of varves deposited on it during a higher level phase of the lake. The surface of the delta, which approximates the water plane of the low level stage of the lake, has an altitude of about 370 ± 5 m a.s.l. For a lake to have maintained this level, all drainage to the St. Lawrence Lowland had to be blocked by a series of dams, with dimensions measuring hundreds of metres high and tens of kilometres long; clearly, the Chaudière glacier itself was the only mass substantial enough to have dammed these valleys. The only outlets that could have carried outflow from the lake are major channels, now occupied by Famine-Daaquam rivers, Lac Veilleux, and Lac Fortin-Joli (Fig. 47), just south of the Notre Dame Mountains. This outflow would have passed into the headwaters of Saint John River and would have reached the Atlantic Ocean via Saint John Valley.

Varves underlying the Gayhurst delta have been penetrated and sampled by drilling. They maintain an average thickness of about 1 cm through their basal 30 m thickness but thicken gradually into couplets several centimetres thick in the upper 20 m; they pass upward with no apparent unconformity into coarse sand and fine gravel with massive, planar crossbeds of the deltaic facies. Thus, if the well graded silt-clay couplets can be regarded as annual deposits, their unbroken 50 m-thick sequence could represent from 3000 to 3500 years of continuous lacustrine cover before the prograding delta encroached over the Gayhurst site. The varves overlying the delta partly have been removed by the Lennoxville glacier, but they may well represent an additional 500 to 1000 years of deposition.

The implication of this apparently unbroken 3000 to 4500 year period of lacustrine sedimentation is that the front of the Chaudière glacier was confined to the zone where the front of the Appalachian Mountains rises above the St. Lawrence Lowland; the glacier front must have remained in that position for at least several thousand years, for it could not have retreated north of the southern edge of the St. Lawrence Lowland without allowing Lake Gayhurst to drain, and it could not have oscillated very far south into the Appalachians without covering the low level outlets or, indeed, overriding the Gayhurst site.

The upper varves represent the readvance of the glacier into the Appalachian highlands, covering the low level outlets and causing the lake level to rise about 50 m by forcing outflow to be redirected through one or more 430 m-high cols near Woburn and on the Vermont border (McDonald and Shilts, 1971). This readvance deposited the Lennoxville Till

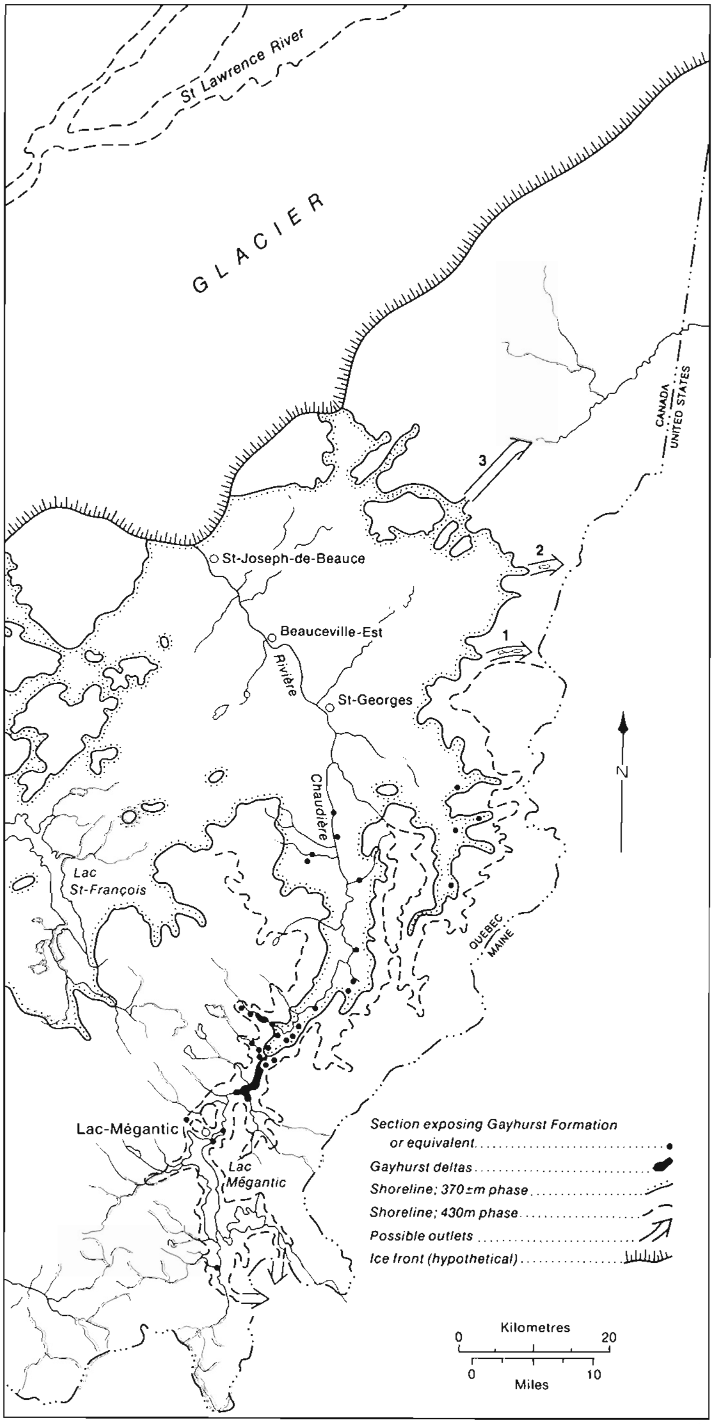


Figure 47. High and low level stages of glacial Lake Gayhurst in the Chaudière Basin. Note that there are three likely outlets into the Saint John River drainage for the low level stage: (1) Lac Fortin-Lac Joli; (2) Lac Veilleux; and (3) Famine-Daaquam rivers. Although all three may have been occupied at various times, the Famine-Daaquam channel, because of its altitude and size, is thought to have functioned longest. Note also the two possible outlets for the high level stage, around either end of Mont Louise. Sites exposing Gayhurst sediments are recorded for the study area only.

which is correlated with surface till over all of the New England states and is considered to have been deposited by the major late Wisconsinan ice advance in eastern North America, equivalent to the Woodfordian substage of the midwestern United States. The initial rate of readvance of the glacier through the Appalachians can be approximated roughly by dividing the distance (60 to 80 km) traversed by the ice front, from the low level outlets to the Gayhurst site, by the number of varves (500 to 1000) overlying the Gayhurst delta. The rate must range approximately 0.16 to 0.06 km per year, a rather slow rate of advance considering that much of the ice front was standing in deep lake water. The figures, however, agree well with the 0.10, 0.02, and 0.03 km per year calculated on the basis of radiocarbon dates from northern and southern Ohio (Goldthwait et al., 1965, p. 89).

Further inferences about the age of the Gayhurst Formation and Chaudière glaciation may be drawn by assuming that the onset of Lennoxville glaciation was roughly synchronous with the onset of the major late Wisconsinan glacial advances in the Great Lakes region, which occurred approximately 22 000 to 24 000 years ago (Willman and Frye, 1970; Forsyth, 1961; Goldthwait et al., 1965). If this assumption and the assumption that there is no significant erosional break during Gayhurst sedimentation are correct, glacial lake Gayhurst must have come into existence about 27 000 to 29 000 years ago; the Chaudière glacial phase would have been completed in the Appalachians also at this time.

The lack of an erosional break within the period of Gayhurst sedimentation explains the presence of only one post-St. Pierre till, the Gentilly, in the St. Lawrence Lowland. Only one till was deposited in the St. Lawrence Lowland because ice cover was continuous from the onset of Chaudière glaciation to the end of Lennoxville glaciation; in other words, the Gentilly Till is stratigraphically equivalent to the Chaudière Till, Gayhurst Formation, and Lennoxville Till of the Appalachian Mountains.

Lennoxville Glaciation – The Major Late-Wisconsinan (Woodfordian) Southerly Ice Advance from the Canadian Shield

The Lac-Mégantic area is covered by till that is associated with abundant indicators of major southeastwardly movement. Indicator trains of rocks, minerals, and trace elements (Shilts, 1973a, 1973b), till fabric, and striae all strongly indicate that the Lennoxville glacier moved out of the St. Lawrence Lowland and swept southward to eastward across the Lac-Mégantic area and into the highlands of adjacent parts of New England. Evidence from New England (Schafer and Hartshorn, 1965) indicates that this advance continued to the limits of Wisconsinan glaciation in the New England states and New York.

As the northeast-southwest trending ice front entered the Lac-Mégantic area, it encountered major topographic prominences, such as Mont Mégantic and the Little Mégantic Mountains. When the ice impinged on the Little Mégantic Mountains (and probably when it impinged on other major prominences), it was blocked temporarily, while the ice front northeast of the ridge advanced rapidly over relatively level terrain. As a result, lobes were formed projecting up the valleys lying on the southeast or down-ice (lee) side of these obstructions. One such lobe projected up Chaudière Valley and advanced into the shrinking 430 m phase of glacial Lake Gayhurst. As this lobe overrode the thick, clayey Gayhurst sediments, it reworked the upper part of the sedimentary column into a very clayey till, the Drolet lentil of Lennoxville Till. Eventually, the ice piling up on the northwest-facing side of the Little Mégantic Mountains grew thick enough to top the ridge and passed southeastward over the advance lobe in Chaudière Valley. The Drolet lentil was preserved in the lee of the Little Mégantic Mountains because it was protected either by ice of the lobe that deposited it or because of its location in the lee of a major ridge which may have been a local zone of less intense glacial erosion. Remnants or inclusions of clay till are seen in places north and south of the ridge of the Little Mégantic Mountains, particularly in Linière and Kokombis Valleys, but clay till other than the Drolet lentil largely was removed or reworked during the general southeastward flow phase of the Lennoxville glacier.

Other lake sediments, deposited near the beginning or end of glacial Lake Gayhurst, have been exposed in 1977 in roadcuts made during the reconstruction of Provincial Route 263 between Sainte-Cécile-Station and Saint-Samuel-Station. Laminated clayey silt and fine sands apparently were deposited in a lake with an altitude of approximately 505 m and an outlet at Saint-Sébastien-Station. The basin to which this lake was confined is presently occupied by Lac Trois Milles and Lac du Rat Musqué. The normal eastward outlets of this basin probably were blocked by the southwesterly advancing lobe of ice that deposited the Drolet lentil clay till. As with the Drolet lentil, the lodgment till immediately overlying the lake sediments is very poor in granodiorite at one site less than 1 km east of granodiorite outcrops; this till is overlain by a granodiorite-rich sandy till which lies directly on the lake sediments elsewhere. The lack of granodiorite in the basal portions of the till supports the southwest movement of the Lennoxville glacier lobe that deposited the Drolet lentil. Unlike the Drolet lentil, however, Lennoxville Till at this site has the normal sandier matrix.

Retreat of the Lennoxville Glacier – Reversal of Ice Flow and Formation of the Quebec Ice Divide

It has become apparent from work done in adjoining areas since the field work for this report was completed in 1969 that the retreat of the Lennoxville glacier front across the Lac-Mégantic region was both preceded and followed by hitherto unknown glacial events of much regional importance. Evidence relating to some of these events exists only in the extreme north and northwest portions of the map area and either was not recorded or was not interpreted properly during field work.

Lamarche (1971) first documented the existence of an extensive area of northward-trending striae in the Thetford Mines map area (National Topographic System 21 L/3) which adjoins the northwest corner of the study area. Later published works by Gadd et al. (1972b), Lamarche (1974), Gauthier (1976), Lortie (1975, 1977), and unpublished work by the author and several other investigators clearly show that: 1) the northward-trending striae record the last ice flow event in the Appalachians in a strip several kilometres wide extending from the Gaspé Peninsula southwestward along the Appalachian front almost to Sherbrooke. (Between Sherbrooke and Asbestos there is a significant area of westward-trending striae that postdate the north-northeastward trending striae.) The reversal of flow was probably originally in response to drawdown in the lower St. Lawrence estuary where rising marine waters accelerated wastage where in contact with the continental ice sheet. Such drawdown probably caused flow of ice from up the valley, creating a "saddle" in the ice sheet along a zone approximating the axis of St. Lawrence Valley. South of the St. Lawrence, ice would have been drawn northward into the "saddle" to replace ice being drawn to the northeast. If the reversal of flow could not keep pace with the rate of wastage in the estuary, a deep re-entrant would have been formed in the valley, eventually cutting off the ice south of the St. Lawrence from any Laurentide source; 2) the southern and southeastern limits of this strip are well defined and appear to mark an ice divide between north-northeastward-flowing and south-southeastward flowing ice. This demarcation line

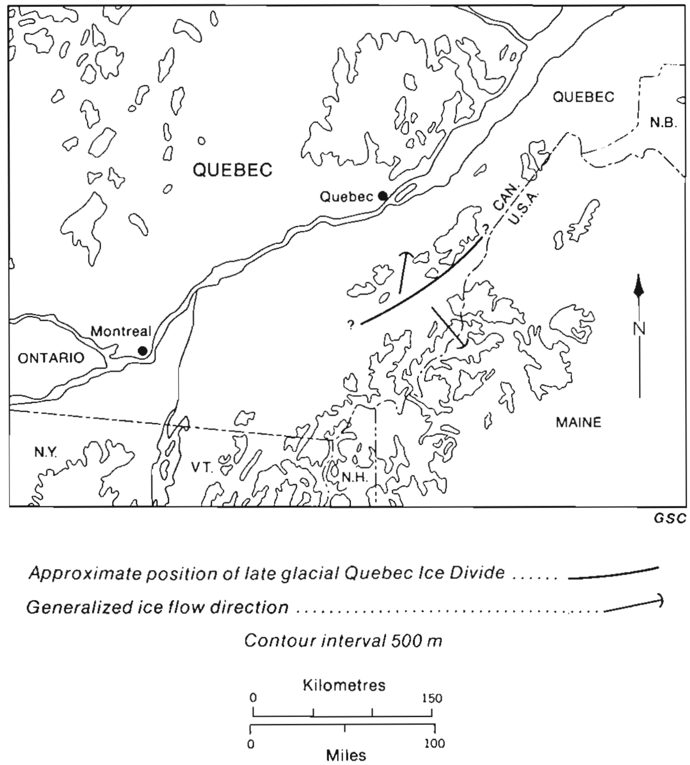


Figure 48. *Map showing the approximate position of the late glacial Quebec Ice Divide. Data are drawn largely from Gadd et al. (1972b), Lortie (1975), and from data in Lortie (1977).*

has been named the Quebec Ice Divide (Shilts, 1976) (Fig. 48). The Quebec Ice Divide is a zone towards which ice fronts south of the St. Lawrence retreated; 3) the Highland Front morainic system (Gadd, 1964b, 1978) and associated proglacial lakes were built and dammed, respectively, by southward-flowing ice from a Laurentide source at a time later than the formation of the northward striae and at a time when the Appalachians between the map area and the Highland Front morainic system were largely or completely ice free. This conclusion is based on the position of the moraine south of northward striae and on the presence of extensive lacustrine deposits in valleys throughout the area of northward striae. Deposition of the latter sediments requires ice damming along the Appalachian front.

Other recently available facts that must be incorporated into any discussion of the deglaciation of the Lac-Mégantic and surrounding areas are numerous dates on marine shells that place marine waters as far west as Ottawa (Richard, 1975, p. 113-115) in the range of 12 200 to 12 800 years B.P. Also, Borns (1973, p. 42) cites evidence consisting of 25 radiocarbon dates on marine shells that "...closely bracket the time of the marine submergence and the formation of the moraines of the coastal region (of Maine) between 13 500 and 12 500 years ago". Ice masses, therefore, must have existed and probably were active south of the St. Lawrence at or very near a time when the Laurentide Ice Sheet was cleaved by marine waters of the Champlain Sea.

From these facts and inferences, it can be concluded that the retreat of the ice front across the Lac-Mégantic area was towards the Quebec Ice Divide and not, as originally interpreted (Shilts, 1970), the retreat of a part of a continuous Laurentide ice front. In fact, some of the morainic fragments in the vicinity of Saint-Évariste-de-Forsyth may have been deposited by northward-flowing ice.

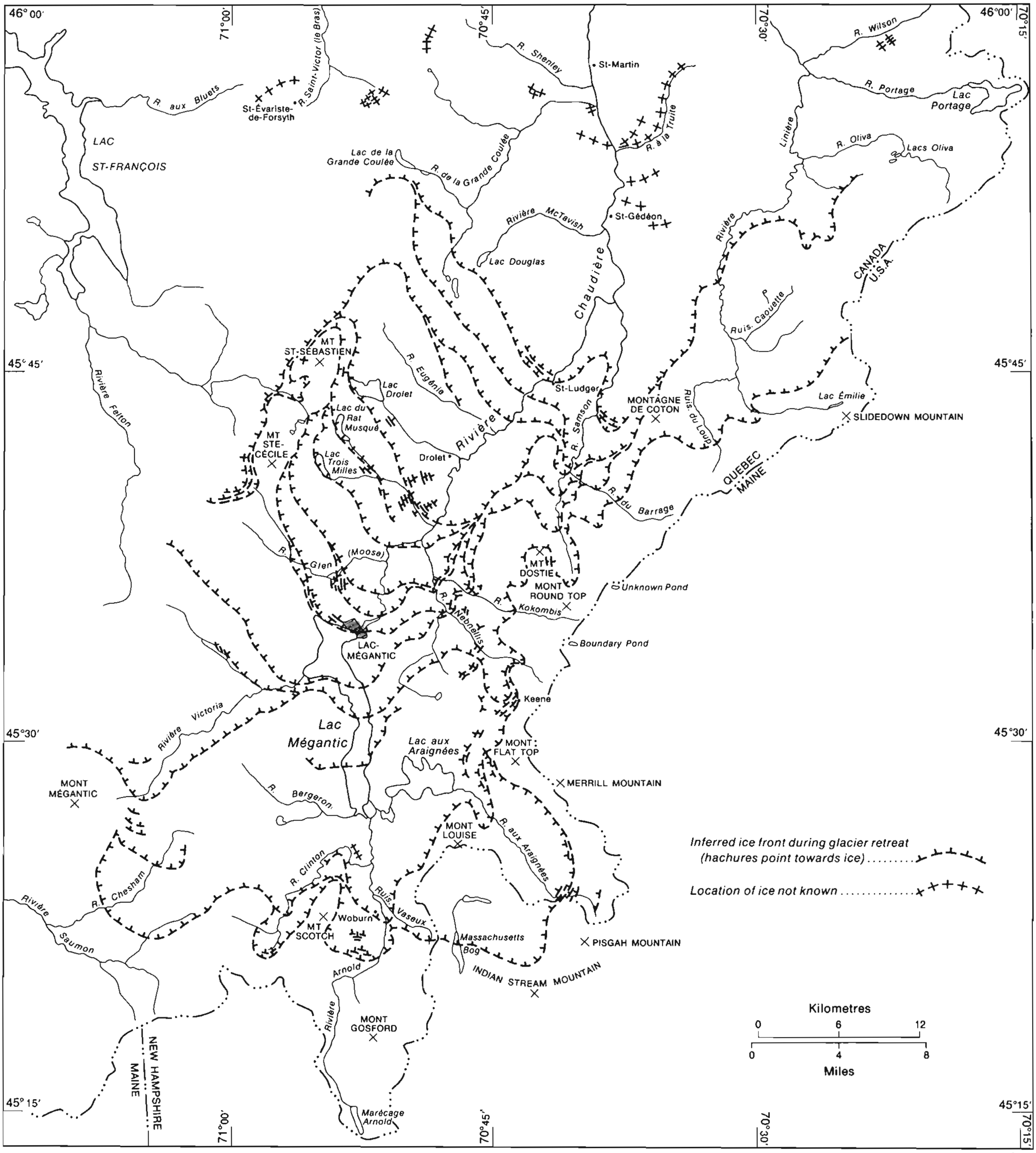


Figure 49. *Recessional positions of the retreating Lennoxville glacier in Chaudière Valley. The lines define ice front configurations as deduced by correlating ice-contact stratified drift, till end moraines, meltwater channels, and other indicators of ice front activity.*

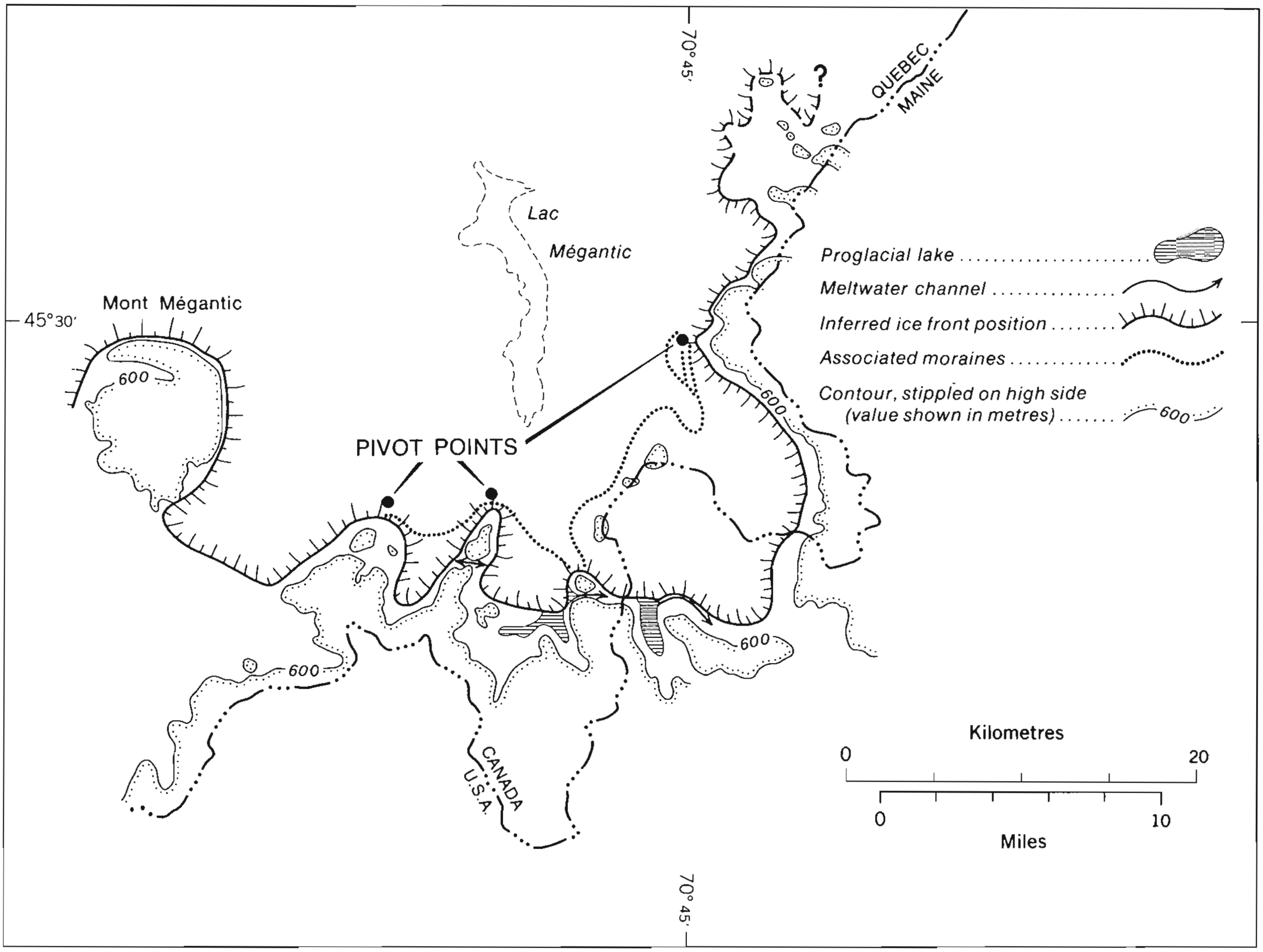


Figure 50. *Ice front configuration at time of construction of the Frontier moraine complex.*

A substantial delta that forms part of the moraine complex between La Guadeloupe and Saint-Évariste-de-Forsyth was built by water flowing toward northwest, possibly directly from ice. If this interpretation is correct, the last vestiges of at least part of the ice mass stranded south of the St. Lawrence may have lain within the map area, probably across Chaudière River between Saint-Ludger and Saint-Martin.

Retreat of the Ice Front Across the Lac-Mégantic Area

In this section the ice front will be described as a feature of the Lennoxville glacier, although from the discussion above it can be seen that the ice front probably represents the southern and southeastern edges of a remnant portion of the Lennoxville glacier – an ice mass shrinking towards the Quebec Ice Divide.

The Lennoxville glacier front retreated generally from southeast to north or northwest across the area, except in the portion of Chaudière Valley between Lac-Mégantic and Saint-Ludger. In this latter area a south-southwestwardly trending lobe was formed in response to ice flow blockage by the ridge of Little Mégantic Mountains after ice had thinned substantially over that obstruction. The shape of the lobe and associated ice flow patterns were similar to those that accompanied the advance of the Lennoxville glacier at the time of formation of the Drolet lentil.

The configurations of the ice front at various stages during its retreat have been inferred by linking disconnected deposits thought to have been formed in ice marginal environments during retreat. Lines drawn through these deposits define recessional positions that are depicted in Figure 49. These positions or form lines are called moraines or morainic systems in this report. Locations and configurations of meltwater channels, eskers, and ice-contact deltas are combined with end moraine deposits of stratified drift or anomalously thick or ridged till to arrive at the recessional positions.

Correlation of ice front features is hampered by the short length of individual depositional segments and by extreme variation in sediment facies that existed in the varied topography along the ice front. Additional difficulties arise where the glacier rested against high ridges along parts of its front and on relatively level terrain or in a proglacial lake along other parts. On steep ridges, vertical reduction of the ice surfaces by several hundred metres occasioned only a short retreat horizontally, whereas in adjacent flatter areas, similar, synchronous thinning caused considerably greater horizontal retreat. Thus, in many places the ice front

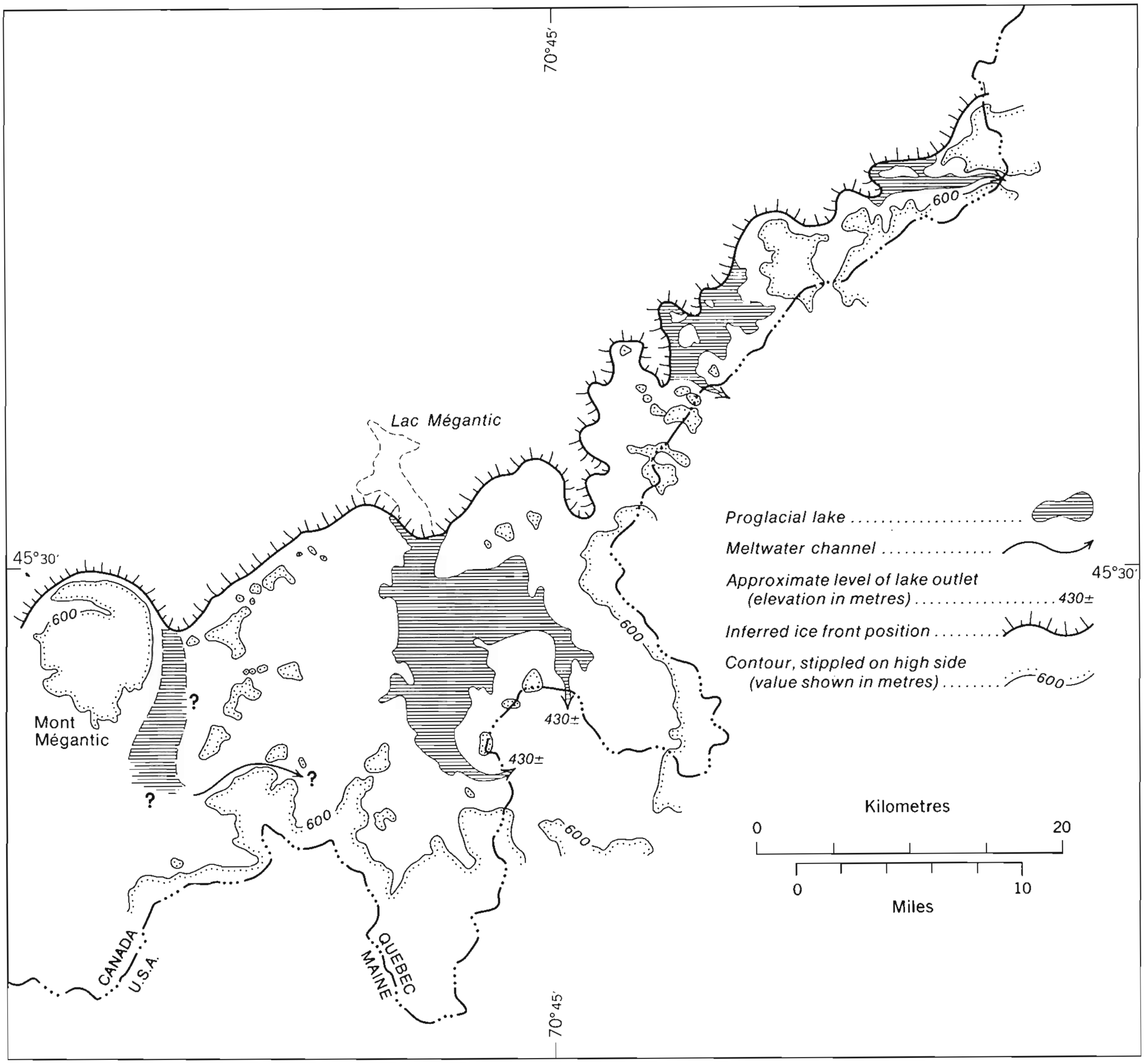


Figure 51. *Ice front configuration at time of formation of the Ditchfield moraine complex. See Figure 34 for details of ice front environments where ice was standing across the Lac Mégantic basin.*

essentially pivoted around the high, steep areas, or "pivot points", such as Mont Mégantic, Victoria River greenstone ridge, Mont Scotch, and Little Mégantic Mountains. Because of this phenomenon, moraines that are widely separated in areas of gentle slopes may converge at the "pivot points".

Figures 50, 51, and 52 show the configuration of the ice front and extent of proglacial lakes at three times when the retreating glacier formed especially well developed ice front features. The limits of proglacial lakes shown east of Chaudière Valley are inferred largely from the altitudes of the lowest possible cols through which they could have overflowed.

Ice-contact deltas of the Ditchfield moraine system (Fig. 34, 51) near Marsboro and 5.2 km south of Lac-Mégantic, and a delta on the northeast flank of Mont Louise are evidence for the former existence of a 430 m-level lake. Paired fluvial gravel terraces along Clinton and Arnold rivers, which seem to be graded to the 430 m lake, are additional evidence of its existence. The outlet of the 430 m lake was at either 1) Coburn Gore, Maine or 2) the headwaters of Upper Hathan Bog, about 2 km east of Mont Louise. Retreat was apparently so rapid that in most areas the surface of Lennoxville Till was neither buried nor modified by lacustrine deposition. North of Lac-Mégantic, thin sand patches and sandy lag deposits are the only apparent result of the proglacial lake. Termination of meltwater channels and subaerial outwash at altitudes about 430 m also is compatible with the presence of a proglacial lake below that altitude.

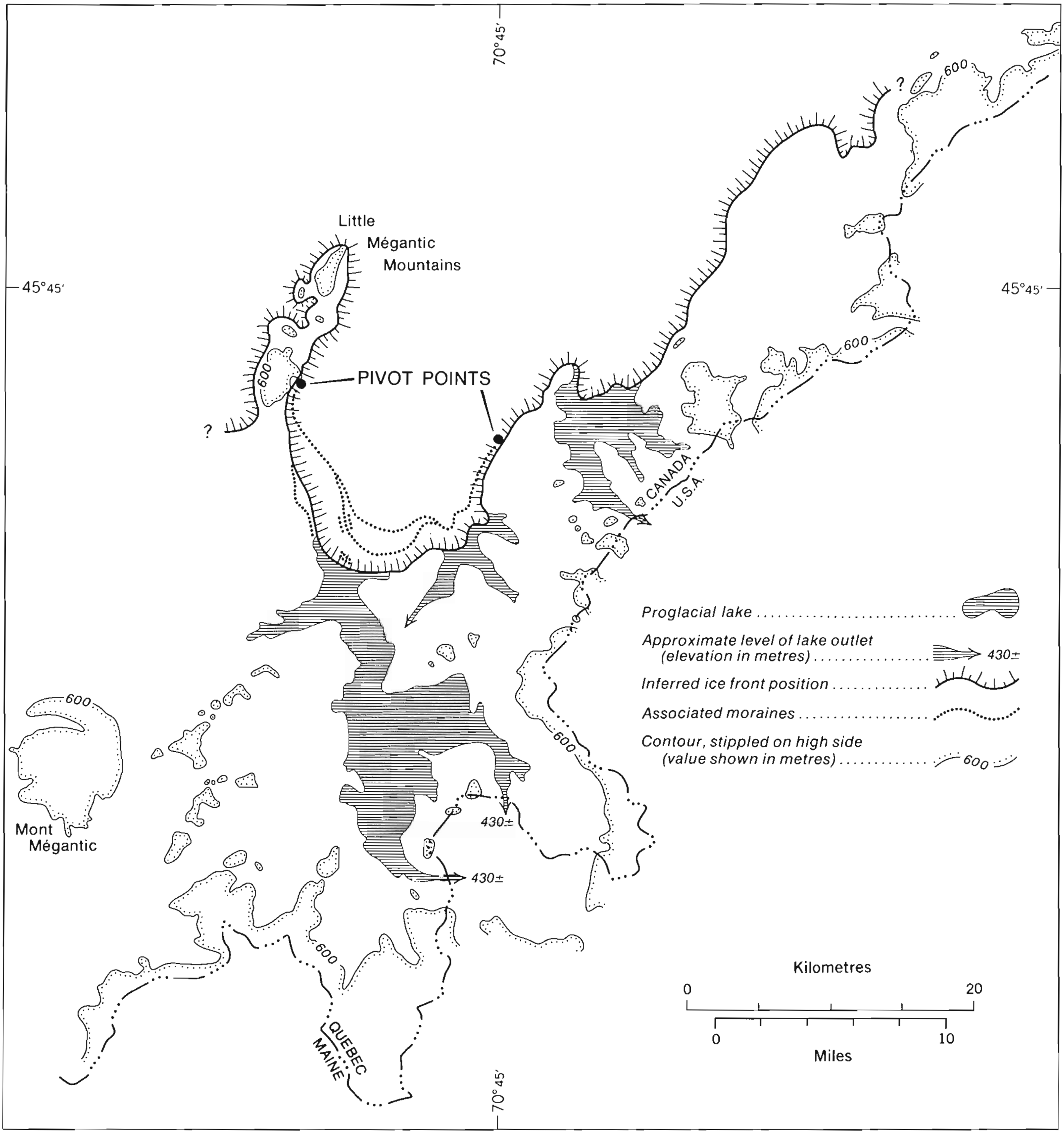


Figure 52. *Ice front configuration at time of construction of the Mégantic moraine complex. Note deep lobation in Chaudière Valley caused by ice turning around the obstruction of the Little Mégantic Mountains.*

Frontier Moraine System

The oldest moraine system is the Frontier System, which is named for its proximity to the Quebec-United States border (Fig. 50). Where it crosses the border north of Chain Lakes, Maine, it comprises several massive, boulder-strewn, northeast-southwest-trending till ridges and fine gravel ridges resting on the west and northwest flanks of Mount Pisgah. The highest ridge lies at an altitude of about 580 m, and the best developed ridges have crests at about 520 m. The whole moraine complex ranges in altitude from 470 to 580 m, with strongest development of moraine-like features at about 520 m elevation north and west of Mount Pisgah.

Where the Frontier moraine system crosses Massachusetts Bog Stream (Maine) between Indian Stream Mountain and the United States-Quebec border, its facies is deltaic with southward-dipping foreset beds; the altitude of the delta surface is about 535 m. The northwest spur of Indian Stream Mountain is cut by several channels between altitudes of 495 to 535 m. Some or all of these channels may have carried outflow from the proglacial lake into which the 535 m-level, ice-contact delta was built; the lowest col in the Massachusetts Bog basin is about 585 m a.s.l., well above the delta surface.

West of the Massachusetts Bog delta, several channels cut across the border. These may have carried meltwater directly from the glacier, but some could have been cut by outflow from proglacial lakes of undetermined altitude that may have existed in Arnold Valley, south of Woburn.

Two complexes of till-ridge and stratified-drift moraines lying southeast and southwest of Mont Scotch are the westernmost recognized segments of the Frontier moraine complex. Mont Scotch produced a deep re-entrant in the glacier front at the time the Frontier complex was built. It is not known whether Mont Mégantic produced a similar re-entrant or whether the ice front continued southwest, close to the border. The fact that westward drainage in upper Saumon and Chesham valleys was still blocked at a later ice front position, as evidenced by an ice-contact delta at ~540 m a.s.l., indicates that the "Frontier" ice front continued close to the border. Furthermore, the Frontier moraine complex may correlate with high-altitude moraines described in the La Patrie area to the west near the New Hampshire-Quebec border (McDonald, 1969).

The northeastward extension of the Frontier system consists of discontinuous moraine ridges, up to 40 m high, that parallel the base of the Boundary Mountains north of Mount Pisgah. The most prominent of these are subparallel gravel ridges lying between altitudes of 490 and 550 m southwest of Merrill Mountain. Till and gravel moraine ridges and meltwater channels also wrap around the west spur of Flat Top Mountain. From this point, it was not determined whether the ice front swung back into the United States or followed a position coincident with moraines of the younger Ditchfield system, along the northwest slopes of the Boundary Mountains. The latter position is probably more reasonable.

The Frontier moraine complex marks the southeasternmost known occurrence of end moraine built by actively flowing ice west of the highlands of central Maine. No evidence of retreat of active ice has been found in the valley of North Branch of Dead River in Maine, southeast of the moraine (H. Borns, Jr., P. Calkin, personal communication, 1968). The only evidence of backwasting of actively flowing ice found in Maine, outside the coastal regions (Borns, 1967), has been reported near Mount Katahdin, Maine (Caldwell, 1966). It is possible that the Frontier moraine complex is equivalent to the Katahdin moraines as they both occur against the flanks of highlands of central Maine. Although the Katahdin moraines also have been tentatively correlated with the Grand Falls moraine of New Brunswick by Lee (1966), these correlations should be regarded as very speculative until more work is done in Maine.

Marking the southeastern limit of deglaciation by actively flowing ice, the Frontier moraine system is the demarcation line separating abundant evidence of glacier dissipation by stagnation in the New England highlands from evidence of glacier dissipation predominantly by active backwasting in Quebec. It is possible that a considerable amount of ice remained stranded in the highlands at the time the Frontier moraine was built. The valley occupied by Chain Lakes, however, must have been largely ice free at this time to permit outflow from the proglacial lake at 535 m in Massachusetts Bog to pass through it.

As the glacier thinned over the ridge extending from Woburn to Mont Louise, the portion that built the Frontier moraine system against the Indian Stream Mountain and Mount Pisgah became detached and stagnated. Abundant evidence of ice stagnation (meandering eskers and disintegration moraine comprising ice-contact stratified drift) is preserved in the low areas now occupied by the headwaters of Ruisseau Vaseux, Quebec and by Arnold and Crosby ponds, Maine.

An end moraine complex composed of stratified gravel-sand deposits extends from just east of Woburn to the north tip of Mont Scotch (discussed in McDonald and Shilts, 1975, p. 125-128). An esker complex parallels the moraine deposits from Woburn to the north flank of Mont Scotch. The moraine cannot be traced along the northwest-facing flank of the Mont Louise ridge but has been identified tentatively northeast of Araignées River where it merges with the Frontier system at Flat Top Mountain. West of Mont Scotch, the younger system is difficult to distinguish from the Frontier system.

Ditchfield Moraine System

The Ditchfield moraine system marks the most strongly developed ice front position in the Lac-Mégantic area (Fig. 34, 51). It lies against the metavolcanic ridge that forms the northwest edge of the Portage Uplands and is traceable from Mont Mégantic to a point near the confluence of Samson and Barrage rivers.

The ice front apparently stayed at the Ditchfield position significantly longer than at other recessional positions. This inference is based on three observations:

1. Ditchfield moraine segments are better developed and more closely spaced (permitting more certain correlation) than those of other recessional positions.
2. Meltwater channels are well developed on the southeast slopes of Victoria Valley. Their large size and excavation in bedrock suggest, qualitatively, a longer period of formation than that required for smaller channels associated with other moraines.
3. Sandy, proglacial lake sediment forms a persistent cover over Lennoxville Till below 430 m altitude south of the moraine system. North of the system, proglacial lake sediments have only patchy distribution. This implies that the proglacial lake at 430 m was present south of the Ditchfield position longer than north and that the Lennoxville glacier retreated rapidly after building the Ditchfield moraine system.

The Ditchfield moraine system is made up of nearly every type of sediment common to the ice front depositional environment. In some places the rush of meltwater parallel to and at right angles to the ice front carved channels in the relatively resistant volcanic bedrock, particularly south of Victoria River, allowing no ice front sediments of any consequence to survive. In other places, as in the Ditchfield area, ice front fluvial systems deposited gravel around and on ice masses that melted, leaving a hummocky deposit. Where the ice front stood in the proglacial lake, a massive ice-contact delta was built. Where fluvial action was limited along the ice front, ridges of till were formed. The interrelationships of these features are illustrated in Figure 34 which can be used as a model for interpreting the environments of deposition of most morainic complexes in the region.

Mégantic Moraine System

After the glacier retreated from the Ditchfield position, ice thinned and the Little Mégantic Mountains blocked southeastward flow into the central part of the study area. This caused ice flow east of the obstruction to swing south-southwestward up Chaudière Valley. The glacier rested against the northwest flank of the Little Mégantic Mountains while the Chaudière Valley lobe retreated northward. Although the lobe was always in contact with the proglacial lake at 430 m elevation, no ice-contact deltas comparable to that of the Ditchfield moraine system were built. Ice front configuration at the time of formation of the Mégantic moraine complex is depicted in Figure 52 which illustrates the presumed relationship of the Chaudière Valley lobe to proglacial lakes and to ice west of the Little Mégantic Mountains.

Timing of Deglaciation

Radiocarbon dates from basal organic detritus in four of five lakes sampled in the Lac-Mégantic area (see Map 1494A) indicate that the area was ice free by at least 11 200 years ago at the latest (Appendix 4). Unknown Pond, Maine, yielded significantly older dates, but inorganic marl in the basal part of the organic section is thought to indicate a depositional environment contaminated with "dead" carbon. Comparison of pollen profiles from this lake with nearby Boundary Pond seems to confirm this conclusion (R.J. Mott, personal communication).

The Highland Front moraine (Gadd, 1964b) must have been formed prior to about 12 000 years ago because marine shells of that age (GSC-936) were found at L'Avenir, Quebec (McDonald, 1968) in deposits that postdate formation of the moraine. Thus, based on this date, combined with the evidence mentioned above and by Gadd (1978) that the Appalachians had to be largely ice free at the time of formation of the Highland Front moraine and its associated lakes, the ice front features of the Lac-Mégantic area had to be formed before 12 000 radiocarbon years ago at the latest.

With marine shells in the Ottawa area dating close to 13 000 radiocarbon years (Richard, 1975) and nonglacial organic sediments on Mont Saint-Bruno, Mont Saint-Hilaire, and near Saint-Nazaire dating 13 000 ± 290 (GSC-1344), 12 570 ± 220 (GSC-419), and 12 640 ± 190 (GSC-312) (Gadd et al., 1972a, b), respectively, it is evident that the Highland Front moraine and, therefore, the older moraines of the Lac-Mégantic area must predate 13 000 years at the latest. This conclusion is dependent on the interpretation of the Highland Front moraine as having formed before any penetration of the sea into the upper St. Lawrence Valley (see Richard, 1976, for recent evidence of readvance of the Laurentide glacier through Champlain Sea).

From the preceding arguments, it is concluded that the ice front of a shrinking remnant ice mass, roughly centred on the Quebec Ice Divide, passed across the Lac-Mégantic area, forming moraines and damming proglacial lakes that drained through central Maine, some time prior to 13 000 years B.P.

GEOTECHNICAL AND ECONOMIC ASPECTS OF SURFICIAL DEPOSITS

Slopes

Four classes of slopes have been discriminated in the Drolet area on the basis of observed slumping and sliding phenomena and materials underlying the slope: (1) till slopes with normal gullying and little slumping or creeping: these are common in all parts of the map area except near Chaudière Valley from Lac-Mégantic to Saint-Ludger and in other valleys with thick glacial fill consisting of several stratigraphic units; (2) steep valleysides: steep valleyside escarpments occur where the Chaudière and other rivers have cut into deep valley fills. These slopes occur largely where Gayhurst Formation sediments were not removed completely during Lennoxville glaciation and are capped by Lennoxville Till or Drolet lentil; (3) slump block scarps: these are sharp fault or fault-line scarps that occur at the margin of major slump blocks (particularly at the confluence of Chaudière and Drolet rivers); (4) rotated till surfaces: these are till surfaces rotated from their original horizontal position by the formation of rotational fault blocks.

Slope types (1) and (4) are sites of shallow gullying and limited mass movement. Type (1) slopes average about 6° and range from 3.5° to more than 10.5° (N=5); type (4) slopes average about 7.5° and range from 7° to 8° (N=3). Both types (1) and (4) are considered to be relatively stable slopes with slight tendencies towards slow soil creep and gullying. Slope type (1) till surfaces have few bedrock protrusions and are overlain by morainal or fluvial gravel patches and by bouldery ablation mantle.

Slope type (2) is the most active of the four classes, and it is considered dangerous to build at the foot of these slopes, to alter them in any way, or to remove deposits from their toes. The slopes may be underlain entirely by till or lacustrine sediment, but the upper portions are commonly till that overlies lacustrine sediments, which form the lower part of the slope. Rotational slump commonly occurs where till overlies a weaker unit, such as varves, but mudflow predominates on slopes cut into or formed wholly of till or similar muds. However, both styles of mass wasting commonly are found together. Type (2) slopes average about 14° and range from 8.5° to 22° (N=11). Stream banks are in this category and may approach verticality.

Slope type (3) is relatively rare and occurs only in the fields of massive slump-faulted blocks near Drolet and in parts of Eugénie River valley. Slopes average about 14° (range 12.5° to 16°, N=3), in sharp contrast to the gentler slopes of the rotated till surfaces (type 4) with which they are paired. Type (3) slopes are significantly modified by mudflows and soil creep and have stability characteristics similar to type (2) slopes.

Physical Properties of Sensitive Sediments

Varved sediments, such as the Gayhurst Formation, and clay tills, such as the Drolet lentil, commonly contain greater than 50% particles finer than 4 µm. Lennoxville and Chaudière tills are not as clayey and contain significantly more sand and gravel. The mineralogy of the <4 µm fractions of all unweathered glacial sediments in the Lac-Mégantic region is predominantly chlorite and illite with minor amounts of quartz, feldspar, and carbonates. No expansible clay minerals have been identified except in weathered samples from less than 1 m depth. The silt-sized fraction of the varved sediments is relatively enriched in chlorite and mica compared to similar fractions in the tills. All of these sediments are poorly sorted (well graded), with the tills being markedly so.

Figure 53

Rotational slump blocks on side of breach through Gayhurst dam. The dam was breached around 1963, and the photo was taken in 1968. Note that one end of each block is lower than the other. Such secondary rotation about an axis perpendicular to the fault plane often results in vertical orientation of the long axis of a slump block. (GSC 201696-E)

A limited number of analyses of Atterberg limits were carried out for Lennoxville Till (19), Dolet lentil (2), Chaudière Till (9), and Gayhurst varves (2).

Lennoxville Till and Chaudière Till are generally similar, having liquid limits (W_l) of 19 to 30% and plasticity indices (I_p) of 3 to 19%, with the magnitude of W_l and I_p being inversely proportional to the amount of sand in the sample. The Chaudière Till samples were collected in a 4 m-high vertical profile (section 10, Appendix 1) where this unit outcrops above a fluvial sandy gravel bed that has served as a source of many of the components in the lower part of the till. The sandier nature of the samples at the base of the till results in values of W_l that range from 15% at the base to 21% at the top and of I_p that range from 3% at the base to ≈10% at the top. This variation clearly illustrates 1) the influence of sandy texture on these parameters and 2) the variability of a till unit that is derived partially from unconsolidated sediments. Three samples collected in vertical sequence from a 5-metre high exposure of Lennoxville Till lying on bedrock at Saint-Gédéon showed little variation from bottom to top (W_l = 24-25%; I_p = 9-11%).

Samples of clayey varves and silty varves and two samples of Drolet lentil were collected from the Gayhurst Formation at the Gayhurst dam site. Liquid limits were 58%, 33%, 40%, and 40%, respectively; plasticity indices were 32%, 14%, 18%, and 20%, respectively.

No assessment of natural moisture content was made for any of these types of samples, but samples of Gayhurst varves and Drolet lentil were observed to flow rapidly when recovered by drilling from depths greater than 4 m below the surface. This suggests that these sediments are near or above liquid limit below the water table.

Seismic Properties

Data from 58 single-ended hammer seismic profiles (see Appendix 3) show little difference in seismic properties between Drolet lentil and Gayhurst Formation sediments but indicate that properties of both units generally differ from those of sandier Lennoxville Till. Apparent S-wave velocities (uncorrected for dip) vary from 4100 to 5700 fps (mean = 5200 fps) for 17 determinations in Drolet lentil and Gayhurst Formation varves. Forty-three determinations of S-wave velocities for Lennoxville Till vary from 5100 to 10 000 fps (mean = 6900 fps). It is concluded that hammer seismic traversing would be a rapid, satisfactory method of outlining areas of thick lacustrine sediments before loading or altering the natural terrain.

Mass Movement

Although various types of slope movements occur on all deforested slopes and stream banks of the Lac-Mégantic region, the most critical, active areas of mass wasting are

Figure 54. *Rotational slump block on east side of Chaudière Valley, northeast of Drolet. View north along rotated (clockwise) surface. This block is more than 1 km long. 'A' is the rotated, originally horizontal surface, and 'B' is an area of alluvial fill deposited by a small stream that flows intermittently between the valleyside and the rotated surface along the entire length of the block. (GSC 148229)*

Figure 55

Small slump block in Drolet Valley. Erosion has produced this conical form.

where Chaudière, Drolet, and Eugénie rivers have dissected terrain underlain by Drolet lentil clay till, which caps up to 55 m of fine grained, varved sediments of the Gayhurst Formation. Unstable, but less active slopes occur where thick Gayhurst and older lake sediments are capped by Lennoxville Till near Saint-Ludger, south of Saint-Martin, in lower Samson River valley, and in some portions of the Grande Coulée and Linière valleys.

Mass wasting forms in the upper Chaudière River valley can be grouped into three genetically significant categories: (1) slump blocks; (2) retrogressive flow slides; (3) mudflows and creep blocks.

Slumping

Slump blocks are cohesive blocks of sediment that have been displaced along normal faults in response to release of confining pressure, primarily caused by erosion of material from valleysides. This type of feature may be subdivided into (1) rotational slump blocks where the plane of failure strikes subparallel to the valleyside and (2) rotational fault blocks where the fault plane strikes obliquely or at right angles to the valleyside and sense of rotation is not clearly related to the trends of valley walls.

Rotational slump blocks are the common form of slope adjustment wherever slopes formed on Pleistocene sediments are oversteepened by natural undercutting or by man, and they quickly form on most newly cut slopes in the region. They range in dimensions from a few metres long by 1 or 2 m wide (Fig. 53) to coherent blocks more than 1 km long by several tens of metres wide (Fig. 54). The arc of failure is usually in varved Gayhurst sediments capped by till or by fluvial terrace gravels. The blocks may stay anchored at one end so that rotation is about axes both parallel and at right angles to the valleyside (Fig. 53). The "crease" between the valleyside and the rotated upper surfaces of the slump blocks commonly serves as an intermittent drainage way and becomes partially filled with sandy, cobbly, peaty alluvium, and/or colluvium. Where drainage leaves the "crease" at the ends of the slump blocks, headward erosion causes the ends of the slump block to migrate towards each other; the block becomes shorter, and ultimately may assume the form of a conical mound which is easily confused with the form of "moulin" kame (Fig. 55).

Rotational fault blocks are large-scale features, and, unlike rotational slump blocks, which move in response to erosional oversteepening at the toe of a slope, they are blocks displaced in response to release of stress as far as several kilometres away from their planes of failure. My interpretation of rotational faulting is a mechanism whereby thick, unconsolidated sediments in interstream areas move towards flanking valleys as material is eroded from the valley axes by major streams. If the sediment in the interstream areas was highly plastic or in a liquid state, it would flow as a viscous fluid towards sites of erosion. The sediments in the Lac-Mégantic area, however, have enough strength in many cases to shear rather than flow, in response to short-term (postglacial) stress release, and the movement takes the form of a series of rotating slices dropping towards the valleys (Fig. 56a, b).

Rotational fault blocks have been observed near the confluence of Chaudière and Drolet rivers and in Eugénie Valley, 2.1 km west of its confluence with the Chaudière (Fig. 57a-e). The asymmetric valley of the mouth of the Drolet River (see Fig. 10, 56a, b) actually may have resulted from slump movement towards Chaudière River shortly after the latter had downcut close to its present level. Subsequent rotational movement towards the Drolet has taken place within blocks already displaced towards the Chaudière (Fig. 57a-c).

Valleys resulting from fault-block rotation are asymmetrical; the fault or fault-line scarp forms the steep valleyside and the tilted upper surface the gentler side. As the rotated surfaces are generally till plains, the presence of boulders (ablation mantle) permits scarps to be differentiated from the rotated surfaces.

Retrogressive Flow Slides or Earthflows

Retrogressive flow slides are common in the marine clays of St. Lawrence Valley (Karrow, 1972) but are relatively rare in the glacial and freshwater deposits of upper Chaudière Valley. On the east side of Chaudière Valley, between the confluences of the Grande Coulée River and Truite River (just south of Saint-Martin), a bowl-shaped depression bounded by an escarpment approximately 2.5 km long is interpreted as the site of a retrogressive flow slide or slides (Fig. 58). The escarpment averages 10 to 12 m high and has horseshoe-shaped portions near Truite River,

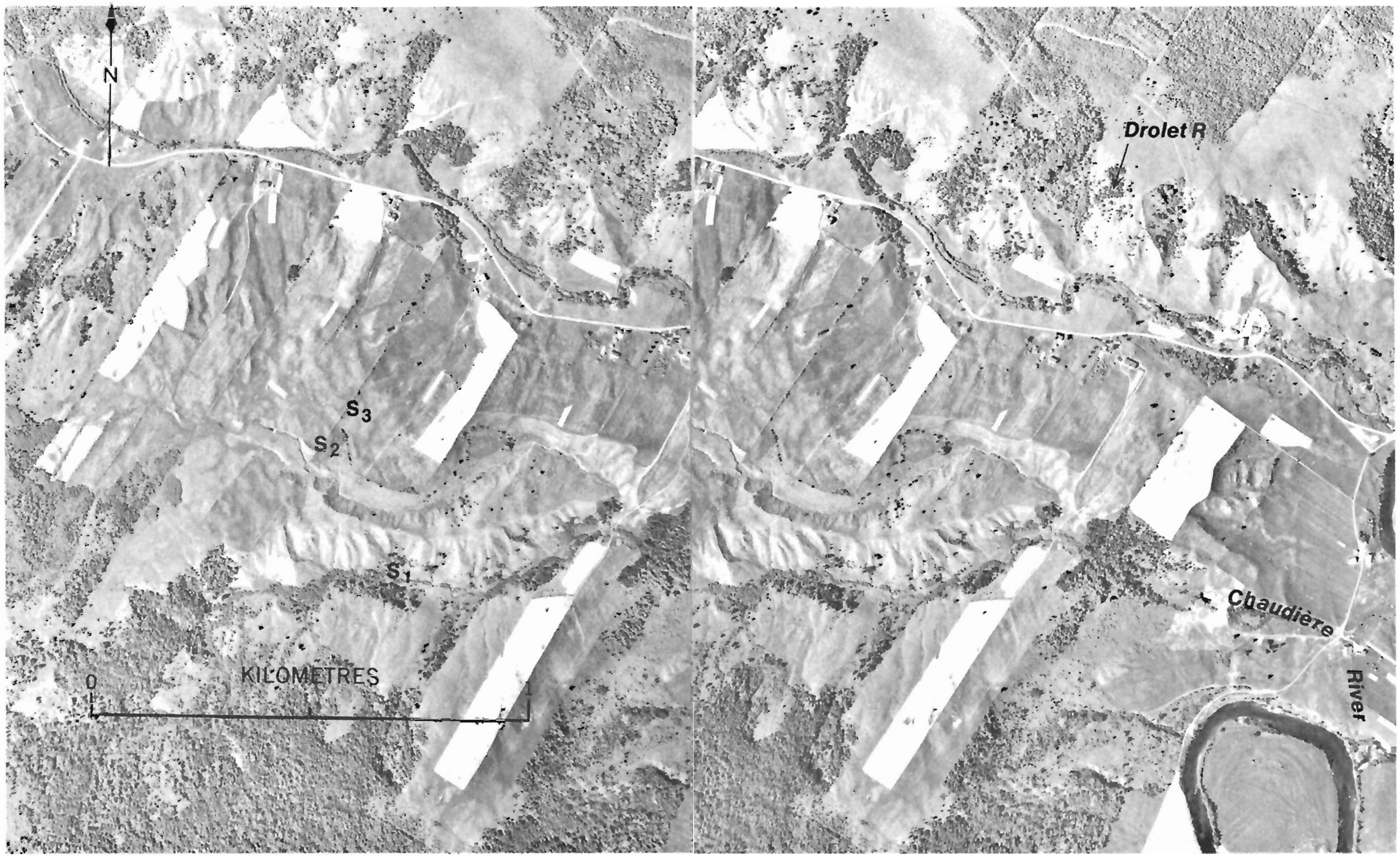


Figure 56a. *Stereo pair of aerial photographs showing location of major faults associated with rotational fault blocks, Drolet area.* S_1, S_2, *and* S_3 *indicate scarps shown in Figures 57a,b,c,d; 55 is the slump block shown in Figure 55. (Ministère des terres et forêts, 1195-135, 136)*

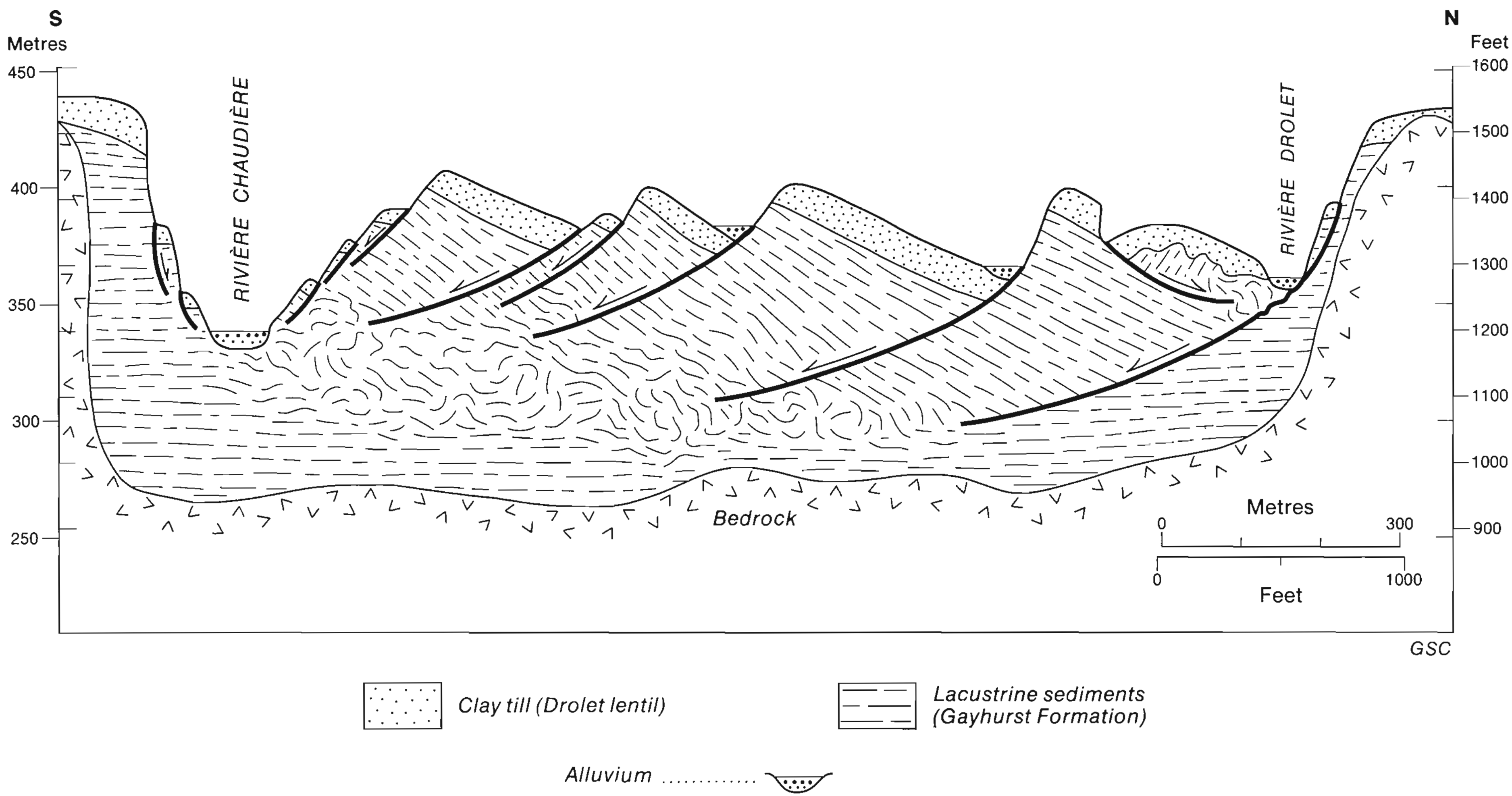


Figure 56b. *Schematic cross-section of fault blocks in vicinity of confluence of Drolet and Chaudière rivers. Note the amount of displacement (>100 m).*

Figure 57

Various ground and aerial views of rotational fault blocks in the vicinity of the confluence of Drolet and Chaudière rivers. The numbers mark the sites of hammer seismic stations and are keyed to data in Appendix 3.

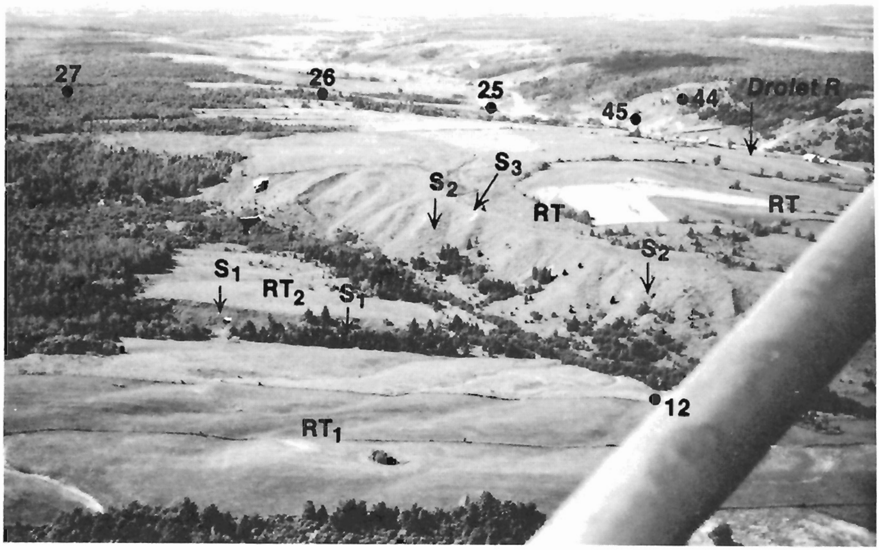


Figure 57a

Aerial view of fault blocks looking northwest from an altitude of about 350 m above Chaudière River; Little Mégantic Mountains can be seen on the horizon. Subscripts after 'S' (fault-line scarp) and 'RT' (rotated till surface) refer to features in Figures 57b, c, d. Note that while most blocks are displaced towards the camera (south), the block bounded by S_3 is displaced north, towards Drolet River. Gullying on escarpments (S) is caused largely by mudflows. (GSC 201696-I)

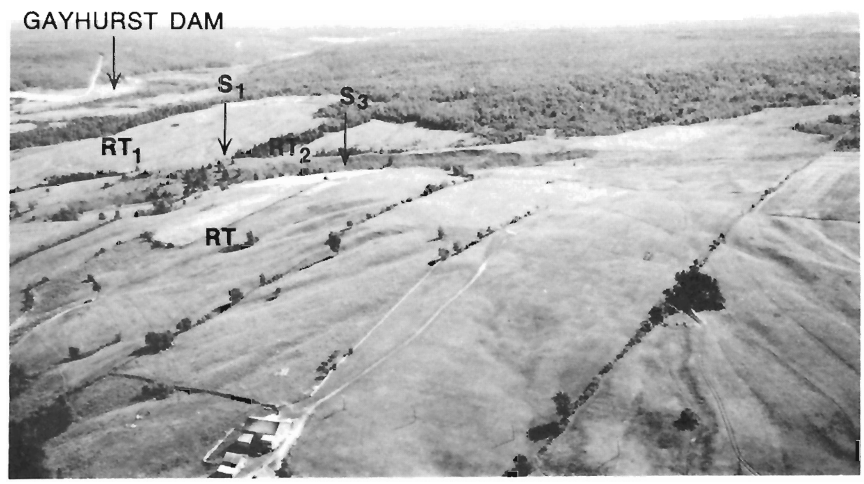


Figure 57b

Aerial view in opposite direction (towards southeast) from Figure 57a from an altitude of about 350 m above Drolet River. Note prominent escarpment, S_3, and slightly corrugated surfaces of rotated till plains. (GSC 201696-D)

Figure 57c

Ground view, looking northeast from crest of ridge formed between S_2 and S_3. Note bouldery ablation mantle on uncleared field in foreground. Field is displaced towards Drolet River (on left). (GSC 203214-L)

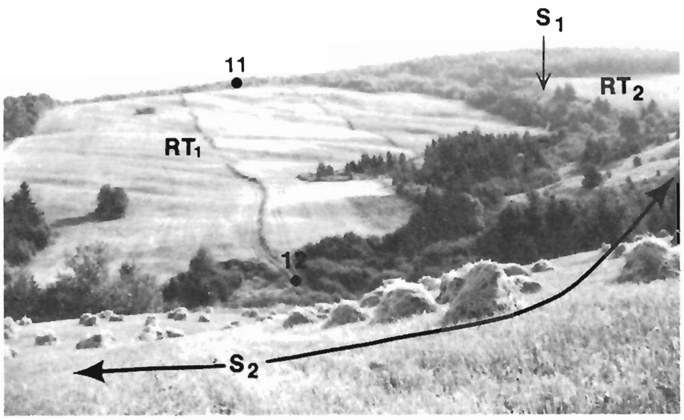


Figure 57d

Ground view of rotated till surfaces and scarps; view southeast from crest of RT_3, the major rotated surface that forms the south side of Drolet River valley. (GSC 148219)

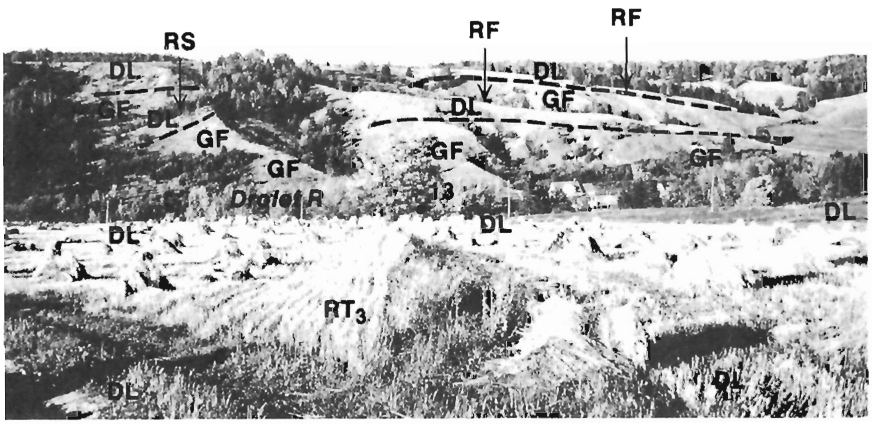


Figure 57e

View from same location as Figure 57d, looking north across mouth of Drolet River. RS – rotational slump block; RF – rotational fault block escarpments; GF – areas of valleyside where Gayhurst Formation outcrops; and DL – areas of outcrop of or surfaces underlain by Drolet lentil clay till. Varves of the lower member of Gayhurst Formation outcrop in the river bed behind the house. (GSC 201696)

suggesting that the feature may comprise elements formed during several flow events. In the horseshoe-shaped portions of the slide the surface of the land in the bowl is still hummocky and ribbed in the manner typical of earthflows in the Grondines, Quebec area (Karrow, 1972, p. 568-569).

The flow slides in upper Chaudière Valley appear to have been stabilized for some time, but the typical frequency and extent of such events are not known. It is entirely possible that similar features are present elsewhere in the valley and have not been recognized during mapping.

Mudflow and Creep

Mudflows and creep are common on slump or fault-scarp slopes, as well as on artificial cuts made in Drolet lentil and Gayhurst Formation sediments in the Drolet region. Local farmers report that rapid mudflows are common in spring, even on vegetated slopes of the Drolet region. A consequence of the tendency of the Drolet and Gayhurst units to flow and creep is the observed instability of roadcuts in the Drolet region (Fig. 59).

Diapirism

The physical nature of fine grained Gayhurst and older lacustrine sediments suggests that they may be able to flow at depth in response to differential loading by ice or overburden. The large displacements of slump blocks in the vicinity of Drolet may well have been associated with subsurface flow of the thick lacustrine sequences that underlie the area of confluence of Drolet and Chaudière rivers. Local residents report that as the reservoir behind Gayhurst dam (just south of Drolet) was filled, the dam and various associated structures showed almost daily signs of movement, which I believe were caused by displacement of silty clay from beneath the load of reservoir water.

In Samson River valley, the pre-Chaudière laminated sediments, common in the river bed for several kilometres upstream from its mouth, are rarely horizontal. In places, particularly in and near section 10, these "old varves" have formed piercement structures that intrude younger sediments. The structures form domes in the river bed and diapirs through the basal portions of the 40 m-high section (section 10). They penetrate the fluvial gravel underlying Chaudière Till and have changed shapes noticeably over the period of observation of the section (1967-1974). A few hundred metres upstream from this section, a classic diapiric structure (Fig. 40) was observed piercing through fluvial gravels in a low terrace.

The diapirism and deformation of the "old varves" in Samson Valley are thought to be caused by "flow" of the silty clay from areas of thick overburden towards areas where the overburden has been removed by fluvial action, that is, the stream valley bottom. Thus, most of the deformation is thought to be postglacial in age; deformation of the laminated silty clay is an ongoing process. Similar dynamic

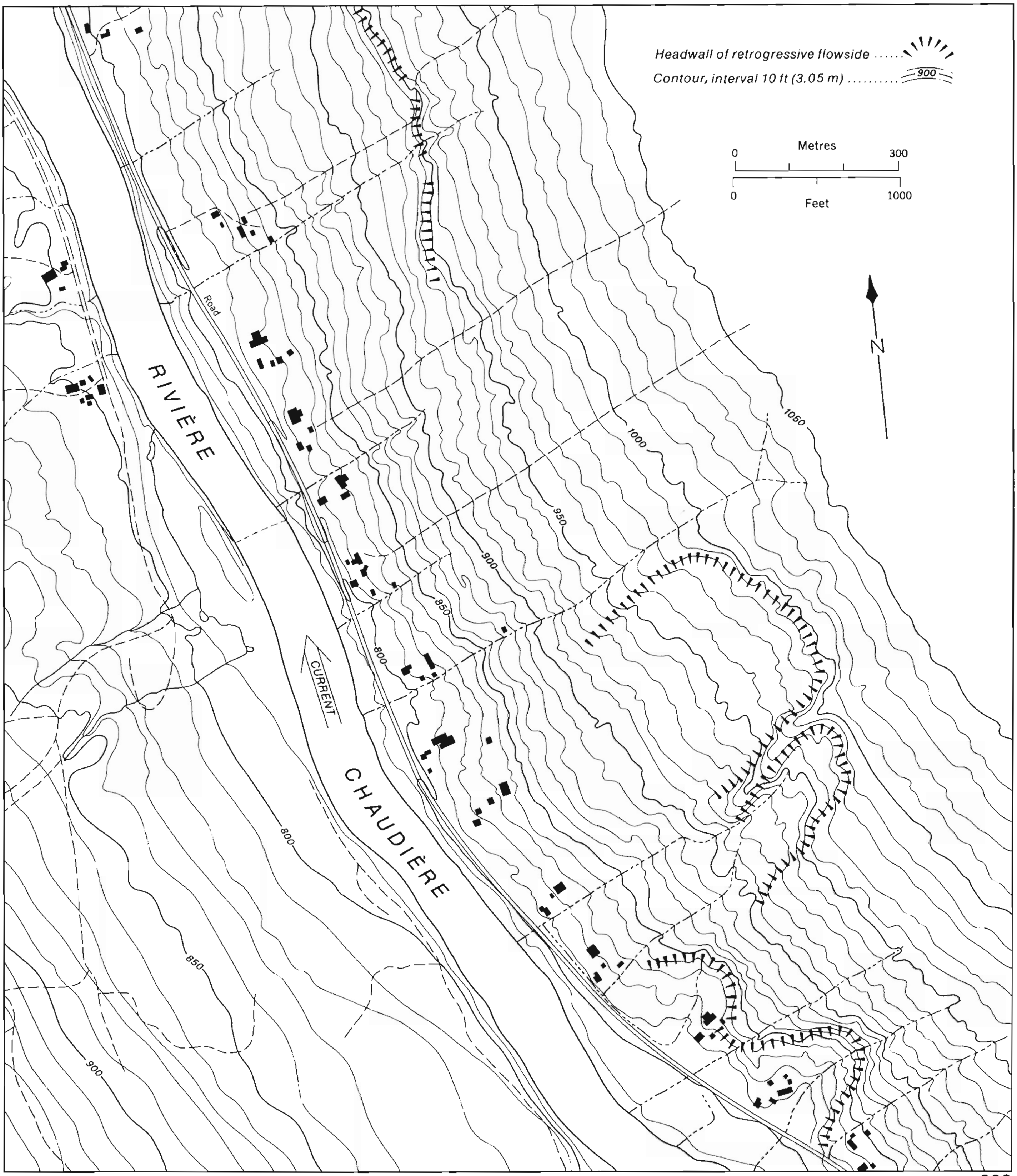


Figure 58. *Detailed topographic map of Chaudière River about 2.8 km south of Saint-Martin, showing scars of retrogressive flow slides on east side of the valley. Surface material on the slope is Lennoxville Till, but stratified lacustrine sediments could be present at depth. The original slopes of the valleysides are not a result of river downcutting; the river flows here through a broad swale in the till surface and has incised very little. (Map based on Ministère des richesses naturelles de Québec; Plan topographique de la rivière Chaudière, 21 E/15, Feuille n° 12, C: 60-54).*

Figure 59. Surface creep and mudflow on two-year old roadcut in varves of the lower member of the Gayhurst Formation, junction of Drolet and Chaudière rivers. (GSC 148220)

diapirism can be expected wherever sensitive silty clay underlies thick overburden in proximity to deeply excavated postglacial valleys. The unequal loading of the sensitive sediments will cause flow from beneath the heavy, thick fill on the valleyside towards the relatively lighter load near the river channel. Areas where stratigraphic data suggest that diapirism potentially could be active are Chaudière Valley between Lac-Mégantic and the Eugénie River confluence; the lower parts of Eugénie, Samson, Wilson, and Drolet rivers; Linière River from Armstrong to about 10 km upstream from Armstrong; and Chaudière River from its junction with Samson River to Saint-Gédéon.

Summary of Slope Stability

On artificial cuts or on freshly undercut river banks, mudflow, creep, and rotational slumping quickly and actively develop. It appears that rotational slump and fault blocks, potentially the most destructive of the mass wasting phenomena, for the most part are presently in equilibrium with the older natural slopes on which they occur; that is, they have not moved for several centuries and will not move significantly in the future as long as the present surface environment (particularly forest cover and stream course) is not altered significantly. Deforestation, dam construction, and natural or artificial alteration of stream courses should be evaluated carefully to discover whether old slump features may be reactivated or new ones developed, as well as whether important earthflows, mudflows, creep, or diapirism will be initiated. Some slump blocks, just downstream from the artificial breach in the Gayhurst dam, apparently have been reactivated by the subtle changes in the erosive capacity of Chaudière River caused by the breach. Dynamic diapirism is present in lower Samson River valley.

Excavation and Erosion Characteristics of Surficial Sediments

The erosion characteristics of various sediments of the Lac-Mégantic region are governed largely by texture and degree of compaction. In general, very clayey sediments (lacustrine varves and clay till) are resistant to erosion by running water. The same is true of gravelly sediments, such as fluvial terrace gravels and outwash deposits. Sediments with subequal amounts of silt and sand and little clay generally are eroded easily except where compacted by glacial overriding.

Excavation characteristics generally are controlled by the degree of compaction and by natural moisture content. Sediment types and their characteristics are listed below.

Chaudière and Johnville Tills

These units are commonly very compact and, although of limited areal extent, occur in valley bottoms where they may form riffles, rapids, or islands in stream beds. If these materials are encountered in excavations, they probably will have to be blasted to be removed.

Drolet Lentil

This unit is resistant to erosion by running water, but where exposed on fault scarps or valleyside escarpments, it is grooved and gullied by mudflow scars (Fig. 57a). Drolet lentil commonly has a high moisture content at depths of more than 2 m and is "heavy" or difficult to excavate.

Lennoxville Till

This unit forms the surficial cover over most of the Lac-Mégantic area. In general, it is moderately erodible, but its resistance to erosion varies with texture and compactness. On the Portage Uplands and in the Boundary Mountains, Lennoxville Till occurs as a thin, sandy, weathered mantle on steep slopes. In these areas it is highly susceptible to gullying and sheet wash when stripped of vegetation cover.

The more clay- and silt-rich facies of Lennoxville Till that occurs on gentle slopes of the Chaudière Hills is not so easily eroded. Where this facies is less than 1 or 2 m thick over bedrock, however, repeated plowing will hasten its removal.

Lennoxville Till is relatively easy to excavate and rarely is so compacted that it must be blasted for removal. Where saturated to or near its liquid limit, Lennoxville Till may flow into excavations and trap excavation equipment or cause it to founder in "heavy" sticky mud.

Gayhurst Formation and Other Lake Sediments

The clayey facies of the Gayhurst Formation and older and younger lake sediments is generally resistant to water erosion but is susceptible to mudflow and slumping. Where these units contain large amounts of coarse silt or fine sand interbedded with thin clay layers, however, they are highly erodible and subject to rapid and deep gullying. Significant thicknesses of the silt- and sand-rich facies have only been observed between the Gayhurst dam and Drolet and in Eugénie Valley about 5 km above its junction with the Chaudière. These facies also may occur in other valleysides of the study area near or below altitudes of 370 to 380 m, the approximate level of major deltaic sedimentation in glacial Lake Gayhurst.

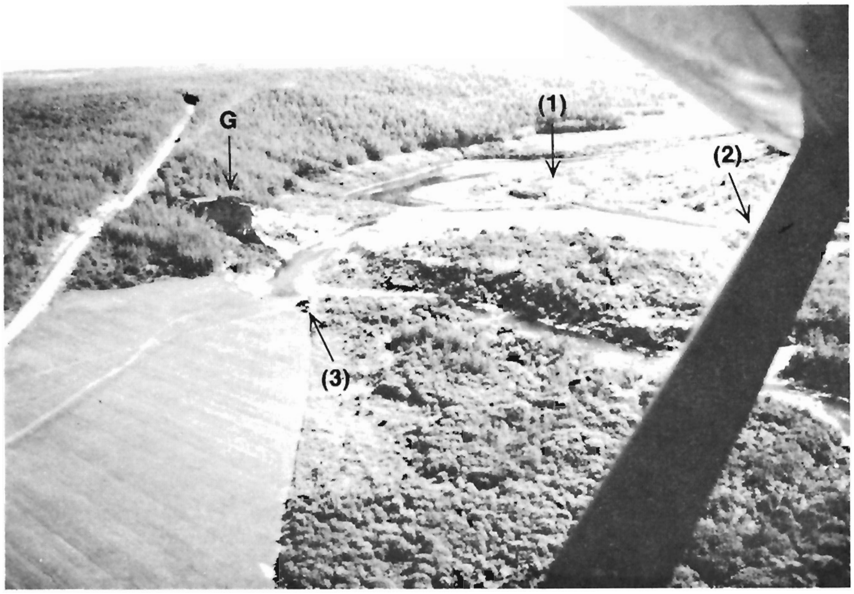


Figure 60

The Gayhurst gully (G), a gorge cut through silty sediments of the Gayhurst Formation as it appeared in August 1968. The gully started forming around 1962 and was destroyed by grading in 1973. It was more than 20 m deep and 400 m long when first observed in May 1967. Note spillway of dam (1) and the old channel of Chaudière River (2). Truck on fluvial terrace in foreground (3) is in process of drilling BH-1 (see Appendix 1). (GSC 201696-J)

Figure 61

View from mouth of Gayhurst gully in 1969. Silty varves of the lower member of Gayhurst Formation can be seen in 2 m-high exposure in foreground. (GSC 154371)

Lennoxville Till, Drolet lentil, and fluvial gravel are relatively erosion-resistant surface sediments that commonly overlie the Gayhurst Formation. Where these sediments are breached, exposing the silty or sandy lacustrine facies, rapid headward erosion of gullies in the silt and/or sand undercuts and causes the normally erosion-resistant sediments to slump so that they, too, may be removed rapidly. The consequences of artificial alteration of surfaces underlain by the silt-sand facies of the Gayhurst Formation must be evaluated carefully to avoid gullying and resulting destruction of man-made structures such as roads, culverts, or road embankments.

On the east side of the artificial breach through the Gayhurst dam, a small, intermittent stream that formerly flowed to the far, west side of Chaudière Valley now enters the river at the breach. The dam was breached on the east side of the valley, and the length of the small stream was halved, resulting in drastic adjustment of its gradient to attain equilibrium grade. To effect this adjustment, the stream cut through its alluvium into silty Gayhurst sediments and, through rapid headward erosion, created a gully about 25 m deep and 400 m long in about six years (Fig. 60, 61).

Gayhurst Formation and other clayey sediments of the Lac-Mégantic area have high moisture contents and are extremely difficult to excavate in large quantities. Where major excavations were made in the Gayhurst Formation to re-route Route 204, construction was slow and difficult.

Glacial and Fluvial Gravel and Sand

Because of their high porosity, sandy gravel and cobble gravel are highly resistant to erosion. Fluvial terraces, which flank many of the major streams of the region, are virtually unmodified by modern erosion, except by undercutting, and glacial gravels are eroded only where they were deposited in river valleys in such a way as to block postglacial drainage. Deposits with high sand/gravel ratios are susceptible to erosion if their natural vegetation is removed. These deposits are minor and generally consist of 1) less than 2 m of lacustrine sand on Lennoxville Till below 430 m altitude or 2) deltas and beaches built into the major post-Lennoxville proglacial lakes at altitudes near or above 430 m. Thick, potentially erodible, ice-contact deltaic sands occur within and for a distance of 10 km south of the Ditchfield moraine, on the east side of Lac Mégantic.

Groundwater

Groundwater is not at present an important factor in the economy of the Lac-Mégantic region. The large cities draw their water from lakes and rivers; rural houses generally utilize springs or shallow dug wells. Few homes have drilled wells, and consequently, not much subsurface information is available outside of the valleys that have stratigraphic exposures.

Bedrock sources of groundwater, commonly are tainted by carbonates, sulphur, and iron that occur in the ubiquitous pyritic slates; unconsolidated deposits generally have restricted permeability and are likely to produce tainted water as well. The scarcity of suitable unconsolidated aquifers is attributed to the fact that at the onset and climax of most glaciations in the area, northward drainage was ponded so that most valleys contain lake sediments sandwiched between tills. The bulk of valley fills in the region comprise relatively impermeable Chaudière Till, Gayhurst Formation, and Lennoxville Till. Massawippi and older sediments include permeable fluvial facies, but seem to have been largely removed during Chaudière glaciation. Consequently, Chaudière Till commonly lies directly on bedrock, and because there was no period of free drainage at low altitudes in large valleys from Chaudière to post-Lennoxville time, the valleys are filled mostly with till and lake sediments of low permeability.

Potential aquifers may be present within three Quaternary stratigraphic positions: (1) Pre-Chaudière sediments: there is evidence for at least three phases of low-altitude fluvial deposition prior to the deposition of Chaudière Till. Although deposits of all three units are exposed only at Grande Coulée River, at least one of them was encountered beneath more than 60 m of younger deposits at the Gayhurst dam and at the base of sections on Samson River. It is possible that these permeable, buried river sands and gravels may be encountered beneath Chaudière Till in other valleys of the region. (2) Gayhurst Formation, deltaic facies: major deltas were built into the low and high level phases of glacial Lake Gayhurst at altitudes near 370 and 430 m, respectively. Coarse grained, permeable, deltaic sands and gravels may be present beneath Lennoxville Till or Drolet lentil at about these altitudes in major valleys. Where valleys intersect these aquifers springs should occur, but where they have not been dissected, they may be artesian reservoirs. Buried deltaic facies of the low-level phase of glacial Lake Gayhurst have been identified in Chaudière, Drolet, and Eugénie valleys. Other major valleys, such as the Linière and Samson, are heavily forested at the critical altitudes and may contain further Gayhurst deltaic deposits. Ice-contact gravel, deposited near the ice front during recession of the Chaudière glacier, also has been discovered above 430 m altitude at some locations beneath Lennoxville Till, but its occurrence is impossible to predict at present. (3) Postglacial gravels: groundwater may be obtained from the gravelly facies of Lennoxville end moraines or ice-contact deltas. These deposits are generally thin, however, and are not ideally situated to receive or trap runoff. Groundwater has been obtained from thick ice-contact deltaic sediments of the Ditchfield moraine system on the east side of Lac Mégantic. According to information from local drillers, these sands and gravels reach thicknesses of more than 40 m.

Resource Potential of Quaternary Sediments

Four types of potentially valuable Pleistocene deposits have been investigated in the Lac-Mégantic region:

1. Sand and gravel deposits are scarce and of poor quality over much of the study area. Consequently, gravel reserves and gravel quality are of primary economic concern in the region.
2. Large quantities of clay and clay till, apparently of fair ceramic quality, have been mapped and roughly inventoried during this investigation. Although distance from large markets is a critical factor to be considered in evaluating their potential economic importance, the possibilities of producing bricks, tiles and other low-grade ceramic products from these deposits warrant further study.
3. Thick peat deposits are not particularly widespread in the region, but do occur in easily accessible areas in sufficient quantities to permit excavation.
4. Placer gold, mined from Quaternary deposits north of the study area in the Saint-Georges-Beauceville region since the late nineteenth century, has not been found in minable quantities in the Lac-Mégantic region.

Sand and Gravel

Gravel quality is gauged partially by the texture of deposits – the percentages of clasts and grains of various diameters. In general, significant percentages of fine sand, silt, and clay are deleterious to aggregate deposits and must be removed by washing.

Gravel quality is gauged further by the relative proportions of rock fragments that may be deleterious to performance in the particular construction materials in which it is used. Carbonaceous limestone, shale, slate, and chert, when present in aggregates mixed with cement, react with cement, causing it to deteriorate. In addition to reacting with the cement, iron sulphides and oxides and ultrabasic rocks cause cement discolouration on surfaces exposed to weathering. Shale, slate, and impure limestone are deleterious when used for gravel surfacing or as asphalt aggregate because of their low resistance to abrasion and their susceptibility to frost splitting. Unweathered, coarsely crystalline rocks, vein quartz, metasandstone, and metavolcanic rocks are generally stable in cement and have good abrasion resistance.

Table 3 lists rock types commonly encountered in gravel deposits of the study area and suggests their possible deleterious or beneficial effects in common aggregate-use situations. The percentages of granodioritic, metavolcanic, contact hornfels, gabbroic, and ultrabasic rocks vary radically from one provenance region to another (see Fig. 17). As a general rule of thumb, any gravel deposit will include subequal amounts of slate and metasandstone with significant proportions of any igneous rocks that lie along or near a line drawn N60°W from the deposit. Suitable reference bedrock maps for the region may be found in publications by Lord (1938), Cooke (1950), Gorman (1955), Reid (1960), and Marleau (1968).

Ice-contact Gravel

Ice-contact gravel was deposited in high-energy fluvial or lacustrine environments near the margins of the Lennoxville glacier during its retreat from the Lac-Mégantic region. The deposits constitute the largest single source of gravel in the region but are most common where morainal belts are well developed in the area south of the latitude of Saint-Ludger.

Ice-contact gravel, because of the vigorous fluvial action of the environment in which it was deposited, tends to have fewer "soft" components (slate, weathered rocks) and less fine sand and silt than younger surface gravels.

Table 3. Rock types commonly found in gravel deposits of the Lac-Mégantic Region

Rock Type	Percentage Range	Performance in Cement Aggregate	Performance in Hot-mix Aggregate	Performance in Road Surfacing
Metasandstone	30-70 (median = 40)	Good	Good	Good
Slate (pyritiferous)	6-50 (median = 40)	Reacts with cement; discoloration on exposed surface, liable to frost splitting	Liable to frost splitting	Poor abrasion resistance, liable to frost splitting
Impure limestone	0-30 (median = 14)	Varies depending on carbonaceous inclusions; fair to low	Good	Poor abrasion resistance; soluble
Granite gneiss	0.5-1	Good	Good	Good
Vein quartz	1-12 (median = 5)	Good	Good	Good
Chlorite schist	0-1	Fair	Poor	Poor
Conglomerate-breccia	0-1	Good	Good	Good
Metavolcanic	0-10	Good	Good	Good
Felsic dyke rock	0-1	Possible discoloration (disseminated pyrite); probably good	Good	Good
Contact hornfels	0-14	Subject to rapid weathering; fair	Good	Good to fair; may be subject to frost splitting
Granodiorite (unweathered)	0-50	Good	Good	Good
Gabbro	0-10	May cause discoloration; good to fair	Good	Good
Serpentinized peridotite Serpentinized pyroxenite (ultrabasic rocks)	0-50	Causes discoloration; highly susceptible to weathering, very reactive with cement	Easily weathered; fair	Poor resistance to abrasion; easily weathered; fair

Deltaic Gravel

Normal streams or streams issuing from ice fronts built deltas (map units 3, 4) into proglacial lakes that filled Chaudière Valley and valleys of its tributaries as long as ice blocked northward drainage to the St. Lawrence Lowlands. The ice front stood along the edge of the Portage Uplands during much of the time that it was retreating from the axial region of Chaudière Valley. Thus, streams heading at the International Boundary (Samson, Loup, Linière, Kokombis, Nebnellis, Arnold, Portage, Wilson, and others) were blocked and filled with high-level lakes whose altitudes were controlled by cols at the headwaters and by spillways that allowed water to drain parallel to the ice front where the ice was in contact with Portage Uplands. The exact configurations of these lakes are not well known – only scattered sand deposits and reworked till attest to their former existence. One deltaic gravel deposit at an approximate altitude of 496 m has been found near Lac Emilie, indicating that a lake existed at that altitude in the headwaters of Linière River; other deltaic gravel deposits undoubtedly also are present in the forested mountain valleys.

The main lake level in Chaudière Valley and in the valleys of its tributaries is about 430 m. Several normal fluvial and ice-contact deltas were formed at this altitude and have been shown to occur from the Woburn area to the north edge of the study area, just north of Wilson River (see Map 1494A). Gravel from these deltas tends to be of finer texture than ice-contact fluvial sediments and in many cases consists predominantly of sand-sized material deposited in massive, gently dipping, foreset beds. The composition of deltaic gravel corresponds closely to that of sand and cobble portions of nearby till.

Deltaic deposits may be much more extensive than shown on Map 1494A. When a need for gravel is anticipated in a particular area, the slopes and deposits just above and below 430 m elevation should be prospected for deltaic or beach gravels. In the heavily forested Portage Uplands, similar careful investigation should be undertaken at altitudes near that of the lowest cols at the heads of major stream valleys.

Fluvial Gravel

Up to 4 m of gravel has been deposited on terraces flanking modern rivers (map unit 6). The deposits are composed primarily of clasts eroded or concentrated from till. They tend to contain larger amounts of unstable components (slate and ultrabasic rocks) and silt and fine sand than adjacent ice-contact or deltaic gravels.

Chaudière River and Linière River fluvial terraces have been exploited extensively north of the latitude of Drolet, particularly for road surfacing material and fill. The gravel makes very poor aggregate and, despite the large areas of terraces shown on Map 1494A, the gravel is thin and reserves are not large. The general scarcity of ice-contact gravels north of Saint-Ludger has necessitated the widespread use of fluvial gravels to satisfy aggregate requirements in this area. A major pitting operation was observed in fluvial gravel deposits on a Chaudière River terrace complex on the west side of the river, just south of Saint-Martin. Here 3 m of slate-rich, poorly sorted gravel overlies laminated silt and clay.

Buried Gravel

Buried ice-contact and deltaic gravel deposits have been exploited in a few places in the region (map unit 1a). The ice-contact deposits are probably portions of end moraines deposited during the retreat of the Chaudière glacier or during minor oscillations of the ice during advance or retreat of the Lennoxville glacier. Deltaic gravels in this category are probably related to various levels of glacial Lake Gayhurst.

More study should be given to such buried gravels as they could provide important sources of good quality gravel in the Saint-Martin – Armstrong, Saint-Gédéon – Saint-Sébastien-de-Frontenac areas where poor-grade fluvial deposits are utilized now.

Summary

Large quantities of deltaic and ice-contact gravel of high quality occur in the southern part of the study area – unfortunately in regions of lowest population density. North of Lac-Mégantic, ice-contact gravels are rare and of good quality only where they occur in the granodiorite provenance region. North of Saint-Ludger, ice-contact and deltaic deposits are rare, and fluvial gravel of poor quality is used for construction purposes.

A plan to conserve the rare gravel deposits between Lac-Mégantic and Saint-Ludger should be developed. They have been used in large amounts for fill on Route 204 where lower grade fluvial gravels would have served as well. Further prospecting should be done for buried ice-contact gravels in the till plains region of the northern portions of the study area, as their use may satisfy future aggregate needs.

Clay Deposits

Large quantities of "common surface clay" (Brady and Dean, 1966, p. 7, 8) exist in the Drolet region. The texture of these deposits ranges from silt and clay with less than 0.5% sand to sparingly stony clay till with about 19% sand. The latter deposit (Drolet lentil) is similar in appearance and mineralogy to the clay-till (McDonald, 1967b, Brady and Dean, 1966) utilized to manufacture bricks and drainage tile at East Angus, Quebec.

The clay fraction ($<2\,\mu m$) is composed of chlorite and 10Å mica with small amounts of quartz and feldspar. Oxidized facies contain some expansible, montmorillonite-type clay within 1 m of the surface. The deposits also contain very small amounts (<0.25%) of phosphatic and carbonaceous animal and plant remains. The clays are calcareous and contain carbonate concretions, but carbonate probably averages less than 4% of the sediment by weight. The firing characteristics of the material should be similar to the deposits north of the study area at East Angus or Saint-Georges, based on mineralogy and sediment similarity. The clay deposits at these latter two sites fire to red colours and are suitable for tile and common brick (Brady and Dean, 1966, p. 23, 24). This type of deposit is present in large quantities in the Drolet area, and it should be evaluated in more detail as a source of raw material for a ceramic industry. Clay deposits of similar mineralogy also occur beneath Lennoxville Till along Samson, Wilson, Linière, and Metgermette rivers, but these deposits are neither as accessible nor as extensive as those of the Drolet region.

Peat

The location of peaty deposits is indicated on Map 1494A and is discussed in the section on postglacial sedimentation.

Placer Gold

Placer gold has been mined for more than 100 years from subtill deposits in the Beauceville – Saint-Georges region, north of the study area. Placer gold also has been reported in small amounts in the modern alluvium of nearly every major stream of the study area (Chalmers, 1898; McGerrigle, 1936). Fluvial gravel, similar in physical characteristics and stratigraphic position to the buried placer deposits of the Saint-Georges region, was found at several exposures along Grande Coulée River (section 3, Appendix 1). A heavy-mineral separate from one of the gravel units, however, was free of gold. Further investigation of pre-Johnville fluvial sediments on Grande Coulée River may be justified in light of the genetic and stratigraphic similarity of these deposits to placer deposits farther north.

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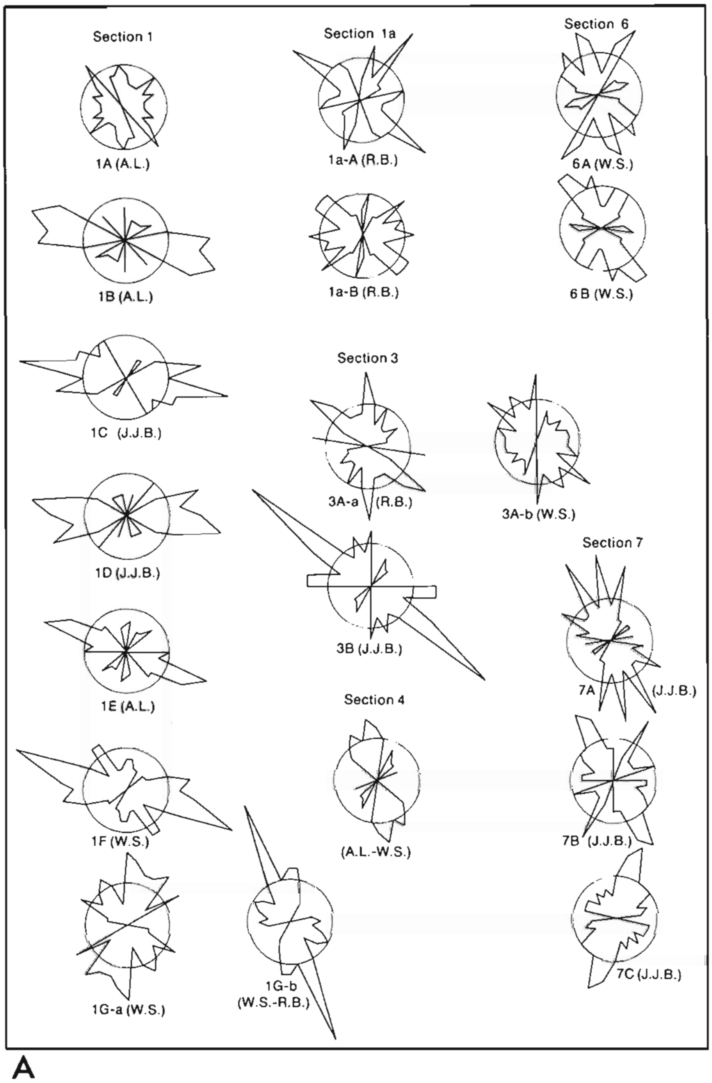
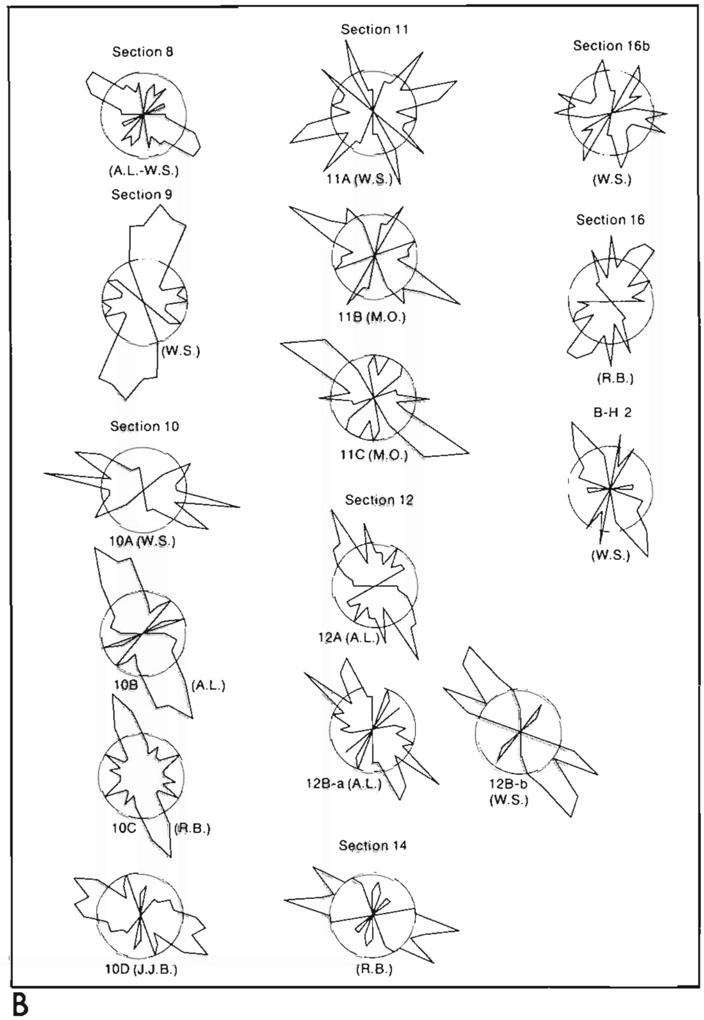
APPENDIX 1

Petrology of tills and descriptions of stratigraphic sections, Lac-Mégantic area, Quebec

Table 4. Stratigraphic Sections, Lac-Mégantic Area. (Stratigraphic sections are located on Map 1494A. Till fabrics are given in Figure 62)

Unit	Thickness (m)
Section 1	
East bank Chaudière River; 45°59.4'N, 70°39.4'W; 3.54 km, N1°W of Saint-Martin. Altitude of top of section ~256 m.	
Compact, fissile, pebbly, grey, calcareous, silty till; oxidized brown in upper 3 m with oxidation penetrating along joints to at least 10 m. Base of till is oxidized upward 0.3 m and contains 0.25 to 0.125 mm-diameter, euhedral, selenite crystals; abundant pyrite cubes in all but oxidized portions. Fabric 1A, 2 m from top Fabric 1B, sample 9, 4 m from top Fabric 1C, sample 65, 9 m from top Fabric 1D, 2 m above base Fabric 1E, sample 13, 0.3 m above base	13.3
Irregular, structureless bed of medium grained sand; oxidized.	0-0.6
Sandy, pebbly, compact, fissile, calcareous till; pervasively oxidized downward about 1 m below sand lens; further oxidized downward along vertical and horizontal joints so that till has aspect of grey blocks in tan, oxidized "matrix". Fabric 1F, sample 10 (unoxidized), 0.3 m below sand lens.	3.8
Loose, sandy, oxidized, massive, gravelly till with very little silt-clay matrix; sample 11 taken about 2 m below upper contact.	5.3
Laminated sand and clay; couplets average 15 cm thick near top, appear to thin downward; sand oxidized in upper 4+ m, unoxidized at base.	15
Grey, compact, hard, calcareous, sparingly stony, sandy till; contains very few stones larger than 5 cm. Fabrics 1G-a and 1G-b measured and sample 8 collected 0.5 m above base of exposure. Till extends below river level; bedrock outcrops about 70 m upstream on opposite side of river.	1+
Section 1a	
East bank, Chaudière River; about 17 m upstream from section 1. Altitude of top of section ~256 m.	
Lennoxville Till: compact, grey, fissile, calcareous, pebbly, silty till; oxidized upward 5 m from base; oxidized downward about 3 m from top. Fabric 1a-A, 6 m above lower contact.	17.7
Sandy, loose, gravelly, oxidized till; lower contact is irregular because of shearing of portions of underlying lake sediments into till; sandy texture apparently results from incorporation of underlying sand. Fabric 1a-B measured about 2 m below upper contact.	4.5
Interbedded fine sand and clay in 10 to 15 cm couplets at top; upper portion of sediment is disturbed and sheared into overlying till; deposit partially is oxidized throughout.	7.1+
Slump to river level.	9.7





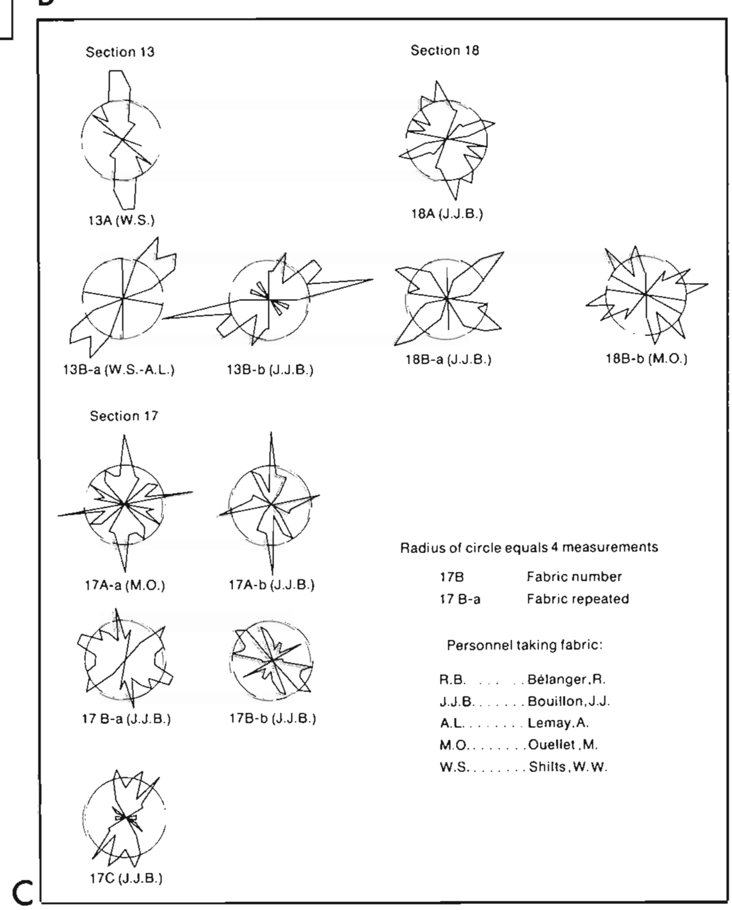


Figure 62

Till fabric measured in tills exposed in stratigraphic sections, Lac-Mégantic area. For precise locations, refer to Table 4, Appendix 1.

Unit	Thickness (m)
Section 2	
Excavation for west footing of Saint-Martin École Polyvalente; 45°57.6'N, 70°39.1'W; 0.48 km S36°E of Saint-Martin church. Altitude of top of section ≈264 m.	
Grey to brown, compact, calcareous, silty, stony, massive till; oxidized to 2.6 m below original surface; Lennoxville Till.	3
Brown, compact, structureless silt with an irregular upper contact; blocks of silt are included as 0.3 m-diameter clasts in till; elsewhere in excavation, similar sediment is horizontally bedded in silt-sand laminae and appears to rest in hollows on an irregular bedrock surface or between thin tills; where bedrock was exposed directly beneath till, striae bear at 0-180° and 114° (no direction determined); silt contains very sparse, finely disseminated organic debris (about 20 g per 200 kg of sediment). Date of this material (GSC-1137) is >20 000 radiocarbon years.	0-1+
Section 3	
North bank, Grande Coulée River (composite of 4 measured sections); 45°55.8'N, 70°42.2'W; 5.06 km S48°W of Saint-Martin. Altitude of top of section ≈313 m.	
Sandy, noncalcareous, loose, massive, bouldery till, oxidized to its base; reaches a maximum thickness of 5 m at east end of a series of sections, thins to 0 m about 200 m to the west; may be a waterlaid end moraine deposit. Fabric 3A-b and sample 28A taken 0.3 m above base of thickest exposure at east end of section. Sample 28 collected at west end of exposure ~1 m below surface.	0-5
Compact, calcareous, silty, pebbly, grey till oxidized tan down to about 3 m from surface; till is not present at east end of exposure but seems to be the only surface till at the west end; slump obscures relationship of the sandy till, described above, and this till. Sample 131 and Fabric 3A-a from about 0.3 m above base of till.	0-5
Grey, laminated, clay-silt in 2 cm couplets; noncalcareous.	1.3
Massive, oxidized, medium to fine sand, no apparent structure.	1.7
Brown, noncalcareous, laminated silt-clay; bedded in 1 to 2 cm-thick couplets.	2
Grey, laminated, noncalcareous silt-clay; same unit as above, unoxidized.	2
Medium to coarse grained, noncalcareous, orange-red, structureless sand; abundant plant and wood fragments up to 1 cm long; bulk sample yielded date of >40 000 radiocarbon years (GSC-1084); unit is present only in western part of section where it is underlain by 0.3 m of stony diamicton similar to that overlying till described below. Diamicton traced at constant altitude across section; in east part of section it separates upper Lake sediment from upper imbricated gravel. At extreme western end of section, exposed by slumping in 1976, a 0.3 m-thick, oxidized, stony diamicton directly overlies the organic sand which, in turn, rests in shallow depressions on the upper imbricated gravel. This unit appears to be overlain by the varves; it is not present in the eastern part of the section.	0-0.4
Grey, pebbly, compact, nonfissile, noncalcareous, silty till; no stones greater than 10 cm in diameter; upper 0.3 m is exceptionally stony diamicton with only about 50% matrix; it is separated from lower part by 2 cm of brown silt; upper part may be colluvium or subaqueous mudflow. Fabric 3B and sample S-91, from 1 m from upper contact with stony zone.	0-1.6

Unit	Thickness (m)
Imbricated, coarse gravel; current direction towards east; stones average 7 to 15 cm in diameter and are heavily coated with iron oxide; ~25 cm of diamicton separates gravel from overlying organic zone in western part of section; lower till directly overlies gravel in central part, and grey, laminated silt and diamicton directly overlie gravel in eastern part.	3
Laminated, noncalcareous silt-clay in 1 cm couplets; upper 1.3 m is oxidized tan and lower 0.3 m is grey.	1.6
Imbricated gravel with pebbles ranging from 2 to 5 cm in diameter; pebbles are well rounded; gravel contains mostly local rock types; current direction to east.	1.3
Coarse sand in massive beds that dip about 10° towards east; sand is oxidized to river level at 291 m; has iron-cemented areas.	2.1
Fine, unoxidized sand with clay partings (sampled in auger hole); clay partings are maroon-grey; unit grades from very fine sand and silt-clay at base into the coarser sand immediately above; 2.3 m below river level, at base of observation, black detritus was found in grey silt; black material may be manganese oxide or iron sulphide precipitate or organic material.	2.3

Section 4

North bank, Grande Coulée River; 45°55.2'N, 70°42.6'W; 6.12 km S43°W of Saint-Martin. Altitude of top ~382 m.

Grey, calcareous, compact, silty, stony till; oxidized tan in upper 3 m. Fabric 4A and sample 59 from 3.1 m below upper surface.	6.4
Laminated, calcareous, silt-clay.	2+
Slump to river.	12.8

Section 5

South bank, Wilson River; 45°58'N, 70°26.4'W; 1.61 km N15°E of Armstrong. Altitude of top ~320 m.

Grey, calcareous, laminated silt-clay in 1 to 2 cm couplets; horizontally bedded and undeformed; some ice-rafted pebbles.	3
Grey, calcareous, compact, massive, silty till; upper 0.3 m appears to be washed and reworked by water; sample 50 collected about 1 m below upper contact. Till thought to be Chaudière Till; Lennoxville Till thought to occur under tree cover farther up slope.	2+
Slump to river level.	7

Section 6

North bank, Wilson River; 45°58.3'N, 70°26.4'W; 1.93 km N15°E of Armstrong. Altitude of top ~312 m.

Dark grey, calcareous, massive, compact, sandy, stony till; several pink granite or granite gneiss stones noted. Fabric 6A and sample 69 from 5 m below surface of cut.	6.6

Unit	Thickness (m)
15 to 20 couplets of grey, calcareous, laminated silt-clay; bedding only slightly deformed.	0.3
Dark grey, calcareous, massive, compact, sandy till; pink granite or granite gneiss pebbles not noted. Fabric 6B and sample 68 from 0.3 m below upper contact; till separated from overlying silt-clay laminae by 2.5 cm of medium grained sand.	0.6
Slump to river level.	13.1

Section 7

North bank, Linière River; 45°56'N, 70°27.5'W; 2.25 km S28° of Armstrong. Altitude of top ~320 m.

Compact, fissile, clayey, stony, grey, calcareous till; oxidized in upper 2 m. Fabric 7A and sample 6 from about 0.6 m above base.	3
Oxidized, loose, structureless sand and boulders of unknown origin; could be washed till or ablation mantle.	1
Sandy, dark grey, very hard, compact, fissile, calcareous till; bottom contact is gradational and indefinite. Fabric 7B and sample 7 from 0.3 m below upper contact. Fabric 7C from 2 m below upper contact.	2.6
Calcareous, compact, grey clay till with clasts and lenses of very contorted laminated silt-clay; grades upward into overlying sandy till.	2.6
Discontinuous fine, structureless sand; appears to be a shear zone.	0.3
Grey, calcareous, contorted silt-clay laminae with numerous overturned folds and low-angle reverse faults; some clay till inclusions.	1
Fine, structureless sand; probably a shear zone.	0.3
Grey, calcareous, contorted silt-clay laminae; some clay till.	1
Fine sand with faint bedding; bedding is contorted into recumbent folds overturned to southwest; sand unit is not horizontal: top surface, strike 300°, dip 16°NE; bottom surface, strike 310°, dip 8°NE. Pebbles and pods of clay till are sheared into the sand.	0.6
Grey, calcareous silt-clay laminae; laminae are contorted with overturned folds and thrusting towards southwest.	3.5
Shear zone dipping northeast; laminated silt-clay with recumbent folds and thrusting to southwest, in core of one fold is a "pod" of grey, calcareous, compact, sandy till, 0.3 m thick and at least 2 m long; base of till is flat and lies on the lower surface of the shear zone; sample 119c in this till.	1.7
Grey, calcareous, laminated silt-clay in 2 cm couplets; horizontally bedded and undisturbed.	1.5
Grey, calcareous, horizontally bedded laminated sand-silt; grades upward into overlying clayey unit.	1.2
Grey, compact, calcareous, clay till.	0.3
Massive, structureless, medium grained unoxidized sand.	1.7
Grey, compact, calcareous clay till with many stones; river level at about 297.5 m.	0.6+

Unit	Thickness (m)
Section 8	
South bank of unnamed stream east of Chaudière River; 45°53'N, 70°37'W; 4.9 km N32°E of Saint-Gédéon. Altitude of top ~282 m.	
Laminated sand and silt-clay, oxidized to base. No evidence of disturbance by slump or overriding ice; contains 0.3 m-diameter clasts of grey till; couplets at base of unit consist of 2 to 5 cm-thick clay laminae interbedded with 15 to 30 cm-thick silt-sand laminae; laminae at base thicken and thin laterally; couplets thin rapidly upward, 20-30 couplets estimated.	5
Interbedded medium gravel and loose, oxidized, noncalcareous, massive, sandy till; stones in both units striated; sample 52A from 1 m below upper surface of till.	6
Grey, calcareous, hard, sandy, pebbly till. Fabric 8A and sample 52b from 0.4 m below upper contact.	1
Slump to stream level.	4.3
Section 9	
Cut on south side of unnamed stream east of Chaudière River; 45°49'N, 70°37.3'W; 6.12 km S22°E of Saint-Gédéon. Altitude of top ~298 m.	
Contorted, oxidized silt-clay laminae; contortion may be due to overriding ice or to slump from higher up on valleyside.	2
Poorly sorted fine gravel and coarse sand with charcoal and other organic detritus; may be colluvium or alluvium at base of a slump block. Probably stratigraphically above all other units.	1
Slump.	3
Calcareous, grey, laminated silt-clay in 1 cm couplets; sediment is horizontal and shows no evidence of overriding; section is near the base of a steep valleyside and Lennoxville Till is thought to form the higher slopes.	1.6
Medium grey, hard, compact, massive, sandy, calcareous till; Fabric 9A and sample 39 from 0.3 m below upper contact.	2+
Slump to stream.	1
Section 10	
Northwest bank of Samson River; 45°46.3'N, 70°37.8'W; 2.74 km S13°W of Béland. Altitude of top ~310 m.	
Compact, sandy, brown, noncalcareous till; oxidized and leached to base. Fabric 10A and sample 14 from about 0.3 m above base of unit. Thins to east end of section where underlain by a westward-dipping recumbent fold in underlying lake sediments.	0-4
Grey, laminated silt-sand and clay with numerous overturned folds and low-angle reverse faults; slightly calcareous. Also occurs as lenticular masses up to 8 m long in overlying till.	1.6
Compact, grey, stony, calcareous till with several large boulders at its upper surface; till is massive and nonfissile. Fabric 10B and sample 15 from 0.3 m below top surface; fabric 10C from 0.3 m above lower contact.	3.6

Unit	Thickness (m)
Grey, calcareous, laminated silt and clay rhythmites, deformed in places at top by glacial overriding. Within this sequence are several stony, till-like beds with thicknesses from <2 cm to about 1 m. Silt-clay laminae above and below stony units are undisturbed. The thickest stony units show evidence of viscous flow in the form of overturned or horizontal folds; 10 to 20, 1 to 15 cm-thick structureless stony beds are intercalated with graded silt-clay laminae in the upper 2 m of this unit in the centre of the section. At the east end of the section, in the same physical position, clayey laminae are interbedded with sandy laminae, and no stony beds were seen. Several 10 to 50 cm-thick beds of massive clay-silt also are intercalated with the laminated beds. Because of extensive slump over much of the section, it is not possible to establish the lateral continuity of the stony, silt-clay, or sandy units. The former two units are thought to be proximal and distal facies, respectively, of density underflows, probably originating by slumping from an ice front.	13.4
Grey, calcareous, compact, clayey to sandy, fractured nonfissile till; sparingly stony, contains small, angular clasts of laminated silt-clay. Fabric 10D and sample 77 from 0.6 m below surface; sample 118 from 1.3 m below upper surface. Underlying sand and gravel grade upward into sandy till. Upper surface of till is fluted with a relief of ~25 cm and is marked with crag-and-tail striae indicating ice flow ~110° towards the southeast.	1.5+
Medium grained sand with crossbedding indicating northward flow; includes lenses of medium gravel that appear to be channel deposits of a small, <6 m wide, meandering stream; gravel contains 5 to 10 cm-diameter clasts of laminated silt-clay with maroon clay layers. The unit is pierced through in several places by diapirs of underlying "maroon" laminated silty clay.	5.5
Grey, calcareous, laminated silt-clay with grey to maroon clay interlayers. Upper contact is irregular, in some places being conformable with overlying gravel-sand and in others being in a diapiric relation. Diapirs of this unit are active and common in the stream channel, below water level, where they commonly are eroded to form circular structures reminiscent of an eroded dome. In a small section, 0.2 km upstream, similar silt-clay laminae unconformably underlie and form a diapir through fine gravel and sand similar to the sandy unit in this section. The varves commonly outcrop in the river bed for more than 2 km upstream and downstream from this section.	2+

Section 11

West bank, Samson River; 45°45.3'N, 70°38'W; 4.83 km S10°W of Béland. Altitude of top ~340 m.

Complex, interbedded, laminated silt-clay and stony clay; 0.3 m-thick units of 5 to 10 silt-clay couplets alternate with 0.6 to 1.3 m-thick stony clay beds; stony clay may be till, subaqueous mudflow or density underflow deposits; laminated sediment is undisturbed above and below each of these beds. Both types of sediment are dark grey except where oxidized; a thin, discontinuous, oxidized sandy till similar to the uppermost till at section 10 was observed on top of this unit at the south end of the section; fabric 11A and sample 27A in stony clay 4 m below surface.	
Compact, grey, massive, calcareous, stony till with high ultrabasic clast content; stones rarely exceed 0.3 m in diameter. Fabric 11B and sample 27B taken about 2 m from base of till.	5.3

Unit	Thickness (m)
Massive silt-clay; grey, calcareous.	1
Medium to coarse grained sand with ripple cross-stratification; highly oxidized by groundwater flowing freely from its base; unit grades into overlying silt.	6.1
Silt-clay rhythmites; approximately 15 couplets; clayey layers are deep red.	0.1
Cobble gravel; well rounded clasts with abundant local grey sandstone and slate; similar to composition and texture of modern river; slate clast imbrication is strong, indicating current direction northward in exactly same sense as the modern river.	0.5-0.75+
Silt-clay rhythmites; identical to those above gravel.	0.15-0.20
Very compact, grey to tan, coarse silt and very fine sand with a few hard, massive, reddish clay layers up to 5 cm thick; base of unit is covered.	0.5 ±
Reddish grey, compact, hard, calcareous, massive till with few pebbles. Fabric 11C and sample 27C from about 1 m below upper contact.	3.5
Laminated silt-clay; calcareous; grey silt and maroon clay laminae.	1.1
Fine, structureless gravel.	5.3
Massive, structureless, fine sand.	2.2
Fine, structureless gravel.	1.8
Slump to river level at 301.4 ± m.	3.5

Section 12

Northwest bank, Samson River; 45°42'N, 70°40'W; 5.5 km S22°E of Saint-Ludger. Altitude of top ~389 m.

Compact, massive, stony, grey, calcareous till; contains several grey granitic erratics that do not appear in a pebble count. Fabric 12A and sample 25A from 0.6 m above lower contact.	8.5
Contorted, grey, calcareous laminated silt-clay.	0-1.3
Sparingly stony, compact, sandy, dark grey, calcareous till with many differentially eroded shear planes dipping northwest; no granitic erratics noted in this unit. Fabrics 12B-a and 12B-b and sample 25B from 1.5 m above river level. Till extends at least 0.6 m below river level.	1.7+

Section 13

North bank, Eugénie River; 45°43.5'N, 70°46.5'W; 5.5 km N84°E of Saint-Samuel-de-Gayhurst. Altitude of top ~382 m.

Massive, grey, sparingly stony clay till; irregularly oxidized to 1 m below surface; sample 30 of unoxidized till at base.	2
Medium grained sand, oxidized and structureless; contact with overlying till sharp and flat and marked by 1 cm of carbonate-cemented sand.	1.3
Fine gravel lens; cut out by grey, clay-till shear block on east side of cut; overlying sediments appear to have been sheared into place over gravel.	0-1

Unit	Thickness (m)
Grey, compact, calcareous clay till, sparingly stony.	0.6
Slump.	3.4
Contorted, laminated silt-clay; overturned folds and low-angle faults.	~2
Slump.	4
Undisturbed, 1 cm-thick couplets of grey, calcareous silt-clay.	0.6
Compact, sandy, grey to grey-brown, calcareous till; Fabric 13A and sample 29A from 0.3 m below upper contact.	2
Slump.	6.2
Very compact, sandy, grey calcareous till outcropping in river bed; Fabrics 13B-a, 13B-b, and sample 29B at river level.	0.6+

Section 14

Roadcut on south side of Saint-Ludger; 45°44.5'N, 70°41.7'W; 0.16 km west of Saint-Ludger church. Altitude of top ~319 m.

Sandy, compact, oxidized, noncalcareous, stony till with inclusions of contorted varves and clay till; numerous shear planes with apparent dips both east and west; a wedge-shaped, dyke-like protrusion of till, 0.3 m wide at top to 0.1 m wide at base, extends 1 m downward into underlying sand (Dionne and Shilts, 1974); trend of wedge is 020°. Fabric 14A measured 0.6 m above base of till.	5
Oxidized, noncalcareous, slightly disturbed silt-clay laminae, apparently sheared into place; laminae are cut by till wedge.	0.1
Massive, structureless, medium grained sand containing tabular clasts of silt-clay laminae to 0.3 m maximum diameter; sand is carbonate cemented 1 cm downward from overlying silt-clay and 1 cm outward from till wedge.	1
Slump to road.	0.9

Section 15

Roadcut on Domtar Newsprint Ltd. lumber road, about 110 m northeast of junction of Caouette River and tributary flowing from Lac Caouette; 45°47.2'N, 70°29.1'W. Altitude of top ~473 m.

Massive, orange-brown silt.	0.3-1
Compact, stony, sandy, silty, till-like deposit; possible colluvium; oxidized.	0.3
Clayey silt with pebbles, oxidized brown with maroon bands; compact; includes 2.5 cm-thick horizontal, flattened seams of charcoal-like organic material at base, 0.3 m above base, and at top; upper organic seam yielded date of 9180 ± 180 radiocarbon years (GSC-856); bedrock knob 10 m north of section bears striae at 135°; roadcut 100 m east of section exposes sediments similar to section 15 overlying compact, grey-brown till with strong fabric trending 130°.	0.4
Coarse, cobble gravel.	0.3+

Unit	Thickness (m)
Section 16	
Type section, Drolet lentil of Lennoxville Till; also type section for middle and upper members of Gayhurst Formation; Gayhurst dam borrow pit; 45°39.9'N, 70°48'W; west side Chaudière River, 5.0 km N79°W of Audet. Altitude of top variable; maximum altitude ~403 m.	
Drolet lentil; compact, sparingly stony, calcareous, dark grey, clay till. (True thickness unknown, unit is not horizontal, but measures 28 m from lower contact to top of pit.) Till oxidized to at least 2 m below surface; stones in till are <1% granite-granodiorite; surface of till mantled by >10% granite-granodioritic cobbles and boulders; sample 45A 2 m from top of pit; Fabric 16 about 3 m above lower contact.	~10
Laminated silt and clay with calcareous concretions; laminae are graded, and coarser grained portions of each couplet have 1 to 5 thin (<1 mm), very fine sand and silt stringers; unit contains pebbles up to 2 cm diameter and rounded clasts of grey till; couplets average 1 cm thick but are 0.5 cm thick at base and 1.5 to 2 cm thick at top; sample 45B from 1 m above base; upper member, Gayhurst Formation.	5.9
Laminated silt and clay, highly disturbed; has flow rolls and general aspects of subaqueous slump; top and bottom contacts are sharp and planar.	0.3
Fine gravel and coarse sand with large-scale foreset beds dipping east-northeast to northeast; amplitudes of foresets range from 1 to >4 m.	3.5
Fine sand at base grading to coarse sand at top; evenly bedded sand with numerous lenses of gravel and cobbles that appear to be ice rafted; about 2 m from top is a 1 m-thick contorted zone of coarse sand and gravel with disrupted and highly folded bedding suggestive of turbidity flow or soft sediment foundering.	18.3
Oxidized, laminated silt-sand and clay; base of pit.	1.8+
Section 16a	
Slump scarp, west side Chaudière River; 45°41'N, 70°48'W; 5.5 km N61°W of Audet. Altitude of top ~378 m.	
Dark grey clay till with few pebbles; compact and weakly fissile; calcareous where unoxidized; oxidized in upper 2 to 4 m; oxidation penetrates along joints to base.	5.6
Laminated silt-clay with well graded, 1 cm-thick couplets; abundant concretions and several striated pebbles and rounded till clasts; contorted in upper 1 m.	3.6
Fine gravel; no apparent structure.	0.3
Fine to coarse, crossbedded sand; stratified in even, tabular units; tends to be finer grained at base than at top.	8.8
Slump.	30
Grey, highly calcareous laminated silt-clay couplets, well graded with abundant concretions to river level.	>4.7

Unit	Thickness (m)
Section 16b	
Gully at east end of Gayhurst dam, east side of Chaudière River; with borehole 1 and section 16 represents type section of lower member, Gayhurst Formation; 45°39.9'N, 70°48'W; 610 m east of section 16. Altitude of top ~360 m.	
Sandy, loose, massive, oxidized, noncalcareous diamicton containing clasts of laminated clay-silt and massive silt; contact with underlying lake silt is irregular and gradational. Fabric 16b and sample S-26 taken 0.3 m above base (unit removed by slumping in 1969). May be poorly sorted alluvium, colluvium, artificial fill or till.	0-1.5
Massive, oxidized coarse silt to fine sand, no current structures.	2
Contorted, coarse sand with highly folded and disrupted bedding; probably disturbed during subaqueous slumping or foundering; identical to contorted zone in sand in section 16 and occurs at roughly the same altitude.	1
Evenly bedded silt and very fine sand with faint small-scale ripple cross laminations and clay partings.	2
Laminated coarse silt and clay; 40 to 60 couplets; abundant flow rolls and sole markings suggesting turbidity flow; physically similar to lowest unit in section 16.	1.3
Evenly bedded, oxidized silt and very fine sand; small-scale ripple cross laminations and clay partings spaced at 0.1 to 0.3 m intervals; probably thick cyclical couplets.	6
Laminated silt-clay in 2 to 4 cm-thick couplets; oxidized brown in upper part; calcareous, grey, and concretionary in lower part (depth of oxidation varies); contains sparse very small organic fragments. No apparent ice-rafted material and <0.1% sand-sized detritus; chlorite comprises about 50% of sand-sized mineral grains.	10
Laminated silt-clay in 1 cm couplets; slightly folded and faulted by normal and low-angle reverse faults to Chaudière River level.	1+
Section 17	
North bank, Arnold River; 45°20.6'N, 70°52.5'W; 4.5 km S19°W of Woburn. Altitude of top ~549 m.	
Oxidized, sandy, loose till; some stratified lenses; may be ablation till; sample 53 collected 5 m from surface.	6.4
Compact, sandy till, oxidized in upper 4.6 m; unoxidized portion is calcareous, olive grey (5Y 4/1). Fabrics 17A-a, 17A-b, and sample 75 from 0.3 m above base.	7.6
Compact, sandy, calcareous till; olive grey (5Y 4/1) but distinctly more yellow-brown than overlying till; at upper surface is a discontinuous sandy zone less than 2 cm thick; 4.6 m below upper contact is 0.6 m of medium to fine grained massive sand. Fabrics 17B-a and 17B-b and sample 74 from 0.3 m below upper contact. Fabric 17C and sample 73 from 4 m below upper contact.	8.2
Slump to river level at about 517 m.	9.2

Unit	Thickness (m)
Section 18	
South bank, Arnold River; 45°20.6'N, 70°52.5'W; 4.51 km S9°W of Woburn. Altitude of top ~549 m.	
Grey, compact, stony, calcareous, silty till in 1 m-thick bands alternating with 1 m-thick bands of clayey massive till with few stones. Fabric 18A and sample B7 taken 0.3 m above base.	6.6
Brown-grey, sandy, calcareous compact, hard, stony till; groundwater seeps out at contact with overlying till. Fabrics 18B-a and 18B-b and sample B6 from 0.6 m below upper contact.	6.6
Slump to river level.	2.6
Section 19	
Roadcut on southeast side of Clearwater Stream valley; 45°16'N, 70°52.5'W; 2.25 km N85°W of Boundary Marker 446. Altitude of top ~824 m.	
Silty, stony, brown colluvium.	0.6
Compact, massive, brown, silty, stony, noncalcareous till; sample 89B collected 0.3 m from top contact.	1
Brown, noncalcareous, compact laminated silt-sand; contains thin (<0.3 m-thick) till or mudflow interbeds.	3.3
Compact, massive, brown, silty, stony till; sample 89A collected 0.3 m from upper contact.	2.6+
Borehole 1	
Fluvial terrace on east side of Chaudière River; with sections 16 and 16b represents type section of lower member, Gayhurst Formation. 45°39.9'N, 70°48'W; about 100 m north of section 16b. Altitude of top ~340 m.	
Postglacial fluvial pebble gravel, oxidized to base.	6.7
Grey, calcareous, extremely plastic, laminated silt-clay in couplets averaging 1 cm thick; some zones appear to be disturbed, but bulk of section is horizontally bedded and undisturbed; some very small (<3ϕ diameter) plant and animal fragments in upper 10 m; selected samples from base contain ice-rafted debris and are largely devoid of organic remains.	30.5
Coarse, unoxidized sand grading upward into very fine sand and laminated silt-clay. Base is base of lower member of Gayhurst Formation.	10.7
Medium grey (N4), compact, calcareous, silty, stony till; sample BH-23 taken at upper contact, BH-23a at 3 m below upper contact, BH-24 from 1.3 m above base; no oxidation.	7.0
Grey, calcareous, laminated silt-clay; highly contorted; bedding often obliterated or vertical.	2.4
Medium grey (N4), compact, calcareous, silty, stony till; sample BH-26 from 1 m below top contact.	2.4
Olive grey (5Y 4/1), calcareous laminated silt-clay; highly contorted.	2.4
Fine gravel; unoxidized; abundant ultrabasic and grey granitic pebbles.	1.2

Unit	Thickness (m)
Till (?); no sample recovered.	2.7
Silt-clay – probably lacustrine; no sample recovered.	1.8
Weathered bedrock (?); no sample recovered.	1.8
Bedrock; vertically dipping, pyritiferous black slate – probably Compton Formation.	3+

Borehole 2

Southeast corner of intersection of Provincial Route 161 and Marsboro road; 45°35.6'N, 70°54.7'W; 4.67 km N50°W of Chaudière River bridge, Lac-Mégantic. Altitude of top ~455 m.

Sandy, compact, grey, stony, bouldery, calcareous till; oxidized to 5 m below surface. Sample number – depth from surface: S30 – 6 m, S32 – 8 m, S33 – 10 m, S34 – 12 m, S35 – 14 m, S38 – 18 m, S47 – 36 m, S48 – 37 m.	40
Compact, grey, calcareous, laminated silt-clay in 0.5 to 1 cm couplets.	5.8
Till (?); only pebbles recovered; pebble count: granite = 10%; ultrabasic = 1.5%; calcareous concretions = 3%; slate/sandstone = 53%; carbonate pebbles = 14%.	2.1
Bedrock; vertically dipping interbedded slate and siltstone with abundant pyrite cubes up to 1.5 cm wide; rock is cut by many carbonate veins.	3+

Borehole 3

South bank, Clinton River; 45°25'N, 70°52.1'W; 3.54 km N10°W of Woburn. Altitude of top ~396 m.

Modern alluvium, fluvial sand and gravel.	4
Grey, compact, bouldery, silty, calcareous till; only pebble samples recovered. Granite pebbles average 9.5%; carbonate pebbles average 11%; ultrabasic rocks average 1% from base to top; percentages of granite and carbonate increase upward.	24.7
Laminated silt-clay; no sample; hole ends at 366 m.	1+

Borehole 4

Lac-Mégantic; 45°34.2'N, 70°52.7'W; test borings for Chaudière bridge at Lac-Mégantic; drilling and logs by Côté, Lemieux et fils, Sherbrooke. (French notes by drillers translated and interpreted by W.W. Shilts.) Altitude of top ~394 m.

Sandy, silty alluvium, modern.	2.1
Grey, silty, sandy till (?).	2.6
Laminated silt-clay.	2.5
Grey sand and gravel.	1
Laminated silt-clay; end of hole.	4.6+

Note: 0.3 km S45°E of this hole, a boring for an elevator shaft in the Foyer de Lac-Mégantic passed through 1 m of fine lacustrine sand (altitude 404 m at top) and then through 9 m of compact, silty, stony, grey, calcareous till; the till may physically overlie the section described above.

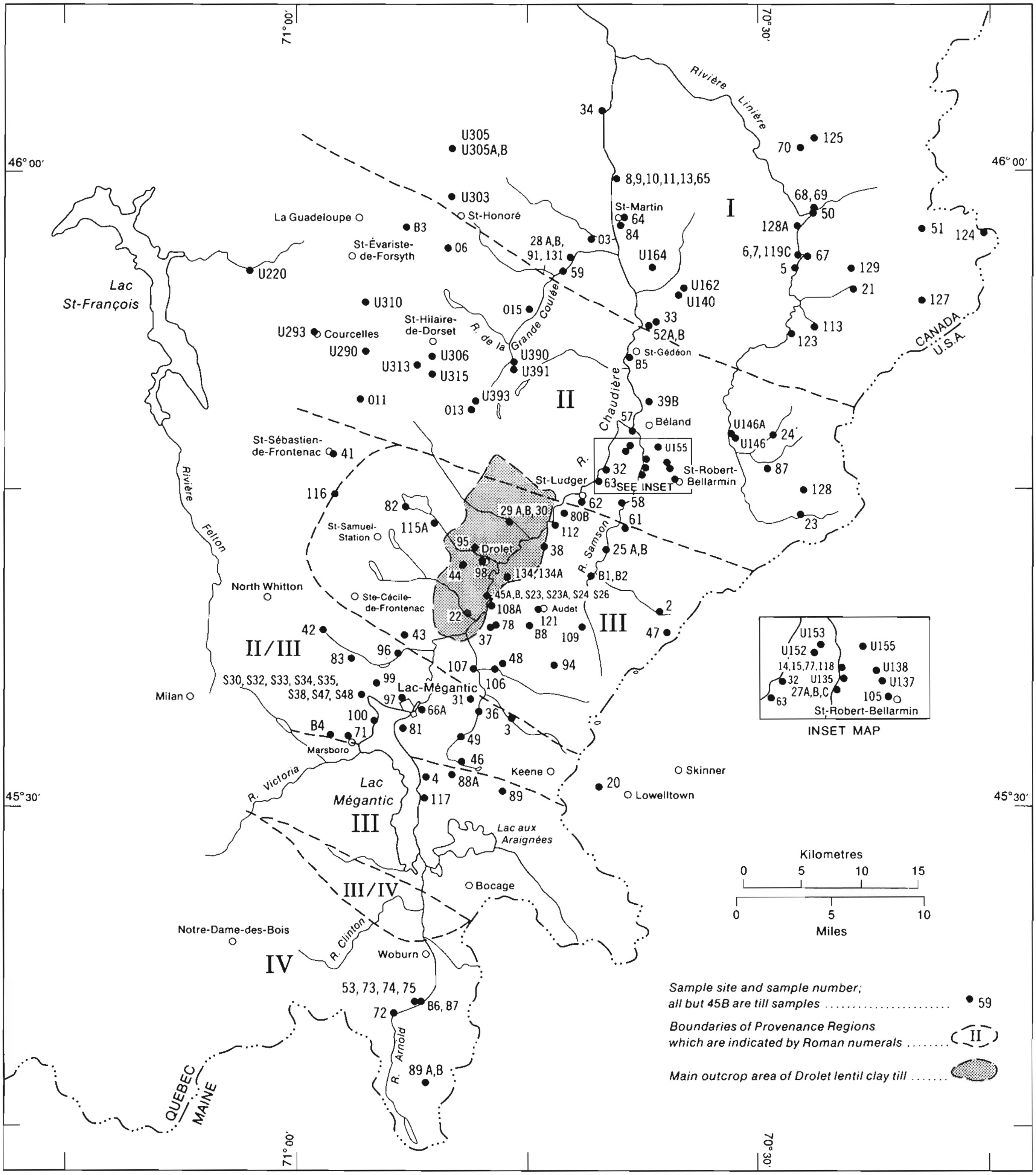


Figure 63. *Till sample locations in the study area. All but "U" samples were collected in 1967-1969 and their analyses are reported in Tables 4, 5, and 6 (Appendix 1). 'U' samples were collected in 1972 and are reported in Table 7 (Appendix 1). Results from Tables 5 and 6 are summarized in Table 2 in text.*

Table 5. Size parameters[1] for tills of the Lac-Mégantic area

Sample No. (see Fig. 63)	% Sand	% Silt	% Clay (<4 μm)	K_G	Sk_I	$\sigma_I(\phi)$	$Mz(\phi)$	$Md(\phi)$
6	21.2	29.8	49.0	0.9236	-0.1091	3.9564	7.6163	7.93
**7	31.8	39.8	28.4	0.9660	0.1581	3.5225	6.2166	5.90
**8	34.8	40.2	25.0	0.9518	0.2432	3.2607	5.88	5.50
9	24.9	37.1	38.0	0.9936	0.0687	4.0469	6.8933	7.08
10	47.2	32.6	20.2	0.9924	0.2581	3.6737	4.8500	4.30
13	25.7	37.2	37.1	0.9460	0.0057	3.9685	6.9166	6.90
14	28.7	44.2	27.1	1.0794	0.0411	3.7311	6.1233	6.10
15	27.6	37.4	35.1	0.9345	0.0438	4.0598	6.6667	6.50
25A	35.1	39.7	25.2	0.9956	0.1804	3.5234	5.9333	5.60
25B	34.9	37.3	27.8	0.9253	0.1855	3.6330	6.1166	5.73
26	36.3	18.6	45.1	0.6793	-0.1466	4.4640	7.0433	7.55
27A	28.8	40.2	31.0	1.0125	0.0523	3.9165	6.3533	6.23
27B	26.0	39.0	34.0	0.9924	0.0309	3.8787	6.7400	6.65
**27C	21.6	33.3	45.1	0.7558	0.0157	3.6568	7.6166	7.65
28A	50.2	32.9	16.9	0.9953	0.1933	3.7553	4.30	4.00
28B	35.9	36.2	27.9	0.9323	0.0715	3.8810	5.8100	5.73
**29A	35.7	44.0	20.3	1.0394	-0.0079	3.5810	5.2666	5.50
**29B	32.8	40.4	26.8	1.0091	0.0636	3.9262	5.9033	5.80
*30	7.2	34.1	58.7	0.9153	0.0358	3.1352	8.9000	8.65
**39B	36.9	42.4	20.8	1.0275	0.0095	3.4421	5.3300	5.50
*45A	2.2	33.1	64.7	0.9079	0.2734	2.4723	9.2833	8.70
****45B	0.2	6.4	93.4	-0.7927	-0.0372	1.9189	10.9700	10.97
**50	20.5	28.7	50.8	0.8641	-0.1236	3.9780	7.8000	8.10
52A	53.2	32.0	14.7	1.0167	0.2764	3.4015	4.2500	3.72
52B	48.9	34.6	16.4	1.0310	0.2455	3.4581	4.5633	4.10
53	34.0	39.4	26.6	0.9848	0.2330	4.0026	5.7866	5.11
65	24.3	38.0	37.6	1.0205	-0.0579	3.9416	6.9466	7.10
68	32.5	34.1	23.4	1.0371	-0.0758	3.6437	5.5366	5.95
69	31.9	42.0	26.2	1.0613	0.0014	3.7902	5.7933	5.91
**73	33.6	38.0	28.4	0.9346	0.0745	4.0954	6.0833	5.91
**74	21.7	44.7	33.6	1.1275	0.0219	3.8482	6.8400	0.75
75	33.6	36.8	29.5	0.9323	0.0890	4.0628	6.2233	5.98
**77	13.6	63.0	23.4	1.6898	0.1574	2.7742	6.6466	6.34
89A	15.6	68.1	16.3	1.6393	-0.0198	2.4798	6.1066	6.28
89B	30.4	53.2	16.4	1.1627	-0.1111	3.1318	5.4100	5.86
***91	29.5	41.3	29.1	0.9774	0.0488	3.8381	6.1300	6.11
**118	15.1	49.0	35.9	1.10	0.140	3.28	7.31	
B4C	44.0	37.3	18.6	0.93	0.12	3.68	4.69	
B-6	31.1	41.6	27.3	1.00	0.11	3.96	6.08	
B-7	12.8	47.1	40.1	1.00	0.11	3.43	7.78	
**S23A	22.6	52.6	24.8	1.3969	-0.1081	3.2958	5.8566	6.32
S33	36.5	36.9	26.6	0.9223	0.0489	3.8083	5.40	5.50
S47	45.5	32.1	22.4	0.9081	0.2773	3.4152	4.9100	4.50
3	29.4	38.9	32.0	0.9859	0.0751	4.0418	6.3133	6.10
4	31.9	34.7	33.5	0.9016	0.0318	4.15	6.3666	6.30
31	35.2	39.0	25.8	0.9928	0.0478	3.7939	5.7066	5.72
32	19.3	47.5	33.2	1.1501	0.1037	3.4973	6.9866	6.71
33	33.2	38.9	27.8	1.0114	0.0254	3.8657	5.9866	6.00
34	27.7	33.3	39.5	0.9604	-0.1090	4.1311	6.8166	7.18
36	31.5	47.0	21.5	1.1461	0.1995	3.2900	5.4633	5.15
37	30.2	30.6	39.2	0.8732	-0.0710	4.3115	6.6466	6.90
38	7.2	40.8	52.0	1.0457	0.1368	3.0000	8.5466	8.10
41	13.17	40.6	45.6	1.2970	0.0039	3.4530	7.9933	7.78
42	49.9	33.9	16.2	1.0245	0.2521	3.4955	4.4366	4.00
43	37.7	35.8	26.6	0.9048	0.2147	3.8030	5.9300	5.43
44	3.5	34.9	61.7	0.9282	0.2077	2.6396	9.0933	8.60
46	25.4	47.8	26.8	1.1780	-0.0362	3.5428	6.1733	6.40
47	22.0	36.9	41.1	1.0132	-0.0670	3.9480	7.2600	7.40
48	5.9	28.8	65.3	1.0770	0.1160	2.8590	9.3335	8.80
49	31.3	38.8	29.9	0.9492	0.0904	4.0046	6.2466	6.00
51	26.2	34.1	39.7	0.8887	-0.0414	4.1034	7.0266	7.10
22	2.1	41.8	56.1	0.9003	0.2804	2.0448	8.9866	8.32
72	33.1	42.4	24.4	1.0141	0.0632	3.8895	5.7466	5.70
78	10.9	35.9	53.1	0.9064	0.0133	3.4209	8.3300	8.30
88A	38.4	38.0	23.0	0.9914	0.1331	3.7778	5.3533	5.15
88B	31.7	36.5	31.8	0.9009	0.0802	4.0234	6.3500	6.15
95	6.6	36.3	57.1	0.9853	0.0836	3.0295	8.8666	8.50
96	2.4	32.2	65.4	0.8335	0.2405	2.5103	9.5100	8.95
117	53.4	28.5	18.2	1.01	0.41	3.65	4.43	
121	30.6	36.2	33.2	0.89	0.04	4.04	6.47	

[1]Parameters are determined by the use of graphic statistics proposed by Folk and Ward, 1957.

Mz – graphic mean grain size

Md – median

σ_I – inclusive graphic standard deviation

Sk_I – inclusive graphic skewness

K_G – graphic kurtosis

* Drolet Lentil (clay till)
** Chaudière Till
*** Johnville Till
**** Varves (Gayhurst Formation)

Table 6. Petrologic characteristics of Lac-Mégantic area tills

Till Sample number (see Fig. 63)	Oxidized (O) Unoxidized (U)	Pebble Lithology: Granodiorite %	Pebble Lithology: Ultrabasic % + Gabbro %	Fine Sand Mineralogy: Potassium Feldspar %	Fine Sand Mineralogy: Plagioclase Feldspar %	Fine Sand Mineralogy: Heavy Mineral (s.g. >2.80) Weight % of fine sand	Fine Sand Mineralogy: Magnetic Minerals Weight % of heavy minerals	Trace Elements in silt and clay (<63 μm) (ppm): Copper	Zirconium	Titanium	Vanadium	Nickel	Chromium	Silver	Zinc	Lead
2	U	6.0	3.0	-	-	3.2	8.2	24	390	5000	67	42	150	0.8	57	20
3	O	-	-	-	-	9.5	9.9	28	320	5900	110	51	160	0.8	73	18
4	U	-	-	-	-	4.0	9.4	39	300	4200	85	60	180	0.9	67	19
*5	U	-	-	-	-	-	-	25	320	5000	96	31	130	0.8	71	24
6	U	0	0	9.8	12.0	2.1	6.7	31	400	5300	85	31	120	0.6	77	36
***119C	U	0	0	16.1	17.0	2.9	6.2	25	530	5000	83	33	91	0.7	76	24
9	U	0	0	2.6	16.8	2.2	5.2	42	280	4300	84	29	110	0.8	68	23
65	U	0	0	8.7	11.4	1.8	10.8	25	290	4500	98	30	66	0.7	69	24
13	U	0	0	10.7	9.9	2.2	5.0	-	-	-	-	-	-	-	-	-
10	U	0	0	11.8	12.9	1.9	6.0	-	-	-	-	-	-	-	-	-
11	O	0	0	12.2	18.0	-	-	-	-	-	-	-	-	-	-	-
**8	U	0	0	13.1	15.4	1.3	4.3	27	480	4400	57	24	89	0.7	64	19
14	O	0	11.0	9.0	11.2	2.8	16.7	37	380	4700	80	120	200	0.6	67	21
15	O	+	3.0	5.4	15.6	2.4	6.9	26	350	4800	79	40	190	0.8	68	23
**77	U	0	0	10.3	17.8	2.5	4.4	19	400	4300	57	21	57	0.7	53	17
**118	U	0	0	11.4	15.7	3.9	2.6	22	360	4600	74	23	65	0.7	68	19
20	O	-	-	-	-	-	-	27	400	4900	110	84	160	0.6	71	21
21	O	-	-	-	-	-	-	42	330	4400	90	30	78	1.1	74	26
*22	U	-	-	-	-	2.3	11.1	43	210	4800	100	46	87	1.0	106	30
23	O	-	-	-	-	2.9	4.3	23	370	4400	66	45	100	0.6	62	21
24	O	-	-	-	-	-	-	24	250	4900	81	34	94	0.6	63	17
25A	U	0	0	9.0	12.9	1.8	3.6	18	620	5100	78	34	82	0.7	58	19
25B	U	+	0	12.1	12.1	2.1	3.1	19	570	5300	73	37	76	0.6	55	19
27A	U	0	6.0	5.7	8.1	2.6	4.7	-	-	-	-	-	-	-	-	-
27B	U	+	34.0	4.0	8.0	3.0	13.2	25	350	4900	90	99	180	0.8	64	25
**27C	U	0	0	10.5	15.5	2.0	4.2	35	270	4800	92	32	84	0.7	83	24
*30	U	0	0	9.6	12.3	1.7	5.2	29	250	5200	93	36	82	0.9	82	24
**29A	U	0	0	6.5	11.5	2.3	7.1	27	330	4400	82	40	84	0.7	62	20
**29B	U	0	1.0	7.6	7.8	2.2	6.2	-	-	-	-	-	-	-	-	-
31	O	-	-	-	-	4.8	9.5	25	310	4300	80	68	220	0.9	69	19
32	U	0	0	-	-	2.3	11.7	24	320	4600	76	35	95	0.6	67	20
33	U	-	-	-	-	1.7	8.6	18	330	4900	80	21	78	0.6	67	20
34	U	0	0	-	-	2.2	5.4	-	-	-	-	-	-	0.7	76	23
36	U	14	4	-	-	4.2	9.8	20	440	4500	64	30	120	0.7	55	16
*78	U	3.0	+	-	-	-	-	30	230	5100	110	35	86	1.1	90	25
*37	U	3.0	+	-	-	4.2	14.1	-	-	-	-	-	-	-	-	-
*38	U	-	-	10.6	23.2	2.8	4.6	28	170	4600	95	30	85	0.7	85	22
**39B	U	+	+	10.4	12.5	1.8	6.2	17	410	4400	64	20	78	0.6	56	18
41	O	0	4	-	-	5.1	7.7	27	270	4300	90	79	170	1.0	78	23
42	O	6.0	2.0	-	-	3.6	9.2	24	340	3500	62	80	130	1.0	60	19
43	O	-	-	-	-	3.8	10.6	28	310	4200	82	100	160	0.9	76	18
*44	U	0	0	11.2	15.5	1.9	6.5	30	220	5100	110	35	100	0.8	85	25
*45A	O	2.4	0	10.7	20.2	1.9	9.3	26	160	4200	86	31	82	1.0	89	27
**S23A	U	-	-	8.3	15.1	3.4	5.3	-	-	-	-	-	-	-	-	-
**S23	U	-	-	-	-	-	-	26	380	5400	91	29	130	0.8	69	20
**S24	U	-	-	9.7	10.0	4.2	5.2	19	330	4300	72	20	92	0.6	62	17
**S26	U	-	-	9.0	10.2	4.7	4.8	30	270	5100	100	34	110	0.7	62	18
46	U	-	-	-	-	5.1	6.3	30	390	4200	65	32	88	0.7	62	18
47	O	-	-	-	-	2.3	6.5	23	260	4700	78	33	100	0.8	80	20
48	U	14.0	3.0	-	-	5.0	10.2	38	160	4500	110	68	110	1.0	92	25

Table 6 (cont.)

Till Sample number (see Fig. 63)	Oxidized (O) Unoxidized (U)	Pebble Lithology: Granodiorite %	Pebble Lithology: Ultrabasic % + Gabbro %	Fine Sand Mineralogy: Potassium Feldspar %	Fine Sand Mineralogy: Plagioclase Feldspar %	Fine Sand Mineralogy: Heavy Mineral (s.g. >2.80) Weight % of fine sand	Fine Sand Mineralogy: Magnetic Minerals Weight % of heavy minerals	Trace Elements in silt and clay (<63 μm) (ppm): Copper	Zirconium	Titanium	Vanadium	Nickel	Chromium	Silver	Zinc	Lead
49	U	14.0	5.0	-	-	4.5	7.4	24	310	4100	71	76	130	0.9	64	19
**50	U	0	0	12.5	19.0	1.5	7.7	33	280	4700	100	38	84	0.9	85	25
51	O	-	-	-	-	1.3	5.5	-	-	-	-	-	-	-	-	-
52A	O	0	0	9.8	10.0	2.1	7.5	22	550	4500	60	26	68	0.7	53	17
52B	U	0	0	7.5	9.8	2.2	6.3	16	800	4200	52	20	61	0.5	44	15
53	O	12.0	+	22.9	22.9	7.5	17.5	32	390	5500	94	42	60	0.7	67	22
75	U	7.0	+	13.3	30.0	12.7	21.3	23	390	7000	110	46	110	0.9	66	19
**74	U	15.0	1.0	20.1	22.1	8.2	12.4	28	320	5600	110	42	110	0.8	71	20
**73	U	18.0	+	20.2	19.4	8.5	12.7	26	450	5500	100	38	99	0.8	68	20
57	U	0	2.0	-	-	3.9	13.4	29	330	4200	80	110	150	0.9	65	23
58	U	-	-	-	-	-	-	20	320	4500	64	22	57	0.6	58	17
59	U	-	-	-	-	-	-	25	310	4000	61	20	56	1.0	64	23
61	U	-	-	-	-	3.5	3.3	25	340	5000	86	39	67	0.8	73	22
62	U	1.0	3.0	-	-	2.2	8.5	21	490	5100	73	36	85	0.8	60	19
63	U	-	-	-	-	2.4	14.5	28	180	4900	94	92	140	1.0	69	22
64	U	1.0	0	-	-	2.3	6.1	25	430	4800	89	31	81	0.8	76	22
66A	U	-	-	-	-	4.5	9.2	28	350	4100	77	89	200	1.0	64	19
*67	U	-	-	-	-	1.8	7.9	31	300	5100	110	39	88	0.9	89	24
69	U	0	0	11.3	11.3	1.9	7.1	14	260	3200	40	20	81	0.6	62	20
68	U	0	0	6.0	17.4	1.5	6.1	18	260	5200	82	25	72	0.6	58	18
70	U	0	0	11.1	10.7	3.1	3.0	23	450	5300	92	32	71	0.6	62	24
71	U	12.0	3.0	13.6	22.4	4.3	7.9	23	420	3800	73	59	140	0.8	67	24
72	U	-	-	12.2	22.1	12.2	11.8	26	420	6500	120	40	89	0.8	67	17
80B	U	-	-	-	-	-	-	25	430	4900	84	35	82	0.9	69	22
81	U	-	-	-	-	3.6	8.8	25	450	4100	67	90	95	0.8	58	18
82	O	-	-	-	-	5.1	9.9	30	500	5100	96	100	140	0.7	71	20
83	U	18.0	6.0	10.6	23.7	4.0	9.7	27	270	3600	76	100	170	1.1	62	21
84	U	-	-	-	-	2.3	4.9	29	390	4700	91	32	57	0.8	67	20
87	U	-	-	4.0	11.3	2.8	8.2	27	240	4800	94	56	93	0.8	73	23
88A	U	13.0	4.0	-	-	4.1	8.2	22	350	3900	63	70	110	0.9	58	21
89	O	-	-	-	-	8.7	11.6	29	320	4600	90	100	120	0.7	67	19
94	U	22.0	0	-	-	4.2	11.9	29	330	4900	100	59	94	0.8	76	22
*95	U	-	-	-	-	2.0	5.4	28	230	5100	100	37	64	0.8	82	23
*96	U	-	-	-	-	2.9	8.2	30	170	5000	110	35	100	1.0	93	27
97	U	-	-	-	-	5.7	8.8	34	440	4000	78	140	170	0.8	67	19
*98	U	-	-	-	-	2.1	6.8	30	240	5100	110	39	76	1.0	94	23
99	O	-	-	10.0	26.2	3.4	7.1	-	-	-	-	-	-	-	-	-
100	U	-	-	-	-	4.4	13.1	29	360	5400	110	44	80	0.9	79	21
*101	U	-	-	-	-	1.6	6.9	23	530	4900	78	39	89	0.8	65	23
102	U	-	-	-	-	-	-	29	410	5300	92	56	100	0.6	75	20
103	O	-	-	10.9	26.8	4.2	13.0	25	380	4900	84	100	140	0.7	74	16
105	U	-	4.0	5.7	9.3	4.4	13.7	26	390	4600	97	130	200	0.8	67	25
106	U	-	-	-	-	3.8	11.7	25	310	4600	91	60	96	0.8	76	19
107	U	16.8	1.5	7.3	31.4	4.4	9.8	29	320	4400	86	63	120	1.0	72	19
*108A	U	-	-	-	-	-	-	34	210	4800	92	38	66	0.9	91	24
109	U	34.0	4.0	10.9	28.6	3.8	9.8	23	340	4700	84	45	110	0.9	71	20
112	U	-	-	-	-	-	-	26	440	4700	90	46	98	1.1	71	22
113	U	-	-	-	-	2.2	5.0	26	450	5000	89	26	70	0.6	72	25
115A	O	-	-	-	-	4.2	10.1	30	310	5000	96	70	170	1.0	71	22
116	U	-	-	-	-	5.4	7.5	28	330	4900	98	78	140	0.8	70	20
117	U	-	-	-	-	4.6	13.6	23	430	4100	70	53	110	0.6	60	20
121	U	24.6	+	10.4	25.8	3.4	13.1	26	290	4900	92	49	98	0.7	59	23

Table 6 (cont.)

Till Sample number (see Fig. 63)	Oxidized (O) Unoxidized (U)	Pebble Lithology		Fine Sand Mineralogy				Trace Elements in silt and clay (<63 μm) (ppm)								
		Granodiorite %	Ultrabasic % + Gabbro %	Potassium Feldspar %	Plagioclase Feldspar %	Heavy Mineral (s.g. >2.80) Weight % of fine sand	Magnetic Minerals Weight % of heavy minerals	Copper	Zirconium	Titanium	Vanadium	Nickel	Chromium	Silver	Zinc	Lead
123	O	-	-	-	-	-	-	28	430	4800	86	34	80	0.9	73	23
124	O	-	-	-	-	-	-	32	390	5000	91	36	66	0.7	83	28
125	U	-	-	-	-	1.7	8.2	22	460	4800	79	30	62	0.7	61	22
127	O	-	-	-	-	-	-	32	510	5400	100	35	82	0.7	71	26
128	O	-	-	-	-	-	-	25	260	5300	110	36	110	0.6	71	22
128A	U	-	-	-	-	-	-	29	350	4900	93	37	62	0.9	73	24
129	O	-	-	-	-	-	-	33	320	5400	120	39	81	1.0	89	24
130	U	-	-	-	-	7.3	7.7	34	380	5200	90	42	82	0.7	76	20
131	U	0	0	-	-	2.5	9.3	25	540	4800	84	27	65	0.6	62	22
28B	O	0	0	20.4	16.8	2.0	9.7	-	-	-	-	-	-	0.6	64	22
28A	O	0	0	9.1	13.4	1.8	7.3	-	-	-	-	-	-	-	-	-
***91	O	0	0	19.0	21.2	2.6	6.9	24	520	5200	90	30	56	0.7	64	21
*134	U	-	-	-	-	2.0	4.6	30	240	4900	99	38	75	0.8	86	23
134A	U	-	-	-	-	3.2	12.5	26	380	4500	89	66	190	0.7	75	24
B1	U	1.3	3.0	-	-	4.1	4.1	22	310	4500	74	29	130	0.5	70	18
B2	U	-	-	-	-	1.8	5.9	20	510	4800	78	33	130	0.5	62	19
B3	O	-	-	-	-	2.7	12.4	38	340	5200	92	92	170	0.7	74	23
B4	U	-	-	-	-	4.9	7.2	25	380	5000	87	49	280	0.7	63	18
B5	O	-	-	-	-	2.5	6.9	31	300	4900	92	69	130	0.8	74	24
B7	U	6.0	1.0	-	-	10.1	16.5	24	330	6700	120	34	200	0.8	76	21
B6	U	9.0	+	-	-	10.1	15.6	21	400	6900	110	32	160	0.8	65	19
B8	O	-	-	-	-	3.1	12.0	22	280	4800	84	49	210	0.8	69	19
S30	U	-	-	-	-	-	-	75	260	3900	73	89	260	1.2	80	18
S32	U	-	-	-	-	-	-	27	280	4400	82	82	210	1.0	71	19
S33	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S34	U	-	-	-	-	6.8	8.0	-	-	-	-	-	-	-	-	-
S35	U	-	-	-	-	-	-	22	200	4300	76	77	270	1.0	68	19
S38	U	-	-	-	-	5.5	6.7	24	330	3800	71	68	230	1.0	58	19
S47	U	-	-	10.9	19.4	4.3	5.3	-	-	-	-	-	-	-	-	-
S48	U	-	-	-	-	-	-	17	270	4000	77	55	220	0.8	61	20
03	U	-	-	-	-	-	-	33	330	4900	100	35	130	0.8	77	27
06	O	-	-	-	-	-	-	41	470	5300	110	100	200	0.8	80	25
011	U	-	-	-	-	2.2	9.3	28	290	4800	97	81	150	1.1	67	26
013	O	-	-	-	-	3.6	21.8	32	380	5100	110	180	250	-	-	-
015	O	-	-	-	-	2.2	12.9	30	350	5000	98	95	170	0.9	67	23

Samples from same section arranged from top to bottom in order of increasing depth below surface.

* Drolet Lentil or other clay till.
** Chaudière Till.
*** Johnville Till.
– Frequency not determined.
\+ Component present in concentration <1.0%.

Table 7. Spectrographic analyses of 13 elements in the <63 µm fraction of till samples in and outside of provenance region II, the zone of ultrabasic dispersal (element concentrations in ppm unless otherwise noted).

	Sample Number see Fig. 63	Cr	Ni	Mg(%)	Fe(%)	Al(%)	Ti	Mn	V	Zr	Ba	Ca	Na(%)	Sr
Samples in the ultrabasic train	U220	418	414	2.51	4.13	5.92	4379	0629	115	301	480	4249	>6.000	075
	U293	282	250	1.93	3.91	5.87	4154	0681	119	318	415	4125	>6.000	065
	U310	366	351	2.28	4.38	6.15	4362	0661	134	400	473	4989	>6.000	075
	U290	195	109	1.13	4.40	6.56	4272	0598	121	265	434	3166	>6.000	061
	U313	195	134	1.74	3.34	6.18	4543	0512	124	289	449	5811	>6.000	075
	U306	146	080	1.21	3.72	6.52	4713	0575	125	332	475	4081	>6.000	071
	U315	166	125	1.26	3.04	5.68	4370	0279	115	362	377	5323	>6.000	081
	U393	238	265	1.64	4.27	6.32	4436	0821	134	347	455	3494	>6.000	063
	U390	213	125	1.86	3.51	5.90	4244	1262	119	275	392	>1.0000	5.743	114
	U391	164	089	1.36	3.67	6.19	4334	0789	133	324	426	>1.0000	>6.000	128
	U152	183	096	1.50	3.63	6.15	4572	0697	122	401	461	3910	>6.000	074
	U153	203	142	1.99	3.62	5.95	4597	0740	118	316	460	4416	>6.000	081
	U135	224	108	1.92	3.40	5.90	4622	0712	119	267	460	>1.0000	>6.000	131
	U155	088	037	1.03	3.09	6.36	4854	0581	120	360	592	5025	>6.000	096
	U138	089	030	0.95	3.69	7.40	5342	0557	141	310	623	4142	>6.000	094
	U137	168	090	1.04	3.28	6.00	4696	0609	120	397	472	3738	>6.000	078
Samples outside the ultrabasic train	U303	090	053	1.21	3.82	6.55	4556	0614	141	295	542	4088	5.804	064
	U305	078	<030	0.83	3.39	6.40	4651	0567	123	411	533	5355	>6.000	096
	U305A	055	<030	0.85	3.10	5.82	4984	0469	123	408	528	4007	>6.000	071
	U305B	074	<030	1.17	3.69	7.13	4543	0688	121	231	624	9237	>6.000	113
	U161	116	051	1.33	3.27	5.76	4589	0620	108	321	486	>1.0000	>6.000	150
	U164	082	032	1.12	3.39	6.51	4955	0581	143	344	580	>1.0000	>6.000	122
	U140	084	<030	1.03	3.29	6.34	4671	0676	122	397	540	4142	>6.000	077
	U162	075	<030	0.91	3.39	5.79	4350	0438	118	335	531	3152	>6.000	058
	U146A	104	032	0.94	3.12	6.03	4817	0538	113	368	477	4487	>6.000	094
	U146	085	046	0.91	3.44	6.18	5101	0498	129	522	538	4071	>6.000	083
	U266	077	<030	0.91	3.38	6.61	4829	0481	128	314	474	4794	>6.000	084

APPENDIX 2

Provenance studies, by X-ray diffraction analysis, of five samples of tills from southeastern Quebec

by

R.S. Dean*

(Originally released as Mines Branch Investigation Report IR69-60, with minor changes)

INTRODUCTION

Five samples described as grey, unoxidized, compact lodgment silt-tills were submitted to the Mineral Processing Division by W.W. Shilts of the Department of Geology, Syracuse University, Syracuse, New York. The samples had been collected from three sections within or near the valley of Chaudière River, between Lac-Mégantic and Saint-Georges, southeastern Quebec. The sections were located 3.7 km north of the Chaudière River bridge at Saint-Martin (samples SCA-8 and SCA-13), on the west bank of Samson River 4.8 km south-southwest of Béland (samples SCA-27B and SCA-27C), and on the north bank of Eugénie River 5.9 km east of Saint-Samuel-de-Gayhurst (sample SCA-29B). In Table 1 additional sampling data are listed, and the samples tentatively have been assigned stratigraphic positions on the basis of information provided by W.W. Shilts (personal communication).

The object of this investigation was to discover and explore, within the limitations imposed by the small number of available samples, any possible mineralogical criteria which might aid in the differentiation and correlation of the various till sheets. Special care was to be taken with regard to the detection of any expansible clay minerals. All information which might prove useful in the course of future applications of the X-ray diffractogram peak-height ratio method developed by Shilts (1967) was to be noted.

PROCEDURE

Each till sample was gently disaggregated in a mullite mortar. Care was taken not to crush the included rock fragments. Fragments coarser than 10 mesh (2 mm) were removed by sieving, and a 1/4 cut of the remaining material was taken with a Jones-type microsplitter. This portion of the minus 10-mesh till was brought into suspension in demineralized distilled water, and the mineral grains having an equivalent settling diameter of approximately 5 µm or less were separated by centrifugation. The -5 µm fraction thus obtained from each sample was examined with a Guinier-deWolff four-sample X-ray powder camera, as was the unseparated minus 10-mesh material.

Oriented mounts were prepared on borosilicate glass slides from portions of each of the -5 µm suspensions. These were scanned with a North American Philips High-Angle X-ray Diffractometer under conditions approximating 0% and 100% relative humidity. The differing humidity conditions were obtained by sealing the sample chamber window with thin polyethylene film and introducing a stream of nitrogen which had either been passed through a "Drierite" column or bubbled through hot (60°C) distilled water. Prior to each examination, the mounts were allowed to equilibrate overnight under humidity conditions approximating those under which the analyses were to be made. The same mounts subsequently were scanned when saturated with ethylene glycol and following heat treatment for one hour at 580°C.

Other portions of the -5 µm suspensions were boiled for approximately one-half hour in an excess of concentrated hydrochloric acid. The residues from this treatment were washed twice with demineralized distilled water and collected by centrifugation at 10 000 rpm in a Sorvall SS-3 Superspeed Centrifuge. Oriented mounts of the acid-treated clays were prepared and scanned with the X-ray diffractometer. The acid-treated residue of one of the samples (SCA-27B) also was examined with the Guinier camera.

Small portions of the minus 10-mesh fraction of each sample were hand-ground for five minutes in an agate mortar, and powder mounts for the X-ray diffractometer

Table 1. Samples investigated

Sample No.	Section Location	Sample Elevation	Depth Below Surface	Till	Ice Movement Direction
SCA-13	45°59.5'N 70°39.5'W	791 ft	50 ft	Lennoxville Till	From northwest
SCA-8	As above	729 ft	112 ft	Chaudière Till	From northeast
SCA-27B	45°45.1'N 70°38.0'W	1045 ft	45 ft	Lennoxville Till	From northwest
SCA-27C	As above	1020 ft	70 ft	Chaudière Till	From northeast
SCA-29B	45°43'N 70°47'W	1150 ft	100 ft	Chaudière Till	From northeast

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Table 2. Mineralogical analyses of tills*

Sample	Size Fraction	Mica	Chlorite	Quartz	Plagioclase	K-feldspar	Calcite	Amphibole
SCA-13	-10 Mesh	C	C	A	B	G	F	-
	-5 µm	B	B	C	C	G	G	-
SCA-27B	-10 Mesh	C	C	A	B	G	F	-
	-5 µm	B	B	C	D	G	F	-
SCA-8	-10 Mesh	C	C	A	B	F	F	-
	-5 µm	B	B	C	C	F	F	-
SCA-27C	-10 Mesh	C	C	A	B	F	G	G
	-5 µm	B	B	C	C	F	-	G
SCA-29B	-10 Mesh	C	C	A	B	G	G	-
	-5 µm	B	B	C	C	F	-	-

*Mineral abundances estimated from "A" (very abundant) to "G" (trace).

were prepared using aluminum holders similar to those illustrated by Diebold et al. (1963, p. 136). Preferred orientation of the layer silicates was reduced by packing these mounts from the rear after the front, i.e. the surface which would eventually be scanned, had been covered with a glass slide.

RESULTS

The results of the mineralogical analyses of the five till samples are listed in Table 2. The mineral abundances shown in this table were estimated from the transmission X-ray diffraction (Guinier camera) data.

Examination of Table 2 suggests that purely qualitative mineralogical analyses provide little or no information which might serve to distinguish Chaudière Till from Lennoxville Till. The most encouraging avenue for future investigation would appear to be the quantitative estimation of K-feldspar, which was judged to be somewhat less abundant within the two samples of Lennoxville Till.

The X-ray diffractograms of sample SCA-27B, which are illustrated in Figures 1 and 2, are typical of those obtained from all five till samples. The diffractogram of the -5 µm oriented aggregate at 100% relative humidity (Fig. 1, Scan 1) was virtually identical to those obtained from the same mount at 0% relative humidity and following ethylene glycol saturation, indicating the absence of detectable quantities of expansible clay minerals. This was also the case for each of the remaining four samples.

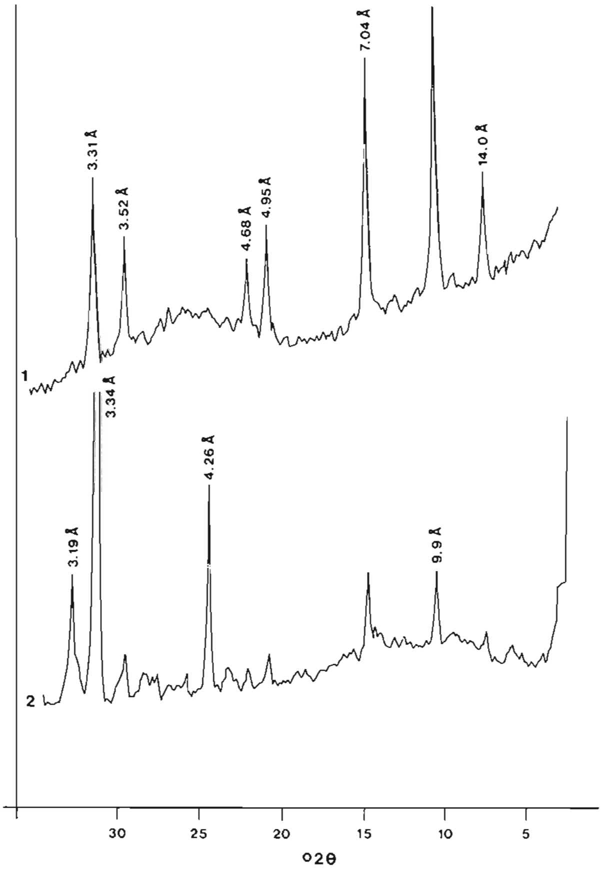
The diffractometer studies indicate a lack of hydration and a degree of structural ordering within the till mica such as are not commonly encountered among shale and soil illites. The X-ray powder photographs of all samples revealed well defined patterns of $2M_1$ muscovite. However, the final definition of this material as muscovite, sericite, or as illite consisting partially of muscovite must await further studies. Surficial clays containing micas with no detectable expansible layers and a strong $2M_1$ muscovite powder pattern have previously been found at Disraeli and Cowansville by Brady and Dean (1966b, p. 40).

The till chlorite yielded sharp and intense basal reflection (Fig. 1, Scan 1) but showed, in X-ray powder photographs, the same apparent layer-stacking disorder that had been observed among the more poorly crystallized chlorites within the Ordovician shales of the St. Lawrence Lowland (Dean, 1962, p. 132). The reactions to heat (Fig. 2, Scan 1) and hydrochloric acid (Fig. 2, Scan 2) treatments were typical of trioctahedral chlorite (Brady and Dean, 1966a, p. 46). The absence from the unaltered tills of mixed-layer systems consisting of chlorite and expansible phases, and the occurrence of these systems within near-surface Appalachian clays (Brady and Dean, 1966b, p. 38), supports the view put forth by Brady and Dean (1966b, p. 40) that the expansible phases are the result of weathering alteration of the chlorite.

Table 3 lists the standard deviations and coefficients of variation (Moroney, 1956, p. 64) of the various peak heights and peak-height ratios obtained from the minus 10-mesh packed-powder mounts. Data from the -5 µm oriented mounts at 0% relative humidity are listed in Table 4.

In Table 3, the northeasterly derived till (Chaudière) shows an increase in the mean 10/4.26Å and 7/4.26Å peak-height ratios of approximately 25% relative to the northwesterly derived till (Lennoxville). In view of the small number of samples and wide scatter of the ratio data, this difference is probably of little significance.

The very large mineralogical difference between the -5 µm and minus 10-mesh size fractions of samples SCA-27B, as shown by the two diffractograms in Figure 1, indicates the magnitude of error which could be introduced by failure to compare samples containing identical particle size ranges. Furthermore, a significant variation in particle size distribution of the minerals in question might result in variations in diffractogram peak-height ratios for a given size fraction which would not be evident within another size fraction of the same sample suite. Hence, the apparent failure of the data in Table 3 to reflect the ratio differences noted by Shilts (1967) is perhaps an indication that conclusions drawn on the basis of peak ratio studies within a particular (minus 230-mesh) size fraction are not necessarily applicable to other size fractions or to the till as a whole.



GSC

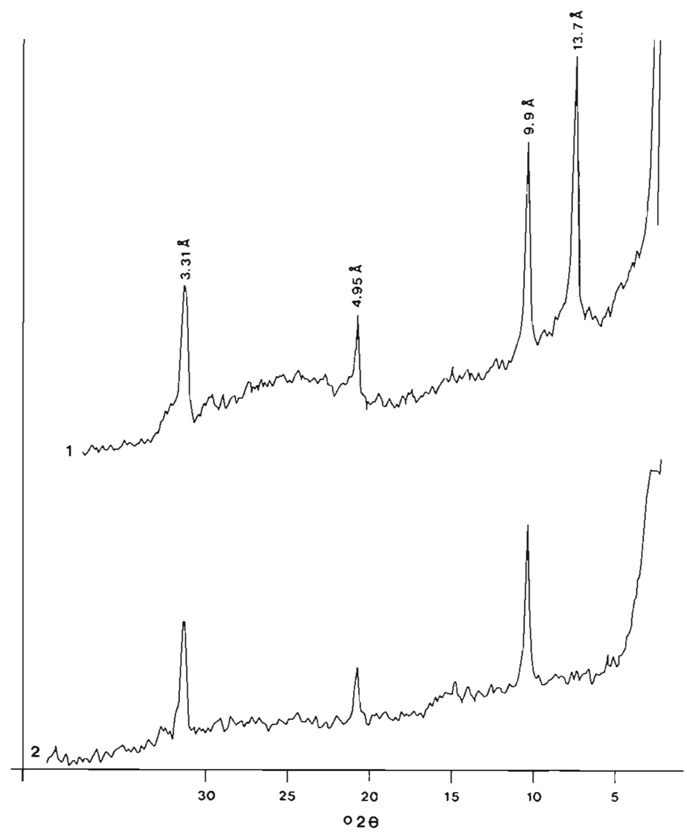
Co/Fe radiation; total scale deflection – 100 counts; time constant – 16; scanning speed 0.5 2θ/minute; 1 slits; proportional-counter detector with pulse-height analyser.

Scan 1 – Oriented mount of -5 μm fraction; 100% relative humidity.

Scan 2 – Packed powder mount of minus 10-mesh fraction; air-dry.

Mica	*– 9.9; 4.95; 3.31Å*
Chlorite	*– 14.0; 7.04; 4.68; 3.52Å*
Quartz	*– 4.26; 3.34Å*
Plagioclase	*– 3.19Å*

Figure 1. *X-ray diffractograms of SCA-27B till.*



GSC

Co-Fe radiation; total scale deflection – 100 counts; time constant – 16; scanning speed 0.5 2θ/minute; 1 slits; proportional-counter detector with pulse-height analyser.

Scan 1 – Heated for one hour at 580 C.

Scan 2 – Boiled in concentrated HCl.

Mica	*– 9.9; 4.95; 3.31Å*
Chlorite	*– 13.7Å*

Figure 2. *X-ray diffractograms of oriented mounts of -5 μm fraction of SCA-27B till.*

Table 3 shows, however, that the 10/4.26Å and 7/4.26Å ratios employed by Shilts (1967) are among the most variable parameters and hence can be expected to differ among samples, although the question remains as to whether or not these differences will be systematic with regard to the various till sheets. It is also worthy of note that similar coefficients of variation, in the vicinity of 35%, were obtained from all ratios which involved reflections from both layer-silicate minerals and quartz or plagioclase. Furthermore, the variability of the intensity of the reflections from quartz, plagioclase, or of their peak intensity ratios, was close to 15%.

An apparent anomaly is evident within the data of Table 3, in that the samples from which the strongest mica and chlorite reflections were recorded (notably SCA-29B) did not also show a commensurate decrease in quartz and/or feldspar peak heights. Three major possibilities are indicated: firstly, the failure of the sample packing technique to achieve a random orientation of mica and chlorite crystallites; secondly, variations in the crystallinity or composition of these same minerals; and thirdly, non-uniform sample mount preparation. In the first case, any preferred orientation of mica and chlorite grains parallel to the surface of the minus 10-mesh powder mount of sample SCA-29B would have caused the basal reflections from these to be selectively enhanced. This situation probably could be rectified by the use of a thermoplastic cement as suggested by Brindley and Kurtossy (1961, p. 1208). Variations in crystallinity, which in this case refers to the effective thickness of mica and chlorite layer sequences, and composition (notably Fe:Mg substitution in chlorite) might best be dealt with, on the other hand, by the addition of an internal standard (Diebold et al., 1963; Klug and Alexander, 1954, p. 415) for the determination of quartz and plagioclase, and hence by subtraction, the layer-silicate minerals (Diebold et al., 1963, p. 132). In the writer's experience, moderate crystallinity variations among layer silicates are especially difficult to detect, as structural disorder within

Table 3. Packed-powder diffractogram peak heights (counts above background) and Peak-Height Ratios

	Sample No.						
	Chaudière Till			Lennoxville Till			
Reflection or Ratio	SCA-8	SCA-27C	SCA-29C	SCA-13	SCA-27B	Standard Deviation	Coefficient of Variation
Mica 10Å	13	17.5	20	9	18.5	4.0	25.$_9$%
Chlorite 7Å	14	21	22.5	10.5	21	4.7	26.$_4$%
Quartz 4.26Å	57.5	38	63.5	53	51	8.5	16.$_1$%
Plagioclase 3.19Å	48	30.5	36.5	37.5	31.5	6.2	16.$_9$%
10/4.26Å	0.23	0.46	0.31	0.17	0.36	0.101	33.$_0$%
7/4.26Å	0.24	0.55	0.35	0.20	0.41	0.125	35.$_7$%
10/7Å	0.93	0.83	0.89	0.86	0.88	0.033	3.$_8$%
4.26/3.19Å	1.20	1.25	1.74	1.41	1.62	0.208	14.$_4$%
7/4.26 + 3.19Å	0.13	0.31	0.23	0.12	0.25	0.073	35.$_0$%
7/3.19Å	0.29	0.69	0.62	0.28	0.67	0.185	36.$_3$%

Table 4. Peak height and peak-height ratios from -5μm Oriented mounts (0% relative humidity)

	Peak Heights			Peak-Height Ratios
Sample	Mica 4.95Å	Chlorite 4.68Å	Quartz 4.26Å	4.95/4.68Å
SCA-13	17	16	2.5	1.0$_6$
SCA-27B	25	20	N.D.*	1.2$_5$
SCA-8	21.5	17	7.5	1.2$_6$
SCA-27C	27	20	N.D.*	1.3$_5$
SCA-29B	33	24	5	1.3$_8$

*N.D. – Not detected.

one constituent of a rock usually is accompanied by a similar degree of disorder in others, i.e., one rarely finds a shale containing well crystallized mica and poorly crystallized chlorite, or vice versa. The low coefficient of variation (3.8%) for the 10/7Å ratio from the powder sample (Table 3) suggests a close association of mica and chlorite in both abundance and crystallinity.

The diffractograms of the -5μm oriented mounts (Fig. 1, Scan 1) suggested that quartz (see Table 4) and plagioclase are much less abundant within the fine fraction of the till than is indicated by the transmission X-ray powder data (Table 2). The principle cause of this apparent anomaly is probably a vertical mineralogical segregation which occurred in the course of the preparation of the oriented mounts. This effect has been shown to be capable of introducing large errors in the quantitative determination of clay minerals of differing sizes (Gibbs, 1968) and should be especially troublesome in dealing with mixtures of layer silicates and quartz or feldspar. Differential settling of mica and chlorite also may have influenced the coefficient of variation of the mica/chlorite peak-height ratios from the sedimented mounts. From the data listed in Table 4, this was calculated to be 8.9% in contrast to the value of 3.8% obtained from the packed-powder mounts (Table 3).

CONCLUSIONS

The till samples consisted of mica, chlorite, quartz, and plagioclase, with minor K-feldspar, calcite and, in one case, amphibole. No expansible layer silicates were detected. No qualitative mineralogical differences were found between tills derived from the northeast and those derived from the northwest. X-ray powder data, however, did suggest that the latter might be relatively deficient in K-feldspar.

Provenance studies of tills based upon mica/quartz and chlorite/quartz peak-height ratios must take into account the following:

1. any sampling error which would result in the inclusion of a nonrepresentative portion of some particular size fraction of the till;
2. possible variations in layer-silicate crystallinity or composition; and
3. errors in mount preparation procedure, leading either to nonrandom orientation of layer silicates within packed-powder mounts or to vertical mineralogical segregation within oriented-aggregate mounts.

ACKNOWLEDGMENTS

Technical assistance was provided by C.H.J. Childe and H.C. James of the Mineral Processing Division, Mines Branch.

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APPENDIX 3

Reconnaissance Hammer Seismic Profiles, Lac-Mégantic Area, Quebec

by

G.D. Hobson*

Introduction

The survey was proposed by W.W. Shilts through B.C. McDonald to assist in the compilation of data pertaining to the mapping and definition of surficial materials in river valleys associated with the Chaudière River basin.

The survey was conducted between June 19 and July 5, 1968 by G.D. Hobson, F.K. Maxwell, R. Lawson.

Instrumentation

A model FS-3 portable seismograph, manufactured by Huntec Ltd., was used to record seismic data. A 16 lb. sledge hammer struck against a steel plate on the ground provided seismic energy. Explosives were not used as a source of energy.

Field Procedure

Seismic profiles were completed at intervals of approximately one-quarter mile along selected roads. Single-ended profiles were surveyed at 58 locations. Surface altitude at all seismic locations was obtained using an altimeter.

Topography

Topographic relief varies between 846 and 1877 feet (257 and 572 m) a.s.l. over the profiles surveyed. Surface relief in the project area is generally abrupt.

Results

Velocities

The histogram of observed velocities versus the frequency of occurrence (Fig. 1) has been plotted using seismic velocities as observed and uncorrected for dip. The first peak has been correlated with the uppermost aerated and soil zones. The peak at about 5000 ft/s has been correlated with a silt-clay, probably the Gayhurst Formation. Subsequent velocity ranges from 6000 to 9000 ft/s probably can be correlated with tills, particularly the range from 7000 to 9000 ft/s with Lennoxville Till. There are insufficient correlatable data to set out the velocities associated with Chaudière Till. Bedrock generally is correlated with velocities in excess of 10 000 ft/s.

Overburden Thickness

The thickness of overburden varies between 3 feet at seismic station 36 and 345 feet at station 23. Rock outcrop is common, but where preglacial valleys exist, overburden is thick. Sections have been compiled for the 10 lines of control.

Table 1 sets out the thickness of overburden and the bedrock altitude for all seismic stations surveyed in the project area.

Correlation of seismic sections with boreholes and stratigraphic sections

A series of location maps and the associated sections set out the surface topography, thicknesses of various overburden strata and the seismic velocities associated with them, and the bedrock topography with its associated seismic velocity (Fig. 2-7B). These various seismic sections are correlated with boreholes and geologic sections where possible.

Borehole 3 near seismic station 3 on profile A (Fig. 2) shows the following comparison with the seismic section:

Borehole 3		Seismic station 3	
			1308 ft
		800 ft/s	1303
	1300 ft		
sand and gravel	1287		
till		5100 ft/s	
	1212		
silt clay	1209 T.D.		1179
		bedrock 14600 ft/s	

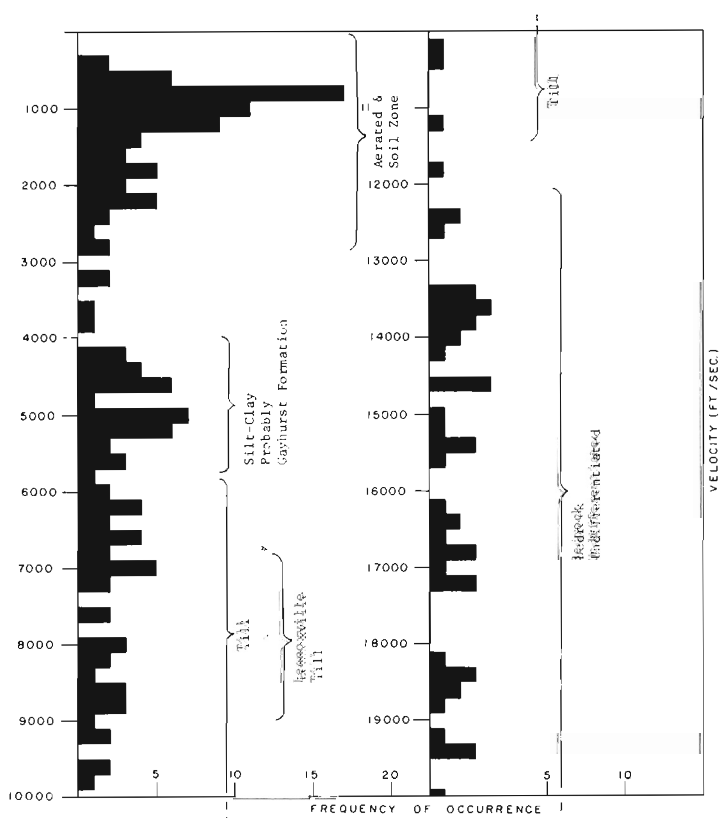

Figure 1

* Formerly with Resource Geophysics and Geochemistry; now Director, Polar Continental Shelf Project

Table 1. Overburden thickness and bedrock elevation, Lac-Mégantic, Quebec

Station[1]	Overburden Thickness (ft)	Bedrock Elevation (ft)	Station	Overburden Thickness (ft)	Bedrock Elevation (ft)
1	174.6	1150	31	107.7	1361
2	180.4	1128	32	60.3	1311
3	129.4	1179	33	212.4	1147
4	149.0*	1171*	34	175.7	1049
5	74.7	1256	35	22.0	1362
6	34.0	1309	36	3.0	1473
7	91.3	1265	37	51.4	1374
8	120.5	1276	38	92.8	1336
9	211.4	1262	39	92.7	1269
10	88.6	1421	40	79.4	1278
11	140.4	1250	41	93.5	1258
12	181.6*	1068*	42	59.9	1282
13	276.6	852	43	213.2	1165
14	291.4	780	44	49.2	1426
15	178.6	930	45	50.7	1220
16	292.4	939	46	188.6	901
17	212.1	638	47	224.6	865
18	157.1	691	48	56.2	1444
19	186.0	667	49	309.6	1195
20	192.9	653	50	132.4	1404
21	156.2	903	51	20.7	1538
22	190.4	845	52	not penetrated	
23	345.0	696	53	not penetrated	
24	40.3	1034	54	not penetrated	
25	90.8	1156	55	not penetrated	
26	291.0	1143	56	15.8	1296
27	179.8	1271	57	29.2	1275
28	142.1	1308	58	61.6	1275
29	42.8	1834	A	0.0	1925
30	18.3	1840	B	0.0	1865

[1] See figures in Appendix 3 for locations of stations.

* Denotes minimum depth calculated.

Profile B (Fig. 3) extends between rock outcrop on the eastern and western extremities with no boreholes or stratigraphic sections nearby. It is anticipated that the material overlying bedrock is till, as indicated by the relatively high seismic velocity associated with it.

Stratigraphic section 12 is located about one mile northeast of profile C (Fig. 4). Some roadcuts near seismic locations 41 and 42 expose 30 feet of till. A comparison of section 12 and seismic location 43 follows:

Section 12

1278 ft

Lennoxville Till

1238

Seismic station 43

1378 ft

1800 ft/s 1365

6100 ft/s

1312

8500 ft/s

1165

bedrock

13 900 ft/s

Figure 5 shows profiles D and E and stations located in the town of Lac-Mégantic. Borehole 2 is located adjacent to seismic station 49, and borehole 4 is adjacent to stations 53 and 54; comparisons follow:

Borehole 2

1490 ft

till

1371

silt-clay 1352

till 1345

bedrock

slate and siltstone

Seismic station 49

1100 ft/s 1485

1490 ft

6300 ft/s

1373

9700 ft/s

1182

16 800 ft/s

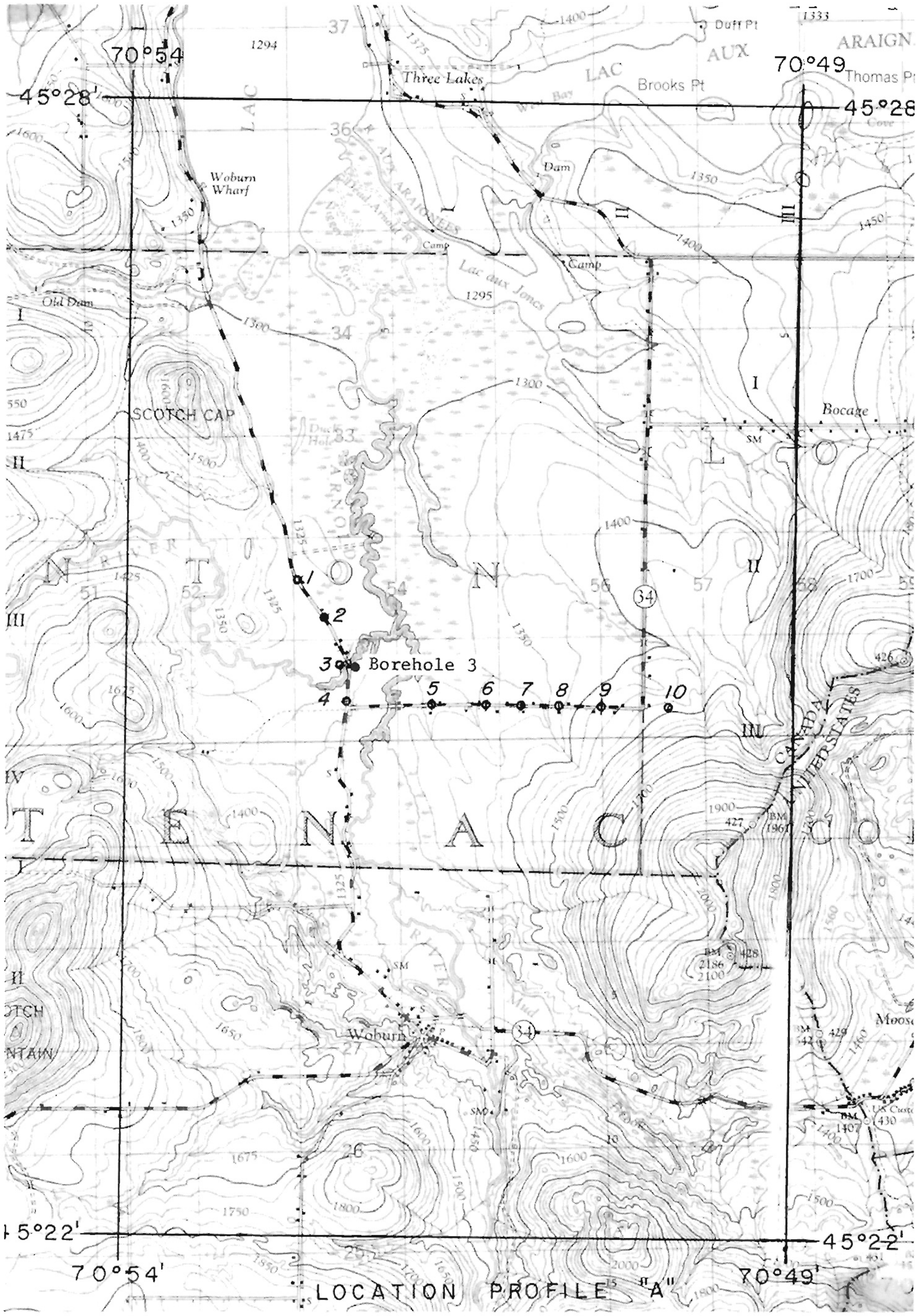

Figure 2

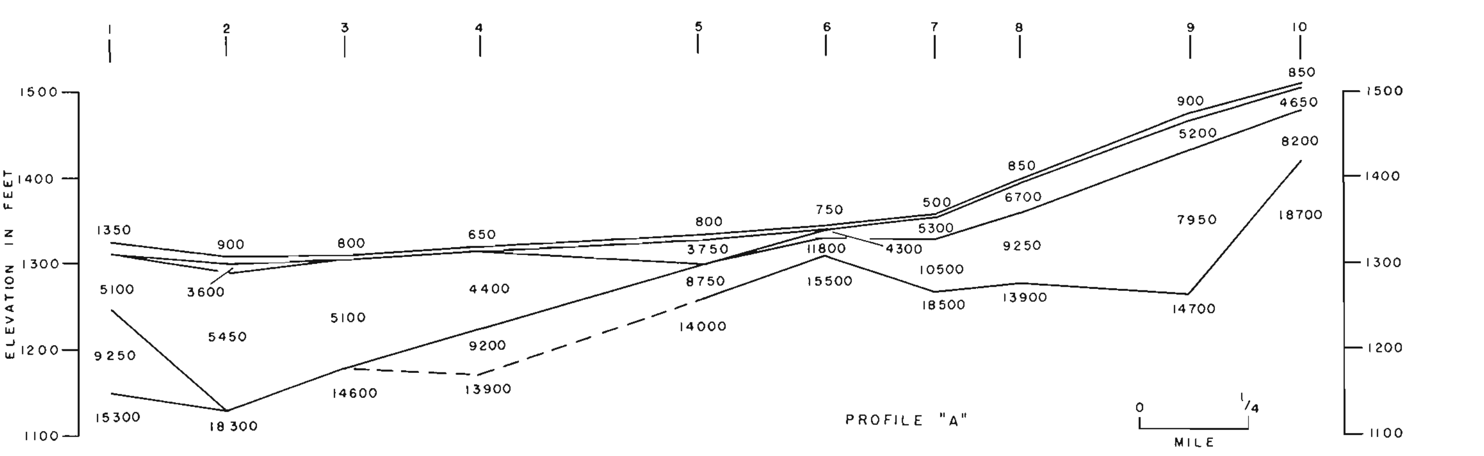

Figure 2A

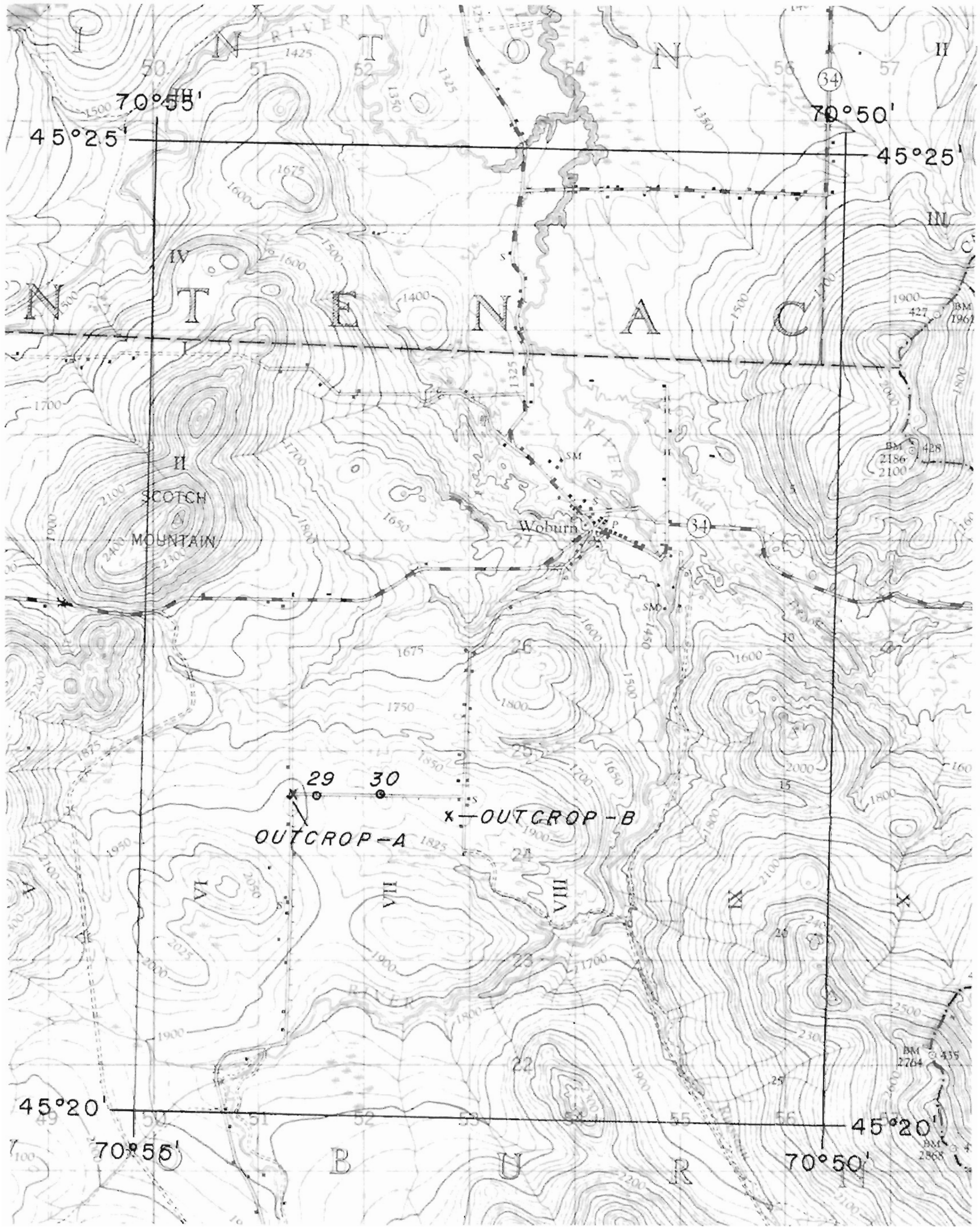

Figure 3

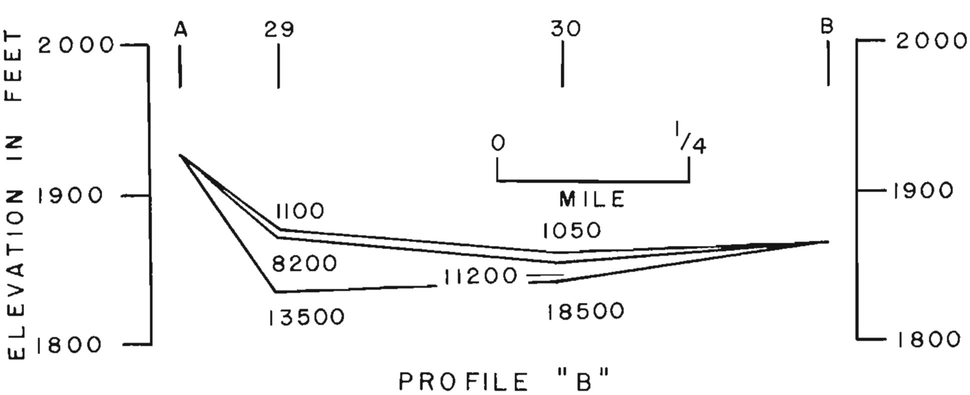

Figure 3A

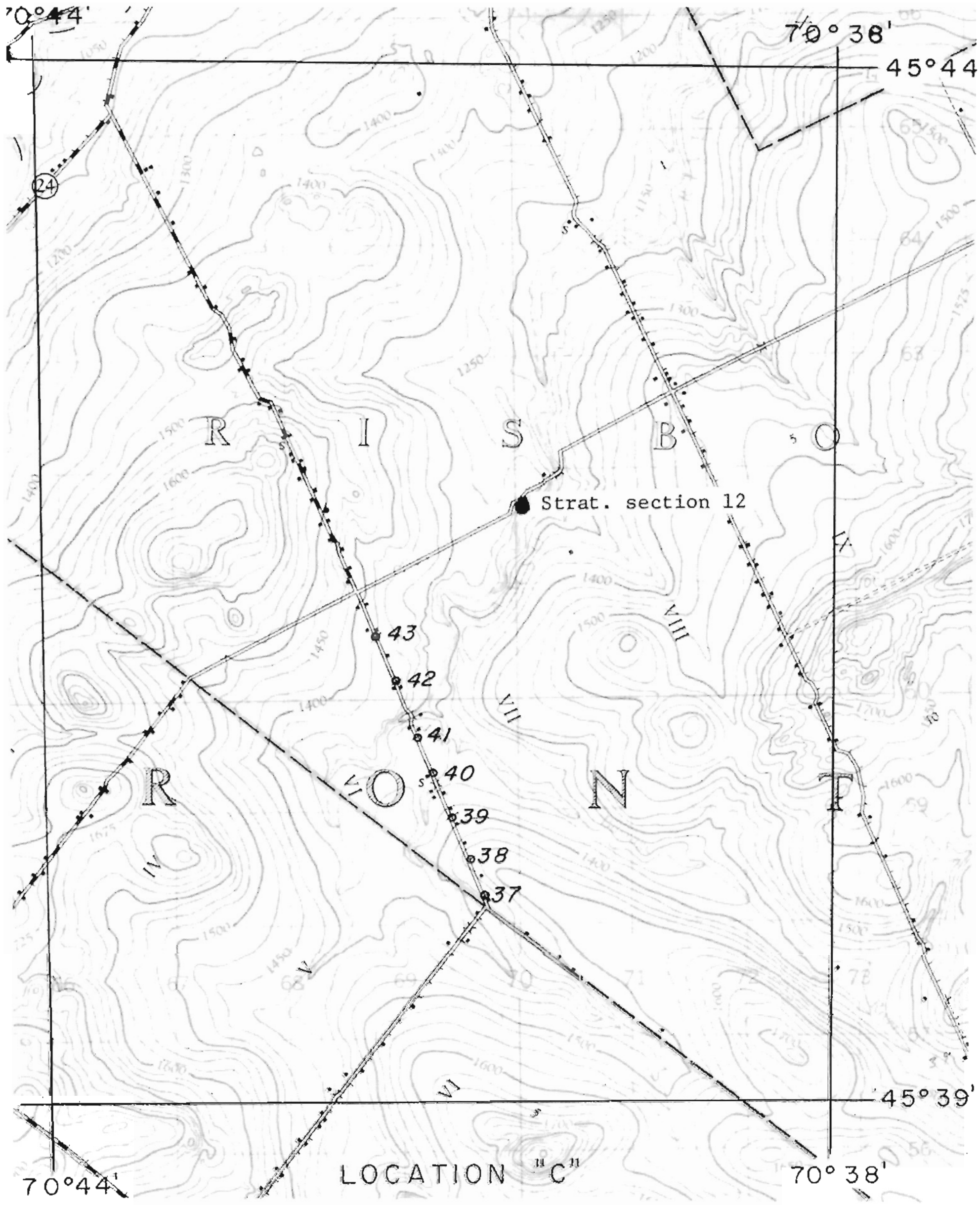

Figure 4

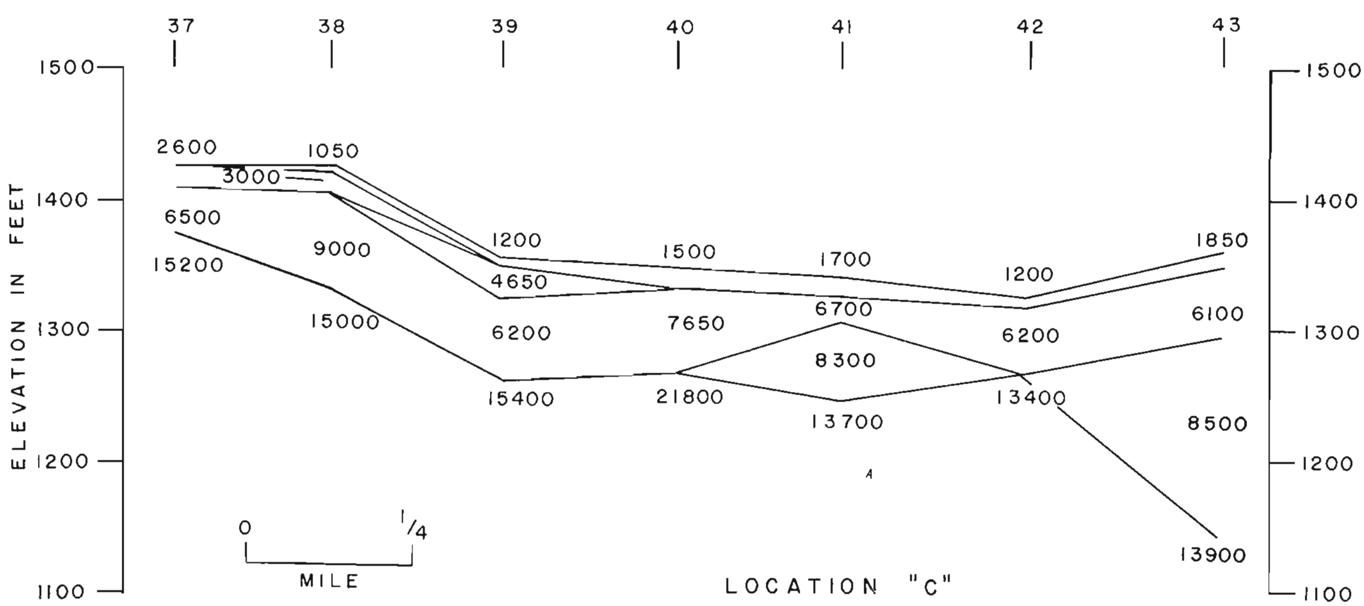

Figure 4A

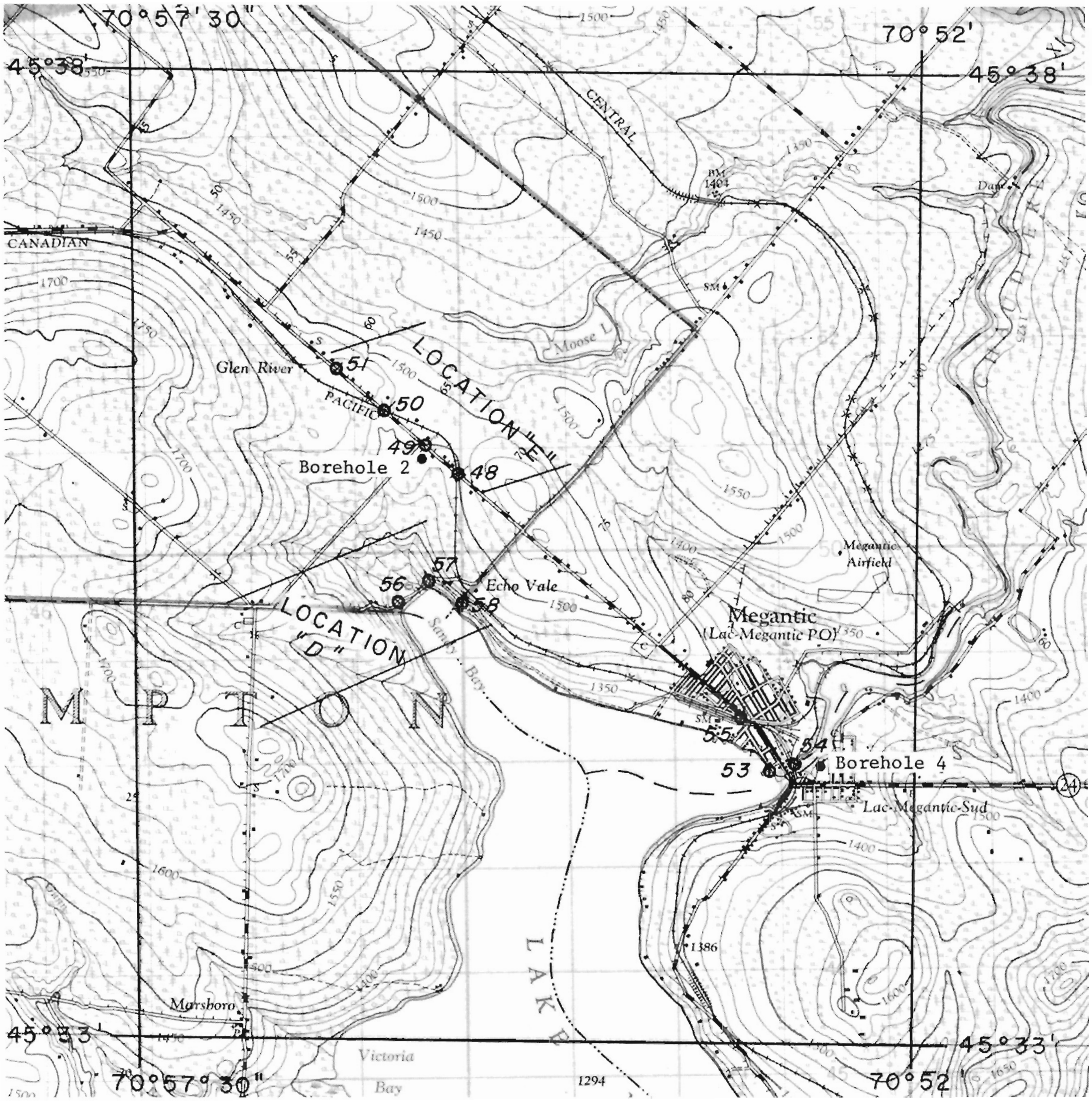

Figure 5

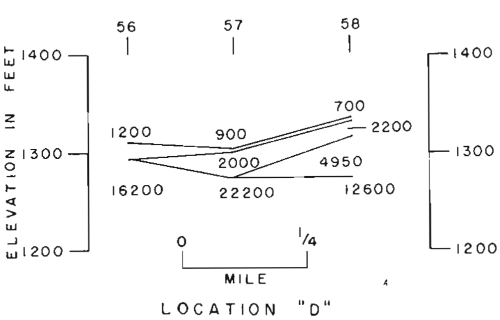

Figure 5A

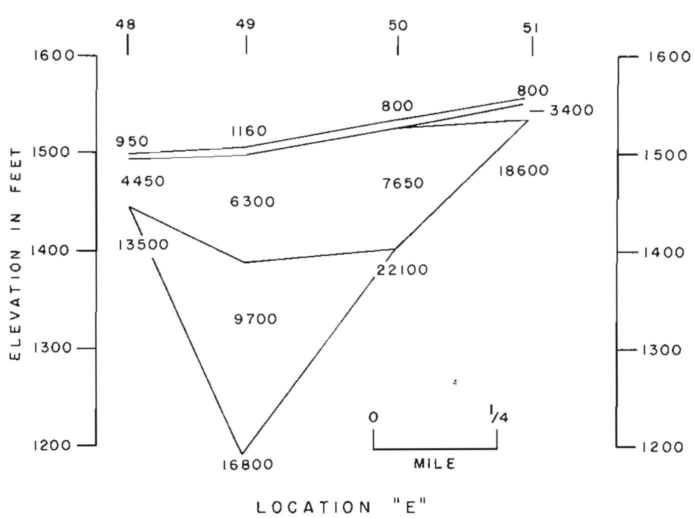

Figure 5B

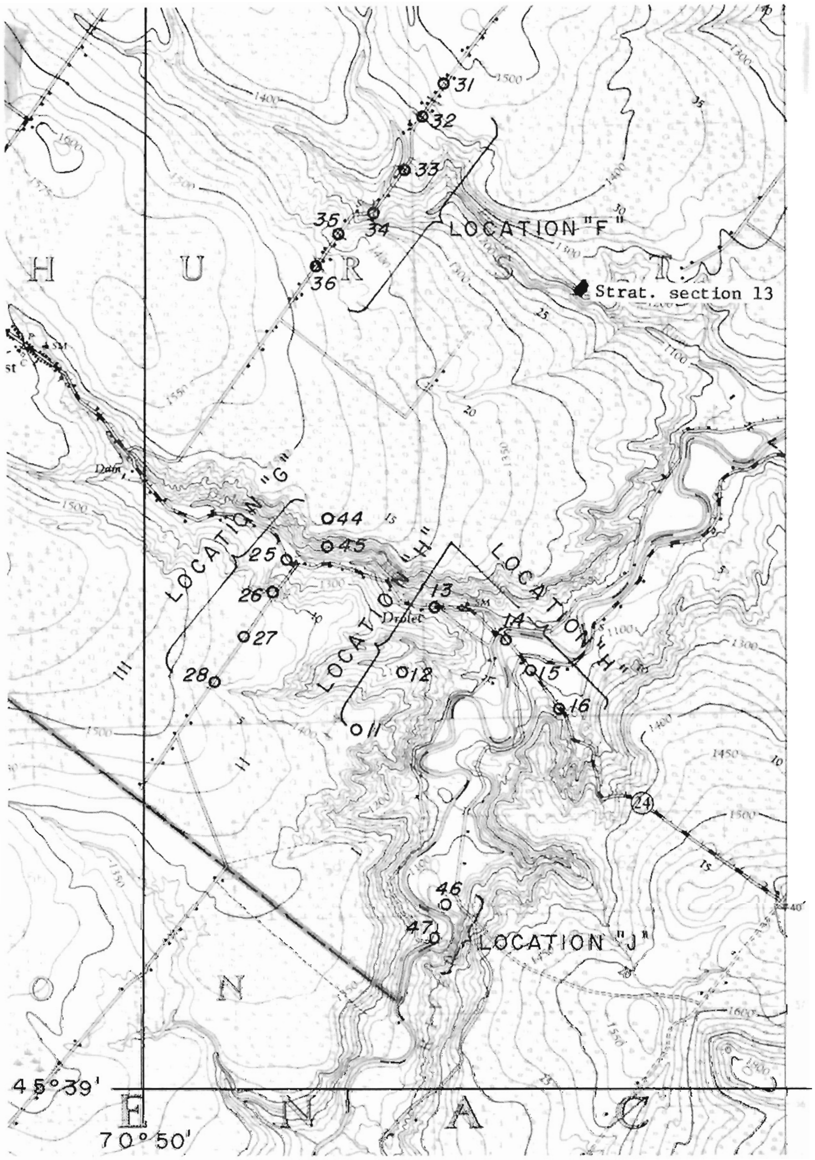

Figure 6

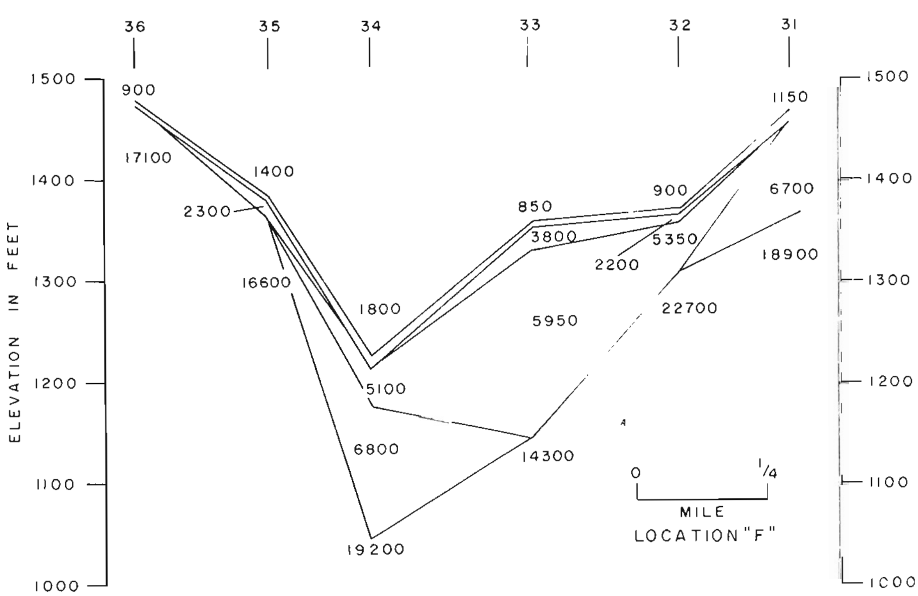

Figure 6A

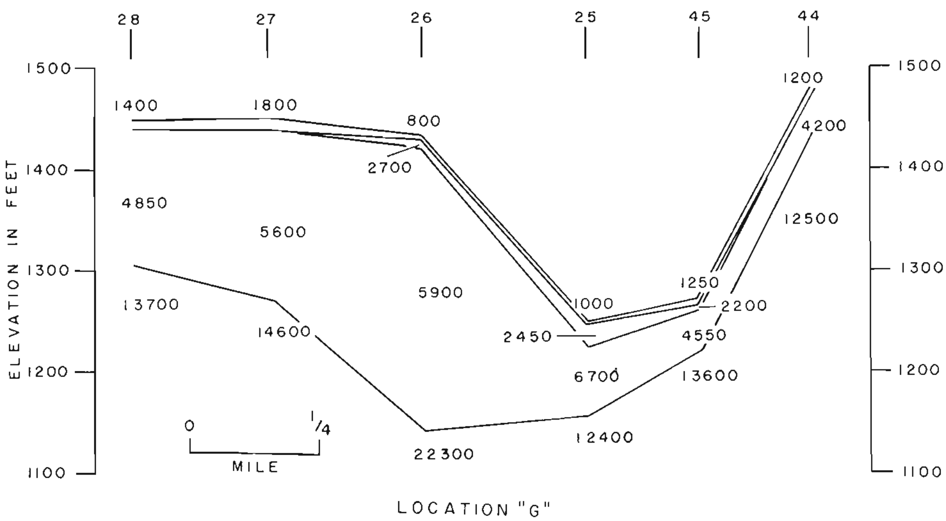

Figure 6B

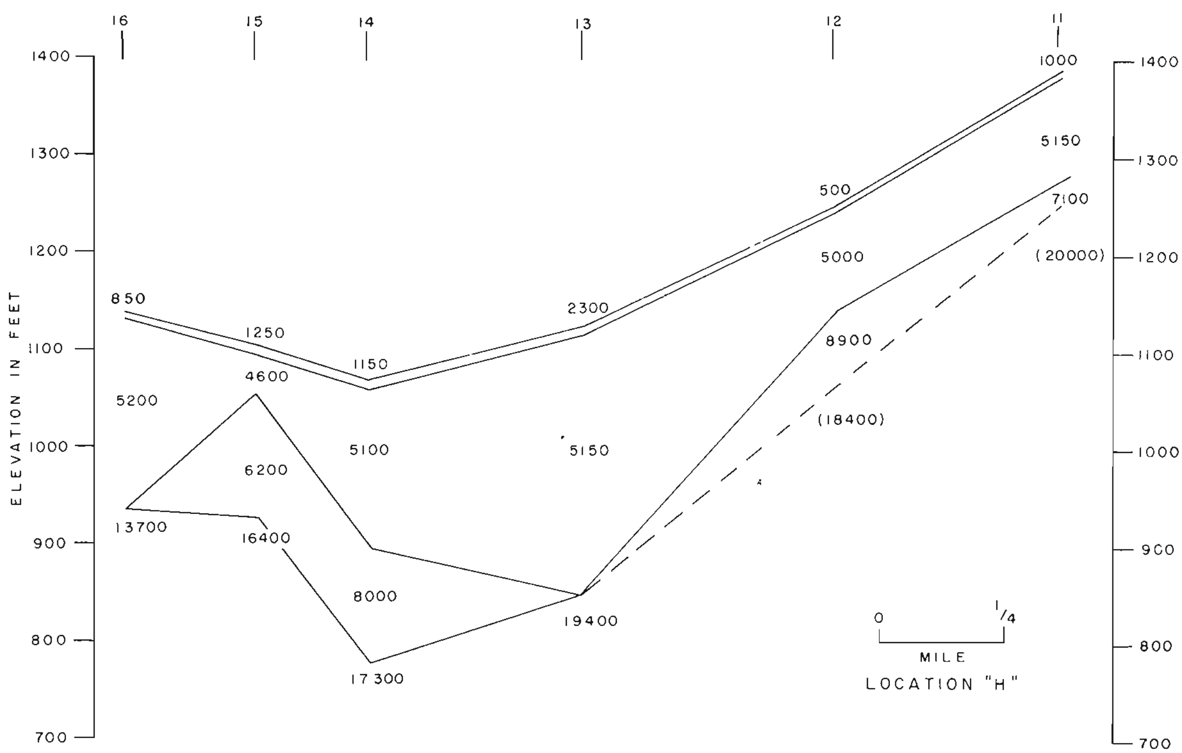

Figure 6C

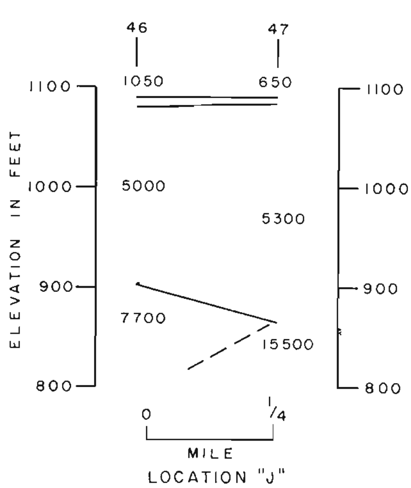

Figure 6D

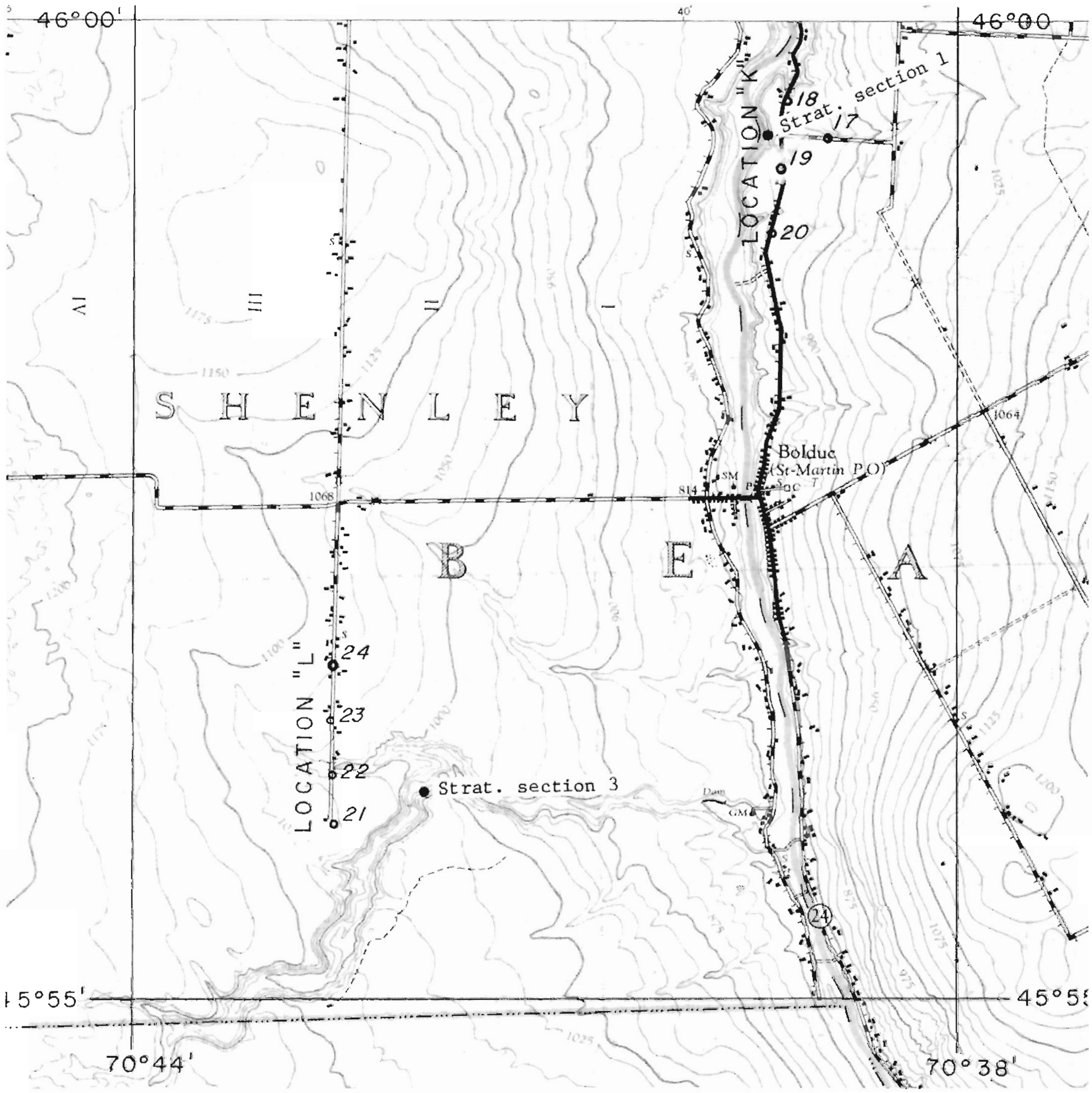

Figure 7

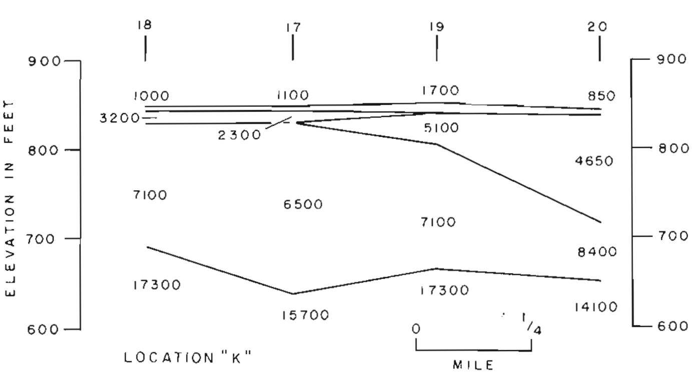

Figure 7 A

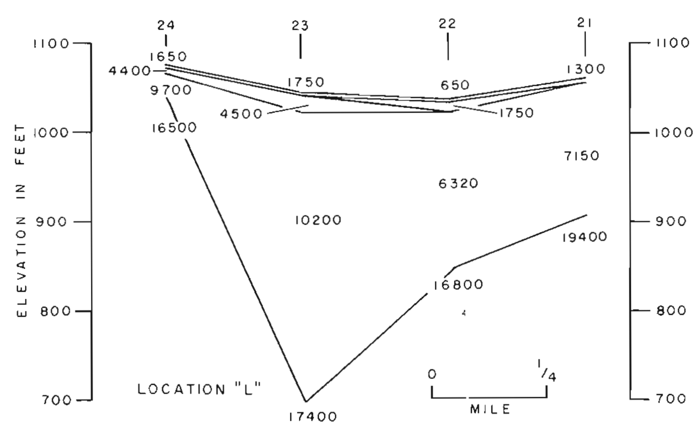

Figure 7 B

It is to be noted that two bedrock velocities have been observed beneath seismic station 49; the correlation above shows that the 9700 ft/s velocity is associated with slate and siltstone bedrock.

Borehole 4		Seismic station 54	
	1292 ft		1292 ft
alluvium	1285	700 ft/s	1288
		5700 ft/s	
till			
	1276		
silt-clay	1268	not penetrated	
sand and gravel	1265		
silt-clay			
	1250 T.D.		

Figure 6 sets out seismic profiles F, G, and H. Stratigraphic section 13 is located in the bank of the river about 2 km southeast of the seismic profile. A generalized section 13 follows:

Section 13	
	1250 ft
till (Drolet)	1234
silt-clay (Gayhurst Fm.)	
	1202
till (Chaudière)	
	1173 T.D.

Stratigraphic section 13 is too far and too different in altitude from profile F to make any reasonable comparison. Also, there are no stratigraphic sections near profiles G and H for comparison. The following, however, is suggested as possibly representing the stratigraphic section in this area:

3 – 40 ft	clay till, Drolet lentil of Lennoxville Till
15	varves
0 – 60	sand and gravel
120	varved clays
0 – 30	medium grained sands
20 – 35	hard till
5	fine gravel
6	lake sediments
	weathered bedrock

Seismic profiles F, G, and H all show significant bedrock depressions underlying topographic lows. These depressions appear to be infilled by lacustrine sediments overlying till.

Stratigraphic section 1 is adjacent to seismic profile K, and section 3 is adjacent to profile L (Fig. 7). Comparisons are set out as follows:

Section 1		Seismic station 18	
			848 ft
		1000 ft/s	843
	840 ft		
Lennoxville Till			
		3200 ft/s	830
	790	7100 ft/s	
silt-clay (Gayhurst Fm.)			
	740		
	~735		
approximately bedrock			
			691
		bedrock 17 300 ft/s	

Section 3		Seismic station 21	
			1059 ft
		1300 ft/s	1050
	1025 ft		
Lennoxville Till			
	1009		
silt-clay			
	986	7150 ft/s	
sand and gravel	945 T.D.		
			903
		bedrock 19 400 ft/s	

The bedrock depression indicated beneath seismic station 23 on seismic profile L may not be as indicated. The velocity of 10 200 ft/s (Fig. 7B) may indicate bedrock, in which case bedrock is very shallow under station 23 and plunges off beneath station 22.

APPENDIX 4

Palynology of Southeastern Quebec

by

R.J. Mott*

Three lake bottom sediment cores from southeastern Quebec have been analyzed in detail. Boundary Pond (45°34'N, 70°40.5'W) and Unknown Pond (45°36'N, 70°38'W) are in Maine, United States of America, a few hundred metres east of the International Boundary with Quebec. Boundary Pond is about 15 km east of Lac-Mégantic, Quebec and Unknown Pond is 5 km northeast of Boundary Pond. The third lake, Lac Dufresne (45°51'N, 70°21'W), is in Quebec about 35 km northeast of Unknown Pond. Elevation of the sites are 603, 489, and 650 m, respectively.

Radiocarbon dates on basal organic sediments were obtained for all three sites: 11 200 ± 160 years (GSC-1294) for Lac Dufresne, 11 200 ± 200 years (GSC-1248) for Boundary Pond, and 14 900 ± 240 years (GSC-1339) for Unknown Pond (Fig. 1, 2, 3). Because the latter date appeared anomalous, a second age determination was made on sediment above the first sample interval, and an age of 12 700 ± 280 years (GSC-1404) was obtained. Radiocarbon dates on basal organic sediments from two other lakes in the area which were not used for palynological study were similar to the Lac Dufresne and Boundary Pond dates: Lac aux Araignées, 12 km south-southeast of Lac-Mégantic, has a basal organic sediment date of 10 700 ± 310 years (GSC-1353), and at Lac des Truites, 15.5 km northeast, a date of 11 000 ± 240 years (GSC-1289) was obtained. Except for Unknown Pond, all the basal dates are similar, suggesting that those from Unknown Pond are anomalously old; pollen evidence corroborates this.

At Unknown Pond and Lac Dufresne a pollen assemblage (Fig. 1, 2) dominated by non-tree pollen characterizes the basal organic sediments. Sedge (Cyperaceae) pollen is abundant along with alder **(Alnus)**, willow **(Salix)**, birch **(Betula)**, grass (Gramineae), and **Artemisia.** Some spruce **(Picea)** and pine **(Pinus)** pollen are present but in relatively small amounts. This pollen assemblage is not represented at Boundary Pond (Fig. 3) where the basal assemblage, although still exhibiting abundant sedge pollen and other non-tree taxa, has more spruce pollen and less birch. Pollen spectra showing abundant spruce occur above the basal non-tree pollen zones at Unknown Pond and Lac Dufresne and correlate with the spruce zone at Boundary Pond.

Similar pollen spectra occur above the spruce pollen zone in the diagrams from all three sites (Fig. 1, 2, 3). With the decrease in the abundance of spruce and non-tree pollen, birch becomes the dominant genus accompanied by balsam fir **(Abies balsamea)**, oak **(Quercus)**, and white pine **(Pinus strobus).** Several other thermophilous taxa also appear in significant numbers at this time. Associated with this change in pollen spectra is an abrupt increase in the numbers of pollen grains. This increase appears to be synchronous at the three sites and emphasizes the anomalous radiocarbon dates obtained from Unknown Pond. Interpolation between the radiocarbon dates from Boundary Pond indicates a date of about 10 000 years for this phenomenon. A date of about 12 000 years for the equivalent level in the Unknown Pond profile indicates an error in the lower radiocarbon dates from Unknown Pond of about 2000 years. The date of 14 900 years probably incorporates an even greater error, but a more accurate estimate is not possible because of the lack of dates from a similar pollen stratigraphic level at other sites.

Subsequent to the pollen assemblages described above, spruce pollen declines further, white pine increases to a maximum and declines as hemlock **(Tsuga canadensis)** increases to a low maximum. Hemlock then decreases in relative abundance as birch pollen increases to maximum values, and beech **(Fagus)** increases significantly. Maple **(Acer)** pollen also increases slightly whereas oak **(Quercus)** declines. Minor fluctuations involving hemlock and some hardwood genera follow until, near the top of the profiles, spruce pollen increases and many other taxa decline in relative abundance. Several radiocarbon dates throughout the profiles date particular pollen assemblages. These dates are shown adjacent to the stratigraphic column for each site.

The major vegetational and climatic conditions that prevailed throughout the last 11 000 years can be deduced from the pollen data. The basal assemblages at Unknown Pond and Lac Dufresne attest to a cool climate and a landscape with scattered herbaceous and shrubby vegetation and few, if any, trees present. Then spruce increased in abundance, and spruce woodland with abundant open areas supporting herbaceous and shrubby vegetation prevailed.

About 10 000 radiocarbon years ago prominent changes occurred in the pollen spectra and the amount of pollen being deposited increased considerably in a short time, indicating a proliferation of trees in response to an amelioration of the climate. Closed forests containing balsam fir and birch as well as spruce formed, and the open areas supporting shrubs and herbs were eliminated. White pine probably was present on the better sites, and various broadleaved hardwoods including oak and maple became prominent. Maple is very poorly represented in pollen spectra and judging by the amount of maple present in the modern forests compared with its pollen representation in surface samples, it must have been even more abundant early in the development of the forests. Spruce and balsam fir then declined as other taxa proliferated, and by about 7500 years ago were much less prominent than previously. A rapid decline in hemlock about 5500 to 6000 years B.P. preceeded by a decrease in pine and increases in birch, probably yellow birch **(Betula alleghaniensis)**, and beech culminated in mixed hardwood forests with less coniferous species present.

This mixed hardwood forest dominated by yellow birch and maple with some beech, other hardwoods, and minor hemlock and pine probably characterized the valleys and lower slopes, whereas white birch, spruce, and fir covered the higher ridges. These associations persisted with only minor fluctuations until about 1500 years B.P. when spruce began to increase in abundance at the expense of pine, hemlock, and most hardwood genera. A deterioration of the climate was the probable cause and ultimately produced the extant forests of the region with the upper slopes and ridges dominated by white birch, spruce, and balsam fir, and the lower slopes and valleys supporting the mixed hardwoods characterized by yellow birch, sugar maple, and beech.

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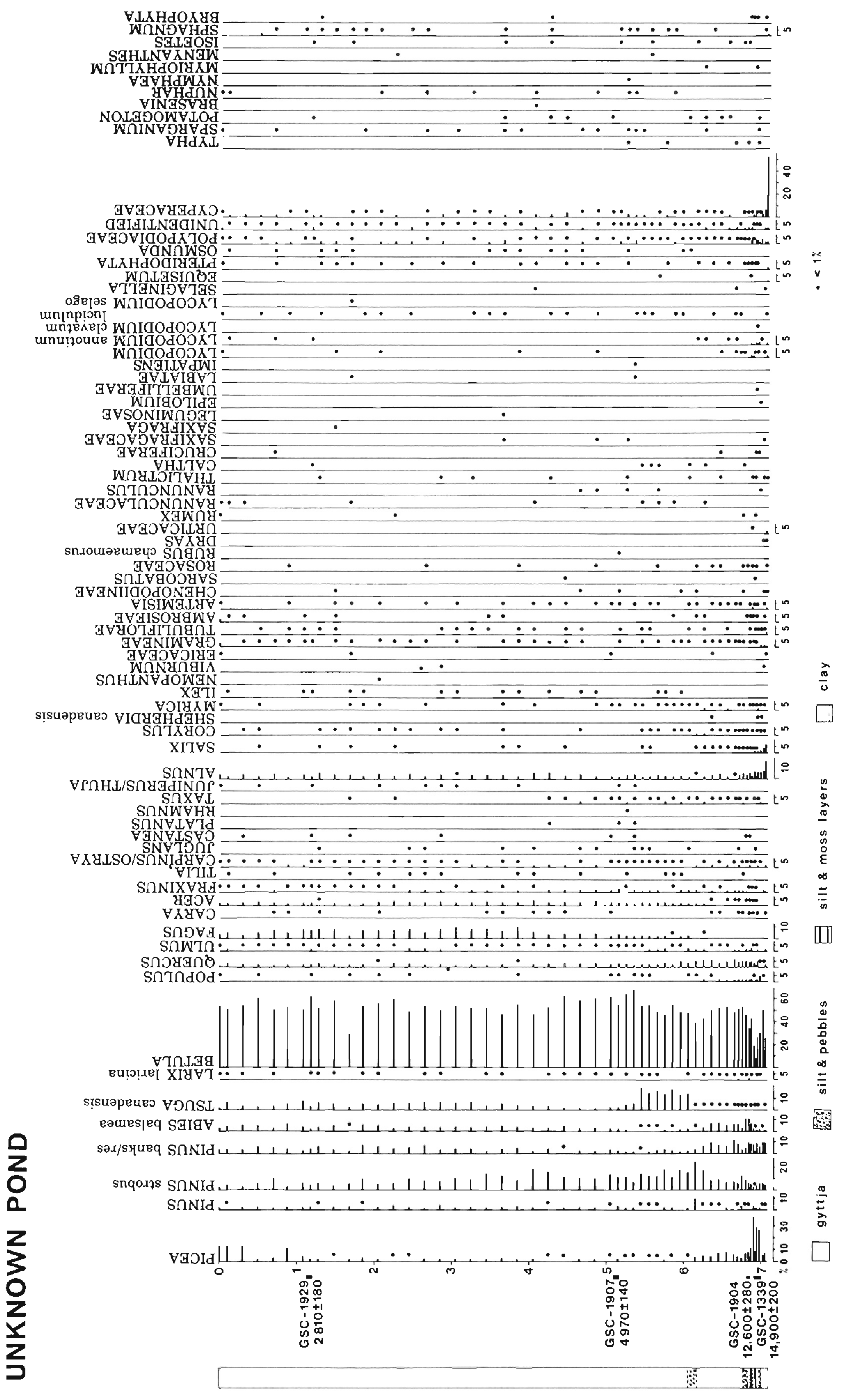

UNKNOWN POND
PICEA
PINUS
PINUS strobus
PINUS banks/res
ABIES balsamea
TSUGA canadensis
LARIX laricina
BETULA
POPULUS
QUERCUS
ULMUS
FAGUS
CARYA
ACER
FRAXINUS
TILIA
CARPINUS/OSTRYA
JUGLANS
CASTANEA
PLATANUS
RHAMNUS
TAXUS
JUNIPERUS/THUJA
ALNUS
SALIX
CORYLUS
SHEPHERDIA canadensis
MYRICA
ILEX
NEMOPANTHUS
VIBURNUM
ERICACEAE
GRAMINEAE
TUBULIFLORAE
AMBROSIEAE
ARTEMISIA
CHENOPODIINEAE
SARCOBATUS
ROSACEAE
RUBUS chamaemorus
DRYAS
URTICACEAE
RUMEX
RANUNCULACEAE
RANUNCULUS
THALICTRUM
CALTHA
CRUCIFERAE
SAXIFRAGACEAE
SAXIFRAGA
LEGUMINOSAE
EPILOBIUM
UMBELLIFERAE
LABIATAE
IMPATIENS
LYCOPODIUM
LYCOPODIUM annotinum
LYCOPODIUM clavatum
lucidulum
LYCOPODIUM selago
SELAGINELLA
EQUISETUM
PTERIDOPHYTA
OSMUNDA
POLYPODIACEAE
UNIDENTIFIED
CYPERACEAE
TYPHA
SPARGANIUM
POTAMOGETON
BRASENIA
NUPHAR
NYMPHAEA
MYRIOPHYLLUM
MENYANTHES
ISOETES
SPHAGNUM
BRYOPHYTA
GSC-1929
2 810±180
GSC-1907
4 970±140
GSC-1904
12,600±280
GSC-1339
14,900±200
0
1
2
3
4
5
6
7
%
• < 1%
gyttja
silt & pebbles
silt & moss layers
clay

Figure 1

LAC DUFRESNE

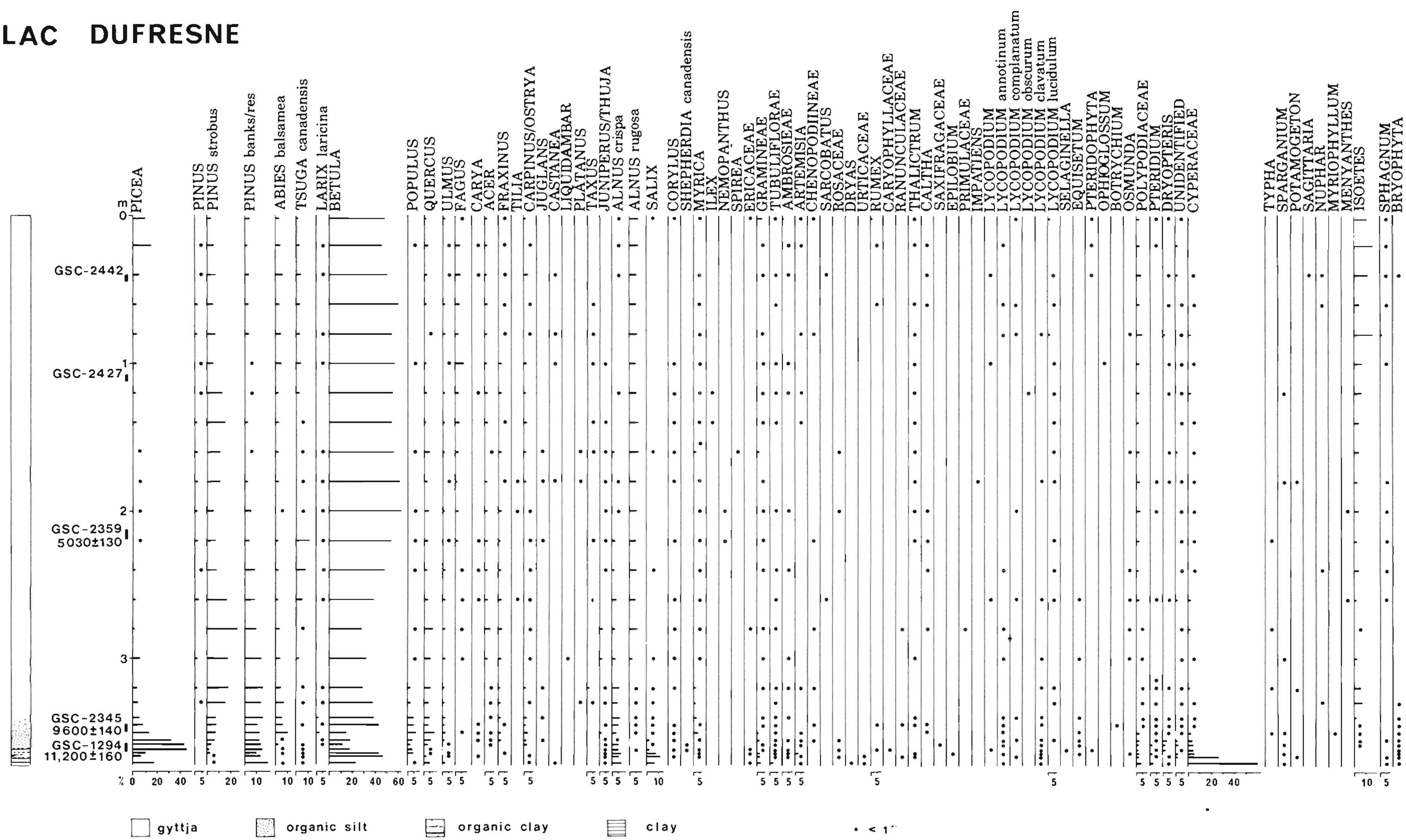
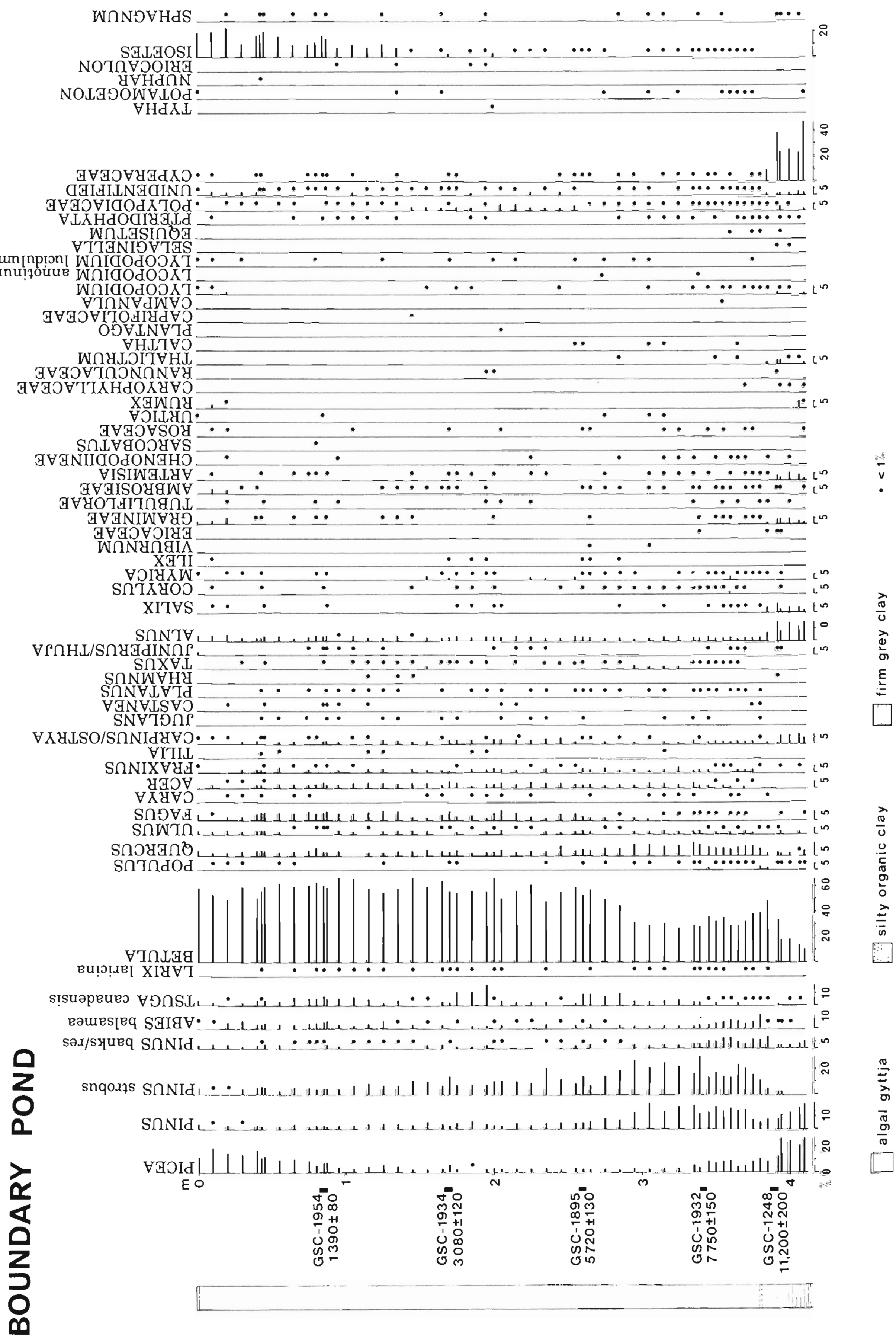


Figure 2


BOUNDARY POND
m
0
1
2
3
4
GSC-1954 1390±80
GSC-1934 3080±120
GSC-1895 5720±130
GSC-1932 7750±150
GSC-1248 11,200±200
PICEA
PINUS
PINUS strobus
PINUS banks/res
ABIES balsamea
TSUGA canadensis
LARIX laricina
BETULA
POPULUS
QUERCUS
ULMUS
FAGUS
CARYA
ACER
FRAXINUS
TILIA
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MYRICA
ILEX
VIBURNUM
ERICACEAE
GRAMINEAE
TUBULIFLORAE
AMBROSIEAE
ARTEMISIA
CHENOPODIINEAE
SARCOBATUS
ROSACEAE
URTICA
RUMEX
CARYOPHYLLACEAE
RANUNCULACEAE
THALICTRUM
CALTHA
PLANTAGO
CAPRIFOLIACEAE
CAMPANULA
LYCOPODIUM
LYCOPODIUM annotinum
LYCOPODIUM lucidulum
SELAGINELLA
EQUISETUM
PTERIDOPHYTA
POLYPODIACEAE
UNIDENTIFIED
CYPERACEAE
TYPHA
POTAMOGETON
NUPHAR
ERIOCAULON
ISOETES
SPHAGNUM
%
algal gyttja
silty organic clay
firm grey clay
• < 1%

Figure 3

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