GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

MEMOIR 359

PLEISTOCENE GEOLOGY OF THE CENTRAL ST. LAWRENCE LOWLAND

with selected passages from an unpublished manuscript *The St. Lawrence Lowland,* by J. W. Goldthwait

N. R. Gadd

Ottawa
Canada
1971
Reprinted 1973
Reprinted 1984

Price, $8.00

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1,450—1971—6154

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MEMOIR 359 — Pleistozäne Geologie des zentralen St.-Lorenz-Tieflands

Von N. R. Gadd

Es wird die Geologie zweier Vergletscherungsperioden erörtert, die ein wichtiges, auf die Zeit vor ca. 65 000 Jahren (frühe Wisconsin-Zeit) datiertes eisfreies Stadium trennt. Auf die zweite Vergletscherungsperiode folgte eine als Champlain-Meer bezeichnete Ueberschwemmung, die reichliche, 9300 bis über 11 800 Jahre alte fossilführende Ablagerungen hinterlassen hat. Die durch spätere Hebung verursachte Flußerosion hat zur Ausbildung von Hochterrassen in zwei Stufenfolgen geführt.

МЕМУАР 359 — Геология плейстоцена центральной части низменности Св. Лаврентия

Нельсон Р. Гэдд

Описываются геологические данные двух оледенений, отделенных друг от друга значительным не-гляциальным интервалом. Последний датируется приблизительно 65.000 лет до нашего времени (1950) (ранний висконсен). За вторым оледенением последовал морской разлив, известный под именем моря Шамплейн, который оставил после себя широко разпространенные отложения, содержащие ископаемые организмы возраста от 9.300 до 11.800 лет до нашего времени. Следующий подъем явился причиной значительной речной эрозии, что привело к возникновению двух групп поднятых террас.

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PLEISTOCENE GEOLOGY OF THE CENTRAL ST. LAWRENCE LOWLAND

Abstract

This report deals with central St. Lawrence Lowland areas in the province of Quebec between Sorel and Portneuf, as measured along St. Lawrence River, and extending south of the St. Lawrence to the vicinity of Drummondville. Thick surficial deposits exposed along major river valleys record two glaciations separated by a significant non-glacial interval. Principal groups of surficial deposits are, from oldest to youngest: Bécancour till[1] and associated sediments, St. Pierre sediments, Gentilly till[1], Champlain Sea clay and sand, and the non-marine high terrace and low terrace sands.

Bécancour till overlies and is in turn overlain by glaciolacustrine silt deposits. These sediments may be of very early Wisconsin age, by virtue of dated materials that unconformably overlie them, but may also be older.

The St. Pierre non-glacial interval is represented by alluvial sand, silty sand, and minor gravel incorporating important heavily compressed layers of peat containing much wood. The optimum climate represented by vegetal remains is sub-boreal forest, and radiocarbon ages are of the order of 65,000 years B.P., thus early Wisconsin.

Glacial deposits record the ponding of glacial Lake Deschaillons at the close of the St. Pierre interval, and the advance of a glacier that overrode the glacial lake and deposited Gentilly till; the retreat of the ice margin across the area is recorded in ice-contact stratified drift of two morainic systems. Drummondville moraine was built under glacial and freshwater influence, and St. Narcisse moraine was built presumably with the ice margin standing in Champlain Sea. That marine inundation followed closely upon or was simultaneous with recession of the ice margin is supported by the presence in the area of several sections in which there is a gradational contact relationship between glaciolacustrine and overlying glaciomarine sediments.

Thick deposits of fossiliferous silt and silty clay occupy the central part of the basin of Champlain Sea, and fossiliferous sand and gravel occupy areas that were at one time under shore and near-shore influences within the Champlain Sea; however, the area lies entirely within the basin of the late-glacial sea and therefore nowhere records its maximum extent or depth. All glacial features at the surface have been modified in some way by the deposits and/or erosive forces of Champlain Sea. Radiocarbon dates of this and adjoining areas place the age of Champlain Sea at or beyond 11,800 years, but also indicate that it may have terminated in this area at least 9,500 years ago.

Isostatic adjustment of the land surface with respect to sea level has caused relative uplift of the lowland, and exposure of the bottom sediments and their erosion first by estuarine and then by fluvial action. Two sets of sand deposits record these erosional events. High terrace sands laid at levels as much as 300 feet above present sea level represent estuarine and deltaic sedimentation; this phase probably began at least 9,500 years ago. More recently alluvial terraces enclosed by steep river-trimmed escarpments were developed at levels between 100 feet elevation and present water levels.

[1] Formational names introduced by Gadd in 1960 were Bécancour Till and Gentilly Till and should be read as such.

Résumé

Le présent rapport traite des régions des basses-terres centrales du Saint-Laurent dans la province de Québec comprises entre Sorel et Portneuf le long du Saint-Laurent et s'étendant, au sud du fleuve, jusqu'à proximité de Drummondville. D'épais dépôts meubles, visibles le long de vallées des rivières principales, demeurent le témoignage de deux périodes de glaciation séparées par un long intervalle non-glaciaire. Les principaux dépôts meubles sont groupés du plus anciens au plus récents: le till de Bécancour et les sédiments de Saint-Pierre, le till de Gentilly, les argiles et les sables de la mer Champlain et les sables non-marins de la terrasse supérieure et de la terrasse inférieure.

Le till de Bécancour recouvre des sédiments de limon glacio-lacustre et repose sous le même type de sédiments. Ceux-ci peuvent être du tout début du Wisconsin, en raison de l'âge des matériaux qui les recouvrent en discordance, mais ils peuvent être également plus anciens.

L'intervalle non-glaciaire de Saint-Pierre est représenté par d'importantes couches de tourbe fortement comprimée contenant de fortes quantités de bois, elles sont incorporées à des sables alluviaux, à des sables limoneux et à un peu de gravier. Les végétaux fossiles représentent un climat optimum de forêt subboréale, et la datation au radiocarbone leur attribue un âge de l'ordre de 65,000 B.P. correspondant donc au début du Wisconsin.

Les dépôts glaciaires attestent la formation du lac glaciaire de Deschaillons à la fin de l'intervalle de Saint-Pierre, et l'avance d'un glacier qui a comblé ce lac glaciaire et formé le till de Gentilly; le recul du front glaciaire dans cette région est attesté par l'accumulation de drift stratifié juxta-glaciaire appartenant à deux systèmes morainiques. La moraine de Drummondville s'est formée sous l'influence d'un glacier et de l'eau douce, tandis que la moraine de Saint-Narcisse s'est formée probablement au moment où le front glaciaire se trouvait dans la mer Champlain. Que la transgression marine ait suivi de près le recul du front glaciaire ou lui était simultanée, le retrait est établi par la présence dans la région de plusieurs coupes où le passage des sédiments glacio-lacustres aux sédiments marins qui les recouvrent est graduel.

D'épais dépôts fossilifères, constitués de limon et d'argile limoneuse, occupent la partie centrale du bassin de la mer de Champlain, des sables et des graviers fossilifères occupent des régions qui se sont trouvées un certain temps soumises à l'influence d'un milieu littoral et sublittoral dans la mer Champlain; toutefois, la région s'étend entièrement dans les limites du bassin qu'occupait la mer vers la fin de l'époque glaciaire; elle ne peut donc attester en aucun endroit l'extension ou la profondeur maximales de cette mer. Toutes les caractéristiques glaciaires de la surface ont été, en quelque sorte, modifiées par les sédiments et l'action érosive de la mer Champlain ou par l'action érosive seule. La datation au radiocarbone de cette région et des régions adjacentes attribue à la mer Champlain un âge de 11,800 années ou plus, mais elle indique également qu'elle a peut-être cessé d'exister depuis au moins 9,500 ans.

Le retour à l'équilibre isostatique entre la surface du sol et le niveau de la mer a provoqué la soulèvement relatif des basses-terres, la mise en affleurement des sédiments du fond, l'accroissement de l'action érosive des estuaires et des eaux courantes en général. Deux ensembles de dépôts sableux sont les témoins de ces actions érosives. Les sables de la terrasse supérieure, déposés à des niveaux qui se trouvent actuellement à quelque 300 pieds au dessus du niveau de la mer, représentent une sédimentation d'estuaires et de deltas; cette action a probablement commencé il y a au moins 9,500 ans. Plus récemment, des terrasses alluviales entourées d'escarpements abrupts découpés par des cours d'eau se sont formées à des niveaux entre 100 pieds et les niveaux actuels des eaux.

Chapter I

INTRODUCTION

Location and Access

The central part of the St. Lawrence Lowland described in this report (Fig. 1) includes the area in the province of Quebec bounded by 45°45′ and 46°30′ north latitudes and 72°30′ and 73°00′ west longitudes, as well as that bounded by 46°00′ and 46°45′ north latitudes and 72°00′ and 72°30′ west longitudes. These areas combined include the following six map-areas of the National Topographic Series: Upton (31 H/15), Yamaska (31 I/2), Trois-Rivières (31 I/7), Aston (31 I/1), Bécancour (31 I/8), and Grondines (31 I/9). In this report these areas are covered by a single map (Map 1197A, *in pocket*) at the natural scale of 1:125,000. It includes parts of Maskinongé, St-Maurice, Champlain, and Portneuf counties on the north shore of the St. Lawrence; and of Nicolet, Yamaska, Lotbinière, Arthabaska, Bagot, Berthier, Richelieu, St-Hyacinthe, and Drummond counties on the south shore.

The area is accessible from Montreal and Quebec by major highways leading to centres in the area such as Trois-Rivières (highway 2), and Drummondville (highways 3 and 9). St. Lawrence River, with its port at Trois-Rivières, makes the area accessible by shipping routes as well.

Previous Work and Development of Present Concepts

Formal geological studies of eastern Canada began with the inauguration of the Geological Survey of Canada in 1842. Before this time, however, many students of natural history had made geological collections, primarily of fossils, and had made important contributions to the literature through the bulletins of various natural history and geological societies. One such contributor to the field of surficial geology was Professor J. William Dawson, who "...first entered on the study of these deposits in Nova Scotia, in the year 1841" (Dawson, 1893, p. 3) and continued studies during his period of teaching at Dalhousie University. When he became Principal of McGill University in 1855 he obtained a commission from the Geological Survey of Canada to study Pleistocene geology of St. Lawrence Valley, with particular emphasis to be placed on Montreal and its environs. He (Dawson, 1893, p. 5):

> ...proceeded in the first instance, to explore the stratigraphical arrangement and fossils of the deposits, dividing the former into the three groups of Boulder Clay, Leda Clay and Saxicava Sand, and raising the known species of fossils in a few years from a very small number to about 200.

In the study of fossils he also "...instituted comparisons between them and the present fauna of the Gulf of St. Lawrence and of the Labrador coast" (Adams, 1900).

Original manuscript submitted January 14, 1963.
Final version approved for publication September 29, 1966.

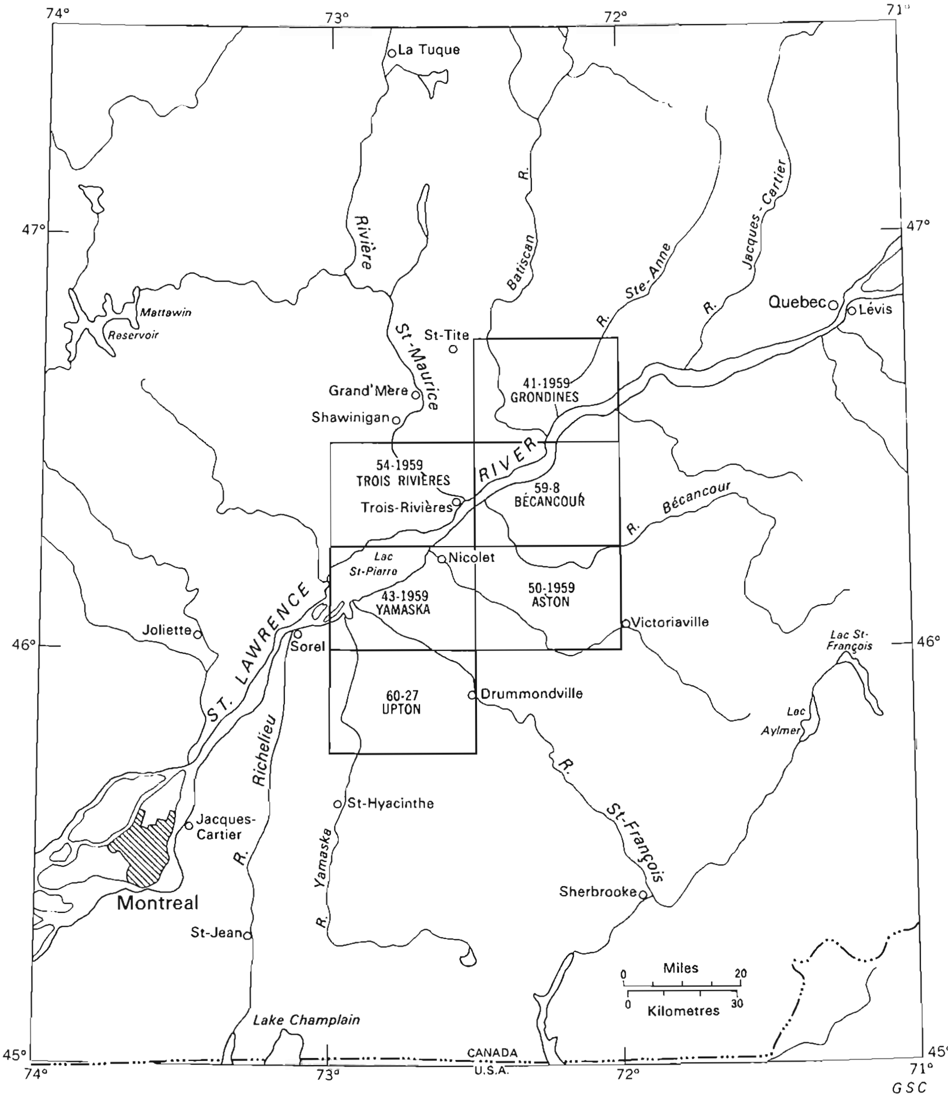

FIGURE 1. Location within map-area of previously published preliminary one-mile sheets.

Sir William E. Logan compiled a symposium of knowledge of the geology of (eastern) Canada as recorded in the reports of the Geological Survey of Canada up until 1863 (Logan, 1863). This contained an eighty-one-page chapter on 'Superficial Geology'. Dawson (1893, p. 6) referred to Logan and this chapter when he wrote:

> ...when, in 1863, Sir William issued his 'Geology of Canada', I was much occupied with college work, and felt that the subject was too immature to admit of full treatment, but placed in his hands my notes up to that date to aid in his chapter on 'Superficial Geology', in which they were incorporated, though in an imperfect manner.

Later publications (Dawson, 1872, 1893) were aimed at removing the alleged imperfections imposed by Logan. In essence the argument between Dawson and his contemporaries arose over Dawson's heavy dependence on the marine drift theory for the formation and emplacement of glacial and glaciomarine sediments, whereas other naturalists of the time, including Logan, were more closely aligned with the modern theory of continental glaciation. The final effort to win his argument was made when Dawson (1893) published privately *The Canadian Ice Age*, which embodies his comprehensive view of the marine origin of the till and some younger sediments in St. Lawrence Valley and other parts of Canada. These views were never adopted by Logan, and hence never appeared in publications of the Geological Survey of Canada. With the death of Sir J. William Dawson in 1900, Canada lost its strongest proponent of the marine drift theory, and the controversy involving it disappeared from the literature.

We dwell here on the work of Dawson not because of the above-mentioned controversy, but because he made other contributions that have had more lasting effects on studies of surficial geology in Canada. We have mentioned the contribution to Pleistocene paleontology; among the species identified by Dawson were: *Leda glacialis* (now *Yoldia arctica* or *Portlandia arctica*) and *Saxicava rugosa* (now *Hiatella arctica*) (Wagner, 1967, 1971). From their relative abundance in clay and sand facies of marine sediments, Dawson coined the names *Leda clay* and *Saxicava sand.* The sediments were considered by Dawson as related facies of one marine episode, the *Leda clay* being the deep-water facies and the *Saxicava sand* the shallow-water or shore facies. These names have been preserved to the present, although indiscriminate use of the terms has caused confusion and misconception in the interpretation of some sediments and physical features of the St. Lawrence Lowland. There has been a tendency to apply the names wherever sand overlies clay in the region, regardless of whether the above-mentioned fossils are present. However, more recent work has proven that in many places where the presence of these two marine sediments has been inferred either one or both may be missing, and that the sediments found in their place are indeed of some origin other than marine.

Another concept that Dawson presented to his contemporaries was that of a single marine invasion of St. Lawrence Valley in postglacial time. He said (1893, pp. 56, 57):

> I believe the Leda clays throughout Canada to constitute in the main one contemporaneous formation. Of course, however, it must be admitted that the deposit at the higher levels may have ceased and been laid dry while it was still going on at lower levels nearer the sea, just as a similar deposit still continues in the gulf of St. Lawrence. On the whole, then, while we regard this as one bed, stratigraphically, we may be prepared to find that in the lower levels the upper layers of it may be somewhat more modern than those portions of the deposit occurring on higher ground and farther from the sea.

This usage of the terms 'upper' and 'lower' in an essentially topographic sense by Dawson, confusing enough in the original, and their subsequent use by contemporaries and later writers in a stratigraphic sense that inferred the existence of an upper and a lower clay, have provided some true conundrums impossible of solution without careful reexamination of all sections involved. Indeed, writers for a period following Dawson and Logan found it most difficult to correlate with earlier work and to discuss the discovery of facies within the units described earlier.

Among early proponents of the theory of continental glaciation was Robert Chalmers. He began formulating his ideas as an assistant on Geological Survey field parties in the Maritimes and gradually developed his concepts as he undertook independent work on surficial geology there and in the St. Lawrence Lowland. From the earliest of his reports Chalmers was careful to define his terms and the limitations of their use in his work, and to present factual observations and then to set down clearly a logical interpretation of them. In this manner he arrived at the deductions that ice accumulated in central New Brunswick, and at most times moved from a central divide both north towards the Gulf of St. Lawrence and south towards the Bay of Fundy (Chalmers, 1886, p. 5GG). This view was reiterated the following year (Chalmers, 1887, p. 19M).

At the time he recognized three agencies, continental ice sheet, local glaciers, and floating ice, which he believed acted in the order cited to produce most of the phenomena observed. Later (1890, p. 16N) he added the process of re-working of glacial till by wave-wash to produce boulder accumulations. This countered the ice-rafting theories of contemporaries (e.g. Ells, 1889, p. 100K). By 1886 Chalmers (1887, p. 8M; 1890, p. 66N) had evidence that there was a defined upper limit to marine submergence in the Maritimes and in St. Lawrence Valley. This conviction was later supported (Chalmers, 1895) by maps showing separately his concept of the extent of marine overlap in New Brunswick, Nova Scotia, and Prince Edward Island, and his view of the extent and direction of movement of glaciation in those areas.

Although contemporary colleagues published statements opposing the theory of continental glaciation and supporting either the marine drift theory or that involving numerous local glaciers (e.g., Ells, 1887, p. 44J), or both (Ells, 1889, p. 100K), Chalmers held to his hypotheses as logical interpretations of facts observed. He always left open the possibility that his interpretations might be incorrect, however, and that new factual data might require their revision. For most areas observed in the Maritimes, Chalmers (e.g., 1888, p. 16N) claimed a threefold sequence of events: (1) continental glaciation, (2) minor secondary glaciers in upland areas, and (3) local redistribution of boulders by shore ice and by wave-washing action. His most expansive hypothesis was based on observations throughout St. Lawrence Valley and particularly in alluvial gold areas in southeast Quebec (Chalmers, 1899). According to that hypothesis the Appalachian region, being higher and in more direct contact with moisture-laden winds from the Atlantic, was glaciated before the Laurentians; hence early northward-moving glaciers formed in the areas he examined in southeast Quebec and the Maritimes. Later, under more severe climatic conditions, an icecap developed over the Laurentian region and produced glaciers that moved southward across St. Lawrence Valley, overriding the Appalachians and reaching some distance beyond. Chalmers recognized two distinct Laurentide glaciers, the first moving southward and southeastward, the second southwestward, but did not record any interglacial beds, although he referred to stratified sediments intercalated between till sheets (Fig. 2). Following the two Laurentide glaciations Chalmers postulated local glaciation, i.e., small isolated caps

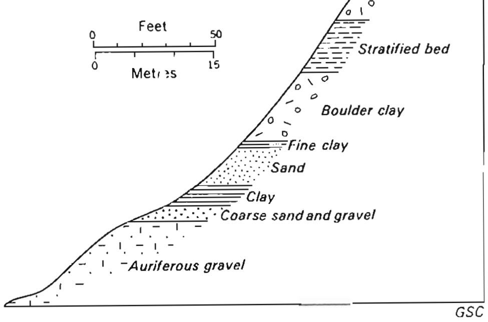

FIGURE 2

Section showing evidence of multiple glaciation near mouth of Rivière Linière (figure modified from Chalmers, 1899, p. 43J when R. Linière was identified as Rivière-du-Loup).

and/or valley glaciers, remnants of the original icecap, in highland areas both north and south of St. Lawrence Valley; their movement was generally towards the lowland areas. Floating ice and wave-wash of sediments below defined levels caused concentration of boulders and re-working of sediments in areas affected by late-glacial and postglacial high-water stages. '*Leda clay*' and '*Saxicava sand*' were deposited during these high-water stages, and these sediments in turn were affected by freshwater erosion and deposition during the time extending to the present. This interpretation still remains as a valid working hypothesis, most of which is supported by more recent studies.

It seems anomalous that the marine drift concepts of Sir J. William Dawson were never published by the Geological Survey of Canada, while those of Ells were common almost until the turn of the century, but perhaps it was because Ells' interpretation dealt chiefly with transport of Laurentian boulders southward across the St. Lawrence and were therefore more conservative than those of Dawson. As Chalmers became more prolific with his publications and began his careful studies on St. Lawrence Valley, Ells wrote less and less on surficial geology and ultimately appended to his works, or referred to, interpretations of surficial phenomena written by Chalmers (e.g., Appendix I of Ells, 1901). The turn away from the marine drift theory towards continental ice-sheet theories seemed general and was exemplified by this apparent suppression by Ells of his earlier theories.

Features of Chalmers' contribution were the above-mentioned maps concerning glaciation and marine overlap and his use of columnar sections, some of which showed more than one till sheet in the stratigraphic sequence (Fig. 2). He was able to show, at least to this writer's satisfaction, as regards glaciation of St. Lawrence Valley that: (1) glaciation was continental and occurred more than once; (2) the main body of ice had its origin somewhere north of the St. Lawrence, hence, a Labradorean or Laurentide icecap; (3) local glaciation in highland areas may have preceded and/or succeeded continental glaciation; and (4) the St. Lawrence Lowland was depressed differentially to a maximum of several hundred feet (as opposed to depression of a thousand feet or more proposed by some contemporaries), and was inundated by marine waters on removal of ice from the valley. He also recognized a limit to the flooding above which identifiable glacial features might be found. Subsequent differential movements of land and sea caused the land to emerge while terraces and escarpments were produced upon it by the bodies of water that have existed in the Lowland since its last glaciation.

In the half century since the most significant of Chalmers' contributions, some detail has been added to the general picture, but no major contradictory evidence has been presented to discredit his thesis. On the contrary, most evidence still seems to support it.

Joseph Keele (1915), in his studies of clay and shale in Quebec, recognized more than one type of clay in the region he studied, and criticized the use of the name 'Leda clay' for "all surface clays other than boulder clays" (1915, pp. 48, 49). Keele supported Chalmers' theory of multiple glaciation in the St. Lawrence Lowland with evidence from Yamaska county. His columnar sections (Fig. 3) show the presence of two till sheets with intercalated stratified sediments which "...seems to indicate that there were two periods of glaciation in this region" (Keele, 1915, pp. 80–82). He also indicated (Fig. 3, sect. 1) the presence of a buried peat bed in the valley of St-François River but did not advance any hypothesis as to its significance. This peat correlates with interstadial peat found elsewhere in the region, as described in a later section of this report. In addition, Keele (1915, p. 82) related the red colour of the older till shown in his sections to the presence in it of 'red Medina shale', or what is now known as the Bécancour River Formation (Clark, 1947).

A. P. Coleman was another observer of the Canadian Pleistocene who strongly supported multiple glaciation in the St. Lawrence Lowland. His reports on Newfoundland

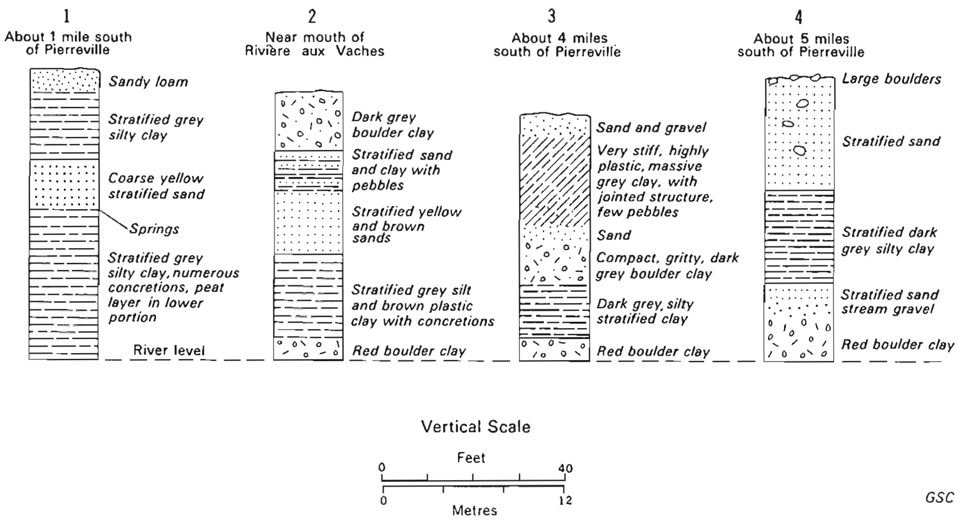

FIGURE 3. Four sections of Pleistocene deposits on St-François River, Yamaska County, from river level to top of bank (after Keele, 1915, p. 81).

(1926), Labrador (1921), Gaspé (1922), and the Great Lakes basin (1927, 1932a, 1941) have many references to sections containing more than one till. He was first to apply the Pleistocene stratigraphic nomenclature of the mid-western United States to Canadian deposits. Because he did not recognize substages of the Wisconsin, however, the uppermost till in any region was, to him, Wisconsin (undifferentiated), intervening material was of Sangamon age, and the next lower till was Illinoian. His stratigraphic correlations are therefore no longer valid, and his sections, though minutely described, cannot be correlated definitely without much detailed work.

The apparent discovery of marine shells in glacial till and of sections of marine clay capped by glacial till or containing many faceted and striated boulders led Coleman (1932b) to postulate an 'Interglacial Champlain Sea'. He felt that (1941, p. 172):

> In all probability there was a marine stage after each of the Pleistocene glaciations wherever the land stood low enough. The evidence of two or three sets of marine beds in the New England States and Long Island, as given by Fuller (1914), Clapp (1908), and others is naturally interpreted in this way and the same is true on the Pacific coast.
>
> In the St. Lawrence region the invasion of the sea following the retreat of the Wisconsin ice probably reached Ottawa and Brockville and the Champlain Valley, but at present it is hopeless to attempt to fix its boundaries because its deposits and fossils are so much like the interglacial ones.
>
> As suggested in "The Geology of Canada" seventy-five years ago, it is most likely that the lower marine deposits are younger than the others...

Though his contemporaries did not readily accept an interglacial sea, there was some support for the view that marine inundation may have been subdivided into more than one stage. From the several recorded sections of marine and glacial material in the vicinity of Ottawa, Antevs interpreted a deep-water marine phase represented by marine clay, a shallow-water phase represented by sands and gravels, and a younger marine transgression represented by a second body of clay (Antevs, 1925, pp. 67–69, 95–97). These events were later distinguished (Antevs, 1939, pp. 712, 713) as deposits of two marine transgressions separated by a freshwater fluvial interval. The older marine episode was the Champlain Sea, which followed immediately upon recession of the last local glaciation; Antevs named the younger marine episode the Ottawa Sea. He considered the upper limit of the Ottawa Sea to be 240 feet at Ottawa, where it is marked by a strongly developed terrace and escarpment, and about 400 feet near Pembroke and Brennan (north of Ottawa). According to his hypothesis a single marine clay was deposited above 240 feet at Ottawa, and two clays occupy the terrace below 240 feet. In other words, the areas of influence of the Ottawa Sea were supposedly characterized by two marine clays, an older Champlain Sea clay and a younger Ottawa Sea clay. This hypothesis was refuted by Mackay (1949) when he observed that more than one clay body existed above 400 feet in the Ottawa area. This writer also opposes Antevs' interpretation (Gadd, 1961), favouring rather that of W. A. Johnston (1916, 1917) who regarded the younger clays to be of lacustrine origin, whence 'Lake Ottawa' (Antevs' own term); Antevs later introduced the term "Ottawa Sea" for the phenomena previously attributed to "Lake Ottawa".

Subsequent interpretations and correlations made by Antevs would seem to be supplanted by a new interpretation that he published while the present report was being written. In referring to these earlier interpretations of the sandy beds between the two clay beds of the Ottawa region Antevs wrote (1962, p. 197):

> . . . these interpretations were never satisfactory. It now seems that the intervening erosions and sand beds were results of the Fossmill and the North Bay drainages. Smaller features in the sediments, such as breaks in the deposition, inconspicuous erosions, and abrupt changes in texture, can have been caused by tidal currents. The new explanation implies that the *Champlain Sea had only one deep-water stage.*[1]

The validity of correlation with the Fossmill and North Bay drainages cannot be argued at this point, except that it would seem to be rather speculative when the correlation is apparently based on the same data as that used for earlier interpretations, and no comparative stratigraphic studies have been published on these two areas in the time since Antevs' original varve studies. It does seem, however, that Antevs has now destroyed his own creation, the Ottawa Sea, and students are thereby free to investigate the validity of the concept of a lacustrine origin for the second, younger clay.

The problem of correlation of glacial-lake history of the Great Lakes basin with the marine history of the St. Lawrence–Champlain basin, both of which depend on recession of the last ice sheet, requires for its solution a detailed knowledge of large intervening land areas. Antevs (1925, Fig. 27) showed an ice-front position that started at Ottawa, passed just south of Montreal through Sherbrooke, and extended eastward from there along the Canadian Pacific Railway. This he said marked the edge of ice at the "Beginning of Marine Stage". In a manuscript prepared for the Geological Survey about 1933, but never published (*see* "Selected Passages from The St. Lawrence Lowland"), Goldthwait disagreed with Antevs' configuration of the supposed ice front. Instead of a straight border trending easterly through Sherbrooke, Goldthwait (1933, Fig. 2) indicated that

> . . . a broad, active lobe occupied the district from Montreal around through Sherbrooke and Chaudière Valley to Quebec City during the closing stage of ice recession. . . partly to conform better with striae requirements, and partly to keep the ice border down on ground low enough to allow the sea in along the line of the marine limit, which we have traced from Gaspé past Quebec to the head of Lake Champlain. (For full text, *see* "Selected Passages from the St. Lawrence Lowland").

[1]The italics are those of the present writer.

MacLean (*in* Dresser and Denis, 1944, pp. 487–527, Figs. 39, 40) outlined ice-front positions apparently lying along the Appalachian front for stages related to Lake Iroquois and Lake Frontenac. His account dealt mainly with a philosophical treatment of earlier literature and added enough from personal observations to make his interpretations reasonable working hypotheses. Flint's writings (1953, p. 909; 1963) add further knowledge on the subject of relations between the glacial Great Lakes and the Champlain Sea, but no definite correlation is yet possible. Limits now established for ages of major events are discussed in Chapter IV of this report.

Many workers have been concerned with the maximum extent of the Champlain Sea, but few have considered its recession. Goldthwait (1911a, 1912, 1914) spent several seasons measuring elevations of the limit of marine submergence in St. Lawrence Valley and of lower terraces of the Champlain Sea. Along with many others, Goldthwait recognized that shore features in the zone of the marine limit are poorly defined and are commonly barren of characteristic marine fauna, but he maintained that absence of fossils was not necessarily a sign of freshwater origin:

> Only by accurately measuring the elevations of all beaches, by properly correlating and reconstructing the warped water-planes they mark, and by drawing such inferences as seem safe from the fossil record and the relation of the shoreline to open sea, on the one hand, or to deserted lake outlets, on the other, may we separate the marine from those of lacustrine origin. (Goldthwait, 1933).

As a result of such a study Goldthwait argued that some of the higher beach levels recorded at Covey Hill, at Montreal, and near Ottawa were in reality those of glacial Lake St. Lawrence (Frontenac–Vermont), and that the limit of the Champlain Sea was in several places 200 feet or more lower than previously recorded. He suggested that the limit came close to 600 feet above sea level in the Montreal–Ottawa region, but was lower at most other points along the St. Lawrence Lowland. Chapman (1937) recorded a tilted marine water-plane that was parallel to the Coveville and Fort Ann stages of Lake Vermont and that attained highest levels near 600 feet north of Lake Champlain in St. Lawrence Valley; thus he in part confirmed Goldthwait's thesis.

Early recession of Champlain Sea was rapid, as recorded by a continuous series of beach ridges with small vertical interval; many of these are discontinuous and indistinct. The discovery of distinct shorelines whose elevations seemed to change little over great distances led Goldthwait (1933) to believe that periods of stability interrupted the uplift and left records at 210 feet at and near Montreal, and at 110 feet near Montreal and Quebec; he intimated further that as water levels dropped below 100 feet

> ...estuarine conditions involving down-valley gradient of the water-plane became well established below Montreal before the Micmac or twenty-foot stage of the lower St. Lawrence.

Goldthwait (1933) described a 50-foot terrace near Lac St-Pierre that the writer agrees is non-marine and also that its origin is related partly to establishment of a local base-level of erosion while masses of glacial debris were eroded from preglacial channels between Lac St-Pierre and Quebec City. That part of St. Lawrence Valley is much constricted and only a very narrow strip of land along the river lies below 100 feet elevation. Goldthwait suggested that in this constricted part of the valley sufficiently strong freshwater currents might have developed to flush out salt water and prevent the formation of marine features below 100 feet. Downstream from Quebec City, however, he observed distinctly marine features at levels as low as 20 feet in the 'Micmac Terrace' (Goldthwait, 1911a, pp. 229–232; 1911b, pp. 291–317; 1913, pp. 50, 51, 77–79).

Over a period of 20 years after the work of Goldthwait, Johnston, and Antevs, very little was written concerning the surficial deposits of St. Lawrence Valley. More recently, Osborne (1950a, 1950b, 1951) postulated a series of glacial and late-glacial events in the area between Montreal and Quebec. His conclusions are based on earlier theories viewed in the light of his interpretation of some new observations.

Osborne theorized that a tongue of ice was advancing southward from the "Parc des Laurentides Ice Cap", north of Quebec City, late in Wisconsin time; this was considered to be a correlative of Antevs' "Cochrane" stage (Osborne, 1951, pp. 241, 242; Antevs, 1931, p. 19). According to Osborne, this ice tongue depressed the lowland, then stagnated and gradually retreated by downwasting, thus opening the St. Lawrence Valley at Quebec and allowing the "Quebec Sea", which he suggested (p. 243) correlates with Antevs' "Ottawa sea", to gain "entry to the lowlands along their northern edge" (Osborne, 1950b, p. 885). In this manner a large body of ice stagnated in the valley. Streams of meltwater from the stagnant ice built a prominent delta northward into the sea at Mont-Carmel, approximately 6 miles southeast of Shawinigan Falls, while marine waters extended over the surface of the rotting ice to deposit only fine sand in crevasses along the south margin of the ice tongue in what is now the Lotbinière region of Quebec. Preservation of these so-called "marine crevasse fillings" involved rather suppositious events during which:

> ...the surface was protected by ice until the sea fell below 210 feet but was exposed to wave action by the time the surface was at 105 feet. (Osborne, 1950b, p. 888).

As some of the "marine crevasse fillings" occur within the map-area of the present report, and as it will be necessary to interpret them in developing the glacial history, the writer will reserve further comment on Osborne's hypothesis for a later part of this report where he proposes to explain the various features described by Osborne as the products of normal recession of a Laurentide ice sheet and the progressive inundation of the St. Lawrence Lowland along its southern margin.

Recent studies of marine molluscs and marine beach levels in the St. Lawrence Lowland (Elson, 1960, 1962a) support Goldthwait's theory of transition from marine to freshwater conditions well above present St. Lawrence River levels, and the presence in some areas of freshwater molluscs has led to the introduction of the name 'Lampsilis Lake' for this body of water (Elson, 1960, pp. 2, 3).

The writer has mentioned primarily those earlier studies that have bearing on work within the area under consideration in this report. For a somewhat broader treatment of the development of studies of glacial history in eastern Canada, the reader is referred to the excellent work of professor Alexander MacLean in his chapter in 'Geology of Quebec' (Dresser and Denis, 1944, pp. 487–527).

Field Work

The writer's first work in the St. Lawrence Lowland was a study of groundwater conditions of Bécancour map-area (31 I/8), which started in the summer of 1950 and continued until 1952. This work involved locating the existing wells in the area and measuring, where possible, surface elevation, depth to water, and total well depth. In addition an effort was made to obtain, by interview with the proprietor of each well, some additional information on quality and quantity of water and the nature of aquifers involved. By means of a verbal report to the Council of the Community of Manseau, the writer described the groundwater situation of the area and of that community in particular. Subsequent development of water supply facilities at Manseau was based on this report and on its interpretation by the late Mr. Roland Deblois of the Quebec Department of Mines. No further publication of the data has been made, but records remain on open file at the Geological Survey of Canada in Ottawa.

A study of the surficial geology of Bécancour map-area became the dominant part of the field program in 1952 and was completed in the early part of the 1953 season. Later in 1953 geological field studies were begun in Aston map-area (31 I/1); these were completed in 1954 when the writer also mapped the surficial deposits of Yamaska map-area (31 I/2). During 1954 the writer supervised the field work of Paul F. Karrow who carried out most of the mapping in Trois-Rivières map-area (31 I/7); minor field mapping and compilation of the Trois-Rivières map for publication were done by the writer (Gadd and Karrow, 1959). Special studies of buried and surface peat deposits were carried out that year by Jaan Terasmae while he was attached to the writer's field party. During 1955 the writer completed mapping of Upton map-area (31 H/15). At the same time Paul F. Karrow started field work in Grondines map-area (31 I/9); his work was completed in that area in 1956.

Mapping procedures included digging many hundreds of test pits and making soil auger borings to determine the surface distribution of the various map-units. Reliable information from well drillers, natural exposures along valleys and ravines, and artificial exposures in gravel pits and in other excavations provided details of stratigraphy on which the glacial history of the area is based.

A number of preliminary publications of the Geological Survey of Canada contain information on these areas and are the basis for the map accompanying this report (Gadd, 1959a, 1959b, 1960a, 1960b; Gadd and Karrow, 1959; Karrow, 1959).

Acknowledgments

Able assistance was given in the field by Garth D. Jackson, Gilles Carrière, and Jean-Paul Charette in 1950; Robert Crouse, Guy Sicard, and Pierre Crépeau in 1951; and Paul F. Karrow, Conrad Bédard, and Phillipe Cardinal in 1952. In 1953, J. Terasmae acted as field assistant for geologic investigations while the writer reciprocated on palynologic field studies commenced that year by Terasmae. The program for 1954 included the semi-independent mapping of the Trois-Rivières area by P. F. Karrow, palynological investigations in the St. Lawrence Lowland, some geological mapping in the Yamaska area by J. Terasmae, and the writer's investigations, all supported by the good assistance of S. J. Syskowski, R. K. Patterson, and R. E. Robinson. The writer was most ably assisted during the 1955 field season by the late Gordon E. Dixon.

Part of the material presented here was the basis for a doctoral dissertation presented at the University of Illinois (Gadd, 1955). Professor George W. White, head of the Department of Geology at that university, gave valuable guidance in office and field consultations during preparation of the dissertation.

To those mentioned above and to the many who have contributed also by discussion of this work, the writer extends his grateful thanks.

Chapter II

PHYSICAL FEATURES

Most of the area studied lies within the St. Lawrence Lowland, but parts of Trois-Rivières and Grondines map-areas extend into the southern part of the Laurentian Highland (Canadian Shield). Maximum relief measured from St. Lawrence River is about 750 feet north of the river and about 450 feet south of it. Within the lowland area land surfaces rise gradually away from the St. Lawrence, and hills are commonly not more than 50 feet high. Along the margin of the Laurentian Highland, however, rocky slopes rise as much as 350 feet above the central plain, e.g., in the north-central part of Grondines map-area along the northeast flank of Charest River valley where Charest River emerges from the highland. Other than these prominent rocky slopes the greatest relief of the area is provided by the incision of rivers, including the St. Lawrence, in unconsolidated materials, and by glacial and aeolian ridges that trend southwestward.

Preglacial Topography

For various reasons, but chiefly because few distinctive glacial erosional forms have been recognized on the exposed bedrock surface of the area, the writer assumes that glaciation removed mainly unconsolidated material and but little bedrock material. It seems safe to assume further that the general topographic form of the buried bedrock surface today is reasonably similar to that of preglacial time. Bedrock controls the topography of the Laurentian Highland and is dominant south and east of the Drummondville moraine (Fig. 4a). These, then, were relatively rugged areas extending northward and southward into higher and more rugged terrain. The nature of the bedrock surface in the flat area between these two hilly regions cannot be known by direct observation, but must be inferred from consideration of other factors.

Superposed on the flat lowland bedrock terrain is a relatively flat plain of unconsolidated material that is characterized by deeply incised rivers and streams. In most of the large streams bedrock is exposed in several places and its surface lies flat or has small dips. Few of the streams have excavated channels in the bedrock, but most have cut down to it at some point. Thus for most of the central part bank height is a reasonable measure of general drift thickness. Borings at the mouth of Nicolet River, however, penetrated nearly 100 feet below river level before encountering bedrock (Lea, 1952). This would indicate that a little-known deep channel that may have carried a large river in preglacial time exists somewhere near the position of the present St. Lawrence. Local relief near the ancient river valley may well have been greater than 100 feet, while surfaces extending 8 to 15 miles each side of it probably were relatively featureless. Bedrock knolls that rise above the modern plain would also have formed low hills in the preglacial topography, however, particularly within the tightly folded belt that underlies part of the St. Lawrence Lowland area.

Drainage

All parts of the area considered in this report and included in the geologic map are drained by St. Lawrence River and its tributaries. Major streams, St-Maurice, Batiscan, and Ste-Anne Rivers on the north shore, and Yamaska, St-François, Nicolet, and Bécancour Rivers on the south shore, have their sources many miles outside the map-area in the hills flanking the St. Lawrence Lowland. Smaller streams north of St. Lawrence River arise within the margin of the Laurentian Highland (e.g., Rivière-du-Loup, Yamachiche River) or on the south flank of the St. Narcisse moraine (e.g., Champlain River). Those south of the St. Lawrence that flow directly to the trunk stream rise on the crest of the Drummondville moraine or primarily from springs in the sand terraces along the northern flank of this moraine.

All streams in the area, including the St. Lawrence, are in a youthful stage of development, as is indicated by the presence of rapids and falls in them; their steeply incised banks in most parts of the area; their relatively steep gradients; and for many of the smaller streams, their narrow V-shaped valleys. Flood plains, commonly a criterion for a later stage of geomorphic development, occur seasonally along some streams in the area, due primarily to unusual ice conditions of St. Lawrence River at the time of spring thaw; some along the St. Lawrence are in part tidal. Neither type indicates a more advanced stage of geomorphic development. The various youthful features shown by the streams in the area signify that postglacial uplift of land surfaces probably has continued to relatively recent times, if not actually right to the present.

Lower courses of many streams in the area dissect planar surfaces of terraces formed during early high-level stages of St. Lawrence River. Thus, much of the interfluve area remains poorly drained and prone to bog development, partly because of the presence of low ridges along the outer margins of the plains at river banks, according to Choinière and Laplante (1948, p. 31), who wrote:

> ...les rebords des berges des rivières, des ruisseaux, des coulées, sont, à peu d'exception, de quelques pieds plus élevés que le terrain environnant. Résultat: l'eau doit parcourir un chemin plus long pour se déverser dans un cours d'eau naturel. Par exemple, dans les paroisses de Saint-Sylvére et de Sainte-Gertrude, plusieurs fermes sises tout près des rives de la rivière Bécancour jettent leurs eaux dans la rivière Gentilly située à plusieurs milles de distance.

This applies also to the margins of abandoned channels, so that surface drainage in the level areas of the region is generally poor. This rarely contributes to good agricultural conditions, but more commonly results in acid soil and bog formation, which have necessitated the construction of elaborate drainage ditch systems in many parts of the area.

Soils

Soils of much of the region are described in Quebec Department of Agriculture reports and maps of the counties of Nicolet (Choinière and Laplante, 1948); Yamaska (Laplante and Choinière, 1954); St-Hyacinthe, including part of Bagot (Baril and Mailloux, 1942); Richelieu (Laplante, Alarie, and Mailloux, 1942); and Lotbinière (Baril and Rochefort, 1957). Of the three zonal soils common in the southern part of the province of Quebec—podzols, brown podzols, and grey-brown podzols—the first two occur most commonly within the surveyed parts of this area.

The ashy illuviated horizon of the soil profile, the A_2, is uncommon and in most places is not more than 3 inches thick, although in well-drained sandy forest soils it has been observed up to a foot thick. Only silicates of the original mineral composition remain in this intensely leached horizon. The B horizon, the zone of maximum accumulation of salts of iron and aluminum, varies considerably in depth and thickness; commonly it occurs about 6 inches below the surface and may be as much as 3 feet thick. In some well-drained sandy soils where the water-table and phreatic fringe fluctuate through a range of several feet, the iron-rich zone may be cemented into an extremely tough layer that can rarely be pierced with a soil auger and can be broken only with difficulty with pick or shovel. This would be the 'Ortstein' or 'hardpan' layer of some of the soil varieties of the area.

Only in very well drained locations are true podzols seen. Baril and Rochefort (1957) indicated that in most parts of Lotbinière county the podzols are well developed and have clearly marked horizons. Elsewhere, and particularly in clay and alluvial soil areas, soil profiles are very slightly developed or incipient (Pl. I). It seems also that the well-developed

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PLATE I. Incipient soil development in clay soil. Note columnar structure of desiccated marine clay subsoil. Yamaska map-area (31 I/2) at north end of bridge across main channel of Nicolet River at confluence of Nicolet and Nicolet Sud-Ouest Rivers.

soils occur mainly in the higher parts of the area that have been exposed to erosion for longer periods of time. This is similar to the relationship found by Putnam (1952, p. 140) for the area between Lac St-Pierre and the Ontario border, where:

> The sands and sandy loam deposits of the old beaches and deltas have tended to develop into podzols which are distinctly acid in reaction and low in fertility. The degree of podzolization varies considerably. The leached horizon of the profile tends to be quite thin along the left bank of the St. Lawrence but is thicker on the flanks of the Monteregian Hills and farther eastward.

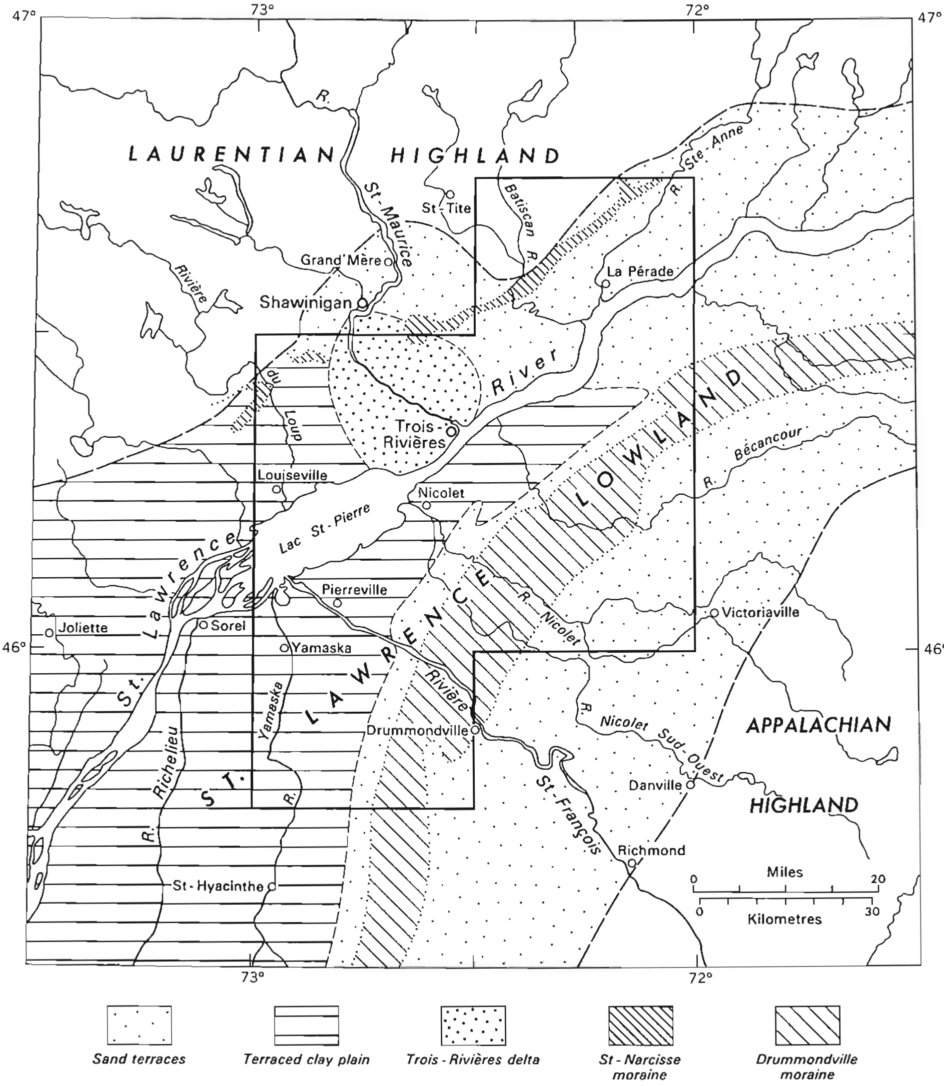

FIGURE 4a. Physiographic divisions of the central St. Lawrence Lowland, showing location and relationships of features described in the text with study area outlined.

For the area east of Quebec, on the Beauport coast, Putnam (1952, p. 141) noted:

> ...at sea level there are wide clay flats utilized as hay meadows. On the terraces there are belts of clay and loam. The surface soils are deep, friable and porous and show little podzolization. ... Further inland at the foot of the Laurentians there are deep sands on which highly podzolized soils have developed.

Because there is linear relationship between age, or length of time since the terrace was abandoned by sea or river waters, and the degree of development of podzol profiles in the

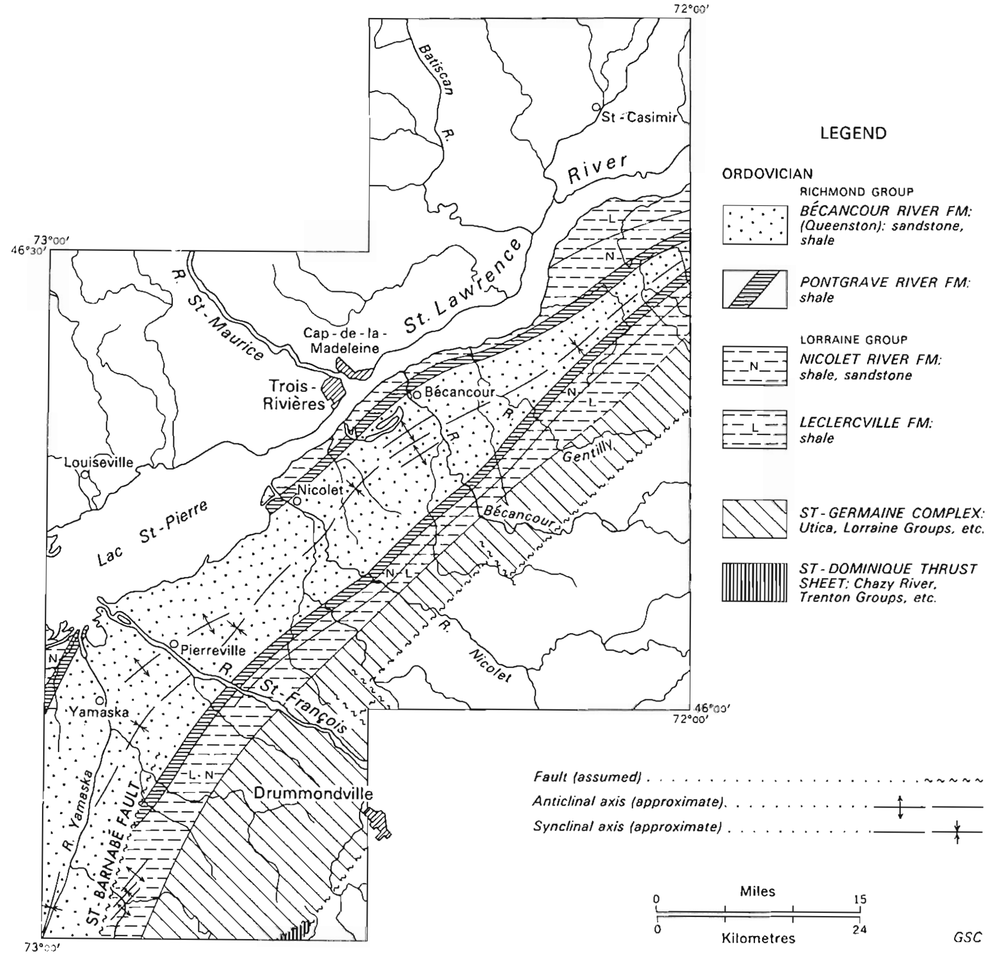

FIGURE 4b. Distribution of Paleozoic rocks and younger intrusions in the central St. Lawrence Lowland (adapted from Clark, 1947).

soils of the terraces, the good development of podzols on higher terraces and poor development on low ones is evidence of progressive uplift and abandonment over a considerable period of time.

Physiographic Divisions

The map-area lies within parts of two major physiographic provinces: Laurentian Highland and St. Lawrence Lowland. The latter is further subdivided (Fig. 4a) in this report to locate and emphasize features of the area that are significant to the discussion that follows.

Laurentian Highland

Included in the Laurentian Highland are about one-eighth of Trois-Rivières map-area (31 I/7)—northwest of a line between the villages of Charette and St-Boniface-de-Shawinigan

—and one-third of Grondines map-area (31 I/9), northwest of a line between Barrage St-Narcisse on Batiscan River, and St-Thuribe on Blanche River. In these areas high rounded hills of granite, gneiss, and other rocks of Precambrian age are prominent and numerous. Although hillcrests are commonly veneered with glacial drift, many summits and most of the steep flanks are bare. Major valleys are steep sided and some resemble the U-shaped valley that is so characteristically produced by valley glaciation. The resemblance is lessened, however, because marine and alluvial sediments have made the valley floors relatively flat and nearly horizontal.

St. Lawrence Lowland

The balance of the map-area is within the St. Lawrence Lowland as defined by Clark (1947, pp. 2–4) and Dresser and Denis (1944, pp. 9, 10). Near St. Lawrence River the area is underlain mainly by very gently folded sedimentary rocks of Paleozoic age, occupying much of the eastern part of Clark's (1947, p. 5) Chambly–Fortierville syncline. Some steeply dipping rocks are found in the river valleys and in surface outcrops along and southeast of a line extending northeastward, approximately from the south-central part of Upton map-area, near St-Eugène-de-Grantham, diagonally across the region to the northeast corner of Bécancour map-area near Fortierville. The steep dips are due in part to folding along the St. Barnabé and other less prominent faults, and in part are probably due to the overthrusting from the southeast of rocks of the St. Germain Complex (Clark, 1947, p. 5). In addition, there is a scarp in the bedrock surface that appears to be, at least partly, a fault-line scarp and perhaps also partly the leading edge of the overthrust sheet. Above the scarp and southeastward to the limit of the map-area, unconsolidated sediments are thin and bedrock is the dominant factor controlling topography, whereas northward, within the lowland area, unconsolidated sediments are the major control.

Moraines, marine and freshwater terraces, and other salient features of the lowland area are described separately below. Physical differences group these features into categories that have apparent environmental significance.

Drummondville Moraine

Along the top of the above-mentioned bedrock scarp, in a belt 2 to 5 miles wide, is a series of low, subparallel ridges of till and other glacial materials. Present local relief is small, generally not more than about 25 feet, but relief just prior to marine invasion of the area was probably much greater. Within the zone designated as Drummondville moraine (Fig. 4a) glacial deposits are thicker than elsewhere south of St. Lawrence River, and the lithology and structure of the ridges show a morainic origin. This belt of modified glacial features, which the writer has named the Drummondville moraine (Gadd, 1955, p. 28), is described in more detail later in this report where it is suggested that the bedrock topography localized the ice margin during a recessional halt.

St. Narcisse Moraine

A striking physical feature that lies just south of the Laurentian Highland in the northern part of the St. Lawrence Lowland is the St. Narcisse moraine (Osborne, 1950a, p. 45; 1950b, p. 884; 1951, p. 225), a prominent ridge that extends northeastward across the area mapped for this report (Fig. 4a). From Mont-Carmel (Valmont) to St-Thuribe it is a nearly continuous ridge, generally less than one-quarter mile wide, broken by the valleys of southward-flowing streams. At St-Thuribe the ridge forks, one branch swinging sharply northward to the highland front and the other continuing northeastward to the edge of the map-area. A ridge extending about 4 miles eastward from the village of Charette, south of the east-trending Yamachiche Valley, is interpreted by the writer to be a western segment of the St. Narcisse moraine that was isolated from the Mont-Carmel sector when St-Maurice River eroded some parts of the moraine and buried other parts under its extensive sand deposits. Studies by Elson (1962b) and Karrow (1957) have extended this moraine southwest and northeast of the area mapped for this report.[1]

Within the map-area the moraine has a relief of as much as 75 feet above the planar areas to its north, forming a low ridge throughout its course. As viewed from the plain to the south, this ridge has an apparent relief of 300 feet or more in places, but only a part of this can be attributed to initial glacial deposition; much of it has resulted from the moraine being built at the top of a southeastward slope in the bedrock surface. In addition, much unconsolidated material that formerly overlaid the region south of the moraine has been removed by erosion since the last inundation of the area.

Abandoned Terraces and Other Shore Features

Shore features, including abandoned terraces, beaches, deltas, scarps, and their related sediments, provide abundant evidence of the occupation of the region by large bodies of water and their recession from the land surfaces. The shore features are superposed on nearly all surfaces of the region except those above 600 feet elevation. Because the sedimentary record in the shore features, in the writer's interpretation, gives evidence of only one post-last-glacial occupation by large bodies of water, it is concluded from this and other evidence that the region was submerged to about the level of the present 600-foot contour at the end of the last glaciation and was subsequently uplifted. Uplift was probably quite rapid initially, then much slower after the first few thousand years, but it may still be continuing at an exceedingly slow rate after some 12,000 years. During this protracted period of uplift, waves and currents worked pre-existing surfaces of glacial sediments and bedrock along the shores, while at the same time deposition of fine sediments occurred in off-shore zones. The shore features described in this section represent, in descending order of elevation, a continuously transitional series of sedimentary environments from marine conditions of Champlain Sea, through several freshwater environments, to modern alluvial conditions.

Principally from the evidence of fossils we know that shore features that occur between 600 and 300 feet elevation were formed in marine environments of the Champlain Sea, whereas those that occur below about 300 feet elevation were formed in freshwater environments. Thus a significant change in environment from essentially marine to essentially fresh water became obvious locally when land surfaces stood, with respect to sea level, some 300 feet lower than at present. The same transition is recorded in parts of the St. Lawrence Lowland both inland and downstream from this region, but probably occurred at different levels there—higher inland, and lower downstream. For a time after transition, as evidenced by sediments in terraces between 300 and 50 feet in elevation, the freshwater currents carried large volumes of sand, and such features as the Trois-Rivières delta and the high level terraces (sand terraces of Fig. 4a, in part) were developed. Then a change of regimen occurred, and the function of the freshwater body became essentially erosional, producing forms classified on Figure 4a as terraced clay plains and then modern alluvial terraces that have distinctive features described in following paragraphs of this report.

[1]Since this report was written, further studies of the St. Narcisse moraine have been published by Parry and Macpherson (1964).

Marine Shore Features

Within the areas shown on the geological map (*in pocket*) as Champlain Sea sand (map-unit 6) are shore features that differ from others in the region; these include beaches, bars, and spits of sand and gravel as well as wave-washed slopes and various boulder concentrations. Similar features are found throughout the area, but the ones occurring within the designated area are distinguished by several characteristics. First, they are imposed on the crests and slopes of hills, and in their orientation and shape conform more or less to the contour of the slope (*see* Fig. 5, *in pocket*). Secondly, they are formed of material readily available locally and are composed of poorly sorted sediment produced in situ or transported only short distances from their place of origin. They represent only a relatively small amount of erosion and are poorly defined, and only few of the individual features may be traced for as much as a mile either on the ground or by use of air photographs. Thirdly, the sediments, including reworked till in some places, commonly contain varying numbers and varieties of fossil shells characteristic of the shore environment of the Champlain Sea.

It would appear that these marine-shore features formed when the Drummondville moraine existed as a shoal, and then later as an island or series of islands in the receding Champlain Sea until it came to a level now about 300 feet above sea level. Discontinuity of the shore features reflects initial irregularity or ruggedness of the morainic topography, and the weakness of the features suggests that sea level was falling more or less continuously during their period of formation so that wave action was short lived at all levels where marine beach features were formed in this region.

Major stabilized dunes probably related in time with the formation of marine beaches are described separately below as 'crêtes de coq'.

Non-Marine Shore Features

The Trois-Rivières Delta

The community of Trois-Rivières at the mouth of St-Maurice River derives its name from the three main channels by which St-Maurice River enters St. Lawrence River. The several islands of alluvium in the mouth of the river constitute its modern delta. Deltas of earlier stages of the river, now uplifted and dissected, and to which the writer here applies the name Trois-Rivières delta (Three Rivers Delta, *in* Gadd and Karrow, 1959), were much more extensive than the modern delta, both in area and in volume of sediment deposited. Sediments (map-unit 8a) are spread over a nearly circular area about 6 miles in diameter centred on Les Vieilles-Forges and bisected by St-Maurice River. The surface of the delta is irregular, but slopes generally towards St. Lawrence River in a series of terraces. Abandoned distributary channels of St-Maurice River are well-marked topographic features within the raised delta, and some channels are accentuated by a partial filling with peat deposits. Most of the westward expansion of the delta may be attributed to the abandoned channel that heads near Marchand Station in the St-Maurice Valley, and extends nearly due south towards Pointe-du-Lac on the St. Lawrence shore. The raised delta is part of a system of sand deposits, described as high terrace sands, that were deposited during early stages of the St. Lawrence River system.

Parts of the Trois-Rivières delta are above the 300-foot elevation, but the sands there are non-fossiliferous at the surface; underlying stratified sands and silts have the characteristic marine shells of the Champlain Sea. The top-set portion of the delta probably formed in a freshwater environment, controlled by meltwater and other drainage from highland sources brought down St-Maurice River.

Associated with the early stages of the Trois-Rivières delta was the deposition of significant thicknesses of medium-grained sand mainly in the area between St. Narcisse and Drummondville moraines, but occurring also partly north and south of them and including most surface sand deposits between 300 and 50 feet elevation. The bulk of the sand lies against the flanks of the moraines in a series of steep scarps and narrow terraces parallel to St. Lawrence River; other sands of lesser volume lying on terraces down to about 50 feet elevation are of the same origin.

High Level Terraces

Erosional terraces in the vertical zone between 300 and 50 feet elevation are cut in marine clay, older unconsolidated sediment, and in places in bedrock. They occur both as narrow discontinuous terraces separated by steep scarps, and as broad, flat terraces separated by small vertical intervals—the former at highest levels and the latter at the lower. In general, also, the volume of sand in the terraces diminishes with elevation so that there is a transition from essentially constructional to essentially erosional types of terraces.

The Trois-Rivières delta has had a significant local influence, and all terraces downstream from it on the St. Lawrence north shore have deposits of sand, few of which are less than 10 feet thick. Thus over a long period of time St-Maurice River provided a continuous, large supply of sand sufficient to build the delta and the sand terraces. Local influence of other tributaries in the map-area has been masked by deposition and redistribution of the deltaic sands. Small streams arising from the margin of the Laurentian Highland, such as Rivière-du-Loup, which flows into the St. Lawrence River near Louiseville upstream from the Trois-Rivières delta, did not build significant deltas; terraces near them are only thinly veneered by sand. Similarly, St. Lawrence River tributaries on the south shore did not build significant deltas. Sand brought to St. Lawrence River by these tributaries was redistributed downstream more or less directly by currents, hence sand spits and bars associated with terraces near these tributaries are wide and thick at the point of confluence and thin both laterally and vertically downstream (i.e., northeast). In most places on the upstream sides of the tributaries sand veneer on the terraces is relatively thin, generally less than 3 feet. Elsewhere a thin sand cover is common, and the high level terraces bear isolated narrow bars of sand a few feet high that parallel the abandoned river scarps. Some of these, from their position on the outer limit of related terraces, may have formed as natural levees caused partly by tidal and/or flooding conditions like those that exist in St. Lawrence River today. Such features are still in the process of formation; some may owe their origin, at least in part, to ice shove, which occurs particularly in the spring when winter ice is breaking up and moving downstream in great masses.

The decrease in volume of sand in successively lower terraces probably resulted from changes in volume and distribution of sand and other sediment during glacial recession. When the ice front stood near the north shore of St. Lawrence River large volumes of sand were deposited in the main channel, but as the ice front retreated glacial sources supplied sand to only some parts of the north side of the valley. Tributary streams from the south acted mainly to erode and redistribute sediments already in the valley. Glacial outwash from highland glacier sources continued to flow down St-Maurice River and other streams rising in the highland, and supplied sand to deltas and terraces of the north shore.

Low Level Terraces and Limiting Scarps

At an unknown time in the more recent development of St. Lawrence River the rate of erosion apparently increased, major river-trimmed scarps were produced, and a series of terraces formed only a few feet above present water levels. The geologic map accompanying this report shows that the major areas of "low terrace sands" along St. Lawrence River lie on the terraces and are bounded on the north and south primarily by the major scarps that are nearly continuous on both sides of the river.

Along the north shore from west of Louiseville to east of Yamachiche the northern scarp is cut in marine clay and has a height of some 25 feet above the highest terrace. Where it encounters the toe of the Trois-Rivières delta between Yamachiche and Pointe-du-Lac the scarp is cut primarily in sands and attains a height of 50 to 75 feet. Depending on the number of higher terraces intersected, the same scarp has heights ranging from about 25 feet to nearly 100 feet as it continues in sweeping curves from Pointe-du-Lac through the city of Trois-Rivières, from Cap-de-la-Madeleine to Batiscan, and from Batiscan to Ste-Anne-de-la-Pérade. Beyond Ste-Anne-de-la-Pérade, the scarp merges with a face resembling the side of a gorge that is cut in the bedrock and extends downstream beyond the limit of the map.

The corresponding scarp on the south shore of St. Lawrence River rises some 25 feet from the low plain flanking Lac St-Pierre to an altitude of about 50 feet. Clay and overlying sand are exposed in the scarp face from the western map-margin about 5 miles west of Yamaska to the vicinity of Nicolet. From Nicolet downstream the southern scarp is cut in a variety of materials. Near Ste-Angèle-de-Laval a related scarp circumscribes an "island" of till-capped bedrock, whereas the main scarp forms the south shore of an abandoned channel through Lac St-Paul; these are cut mainly in bedrock. From Bécancour to Gentilly the scarp exposes bedrock, till, marine clay, and sand, and intersects progressively higher abandoned terraces so that its height increases from west to east from about 25 feet to nearly 50 feet. From Gentilly to the east margin of the map-area the scarp increases in height to a maximum of about 125 feet near St-Pierre-les-Becquets and Deschaillons. As a result these two places have a magnificent vista of St. Lawrence River. Here the very steep scarp is cut primarily in the varved silts of Lake Deschaillons (map-unit 2).

Parts of the limiting scarps have been described in a number of publications by J. W. Goldthwait; the highest level of the terraces between them is part of what Goldthwait (1911b, p. 305; *see* also "Selected Passages from The St. Lawrence Lowland") named the Micmac Shoreline.

Flood Plains

Seasonal flooding of the banks of St. Lawrence River and of its major tributaries is caused chiefly by blockage of the central stream by winter ice and by ice jams during spring break-up. Such blockages are generally associated with the melting of winter snow, which swells the volume of all rivers and streams. When the seaward flow of meltwaters is impeded by ice, the streams overflow their banks and flood adjacent low-lying ground.

Because most streams in the area tributary to St. Lawrence River have deeply entrenched valleys, flooding is restricted to narrow belts along the stream valleys, although the streams may rise at times 20 or 30 feet above normal water levels. Alluvial deposits along the streams (map-unit 9) are in very narrow discontinuous bands. Along St. Lawrence River, flood plains, as much as nearly 5 miles wide near the mouth of St-François River, are nearly continuous; some flooding occurs each year and farmers must carefully control use of their lower pasture fields to avoid miring their stock in the soft mudflats.

An event that occurs nearly every spring is the reversal of flow in the abandoned channel occupied by Lac St-Paul on the south shore opposite Trois-Rivières. During that time water flows northeastward through the lake to Bécancour River, near the village of Bécancour. Normally Lac St-Paul drains northwestward through a small stream that meets St. Lawrence River about 2 miles upstream from Ste-Angèle-de-Laval.

Tidal Flats

During periods of normal or low flow in St. Lawrence River, the tidal influence is expressed by the regular appearance of tidal flats above water. Tides are barely perceptible in Lac St-Pierre, but the tidal range is about 1 foot at Trois-Rivières, 3 feet at Batiscan, and 7 to 8 feet at Grondines (Serv. Hydrograph. Can., 1963, p. 2). At times and at some places the mud bottom of the river is exposed, but commonly the bottom remains awash and bottom-growing reeds and grasses are exposed on shore flats as wide as a mile or more and also on some mid-stream shoals; these are shown as stippled areas in St. Lawrence River on Map 1197A (*in pocket*).

Linear Sand Features

The region discussed in this report was almost completely inundated in the late-glacial time and has emerged only fairly recently. As may be expected it bears many marks of wave work and of shore and channel currents of various kinds; wind, too, played a great role in fashioning the terrain before vegetation covered and stabilized the surface. As a result, throughout the map-area there are numerous sand features that typically for this region occur as linear ridges. They are recognizable as stark white lines and stripes on air photographs (Pls. II, III). Although on cursory examination most of these linear features appear identical, certain physical characteristics allow their separation into significant categories. Generally these sand ridges are shore and near-shore features such as beaches, bars, spits, levees, and dunes, which are here subdivided into three main groups: marine shore features (described on a previous page); 'crêtes de coq'; and shore features probably of lacustrine or fluvial origin. These various ridges are common in all sand deposits of the region, but their pattern is generally so complex that they cannot be mapped individually at the scale of the geological map accompanying this report. Some, however, have been mapped individually, as for example, areas of high terrace sands mapped on the terraced clay plain for 8 to 10 miles east of Yamaska River where belts of linear ridges are mapped together as map-unit 7. Figure 5 (*in pocket*) shows the distribution of some of these features within Bécancour map-area (31 I/8). In this figure the crest-lines of a representative number of the larger linear sand ridges have been transposed from air photographs to a topographic map.

Crêtes de Coq

One of the linear features shown in the southwest corner of Figure 5 is a bifurcated ridge that encloses Louise Lake at its apex. The writer has adopted, for this ridge and others within the area of a similar nature, the name 'crêtes de coq' (singular crête de coq), which is used by local residents near the villages of Manseau and Ste-Marie-de-Blandford for some of the large sand ridges with which they are familiar. The name means cockscomb and describes admirably the narrow, elongate, sharp, and irregularly crested sand hills of considerable relief. They occur over much of Nicolet and Lotbinière counties and are the same features Osborne (1950b) called "marine crevasse fillings".

The largest and most prominent of these ridges, which has a maximum relief of about 60 feet, is that shown on Plate II (*see* also Fig. 5). Near its highest point, at the west end, the ridge bifurcates and two limbs extend eastward, both declining in summit elevation until they merge with the surrounding plain. Near its apex the ridge has a complex form of coalescent small V-shaped ridges whereas the limbs of the ridge are fairly straight with but minor crenulations. Minor active blow-outs along the ridge suggest one manner in which some depressions and minor irregularities may have occurred. In this spectacular example the limbs of the ridge may be followed almost continuously for distances of nearly 2 miles. Smaller

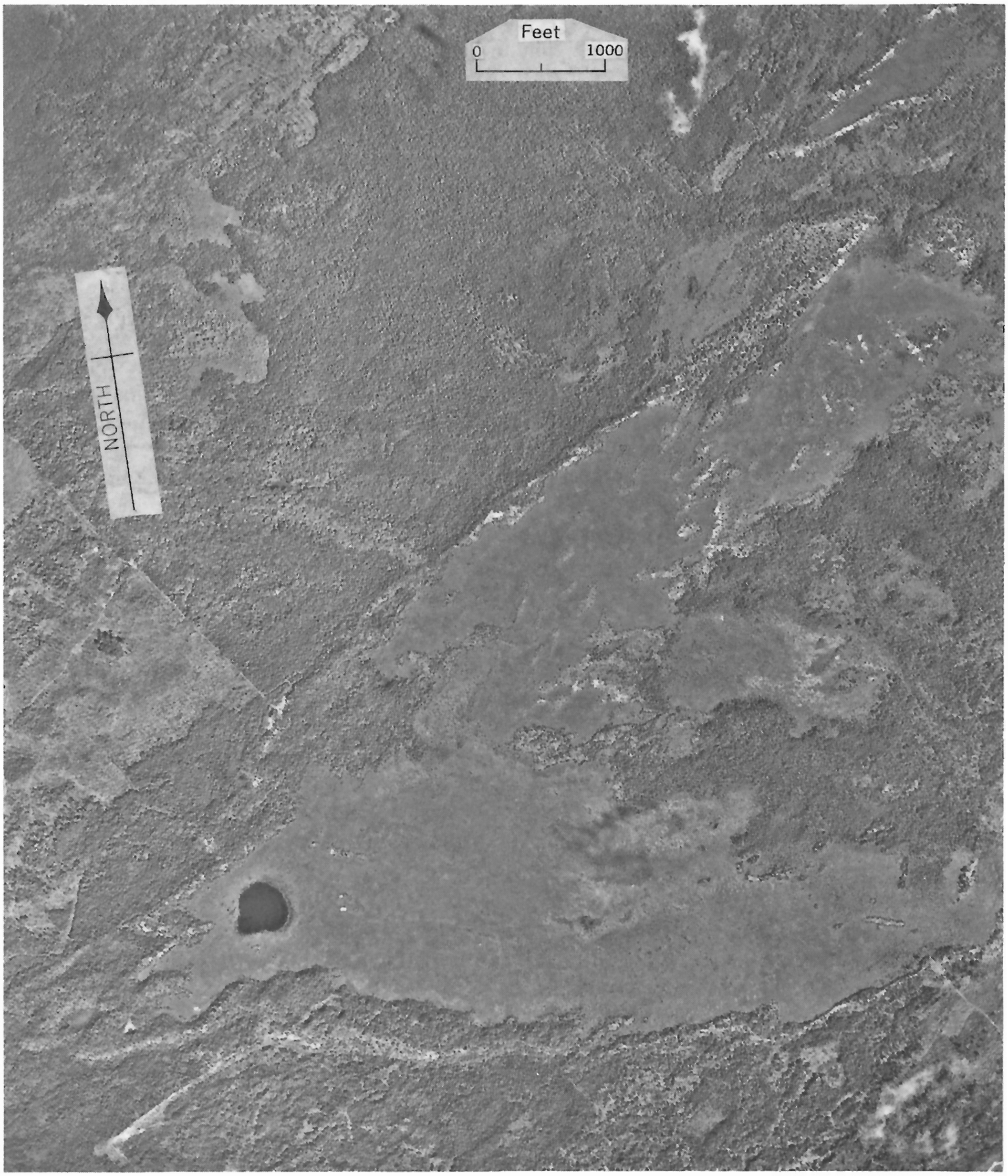

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PLATE II. Air photograph of crêtes de coq in the southeast corner of Bécancour map-area (31 I/8); Lake Louise is in the apex of the most prominent bifurcated ridge. The apex of the ridge comprises a number of coalescent V-shaped ridges, whereas the limbs are relatively straight with only minor crenulations; most white areas are actively blowing sand.

RCAF A12802-35

PLATE III. Air photograph of crêtes de coq and active sand dunes in Aston map-area near the village of St-Rosaire. The group includes simple straight ridges, some with minor hooks at the western end, individual small V-shaped ridges, and more complex types combining these components. Individual ridges are about 25 feet high.

ridges of the same type in other parts of the region (map-unit 7) are generally smoother in outline and more regular in plan, perhaps because their smaller relief (20–30 feet) has made them less susceptible to deformation by wind action and to the production of disfiguring blow-outs. Smaller dune forms that are more common than the complex forked type shown on Plate II include simple elongate ridges, low elongate ridges with terminal hooks at their western end, and small individual V-shaped dune ridges. Plate III shows various simple forms as well as complex forms and active dunes near St-Rosaire in Aston map-area.

The crêtes de coq are aeolian in origin. Thus, though now stabilized by vegetation, they are susceptible to wind erosion, and many dunes have been reactivated where fires or activity of man have removed the cover. Small blow-outs have occurred in a few places where large trees have been uprooted.

The most common dune form of the crêtes de coq is an elongate ridge with a small terminal hook. Where they are numerous, however, major elongate dunes intersecting at small angles form long V-shaped ridges that are usually complicated by accretion of smaller arcuate dunes near the apex. The dunes occur in a belt of thick sand deposits, some of which bear the typical shore fauna of the Champlain Sea, and are generally oriented parallel with proven or inferred shorelines of that sea. It is therefore most probable that the dunes formed as shore or coastal dunes related to former shorelines with their orientation either parallel or at small angles to these shores.

Shore Features of Lacustrine or Fluvial Origin

Marine shore features and crêtes de coq exist above 300 feet elevation, and have affinities with the marine environment. Other linear sand features of the region, described below, are in the vertical zone between 300 feet and present water levels, are not related to the marine environment, and have physical characteristics that relate them to the estuarine, lacustrine, and fluviatile environments that existed in the St. Lawrence Lowland in post-Champlain Sea time.

Several hundreds of low, smooth-topped ridges of stratified fine sand occur in all parts of the area below about 300 feet elevation. They generally have a relief of not more than 5 feet and range in width from a few tens of feet to 100 feet or more. The ridges are discontinuous, but some of them may be traced for several miles with the use of air photographs.

General distribution of the non-marine ridges in the Bécancour area is shown on Figure 5, and details of some ridges from that area are shown on Figure 6. From these two figures it may be seen that some of these abandoned shore features are cuspate, with arcs between cusps concave towards St. Lawrence River. Many cusps are asymmetrical, with their axes pointing downstream with respect to the river (Fig. 6a). Series of cusps that were probably formed by the same processes, but at successively lower stages of the major water body, show a downstream progression of apices from the highest to the lowest (Fig. 6b, c). The apices of cusps are joined in places by weak stream channels now either abandoned or carrying intermittent streams (Fig. 6c). These channels at one time presumably carried sediment that formed minor deltas and localized the cusps. The materials were in turn redistributed by a current flowing consistently in the same direction so that successively lower cusps followed one another in a downstream progression. Truncating relationships are common (Fig. 6d, e, f). In many places a series of two or more sand-capped scarps is truncated by a lower scarp, thus producing double-swing or multiple-swing cusps. Former shorelines, besides being marked by beach ridges of sand, are marked in places by steep scarps with associated short, straight ravines and abandoned tributary channels, most of which end abruptly at the escarpment (Fig. 6g).

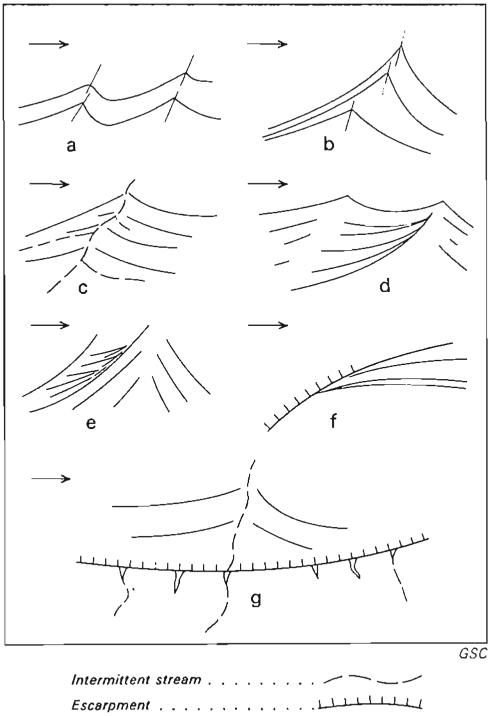

FIGURE 6

Diagrams at variously exaggerated scales, showing details of some relationships of abandoned shore features shown in gross outline on Figure 5; plan views. Arrows show direction of flow of St. Lawrence River which is presumed to have been the same during formation of these features.

Scarps and sand ridges of the same type as those described above have formed at and very near the present level of St. Lawrence River. It seems reasonable to assume, therefore, that the system of forces active on St. Lawrence River today were active during the formation of scarps, terraces, and shoreline ridges that now occur at elevations as much as 300 feet above present water levels. If this assumption is valid it is necessary to visualize a large scale fluvial system of which the St. Lawrence was the principal stream that attained widths of nearly 40 miles within the area covered by this report. At such a size the system must have been a broad estuary, and at larger stages there would have been broad lake-like expansions similar to but much larger than the modern Lac St-Pierre. Strong shore currents and a shifting channel were necessary to produce the physical features described and the sorting and bedding of sediments of which some of them are built.

Abandoned Stream Channels

Although the strand or shore features described above as being related to stages of development of St. Lawrence River occur on opposite sides of the broad St. Lawrence Valley, and at about the same elevation on both sides, it is not yet possible to define successive channels and describe the history of migration of St. Lawrence River during its early development. This is mainly because of (1) the numbers of features, (2) the small vertical intervals between terraces, and (3) the distance between the two sides of the river, particularly in its very early stages. However, smaller abandoned channels related to smaller tributary streams, or to subchannels of St. Lawrence River itself, are readily recognized in some parts of the area.

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PLATE IV. Air photograph mosaic showing digitate delta and abandoned channel of Bécancour River at ancient shoreline near 300-foot elevation. Maddington Falls and Bécancour River, Aston map-area, are shown at the south of the area pictured.

A broad channel, nearly a mile wide over most of its length, lies at about 100 feet elevation on a sand terrace between Champlain and St. Lawrence Rivers (*see* geologic map); it is now occupied by a major sphagnum bog in that area.

Smaller channels, similarly bog-filled, occur along both sides of St-Maurice River in the area designated as the Trois-Rivières delta. These represent former distributary channels of St-Maurice River. Radiocarbon ages of the peat in the channel-bottom bogs (discussed later in the report) indicate that the delta developed and extended southward as water levels in the St. Lawrence channel dropped.

A short, straight channel with its associated digitate delta, north of Maddington Falls, probably indicates a former connection of the Bécancour River with an ancient shoreline near the 300-foot elevation (Pl. IV).

A more recently abandoned channel is occupied by Lac St-Paul (south shore of St. Lawrence River at the centre of the area discussed in this report). Part or all of the water of St. Lawrence River was previously carried in a channel at least one-half mile wide on the south side of the till-capped bedrock 'island' that lies partly within the village of Ste-Angèle-de-Laval. The downstream part of the Lac St-Paul channel, which leads northward and eastward to the Bécancour River, has been abandoned by St. Lawrence River except during high spring flood season, owing to the deepening of the main channel and also to the silting of the Lac St-Paul outlet by Bécancour River. Lac St-Paul now drains to St. Lawrence River by a very low gradient connection, Godefroy River, but in time the lake will probably become a truly isolated oxbow lake.

Chapter III

SURFICIAL DEPOSITS

This chapter deals primarily with the nature, distribution, and probable origin of Pleistocene unconsolidated sediments mapped in the central part of the St. Lawrence Lowland region. In recognition of the fact that such unconsolidated deposits are erosional products of the bedrock, however, and that the direction of glacial transport may be deduced from the erratic distribution of these products, it is necessary to give some account of the nature and distribution of bedrock in the study area and its environs. As details of the bedrock geology can be found in the recent reports by Clark (1947, 1961) and Béland (1961), only a brief account is necessary here to show the general patterns of distribution and lithology and of interrelations between unconsolidated and consolidated rocks.

Relationship of Surficial Deposits to Bedrock

Table I, drawn from Clark (1947) and Béland (1961), gives the lithologies of formations likely to be encountered in the area considered in this report and shows their stratigraphic relationship. The general distribution of the Paleozoic sediments and of younger intrusive rocks south of St. Lawrence River is shown on Figure 4b (*from* Clark, 1947). Between the north shore of St. Lawrence River and the Laurentian Highland (not shown in Figure 4b) dark grey to nearly black 'Trenton' limestone occurs in a wide belt parallel to the St. Lawrence (Clark, 1961). This is the main source of black limestone pebbles in unconsolidated deposits described later in this chapter. In general the St. Lawrence Lowland area is underlain by Paleozoic strata, and those observed in connection with the present study are in relatively flat lying to gently dipping attitudes. The Laurentian Highland is underlain by Precambrian rocks, such as those described by Béland (1961) in the Shawinigan area; such rocks are common in the Laurentian region between Trois-Rivières and Quebec City where they were subject to erosion and glacial transport into the areas studied.

Pebbles and boulders in unconsolidated glacial sediments in the Laurentian Highland and in a belt along the southern margin of the highland, even where underlying bedrock is Paleozoic sediment, are mostly of the more resistant Precambrian granites and gneisses. The abundance of Precambrian erratics diminishes southward as the Paleozoic pebbles become more common and ultimately dominant; this constitutes proof of ice movement from north to south. Some rock types found as erratics in lowland areas (e.g., a huge boulder of coarsely porphyritic granite which the author identified as Pine Hill granite similar to that in the vicinity of Shawinigan Falls (Béland, 1961, pp. 27, 28)) indicate more directly a glacial transport of material in a generally southerly direction.

Lithologies of the tills show that continental glaciers moved southerly over the region, encountering in turn Precambrian, Trenton, Utica–Lorraine, and Richmond rocks; a second belt of Utica–Lorraine rocks; and then the St. Germain Complex (Table I; Clark, 1947, 1961).

TABLE I — *Table of Bedrock Formations*[1]

Era	System	Group	Formation or Member	Lithology
Paleozoic (*after* Clark, 1947, pp. 10, 11)	Ordovician	Richmond	Bécancour River	Unfossiliferous red sandstone and shale
			Pontgravé River	Grey calcareous shale
		Lorraine	Nicolet River	Shale and sandstone
			Leclercville shale	Dark grey to light grey sandy shale and thin-bedded limestone
		Utica	Lotbinière shale	Dark grey to dark brown shale
		Trenton		'Trenton limestone'
Unconformity				
Precambrian (*after* Béland, 1961, p. 10)	Morin Series			Diabase dykes
				Pine Hill granite
				Pyroxene diorite, pyrox. qtz. diorite, pyrox. granodiorite
				Anorthosite–gabbro complex
	Intermediate to acidic intrusive and metasomatic rocks			Granite pegmatite
				Granite gneiss, coarse augen granite
				Granodiorite, quartz diorite, diorite
	"Grenville Series"			Meta-quartzite
				Silicated crystalline carbonate rocks
				Quartz–biotite paragneisses
				Pyroxene and/or hornblende gneiss and meta-gabbro

[1]For sources of information *see* Clark, 1947, pp. 10, 11; Béland, 1961, p. 10.

Characteristic pebbles of each of these groups in turn become common to abundant in the pebble count of the tills within and south of the area of outcrop of each. All tills in lowland areas north of St. Lawrence River are similar in their dominant content of Precambrian rocks and of limestone and shale pebbles of the Trenton. South of the St. Lawrence, within the area studied by the writer, the tills may be distinguished by lithology. The lower (older) till sheet is characterized by red Richmond shale and sandstone. The younger till sheet, isolated in most places from Richmond rocks by intervening glacial sediments, commonly has a grey colour that is more directly related to rock types that occur north of the St. Lawrence. The younger, grey till also commonly has a relatively higher content of Trenton pebbles than the underlying red till. The real difference between the two tills is probably related to the amount of dilution of each by locally derived bedrock fragments.

Terminology of the Unconsolidated Sediments

All glacial events and some non-glacial events in the Pleistocene geologic history of the area described in this report are considered to have occurred within the Wisconsin Glaciation. In the regions under study the earliest known glacial stade of the Wisconsin, here named the *Bécancour Stade*, is defined as the glacial event represented by Bécancour till[1] and associated glacially derived sediments, represented here chiefly by underlying and overlying varved silts. This till is most probably early Wisconsin rather than pre-Wisconsin as previously denoted (Gadd, 1960b, pp. 8, 9).

The *St. Pierre Interval* (Gadd, 1960b, p. 10) has yielded finite radiocarbon dates of the order of 65,000 years B.P., which suggest its correlation as an interstade within the Wisconsin Glaciation rather than as pre-Wisconsin as the writer originally believed. St. Pierre sediments comprise non-glacial fluvial and bog deposits that formed during the St. Pierre Interval. The climatic fluctuation recorded by organic remains in these sediments is a continuous cycle, beginning with subarctic conditions at the close of the Bécancour glacial stade, reaching a maximum of boreal forest conditions, and reverting to subarctic at the onset of a subsequent glacial episode.

The second Wisconsin glacial event of the area, which is also considered to be the 'last' glacial invasion of this central part of the St. Lawrence Lowland, is here named the *Gentilly Stade*. The beginning of the stade is represented by the base of Deschaillons varved sediments. Glacial events of the stade include deposition of Deschaillons varved sediments, Gentilly till[1], and associated glacially derived sediments; the formation of the recessional Drummondville and St. Narcisse moraines; and related ice-contact, outwash, and glaciomarine sediments. Apparently catastrophic flooding of the St. Lawrence Lowland by the Champlain Sea is the event that closes the Gentilly Stade in this region. Within this area, then, the Gentilly Stade probably occurred between about 65,000 years B.P., the approximate radiocarbon age of the St. Pierre Interval, and about 11,500 years B.P., the approximate radiocarbon age for the onset of the Champlain Sea episode.

St. Narcisse moraine, and related glacial and glaciomarine strata, apparently were deposited entirely within the time of the Champlain Sea episode, and therefore when better known may require reclassification as a sub-stade or as a separate glacial event. At present it is best included within the Gentilly glacial stade.

Champlain Sea marine episode began when the sea breached an ice dam near Quebec City (Gadd, 1964; also Karrow, 1961, p. 99) to mingle with fresh water of the preexisting

[1]Formation names introduced by Gadd (1960b) were Bécancour Till (p. 8) and Gentilly Till (p. 14) and should be read as such throughout this text.

glacial lakes and form an extensive body of brackish water in the St. Lawrence Lowland. This invasion of the lowland occurred about 11,500 years B.P. and may have ended in this region with the inception of freshwater fluvial conditions at levels of about 300 feet altitude some 9,500 years B.P. The principal sediments of the marine episode have been named Champlain Sea sand and Champlain Sea clay (Gadd, 1960b, p. 16).

Post-Champlain Sea terraces of sand considered to be of freshwater origin and related aeolian features, some of which are described herein as *crêtes de coq*, are considered to have been formed during Wisconsin time because of the probable relation of the voluminous sand deposits in them to wastage of the ice sheets. The end of glacial influence is thought to be related to an apparent transition in the régime of St. Lawrence River from a dominantly depositional to an essentially erosional role; the lowermost raised terraces of the St. Lawrence and related sediments are therefore shown as postglacial in Table II.

Glacial Deposits

The ground moraine deposits in the area discussed in this report comprise two tills of different ages and locally of different colours. The older of these is the Bécancour till (Gadd, 1960b, p. 8), which is commonly brick-red; the younger Gentilly till (Gadd, 1960b, p. 14) is commonly dark grey.

Bécancour Till

This till is most extensively exposed along Bécancour River between the village of Bécancour and St-Wenceslas River, a tributary of the Bécancour. Other exposures are found near Bécancour River and Lac St-Paul and are best seen in escarpments parallel to St. Lawrence River. A few small exposures are known in the southeast quarter of Bécancour map-area (31 I/8), in the southeast half of Aston map-area (31 I/1), and in the southeast corner of Upton map-area (31 H/15). Bécancour till or correlative is known north of St. Lawrence River in only one section, which Karrow (1957, p. 46) called the Grondines section.

Thickness of the Bécancour till is not well known because most exposures are only partly exhumed, but a small number of sections and a few borings indicate that the common thickness is about 10 feet. The maximum observed thickness of this till is 55 feet in a section 500 feet northeast of St-Wenceslas River on the east bank of Bécancour River.

Bécancour till derives its red colour, which is common locally, from the underlying red shale of the Bécancour River Formation. Although usually present in small amounts, red shale may be a major constituent of the till; boulders of red shale are rare, but cobbles and pebbles of it are common. Most of the pebbles, cobbles, and boulders in the till are of igneous and metasedimentary Laurentian Highland rocks, however, with grey and pink granite gneiss predominating. A green to greenish grey hypersthene granite, usually coarsely porphyritic with microcline crystals, is a common component of the red till; this green granite resembles rocks that are associated with the Pine Hill granites of the Morin Series in areas north of Quebec City and others that occur widely in the Laurentian Highland north of Trois-Rivières (Béland, 1961). These granitic components thus indicate source rocks for the till in the Canadian Shield to the north. Siliceous sand and finely comminuted sedimentary rocks, mostly calcareous, form the bulk of the sand, silt, and clay fractions of the red till; but Karrow (1957, p. 30) also reported chlorite, illite, quartz, feldspar, and probably amphibole in the clay fraction of this till. At some places, where the till directly overlies non-calcareous shales, e.g., Bécancour River Formation, thin sheets of till are entirely non-calcareous to very faintly calcareous as a result of the local dominance of shale; in such places,

TABLE II *Table of Surficial Formations*

Era	Epoch	Age	Stade or Episode	Lithologic units
Cenozoic	Quarternary (Pleistocene)	Postglacial	Early to modern stages of St. Lawrence River	BOG DEPOSITS: mainly peat, some muck; lower parts of some bogs were deposited during late Wisconsin LOW TERRACE SANDS: mainly alluvial sand, some silt and peat, chiefly in abandoned St. Lawrence River terraces; minor modern alluvium
		Wisconsin	Late Wisconsin non-glacial episode	HIGH TERRACE SANDS: well-sorted medium- to fine-grained sand, some fine gravel of deltaic and fluviatile origin
				AEOLIAN SAND: fine well-sorted and rounded in simple and complex elongate dunes; may be partly contemporaneous with high terrace sands
			Champlain Sea Episode (non-glacial)	CHAMPLAIN SEA SAND: includes material ranging from well-sorted uniform fine sand, to very poorly sorted, to unsorted lag gravel; generally fossiliferous
				CHAMPLAIN SEA CLAY: includes clay, silty clay, silt, and sand in various combinations and in three main facies; mottled, stratified, and massive; all facies contain some boulders; generally fossiliferous
			St. Narcisse Episode (glacial)	GLACIAL AND GLACIOMARINE DEPOSITS: acid sandy till mainly of Laurentian rock components; glaciofluvial, glaciolacustrine, and glaciomarine sediments related to St. Narcisse moraine
			Gentilly Stade (glacial)	GLACIOLACUSTRINE DEPOSITS: discontinuous thin beds of grey varved silt grading upward into Champlain Sea clay
				GENTILLY TILL: calcareous, sandy grey till, varied texture; many exposures are wave washed
				DESCHAILLONS VARVED SEDIMENTS: grey varved silt and silty clay; about 500 varves

TABLE II (*cont.*)

Era	Epoch	Age	Stade or Episode	Lithologic units	
Cenozoic	Quarternary (Pleistocene)	Wisconsin	St. Pierre Interval (non-glacial)	ST. PIERRE SEDIMENTS	Compressed *Sphagnum* and *Carex* peat; some wood
					Stratified fine sand; some gravel; a few silty sand layers
			Bécancour Stade (glacial)	GLACIOLACUSTRINE DEPOSITS: discontinuous beds of grey varved silt, in places with red winter layers	
				BÉCANCOUR TILL: calcareous sandy to silty till; brick-red colour in most sections in this area	
				GLACIOLACUSTRINE DEPOSITS: red varved silts	
Bedrock					

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PLATE V. Bécancour till overlying contorted red varves. Looking northeast along shore of St. Lawrence River at Cap Levrard.

also, the deposit is a clay till comprising igneous pebbles and boulders in a matrix that is the product of crushing a shaly bedrock. In a thicker till sheet overlying non-calcareous shale, the basal part of the sheet is clay till and there is an upward gradation into normal sandy till.

Bécancour till is commonly homogeneous, but in some places shows evidence of minor fluctuations of the ice front and at others of incorporation of proglacial sediments. At one place along Bécancour River near St-Wenceslas River, beds of sand and gravel are interbedded with irregular masses and sheets of till; in the Grondines section, "Pink and grey varves are included in the lower till as irregular contorted masses" (Karrow, 1957, p. 46).

Bécancour till is usually found directly superposed on bedrock. It overlies red varves (Pl. V) at Cap Lévrard as well as at Cap Charles (Karrow, 1959) and at a few other places in the area (*see* sections 59, 60, 65, and 68 in Appendix I). It is in turn overlain by sands and peat deposited during the early Wisconsin St. Pierre interstadial interval, by grey Gentilly till, and by marine Champlain Sea clay in many other sections. Although it is unquestionably older than the early Wisconsin deposits, the writer nonetheless believes that it is Wisconsin.

The orientation of the long axes of 20 to 50 pebbles chosen at random was measured in each of several sections and these showed a preferred orientation between south and southwest. Not enough pebbles were measured to give a statistically reliable result, however, so that this preferred orientation can be considered as only a suggested rather than an established direction of ice movement. Nevertheless it agrees with the north to south direction shown by the indicator boulders in the Bécancour till.

Gentilly Till

Map-unit 3 on the accompanying geological map shows all known outcrops of Gentilly till (Gadd, 1960a, p. 14) in the area that can be shown at this scale. Although of wide distribution, the Gentilly till has only a few natural exposures here, but large numbers of borings and excavations have proven its existence in most of map-unit 3. Because the whole area has been reworked by wave action during the Champlain Sea episode, thus producing large volumes of bouldery, coarse lag gravel, it was not possible to delimit zones of little-modified till from those of deeply reworked till or from coarse glaciofluvial gravels south of St. Lawrence River; thus all have been included under the heading of Gentilly till. Although hard to distinguish in the broad zone of the Drummondville moraine, glaciofluvial and outwash deposits have been mapped separately in the St. Narcisse moraine and its vicinity (map-unit 4). Till and related sediments of the St. Narcisse moraine (map-unit 3a) are significantly younger than Gentilly till, but because they are related to a recessional halt of the last Wisconsin ice sheet, they are shown as a subunit of the till unit that is the chief deposit of the Gentilly Stade of the Wisconsin.

Gentilly till is typified by the material exposed in excavations in the village of Gentilly (Gadd, 1960a, p. 14); it has a sandy to sandy silt matrix composition. The composition of till of the same age from Grondines map-area is shown on Figure 7 (after Karrow, 1957). It occurs in river-bank sections along St. Lawrence River and its tributaries. Natural exposures in the area show the till sheet to be 7 to 10 feet thick in most places with a maximum of about 60 feet (*see*, for example, sections 23 and 56 in Appendix I).

The Gentilly till is generally strongly calcareous, stony, and sandy with a low silt content, and is sufficiently permeable to provide water for shallow wells. In some places decreased permeability results from high silt and clay content of the till. There appears to be a general decrease in particle size of component materials southward across the area away from the Laurentian source of crystalline rock material; this apparent decrease may be the result partly of progressive comminution of Precambrian rocks and partly of increases in amounts of admixed limestone, shale, and Pleistocene clays.

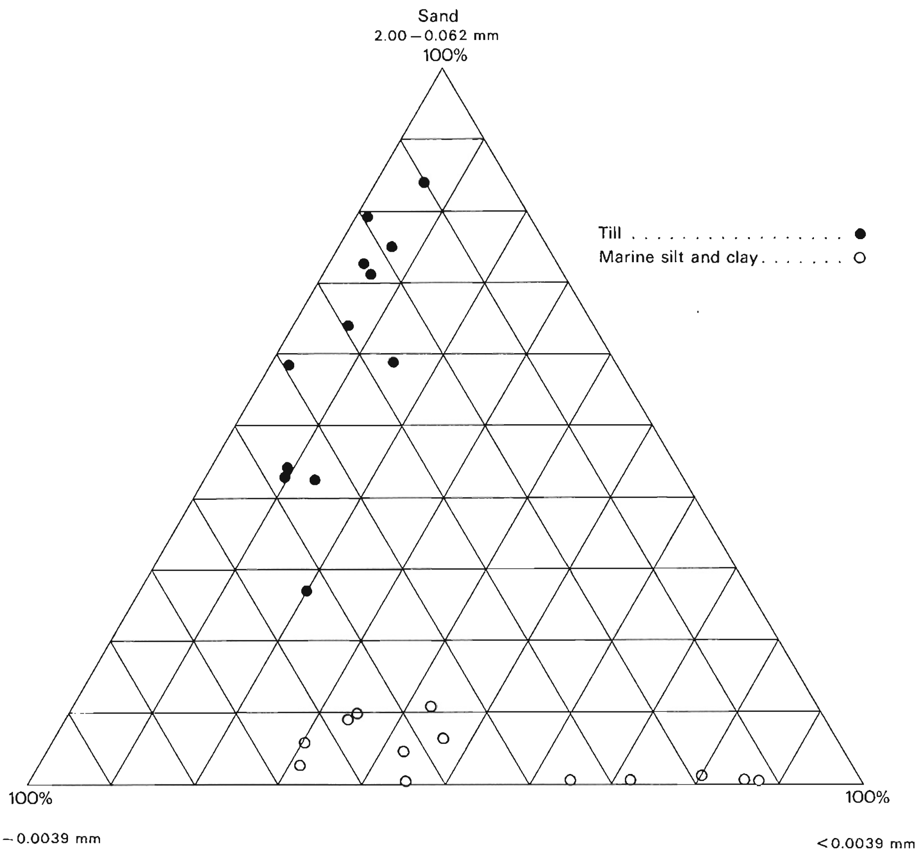

FIGURE 7. Size analyses of Gentilly till and marine silt and clay, Grondines map-area (modified from Karrow, 1957).

Clay and silt fractions of the till are rock flour of the various source rocks. According to Karrow (1957, p. 42) "... there is every indication that only mechanical break-down of the crystalline rock has occurred and little or no chemical alteration has taken place". The sand component is dominantly quartz and feldspar, and larger components, including boulders as much as 8 feet in diameter, are chiefly of granitic igneous rocks. In the pebble and cobble sizes, pink and grey biotite granite and granite gneiss are the most abundant; sedimentary rocks of local origin—mainly black, grey, and brownish limestone—are an essential constituent; metamorphic rocks are rare.

The Gentilly till rests directly on bedrock, Bécancour till, intervening St. Pierre sands, or on Deschaillons varved silts. Thus the glacial episode represented by the Gentilly till is separated from that of the Bécancour till by an erosional interval and a period of proglacial stream and lake deposition. The Gentilly till is overlain in a few places by varved clays that grade upward into typical marine clays of the Champlain Sea. However, it is older than the Champlain Sea sediments everywhere.

The orientation of pebbles observed in some fresh exposures of Gentilly till within Bécancour map-area (31 I/8) indicated a southerly ice movement, but the thick blanket of reworked material in most places precluded an adequate study of till fabrics. Eight glacial striae uncovered below Gentilly till at Rivière du Moulin, near highway 3, range from S8°W to S27°W.

Drummondville Moraine

The Drummondville moraine (Gadd, 1955, p. 28; 1960b, p. 2) consists of a broad belt of low, subparallel, smooth-topped ridges of glacial sediments, mainly of Gentilly till. The belt trends northerly to northeasterly across the area (Fig. 4a), but in many places is not readily recognizable on the basis of topography alone.

The moraine has been identified mainly on the basis of data not easily obtained at the surface. Mainly from borings comes the information that in addition to Gentilly till, which is the principal element of the ridges, there are many occurrences of coarse, well-bedded gravels in pockets, or intimately related with thin sheets of till; none of these could be mapped separately. A few pits have been opened in the glacial gravels (Pl. VI), but because of their small size most of them have been exhausted quickly and abandoned. Wherever these glacial gravels have been observed, however, they are mainly in steeply dipping, well-defined beds, are crossbedded, and exhibit channel structures. Although orientation of such structures varies widely, there is a general southward trend of dips and crossbedding that would indicate deposition of the gravel from sources north of the ridge in which they occur. Glacial origin is indicated by the presence in the gravels, often in great abundance, of faceted and striated boulders and by the angularity of most of the grains and pebbles. These gravels are unfossiliferous, but where they were obviously reworked by marine shore erosion fossiliferous zones at the surface have stratification that is subparallel to the surface and truncates the structure of underlying unfossiliferous strata.

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PLATE VI. Southward-dipping coarse, bouldery glaciofluvial gravels of the Drummondville moraine; near Highway 9, northwest of Drummondville.

The writer believes that the Drummondville moraine originally had a typically rugged morainic topography but that it was destroyed by wave action in the Champlain Sea. The main criterion for this belief is the existence of a thick layer of coarse, angular, unsorted, bouldery lag gravel (Pls. VIIA, B) over most parts of the Drummondville moraine. Such lag gravel contains the same rock types in its pebbles and boulders as are found in the coarse fraction of Gentilly till and so are considered to have a common origin. However, the lag gravels also contain shells that are typical of the shore facies of Champlain Sea, in many places both within the moraine and in areas of ground moraine. It would be legitimate to classify the fossiliferous lag gravels as a shore facies marine sediment, but the author has chosen to include most of such gravels with underlying glacial sediments from which they are derived for purposes of areal mapping to emphasize the origin of the material and the glacial history of the area.

The subdued morainic topography of the Drummondville moraine is matched by that of moraines near Fort Covington, New York, described by MacClintock (1954, 1958; MacClintock and Terasmae, 1960), and the lag gravels of the Drummondville moraine are the equivalent of the 'winnowed till' of those New York moraines.

PLATE VII A

Reworked till or lag gravel derived from underlying till of the Drummondville moraine; such material is more commonly exposed in the moraine than is the Gentilly till. Highway 13 between St-Leonard-d'Aston and Notre-Dame-du-Bon-Conseil.

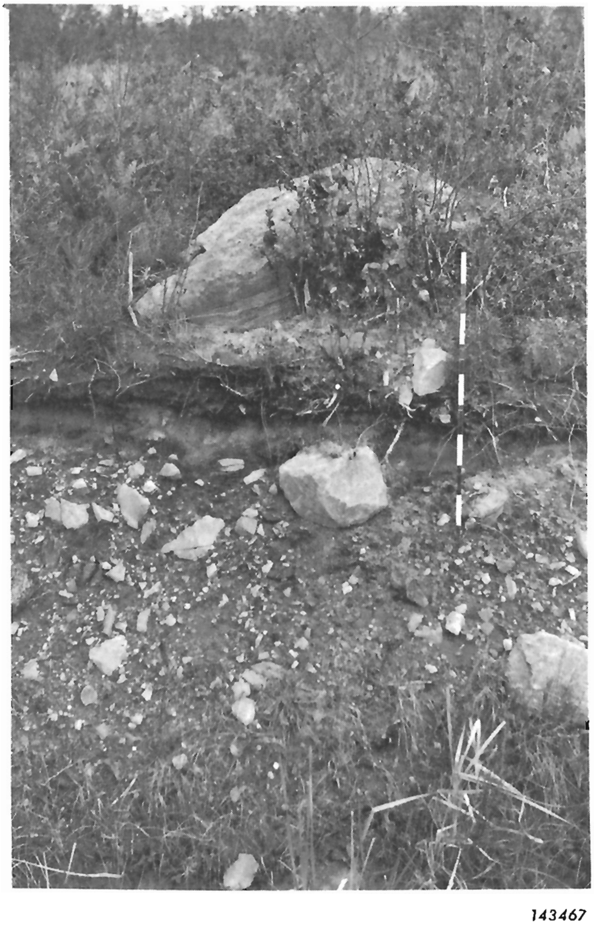

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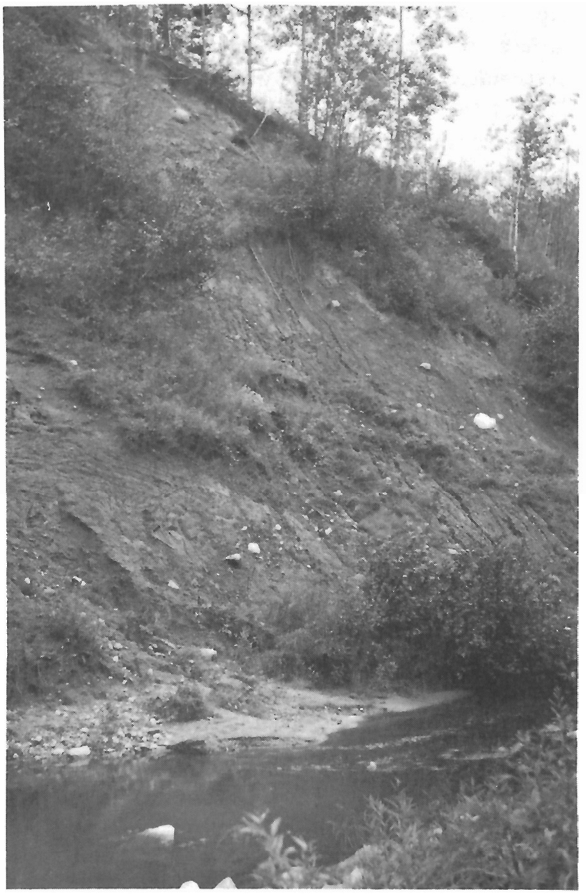
PLATE VII B. Subdued ridge of the Drummondville moraine showing a smooth surface and concentration of boulders that represent modification of the moraine by wave action in Champlain Sea.

St. Narcisse Moraine

The St. Narcisse moraine (Fig. 4a), which formed later than the Drummondville moraine, has been modified somewhat less by wave action and retains much of its original topography, but is otherwise similar in structure and materials to the Drummondville moraine. In the St. Narcisse moraine, blocks and boulders are dominantly of Precambrian material, and the composition of the clay fraction of materials there also reflects the same source (Karrow, 1957, p. 42). Although the till of the St. Narcisse moraine overlies contorted fossiliferous marine silt and clay in several sections (Pl. VIII), the texture of the till remains sandy. Because soft sediments such as Champlain Sea clays probably would have admixed readily with till of an overriding ice sheet, the absence of such admixing in the St. Narcisse moraine suggests that the advance of the ice front into the marine basin must have been over a short distance and thus represented a marginal fluctuation rather than a regional readvance. Under these conditions there could have been little or no deflection of the glacier along the valley of the St. Lawrence, so that the glacial movements are interpreted as having been southeastward, or normal to the moraine, rather than southwestward, and parallel, as suggested earlier by Osborne (1950b).

Sheets and masses of till exposed in the St. Narcisse moraine and at places north of that moraine constitute the most sandy facies of till noted in this report as belonging to the Gentilly glacial stade. They reflect the nearby Laurentian source rocks in their composition. In most sections this facies of till is devoid of pebbles of Paleozoic rocks and is only slightly calcareous. This till and related glaciofluvial sediments are shown as unit 3a on the geologic map accompanying this report. Like other sediments of the St. Narcisse moraine the till is

PLATE VIII
Till of the St. Narcisse moraine over contorted fossiliferous marine silt and clay. East bank of Rivière du Lard, $1\frac{1}{4}$ miles Southwest of St-Narcisse Station.



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modified by wave action of the Champlain Sea. In addition, the writer noted (Gadd, 1955, p. 117) a section in the St. Narcisse moraine where two 30-foot till sheets were separated by about 20 feet of fossiliferous marine clay. More recent observations at this section reveal that the upper till lying on marine clay contains abundant foraminifera. Such occurrences support the view that formation of the St. Narcisse moraine was a glacial phenomenon that occurred while the St. Lawrence Lowland was occupied by the Champlain Sea.

In his definition of the moraine Osborne (1950b) stated that an ice margin stood on the south flank of the moraine, and that a tongue of ice lying in the St. Lawrence Valley, moving upstream (southwestward) along the valley, formed the St. Narcisse moraine more or less as a lateral moraine. One would therefore expect that Paleozoic sedimentary rocks (mainly limestone from bedrock south of the moraine) should occur plentifully as pebbles and boulders in the materials of the moraine. This is not the case, however, for the moraine is essentially free of such boulders and pebbles. Osborne also claimed that northward-dipping beds of gravel and sand within the moraine, particularly at Valmont (Mont-Carmel), showed that the moraine was partly formed by glacial streams flowing northward from the ice mass. The writer's close examination of the moraine at Valmont and elsewhere showed many exposures of sand and gravel containing strata dipping to the south. Indeed, strata near the surface of the moraine commonly dip in several directions, because most such strata, being of secondary origin owing to wave erosion of the moraine, conform with the dip of the surface slope. New, deep excavations in the core of the moraine in a number of places show that below the zone of superficial modification caused by wave action, the moraine contains much stratified glaciofluvial sediment with dominantly southward dips.

These observations, together with those of Karrow (1957, p. 44) on glacial phenomena within and north of the St. Narcisse moraine, are the basis for the writer's opposition to Osborne's (1950b) interpretation and acceptance of the hypothesis that ice moved southward to the St. Narcisse moraine from the Laurentian Highland and stood on the north side of the ridge while it was in the process of formation. Because of relationships to marine sediments and fauna it would appear that the St. Narcisse moraine was at least partly contemporaneous with Champlain Sea, and that the ice sheet itself constituted the north shore of Champlain Sea while St. Narcisse moraine was being built.

Both the till and the glaciofluvial sediments of the St. Narcisse moraine have been modified by marine wave action, and the initial irregularities of the surface were thereby removed or smoothed. A coarse lag debris is commonly found on the crest of the St. Narcisse moraine (Pl. IX), but well-bedded coarse gravels are also common in its core (Pl. X). Although marine fossils are not common in the St. Narcisse moraine, they are found at some places in concentrations of cobbles and boulders and in some of the gravels, and therefore indicate that many such deposits in the moraine were formed on storm-tossed shoals or beaches in the Champlain Sea. The dominance of acidic rocks in the original deposit made it an inhospitable environment for the support of living colonies of molluscs, and the present acidic soil condi-

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PLATE IX. Bouldery lag gravel developed on sandy till of the St. Narcisse moraine; 4½ miles east of St-Stanislas.

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PLATE X. Stratified coarse beach gravel developed on crest and north flank of St. Narcisse moraine a mile east of St-Stanislas. Note dip conforming with slope of the surface. View westward along north flank of moraine.

tion in the moraine has not favoured the preservation of their fossil shells. Parts of the St. Narcisse moraine north of Bournival are composed largely of glaciofluvial and other sediments common to the ice contact depositional environment and have been mapped separately (map-unit 4) from those parts of the moraine composed primarily of glacial till. Similar coarse ice contact stratified sediments are found in other parts of the area, but are not readily mappable. Classification of the steeply dipping stratified sediments of the Valmont (Mont-Carmel) part of the moraine has been a problem. Northward dips have been observed mainly in the pits on the northern flank of the ridge, but southerly dips are as common on the opposite flank. The good sorting of this sediment speaks against deposition directly from the ice, but general coarseness and angularity suggest short distance of transport from glacial sources. A few casts of marine shells, mainly of *Hiatella*, have been found in silty layers deep within this mass of sediments. With regard to origin, it seems possible that a glacial stream flowing along the north flank of the St. Narcisse moraine may have debouched into the marine basin at a break in the moraine, which corresponds with St-Maurice Valley, and there built a thick, broad delta of coarse material. Another possibility is that delta-like fans were built out into St-Maurice Valley by shore currents acting along both sides of the moraine, removing and redepositing fine parts of the glacial sediment. Marine shells would be only poorly preserved in a body of well-drained siliceous sediment where the environment would be acidic, which is probably why only a few casts of fossils are found at Mont-Carmel. The sediments there show and preserve phenomena of both glacial and marine environments, but the glacial affinities are more pronounced. The writer has therefore chosen to classify these sediments as glaciomarine.

Outwash Terrace Deposits

A series of outwash terraces that formed north of the St. Narcisse moraine, and therefore is younger than the moraine, occupies the upper part of Yamachiche Valley and extends northward to between Lake Patterson (northwest corner of Trois-Rivières map-area) and Lake Royer. The sediments are coarse, angular gravels and coarse sands of Precambrian rock components. Where they occur below the maximum level of marine submergence, glacial and marine sediments intergrade and interfinger in a complex manner, and in places the marine sediments contain channels filled with glaciofluvial sediments. These relationships indicate that glacial sources in the highlands north of the channels produced outwash gravels during and after recession of the marine waters from this part of the area.

Béland (1961) mapped an esker above the marine limit in the adjoining Shawinigan map-area (31 I/10). Its trend and proximity to the glaciofluvial sediments found in the northwest part of Trois-Rivières map-area (31 I/7) suggest to the writer that it is genetically related to the outwash terraces in the upper part of the Yamachiche Valley, the esker being the highland segment of an esker–outwash system, the terraces being the submarine and/or post-marine segment. Other such complex glaciomarine relationships have been observed along the north flank of the St. Narcisse moraine and at other places in Grondines map-area (Karrow, 1957, p. 40). All such relationships show that retreat of the ice front, which in this area was accompanied by minor oscillations of its position, was simultaneous with marine conditions in St. Lawrence River.

Glaciolacustrine Deposits

At least four, separate glacial-lake episodes of different duration are recorded in glaciolacustrine sediments of the central part of the St. Lawrence Lowland. Glacial lakes formed in some part of the lowland at the onset and during the retreat of each of the two glaciations recognized in the area. Varved silts underlie and overlie both the Bécancour till and the Gentilly till. Varve-like sediments of glaciomarine origin are also found, and in some places are distinguished from glaciolacustrine varves only by the fossils they contain.

Pre-Bécancour Till Silts

The oldest of the four varved silt sequences predates the deposition of Bécancour till and is the oldest unconsolidated sediment known in the region. It occurs in an escarpment at points along the south shore of St. Lawrence River and in a few sections in valleys tributary to the St. Lawrence. Near Cap Lévrard it is overlain by red Bécancour till (Pl. V). Near Cap Charles a slumped and rotated mass of these silts is exposed in the gently sloping river terrace (Pl. XI); contortion of the upper foot of these strata suggests that they were overridden by ice, but no till is exposed.

Varved silts of this pre-Bécancour sequence are brick-red to reddish grey with winter layers about one-half inch thick alternating with lighter coloured summer layers about an inch thick. They are composed primarily of silt-sized material with some clay; summer layers contain partings of very fine crossbedded sand. The beds are generally calcareous, but summer layers effervesce much more strongly and consistently with application of cold dilute hydrochloric acid, indicating a higher carbonate content. The thickest known section of these reddish varved silts (Pl. XI) shows about fifty varve pairs. No organic matter was observed in any section of these sediments.

152650

PLATE XI. Slumped reddish varved clay, dipping southward towards the St. Lawrence River scarp on the right, and truncated by erosive action of St. Lawrence River; Cap Charles, looking downstream.

Post-Bécancour Till Silts

The second varved silt sequence to be deposited in the area is related to the retreat of ice that deposited the Bécancour till. Along the St-François River varved sediments occur between Bécancour till and interstadial sediments of the St. Pierre Interval (sections 98, 99, 109, and 110, in Appendix I). These are clearly different from and younger than the pre-Bécancour silts just described, and were deposited in the St-François River area during retreat of the ice that deposited the Bécancour till. No other varved strata of similar age have been positively identified elsewhere in the area.

At the mouth of Rivière aux Vaches, on the west bank of St-François River, the varves near the basal contact with red Bécancour till are about one-quarter inch thick and thicken upward to about one-half inch. Varves near the top of the sequence are sandy and grade upward into bedded sands deposited during the St. Pierre Interval. Characteristically, the winter layers and some summer layers of these varve silts are brick-red, the same colour as the underlying Bécancour till and Bécancour River shale. The summer layers are red, where clay and silt are dominant, but are grey to buff where sand is abundant or dominant. On the opposite bank of St-François River, in a section designated by Terasmae (1958, p. 19) as the Pierreville section (a ravine about 1½ miles downstream from Rivière aux Vaches and 1½ miles southeast of the village of Pierreville), the varve sequence that underlies peat-bearing sands and rests on red Bécancour till consists primarily of grey sediments, but in the lowest 5 feet of section winter layers are reddish grey to brick-red. The pairs of layers are ½ to 1 inch thick. In at least one other exposure about 1½ miles upstream from the above-mentioned section, the strata have the same distinctive colour banding of red and grey. In other nearby exposures along St-François River thin deposits of varved silts lying directly on Bécancour till are entirely red or reddish grey, similar in colour to the pre-Bécancour till varved silts at Cap Charles and Cap Lévrard.

Deschaillons Varved Sediments

Lake Deschaillons is the name given (Karrow, 1957, p. 61) to an undefined body of water ponded in the St. Lawrence Lowland during the advance of the ice sheet that laid down Gentilly till. Deschaillons varved sediments (Gadd, 1960b, p. 12) is the name given to its characteristic sediments. Because the lake was overridden by the ice sheet its limits and shorelines are not known; nonetheless it is obvious from data given below that a large preglacial lake existed for about 500 years in the part of the lowland discussed in this report. Lake Deschaillons and its sediments are named after the village of Deschaillons on the south shore of St. Lawrence River where the silty clay and underlying sand have been the basis of a thriving, long-term commerce in brick-making; the type section is the southern face of the 'clay pit' of the Montreal Terra Cotta Company.

Deschaillons varved sediments occur in a belt about 53 miles long between St-François River and Leclercville; the belt is generally 15 to 20 miles wide, although perhaps only about 6 miles wide at the eastern end (Karrow, 1957, p. 38). There are good exposures in St-François, Nicolet, St-Maurice, Petite Rivière du Chêne, and Ruisseau l'Espérance Valleys, and in nearly continuous sections along St. Lawrence River from the vicinity of Rivière aux Glaises (about 2 miles east of the village of Gentilly) to the east bank of Grande Rivière du Chêne at Leclercville. Thick deposits are found also in the abandoned river escarpment between the community of Ste-Anne-de-la Pérade and the mouth of Lachevrotière River, north of St. Lawrence River.

The thickest deposits of Deschaillons varved sediments are preserved in the scarps on the south shore of St. Lawrence River. They are 67 feet thick at the St. Pierre section (section 58 in Appendix I), about 75 feet thick in the scarp beneath the Roman Catholic church at St-Pierre-les-Becquets, approximately 80 feet thick in the brick yard of the Montreal Terra Cotta Company at Deschaillons, and approximately 90 feet thick in river scarps about a mile upstream from Leclercville.

Deschaillons varved sediments are dominantly of silt, are grey, and exhibit graded bedding. Most varve pairs are about an inch thick (Pl. XII) and a few varves in some sections are thicker; but in most thick sections varve pairs as thin as one-sixteenth inch occur in the upper and lower several feet of exposure, while thicker strata occur in the middle part of the section. These vertical variations of varve thickness, which are fairly consistent in known deposits of Lake Deschaillons, probably reflect varying conditions during the history of formation of the lake. Thin beds at the beginning of the sequence may indicate a distant source of glacial meltwater, thicker beds in the middle of the sequence may indicate the normal ice front or near-ice conditions, and thin beds at the top of the sequence may indicate the conditions of increasing cold and smaller flow of meltwater during the advance that ultimately overrode Lake Deschaillons and eroded and contorted its deposits as the Gentilly till was laid on them.

The grey varved silts are stiff and resist subaerial erosion to the extent that their deposits form very steep to nearly vertical escarpments along the banks of rivers and streams that have cut their valleys through them. Part of the reason for their resistance is their probable partial consolidation caused by the pressure of overriding ice.

The mineral composition of the clay fraction of the varves is similar to that of the Gentilly till (Karrow, 1957, p. 38); both contain chlorite, illite, quartz, feldspar, and amphibole as principal mineral components. Free carbonate content of the varved silts, as recognized by testing with hydrochloric acid in the field, varies considerably; some deposits effervesce freely, particularly in the light-coloured (summer) layers; others effervesce little or not visibly,

PLATE XII

Typical Lake Deschaillons strata; each varve pair is about 1 inch thick. North flank of ravine at St. Lawrence River scarp about 1 mile upstream from St-Pierre-les-Becquets.

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although the reaction is generally audible. The concentration of free carbonate in some places may be related to movement of groundwater and deposition of calcium carbonate from it (see following section on concretions).

In a great many exposed sections the Deschaillons varved sediments rest conformably on stratified sand deposited during the St. Pierre Interval (Pl. XIII). In some exposures the varved sediments are overlain by Gentilly till (Pl. XIV) and locally are contorted in their upper part below the till. Lake Deschaillons, therefore, formed after the St. Pierre Interval but before the ice sheet of the Gentilly glacial stade advanced into this area. It probably formed as a proglacial lake just prior to this advance.

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PLATE XIII. Stratified non-glacial sands beneath Lake Deschaillons silts in the Deschaillons brickyard. Note bedding and channeling structures accentuated by concentrations of heavy minerals in the sands. (Photo by Joseph Keele, ca. 1915.)

PLATE XIV

Grey varves of Lake Deschaillons overlain by grey sandy till in St. Lawrence River escarpment $1\frac{1}{2}$ miles upstream from St-Pierre-les-Becquets. Blade of pick marks contact.

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The Deschaillons varved sediments and some of the underlying sand are used in the production of terra cotta products. Common brick, terra cotta insulation tile, flue tile, drainage tile, and roofing tile are produced by several small plants that have operated near Deschaillons (45 miles upriver from Quebec City) for at least 50 years. The brick is made by pressing or extruding a moistened and puddled mixture of sand and silt; it burns to an even deep red colour. An analysis of the brick-making qualities of the varved silts and of other similar materials in the region has been made by Keele (1915).

Concretions and their Origin

Carbonate concretions in the Deschaillons varved strata undoubtedly represent secondary concentration of salts from the groundwater. Thin, flat, discoid concretions apparently without nuclei other than the sediments themselves, occur in the light-coloured (summer) layers of varves at various places along St. Lawrence River (Pl. XV). In thin-bedded varves of the St. Pierre section, entire summer layers are petrified in similar manner over distances of 10 feet or more along the exposure. At one place the writer observed, that although the concretions were nearly circular where exposed at the face of the stream-cut bank, those dug out from the same layers but farther from the face had a more tabular form. About 30 inches in from the face of this exposure the writer uncovered a more or less circular concretion that could be removed as a unit, but was of different degrees of consolidation in its two halves. The outer half of the disc was just as hard as the concretions found at the face of the cut bank, but the inner half could be broken away easily by hand and had a malleable, putty-like consistency. The same condition was found in one of the sheet-like concretions in thin-bedded varves at the St. Pierre section. Thus the induration of concretions of this type would

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PLATE XV. Calcareous concretions formed in the lighter coloured (summer) layers of Lake Deschaillons grey glacial varves as exposed in a river-trimmed escarpment of St. Lawrence River, approximately 2 miles upstream from St-Pierre-les-Becquets. The largest concretion, on the right, is about 9 inches in diameter.

seem to be related to proximity to the exposure face. It is possible that evaporation of groundwater at the exposed face of the varved deposits causes crystallization of the carbonates and final hardening of the concretions.

The form of these concretions is probably related to fracturing of the parent mass of sediment. The strata shown in Plate XV, for example, are cut by numerous vertical fractures that pass between adjacent concretions. In plan these fractures form a rectangular to polygonal network. The writer suggests that as desiccation occurs at the exposure face, carbonates are concentrated first in the more porous and permeable light-coloured (summer) layers by evaporation of horizontally moving groundwater, then the mass of clay shrinks because of drying, and fractures develop at its outer exposed edge. These fractures extend vertically through the entire section, but horizontally only a few feet into the body of sediment, penetrating indurated and semi-indurated concretionary layers and breaking them into rectangular to polygonal plates. Surface water percolating vertically through the fractures dissolves out the free carbonates, rounding and smoothing the concretionary plates into tabular discs. Completely indurated discs are concentrated on terraces at the base of the scarp as mass wastage of the varved silts progresses. Irregularities on the surface of concretions, which represent accretion of carbonates along minor fractures that terminate on the upper surface of the concretion, are soon smoothed away by erosive action of waves and currents. Vertical joints are less common in the thin-bedded varves than in the thicker varves, and therefore tabular concretions of some size may be preserved more commonly in thin-bedded sediments.

Post-Gentilly Till Silts

The fourth glacial lake episode of the region is represented by only a few feet of varved sediments that occur between the Gentilly till and the base of the Champlain Sea clays. In sections along Nicolet River, between Ste-Monique-de-Nicolet and the confluence of the Nicolet and the Nicolet Sud-Ouest Rivers, from 2 to 4 feet of gravel, sand, and thin-bedded varves lie between Gentilly till and Champlain Sea clay. The lacustrine varves are at the base of the marine clay sequence and grade upward into it (*see* Appendix I, sections 118, 122, 123, 129, and 130). The relationship is clear where Rivière aux Vaches meets the west bank of St. François River. There, from the upper surface of an 8-foot sheet of Gentilly till, 1½ feet of well-defined, grey, non-fossiliferous varved silts grades upward into similarly banded and slightly sandy silt that contains marine foraminifera. This in turn grades upward, within 2½ feet, to massive, uniform, marine silty clay containing fossils mainly of the pelecypod *Yoldia*.[1] Thus the complete transition from glaciolacustrine to marine environment is recorded in a 4-foot section of sediment. The evidence at this Rivière aux Vaches section suggests strongly that the glacial-lake environment was short-lived and changed to the Champlain Sea environment without erosional interval.

Younger, apparently varved sediments in the city of Shawinigan Falls, in an excavation opposite the Post Office, are products of a glaciomarine environment. They have the rhythmic stratification of glacial origin and the fossils (mainly the pelecypod *Hiatella* sp.) of the marine environment. These are probably the characteristic sediments of a Shawinigan Falls embayment in the Laurentian Highland and probably date from the maximum of the Champlain Sea. They would then be somewhat younger than stratified sediment occurring at the base of the marine Champlain Sea sedimentary sequence. Karrow (1957) referred to glaciomarine sediments having similar age relationships near the St. Narcisse moraine and in areas between this moraine and the Laurentian Highland.

[1]This name is now superceded by *Portlandia* sp. (F.J.E. Wagner, pers. com.)

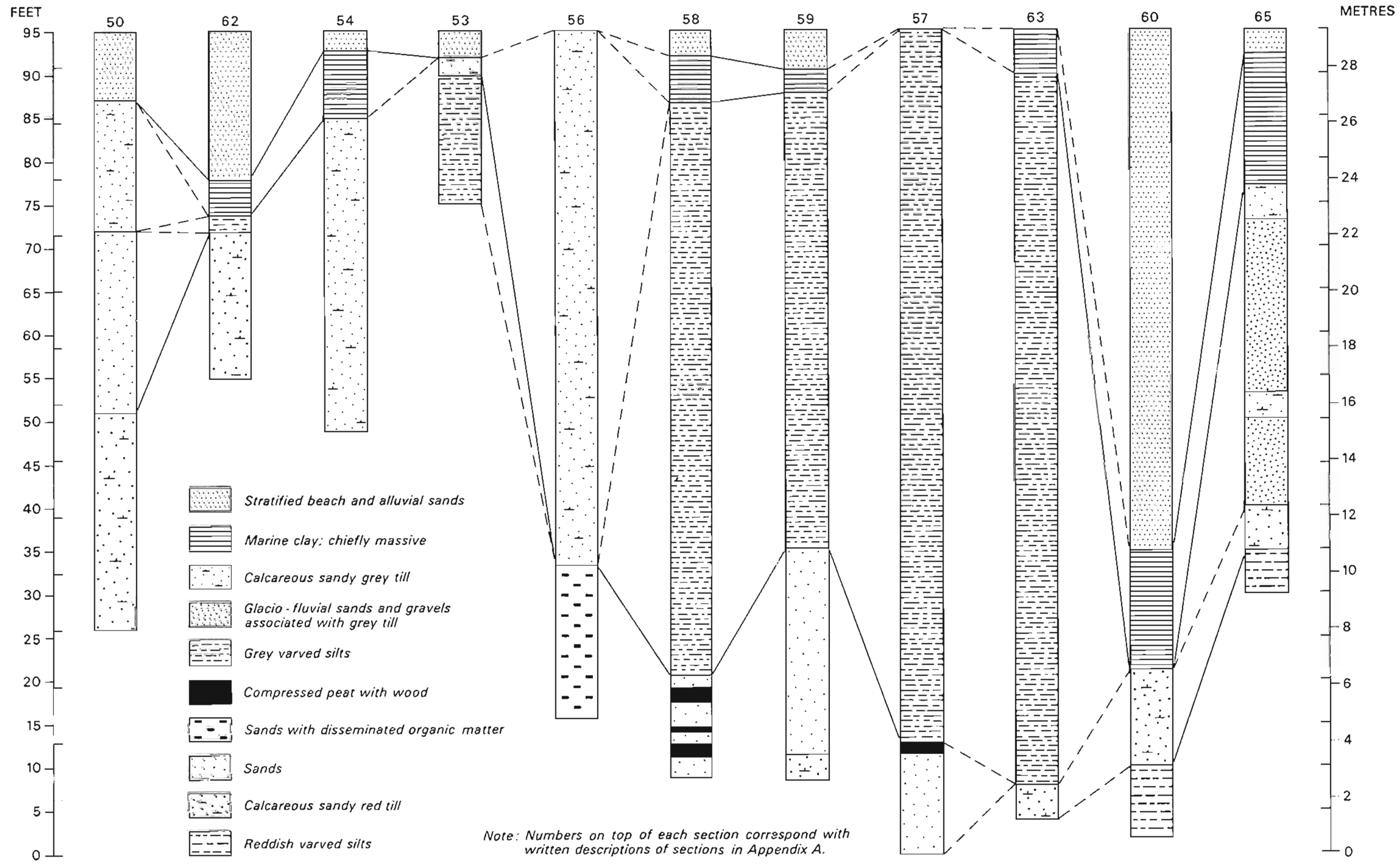

FIGURE 8. Sections along St. Lawrence River escarpment between Gentilly and Deschaillons. Sections 58 and 59 are the St. Pierre section.

Interstadial Deposits

A non-glacial interval between the two glaciations of the region is represented by fresh-water sediments, mainly of fluvial origin. Sand, some gravel, and peat were deposited in the channels of an extensive river system--perhaps the equivalent of St. Lawrence River—which developed after the retreat of the ice sheet that deposited the Bécancour till.

Keele (1915, pp. 82, 83) discovered outcrops of the peat, associated sand, and varved silts, and recognized that they belonged to a time between 'glaciations'. He gave no special attention to the peat, but merely signified its presence in one of his text-figures (1915, Fig. 8).

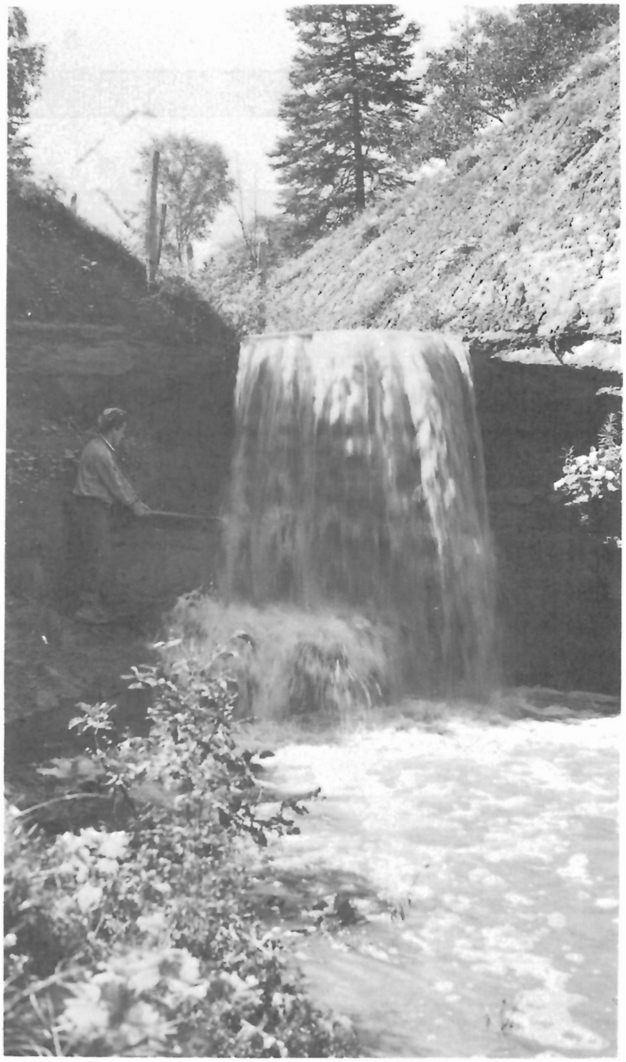

PLATE XVI

Exposure with three layers of buried peat in the St. Pierre section. The upper peat layer forms the lip of the waterfall. The man holds a pick at the second layer of peat and stands on the third. Material between the peat layers is sand; glacial Lake Deschaillons varved silts form the slopes above the upper peat layer. View looking westward up the ravine.

143310

More recent discoveries by the writer and subsequent studies of the materials have proven that peat beds, correlative with the one bed discovered by Keele, contain the palynologic record of interstadial climates of the very early Wisconsin (Terasmae, 1955, 1958).

St. Pierre Sediments

The writer (Gadd, 1960b, p. 10) has applied the name St. Pierre sediments to the interstadial sand, gravel, and peat in this region, with its type section near the village of St-Pierre-les-Becquets. The village is on the south shore of St. Lawrence River, opposite the mouth of Batiscan River, and about midway between the mouths of Rivière aux Orignaux and Petite Rivière du Chêne. The St. Pierre section (Fig. 8; also section 58, Appendix I) is in an unnamed ravine approximately a mile south along highway 3 from the village. It is within the property of Lucien Laroche, lot 4, concession 1, St-Pierre-les-Becquets Parish, Lévrard or St-Pierre-les-Becquets township, Nicolet county. The ravine is occupied by an intermittent stream about a mile long that empties into St. Lawrence River. At 0.4 mile upstream from the culvert on highway 3 is a 10-foot waterfall (Pl. XVI), the lip of which is an indurated and compressed 1-foot layer of peat. The best exposures occur at the waterfall and in the north wall of the ravine for several hundred feet downstream from it.

Two other sections containing important beds of interstadial peat have been named. Les Vieilles-Forges section is on the west bank of St-Maurice River near the southern entrance to the village of Les Vieilles-Forges, about 7 miles upstream from Trois-Rivières. Good exposures are readily accessible by foot paths leading from the highway along the small stream at Les Vieilles-Forges that crosses the highway at the major curve south of the village. Another exposure where stratigraphic relations are readily seen is the Pierreville section. It is named for its location about 1½ miles southeast of Pierreville in a deep ravine between the road and the east bank of St-François River. This is the section at which Keele observed peat beds (as mentioned previously in this section), but exposures due to gully erosion were much better and relationships much clearer when the writer examined the section in the early 1950s. In addition to these particularly good exposures, there are outcrops of St. Pierre sediments in all the major tributary valleys and on the south shore of St. Lawrence River in the general area between the St. Narcisse and Drummondville moraines. Outside the map-area, similar sediments are known to the writer only upstream from Leclercville in the valley of Grande Rivière du Chêne.

Exposures of non-glacial sands 10 to 15 feet thick are common (Fig. 8; also sections 50, 57, 58, and 59 in Appendix I), but thicknesses of 25 feet or more have been estimated in some places where hand-auger borings have been made below exposed sections. Most of the sand is grey in its unoxidized state, yellow-buff to iron stained where oxidized. Commonly the sands are well sorted, clean, uniformly fine grained, and contain few pebbles. In some sections, however, the sands are heavily charged with disseminated organic matter and thereby have acquired a brown colour. The sands in places contain silt and clay in minor amounts, particularly where they underlie peat beds. Probably the silt and clay concentrations represent slack-water areas or abandoned stream meanders in which bog deposition could readily develop. Karrow (1957, p. 32) indicated an anomalous montmorillonite content in a greenish clay underlying a peat bed at Les Vieilles-Forges, and suggested that secondary montmorillonite may have formed from other silicates in the presumably reducing environment beneath a peat bog.

Stream crossbedding and channelling structures in the sands indicate flow in the same general direction as the present drainage system. Concentrations of heavy minerals, chiefly magnetite, accentuate the bedding structures (Pl. XIII). In a few localities, such as Bécancour

River valley north and northeast of Aston Station, gravelly sands occur in considerable thickness, and crossbedding structures are shown principally by pebble concentrations (Pl. XVII).

Another facies of the St. Pierre interstadial suite is a gravel observed mostly in a few sections along the westerly flowing part of Bécancour River (Pl. XVIII), and in the St-François River in sections on the northeast bank of the river between 5 and 6 miles upstream from Pierreville; minor exposures are also known along other large tributaries of St. Lawrence River. In all these places the gravel is composed almost exclusively of well-rounded tabular pebbles and cobbles of the local bedrock, which is principally grey or red shale. In a number of the exposures these gravels are more or less cemented by deposition in them of secondary calcium carbonate. In several localities it has been noted that the source rock outcrops in the present stream bed within a few hundred yards of the buried gravel, and it is assumed that the interglacial stream also encountered the same bedrock from which it easily eroded large numbers of rock fragments that were transported a short distance downstream and redeposited as gravel. Rounding of local shale pebbles, as seen from transport in present streams, is very rapid.

Peat beds, wood, and sediments containing disseminated organic matter, which are interbedded with the sands and gravels described above, may be considered the fossiliferous zones of the St. Pierre sediments. From these beds, primarily, Terasmae (1957, 1958) has extracted fossil pollen grains that permit analysis of the paleoecology and paleoclimatology of the period of deposition of these sediments. Wood and peat preserved in the peat beds is the material that has given relative ages by carbon-14 datings (Broecker and Kulp, 1957; Preston *et al.*, 1955; Rubin and Suess, 1955; Dreimanis and Packer, 1959; Dreimanis, 1960).

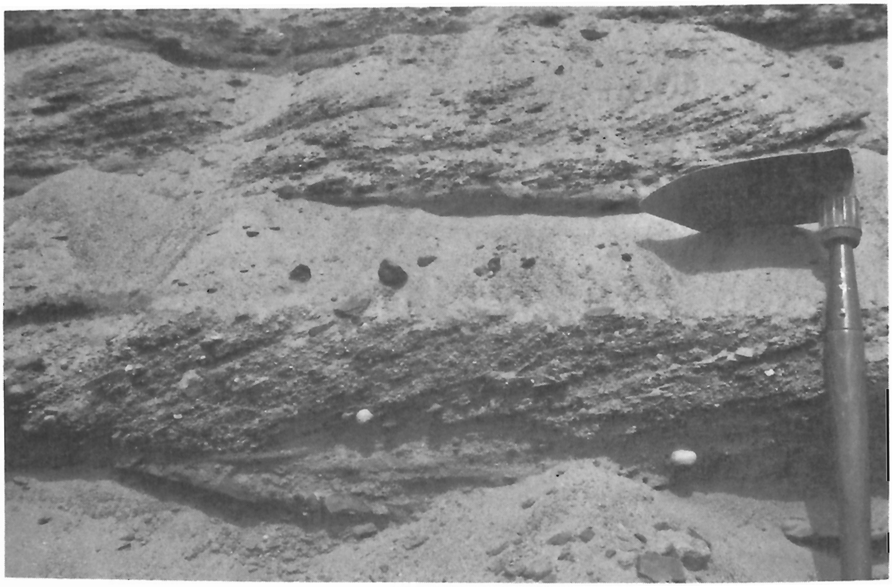

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PLATE XVII. Crossbedded gravel and gravelly sand formed during the St. Pierre Interval; north bank of Bécancour River approximately 2 miles northeast of Aston Station.

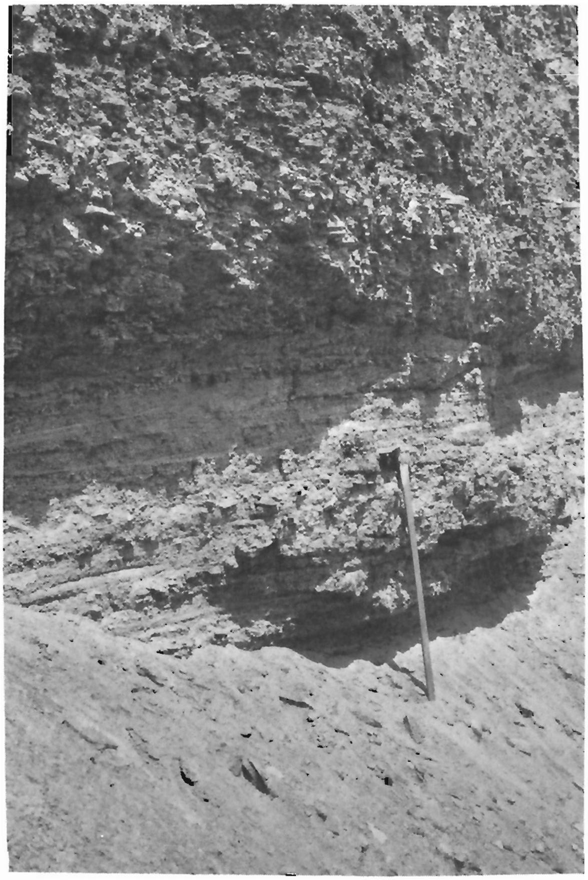

PLATE XVIII
Shale-pebble gravel formed during the St. Pierre Interval indicates intensive erosion of bedrock locally during this non-glacial episode; Bécancour River valley north of Aston Station.

143333

The buried peat strata are found in many of the sections in which Lake Deschaillons silts and St. Pierre sands are exposed, but are most abundant in the St-François, Nicolet, and St-Maurice Valleys and along the south shore of St. Lawrence River near St-Pierre-les-Becquets.

Bands of sand, silty sand, and silt containing sufficient organic matter to give them a generally brown colour are several feet thick in numerous sections, but strata composed essentially of organic matter are somewhat thinner. The thickest organic layer observed in the area is in the St. Pierre section where compressed peat and wood occupy layers nearly 2 feet thick (Pl. XIXA). At Deschaillons flattened twigs of wood are scattered along a bedding plane in the St. Pierre sands (Pl. XIXB); in the section at Les Vieilles-Forges rooted stumps of trees, some of which are known to be spruce, as much as 6 inches in diameter have been observed in peat layers (Pl. XXA). Detailed descriptions of these various peat beds have been given by Gadd (1955) and Terasmae (1955, 1958).

The peat is generally so highly compressed that it is difficult to cut with a pick and therefore resists erosion to the extent that peat layers stand out in relief in section faces and can often be recognized by their prominence even where covered by a wash of clay or sand from overlying strata (Pl. XXB). A heavy growth of vegetation above the peat beds may be caused

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PLATE XIX A. Dark band is compressed peat layer in the St. Pierre section. Note flattened twigs at base of bed at left of photo. Metre stick gives scale.

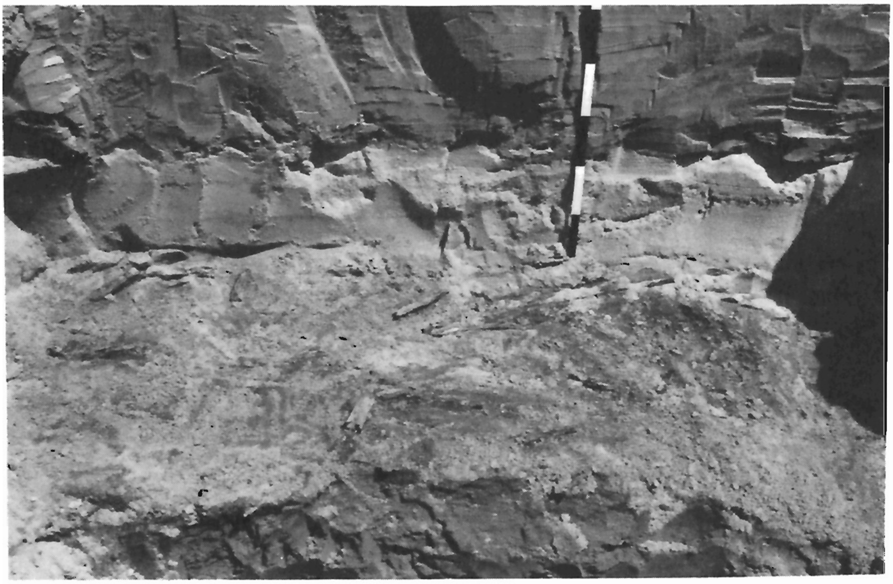

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PLATE XIX B. Section in the Deschaillons brickyard. Thin-bedded, dark grey silts of glacial Lake Deschaillons lie conformably on the undulating upper surface of interstadial sands. Pieces of flattened wood and bits of sphagnum moss lie on the excavated platform at the base of the metre stick, 20 centimetres below the base of the varved silts.

143461

PLATE XX A. Rooted black spruce stump exposed in excavation of compressed peat layer; Les Vieilles-Forges section.

143448

PLATE XX B. One-foot-thick compressed peat layer in Les Vieilles-Forges section, west bank of St-Maurice River. The peat stands out in relief because of its greater hardness and resistance to erosion than beds above and below. Note also the thick growth of vegetation in the zone above the impermeable peat bed, that is watered by springs.

by springs that issue along the surface of the impermeable beds. Some tabular blocks and rounded 'boulders' of peat are found in the stream beds at distances as great as several hundred feet from some outcrops and serve as a clue to the location of strata in place.

The horizon of peat beds within the St. Pierre sediments is locally marked by the presence in the sand of small flecks and patches of the mineral vivianite, a hydrous ferrous phosphate ($Fe_3P_2O_8.8H_2O$). The writer suspects that this mineral forms as a secondary product of decomposition of wood and woody peat, from which phosphorus may be derived, under the action of groundwater carrying ferrous iron in solution. Vivianite is also associated with peat and wood, in some places as encrustations on bits of wood. Although pure vivianite is white and might pass unnoticed, the mineral that occurs in these deposits is impure and has a deep blue colour that contrasts sharply with the sediments in which it is found. The writer has noted that in some occurrences the freshly exposed mineral is white to light grey, rapidly changing to deep blue on exposure to air.

A freshwater environment for formation of the peat beds in the St. Pierre sediments is indicated by the dominance in the organic layers of *Sphagnum* and *Carex* peat. The wood present probably is mainly spruce (Terasmae, 1958). Beetle remains, mostly wing covers and carapaces, of glistening black or irridescent green and blue are found chiefly in the more fibrous layers of peat. These are species of the genus *Donacia* (W. J. Brown, Canada Department of Agriculture, in communication with E. L. Bousfield, National Museum of Canada, 1950), insects that inhabit freshwater bogs and feed on the plants and their pollen. The common association with bedded sand showing structures typical of stream action strongly suggests that the bogs in which the peat formed occupied the abandoned channels of meandering streams.

Studies of pollen from underlying silts and overlying varved clays (mainly in the St. Pierre section) and of intervening sand and peat layers led Terasmae (1958, p. 20) to conclude "... that the St. Pierre interval was not an interglacial stage but rather an interstadial substage of 6,000 to 7,000 years' duration" which had a relatively uniform climate throughout; at its warmest was ". . . about 3 to 5 degrees Fahrenheit lower than present"; and that some parts of the sequence, at least, represent "... conditions much the same as those in the present Boreal forest region". There is evidence of an early 'subarctic' climate in pollen collected from varved silts underlying the Pierreville section, a continuous record of rising temperatures to near present conditions in the organic sediments, and then a decline towards subarctic conditions, recorded in pollen from the silts of glacial Lake Deschaillons overlying the peat beds in the St. Pierre section. Thus the St. Pierre Interval apparently began and ended with glacial conditions.

Palynological evidence and the estimated short duration of the interval, coupled with radiocarbon dating of more than 40,000 years, led Terasmae to suggest (1958, p. 27):

> ...that the St. Pierre interval may well represent one of the postulated non-glacial intervals during the advance of the Wisconsin glacial stage. This concept helps to explain the absence of a marine invasion of the St. Lawrence Lowlands early in the St. Pierre interval, because during the advance of the Wisconsin ice the weight of its mass and the length of its duration were not sufficient to depress the land below sea-level as was the case at a much later date, when the Wisconsin ice receded from the St. Lawrence Lowlands.

Radiocarbon Dating of the St. Pierre Peat Beds

Wood obtained from the middle peat bed of the St. Pierre section was first analyzed at the Lamont Geological Observatory and its age reported as 11,050 ± 400 years (Kulp, 1953, written communication with Geological Survey of Canada). This date was the basis for correlation with the Alleröd and Two Creeks Intervals (Gadd, 1953). Subsequent datings of this and correlative wood and peat samples (Table III) led to a revision of the correlation (Terasmae, 1958; Gadd, 1960b), as stated in the above quotation from Terasmae. In effect, excepting the original date, all datings of the St. Pierre Interval reported up to 1959 were beyond the limit of the radiocarbon dating method employed. More recent datings by the late H. de Vries on his own collections of wood and peat from the Pierreville bed and from the upper portion of the St. Pierre sections give finite dates of 67,000 ± 2,000 (GRO–1711) and 64,000 ± 1,000 (GRO–1766) years respectively, and thus support the post-Sangammon–early Wisconsin position suggested by Terasmae (1958, p. 27). Further work already begun, or at least projected, but left unfinished by de Vries (correspondence with Dreimanis, March 24, 1959) was aimed at a more careful study of the age range of the St. Pierre Interval 2nd of its possible correlation with work in Denmark and the Netherlands (Andersen, de Vries, and Zagwijn, 1960; Zagwijn, 1961).

TABLE III | *Table of Radiocarbon Dates*

Sample No.	Location	Date (years B.P.)	Reference
ST. PIERRE INTERVAL			
W–189	St. Pierre section	> 40,000	Rubin and Suess, 1955
Y–242	St. Pierre section	> 30,840 > 29,630	Preston *et al.*, 1955
Y–254	Les Vieilles-Forges	> 29,630	" " "
Y–255	" " "	> 30,840	" " "
Y–256	Pierreville section	> 29,630	" " "
L–190A	St. Pierre section	> 40,000	Broecker and Kulp, 1957
L–369A	" " "	> 44,000	Olson and Broecker, 1959
GRO–1711	Pierreville section	67,000 ± 2,000	Dreimanis, 1960
GRO–1766	St. Pierre section	64,000 ± 1,000	" "
CHAMPLAIN SEA TIME			
Y–233	Notre Dame des Neiges, Montreal, Que.	11,370 ± 360	Preston *et al.*, 1955
L–639B	Kingsmere, Ont.	11,320 ± 130	Lamont natural radiocarbon dates, IX, Radiocarbon V. 6, 1964
Y–215	Hull, Que.	10,630 ± 330	Preston *et al.*, 1955
Y–216	Uplands, Ont.	10,850 ± 330	"
GSC–90	Pembroke, Ont.	10,870 ± 130	Dyck and Fyles, 1963, p. 44
GSC–187	Kingsey Falls, Que.	11,410 ± 150	Gadd, 1964
POST-CHAMPLAIN SEA TIME			
L–441C	St-Germain-de-Grantham	9,500 ± 300	Olson and Broecker, 1961
GRO–1922	St. Adelphe, Que.	8,480 ± 80	Gadd and Karrow, 1959

Champlain Sea Deposits

During the final retreat of Wisconsin ice, from the area covered by this report, and for some period of time after its disappearance, the depressed area of the St. Lawrence Lowland was occupied by an arm of the Atlantic Ocean that has become known as the Champlain Sea. The configuration of the depression and therefore of the Champlain Sea is not known in detail, but it seems to have had its maximum depth near Montreal where shorelines are now found at elevations near 600 feet according to early estimates, but are probably not more than about 545 feet (Prest and Keyser, 1962, p. 31). The depression of the land was progressively less downstream from Montreal, so that Champlain Sea beaches occur at progressively lower levels northeast of the area studied here (Goldthwait, 1913, 1933). In the six map-areas covered by this report the writer's observations indicated that all land south of St. Lawrence River and all below 600 feet north of the St. Lawrence was inundated by the Champlain Sea.

At least two factors make it impossible to give definite limits to marine submergence in this area. First, the building of the St. Narcisse moraine in the Champlain Sea means that active glaciers occurred along the Laurentian Highland and at some time partly flanked the shore exposed to the sea; therefore few shoreline features were developed on ground surfaces north of the St. Lawrence during this time. Within the area no land south of the St. Lawrence stands at an elevation great enough to record the maximum levels of the Champlain Sea. Secondly, the slopes that eventually were exposed to wave action by removal of glacier ice were steep, south-facing slopes of the Laurentian Highland that were bare or only thinly veneered by glacial deposits. The bedrock is resistant crystalline rock, providing little material on which shore features might be imprinted. Consequently, although sea levels may have risen higher, there is no clear record in this region of marine shores above present levels of about 600 feet.

As the land was uplifted following recession of the ice, waves attacked the exposed shorelines, modifying the shapes of features made from glacial materials, and even of some bedrock features, and removing the fine sediment from the surface and near-surface, leaving behind coarse, variably sorted lag gravels. The fine sediments (clay, silt, and sand sizes primarily) were transported to deeper parts of the basin, where along with similar sediments of glacial origin, they formed the off-shore sediments of the Champlain Sea.

Shore Facies

This section is meant to deal with sediments that fall within the original definition of "Saxicava sand", i.e., fossiliferous shore-facies sediments of the Champlain Sea. However, there is a large body of sediment, that although fossiliferous, is rather difficult to classify because it does not belong properly to any one depositional environment or class of sediment. The problem is that the region was inundated completely and progressively by Champlain Sea as the ice front retreated northward across the area, and under these conditions there is a range of environments between glacial and marine with very complex interrelations. Well-sorted fossiliferous sediments on the one hand, and unsorted non-fossiliferous sediments on the other may readily be distinguished as end members of a series; but there exists a wide range of combinations, such as unsorted but fossiliferous sediments, or well-sorted and non-fossiliferous sediments, that may be interpreted in more than one way. For example, material might be variously classified if it is fossiliferous and contains elements that are coarse, unsorted, angular, heterogeneous as to size, and differs from lodgement till only in that it lacks or contains little of some of the finer grades common to till (clay, silt, fine sand), but grades downward into unfossiliferous fresh material that most geologists would recognize as glacial till of a ground moraine or lodgement till variety. One might suggest that it was ablation till deposited from ice in a subaqueous marine environment, or that it was the product of reworking by a process of surging (the writer prefers this term to MacClintock's 'winnowing') through wave and current action in a marine body of water of till deposited subglacially, and shortly thereafter flooded by marine waters. Either interpretation could account for the gradational contact between non-fossiliferous glacial till and fossiliferous debris that differed only slightly from the till and most probably was genetically related to it.

The example given above represents a very common condition in the area under consideration and may be found generally in the Drummondville and St. Narcisse moraines and in other parts of the area where glacial till is at or near the surface. These deposits have been designated as 'reworked till' or 'lag gravels' in preliminary publications (Gadd, 1959a, 1959b, 1960a; Gadd and Karrow, 1959; Karrow, 1959). Where the underlying material is till, the transition gradational, and the 'reworked' deposit fossiliferous, it is not difficult to accept that the sequence of events represented involved a glacial event followed by a glaciomarine or marine episode.

In a different but quite common case, however, a satisfactory interpretation is not as simple. On gravelly parts of the St. Narcisse and Drummondville moraines, and in other parts of the area where ice-contact stratified drift is present, there are many exposures where several feet of unsorted, generally non-fossiliferous, coarse, angular gravel with numerous boulders (e.g., Pl. IX) lie on well-stratified sand and gravel; the upper layer of material in many places is very similar to the type of material previously described as 'reworked till' or 'lag gravel'. Some workers have interpreted the upper debris as till and have suggested a readvance of an ice sheet to account for it. The writer believes, however, that it is a true lag gravel derived from underlying ice-contact sediments, and although they are generally unfossiliferous, the presence of a few whole shells and of fragments of marine shells in a relatively few places allows for their interpretation as marine gravels. Minor differences in the reworked material overlying till and the lag material overlying ice-contact sediments are probably due to basic differences in the parent materials; the presence or absence of marine shells is thought to be a function of the depth of leaching, which is less in debris underlain by till than in similar material underlain by sand and gravel.

The writer considers it to be an axiom of glacial studies in areas that have been subject to the inundation by the Champlain Sea that glacial sediments not buried by the deposits of that sea will have been modified more or less by the wave and current action of the Champlain Sea, and that in general one may expect to find a veneer of coarse, poorly sorted to unsorted debris, or lag gravel, on the primary glacial sediments. Such debris may or may not be fossiliferous, depending on conditions in the marine environment and on the degree and depth of leaching at the exposed surface since the readjustment of sea and land levels.

The reworked till and morainic sediments contain only sporadic fossils, with species of the pelecypods *Hiatella*, *Macoma*, and *Mytilus* the dominant types found. The shells are generally broken, worn, or otherwise poorly preserved; however, some pockets have been found in which well-preserved shells are abundant. In many pits where reworked material rests on till, shells are abundant in the contact zone, i.e., upper part of till and lower foot or so of reworked material, but sparse in the wave-washed debris. Material thus reworked from previously higher parts of the ridge may have slumped and encroached on the shell bed that lay just offshore from the storm beach.

The foregoing deals with glacial materials 'surged'—or as MacClintock would phrase it 'winnowed'—by the action of storm waves and relieved of fine sediment, while coarser sediments remained more or less in place. Minor transport provided little or no stratification in some places, relatively good stratification at others, but in all sorting is poor. Marine sediments so formed veneer or blanket modified pre-Champlain Sea glacial terrain.

Beaches are rare in the zone of marine erosion, and where present, have no preferred orientation, but conform to the outline of the glacial ridges or knolls. Factors that may explain the paucity of beaches in these wave-washed materials are as follows: (1) the possible existence of an initial cover of coarse ablation moraine in some parts of the area; (2) initial coarseness of the glacial materials; (3) 'surging' of the coarse materials by tides, currents, and waves before exposure in the beach zone; and (4) the probable short period of exposure to wave action at any one elevation.

In a very few localities fossiliferous well-sorted gravel and sand in well-defined beaches and in extensive flat sand plains (map-unit 6) represent the transported sediments, products of wave-wash and glaciofluvial transport to the shores, that were redeposited in the shore and near-shore environment of the Champlain Sea. In a well-defined beach at the water supply wells of the village of Ste-Gertrude (at the curve in the road 2 miles southeast of Villiers - Ste-Gertrude P.O., south-central part of Bécancour map-area, 31 I/8) well-sorted, stratified, rounded gravel and coarse sand contain an abundant fossil fauna. The following were identified by Dr. F. J. E. Wagner from a collection made by the writer:

Mya truncata var. *uddevalensis* Forbes
Tethea logani Dawson
Hiatella arctica Linné
Balanus sp.
Mytilus edulis Linné
Macoma balthica Linné
Mya arenaria Linné
2-inch columella of an unidentified gastropod

Mytilus edulis and *Mya arenaria*, although their depth range is from the intertidal to the several fathom zone (Bousfield, 1960, pp. 26, 37), are common in shallow water, and therefore their presence suggests a shore environment for sediments in which they occur. Some other shells in the deposit are more characteristic of deep water; they may have lived in deep water and become incorporated in the shore sediment during receding or off-lap stages of Champlain Sea. A few of the shells, such as the much-worn unidentified gastropod listed above which the author believes may be a species of *Neptunea*, could have originated in very deep water and floated ashore.

Shoreward from this fossiliferous gravel the escarpment and backshore are strewn with boulders (Pl. XXI). Glacial till occurs at depths of about 2 feet beneath the bouldery lag deposit and underlies the beach gravel at the base of the escarpment. Other similar features are shown as linear areas of map-unit 6 (Map 1197A, *in pocket*) within the Drummondville moraine belt.

Broad, relatively flat sand plains occur near highway 9 and northward from it to the vicinity of the Drummondville moraine. These sand plains probably also extend for several miles southward beyond the limits of the map-area and occupy many flat areas between highway 9 and the Appalachian Highland. Here the sand deposits, in places more than 3 feet thick, consist of thin-bedded, relatively pebble free, fine- and medium-grained sand. Where drainage is good they may be leached of free carbonates to 3 or 4 feet below the surface and in that zone are oxidized to a yellow-buff to rust-mottled colour. Below the zone of oxidation the sands are generally grey, have partings of black heavy-mineral concentrations, and are generally strongly calcareous. Fossils, though not abundant in much of the sediment, are found throughout map-unit 6; *Macoma* is the most common genus, with *Hiatella* and *Mytilus* also present locally. It is common to find these shells well preserved and as matched pairs of valves in positions indicating burial in place.

In areas where they have been mapped, the marine sands are the uppermost (hence youngest) sediments, except for dune sand redistributed at their surface. They are younger than Gentilly till and occupy depressions in the Drummondville moraine as well as the

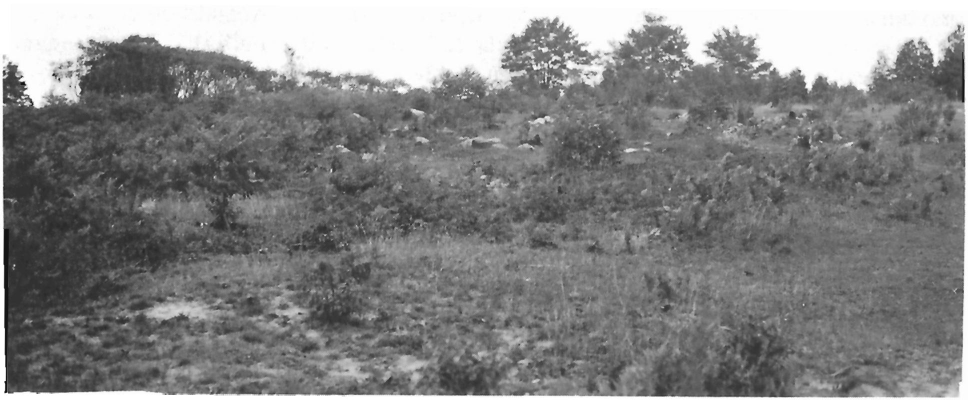

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PLATE XXI. Marine beach gravel in foreground and boulder-strewn till ridge in background, that forms wave-cut scarp above the beach deposit, 2 miles southeast of Ste-Gertrude, at water-supply reservoirs for that village. View looking southeast from roadway.

broad depression between that moraine and the Appalachian Highland. These marine sands are poorly drained in most of their area of outcrop and support much bog to semi-bog vegetation. Where naturally or artificially drained, they provide easily tilled sandy soils that support a moderate agriculture. The sands are highly permeable and provide potable water to a large number of shallow wells throughout the region.

Off-shore Facies

Off-shore bottom sediments of the Champlain Sea include clay, silt, and sand. These fine sediments are the equivalent of "Champlain clay" as referred to by some early Canadian geologists, of "Leda clay" and "Saxicava sand" as defined by Dawson (1893), and of "Hochelaga Formation" of Woodworth (1905) and Karrow (1957). The choice of a name for the sediments from those proposed in the literature presented several problems. "Champlain Formation" and "Champlain clay" are terms that are preoccupied (Wilmarth, 1938). The generic name *Portlandia* has precedence over *Leda* (cf. Wagner, 1967, 1971), and *Hiatella* has precedence over *Saxicava* (Grant and Gale, 1931; Dodge, 1952), thus it would only add to the confusion to revise Dawson's terms 'Leda clay' and 'Saxicava sands'; also current rules of stratigraphic nomenclature do not recognize the use of generic names of fossils as formation names. The name proposed by Woodworth, "Hochelaga Formation", did not receive recognition by his contemporaries or to any extent by subsequent writers. The name Champlain Sea is the only one that has been preserved through the years and has been recognized internationally as the name applied to the post-glacial or late-glacial marine inundation of glacially depressed areas of the St. Lawrence Lowland. For these reasons this writer prefers the terms *Champlain Sea sand* and *Champlain Sea clay* for the sediments deposited in the Champlain Sea (Gadd, 1960b, p. 16) and uses these terms in the text that follows.

Off-shore sediments of the Champlain Sea occur with a considerable range of thickness and a variety of facies throughout the areas mapped. The sediments occur as thin layers in small pockets or depressions among the knolls and ridges of the Drummondville moraine; a few occur among parts of the Laurentian Highland, but none are known along the crest of the St. Narcisse moraine, although it was also covered by the Champlain Sea. Elsewhere in the region, but particularly in the area between the Drummondville and St. Narcisse moraines, thick masses of fine marine sediment are extensive. Abandoned St. Lawrence River scarps along the highway from Baieville to Nicolet on the south shore, in the vicinity of Louiseville and Yamachiche, and between St-Maurice and Ste-Anne Rivers on the north shore are cut principally in marine 'clay'. Yamaska, du-Loup, Yamachiche, and Champlain Rivers, and the lower part of Batiscan River flow through broad areas of clay-like sediment and expose many 50-foot sections of it; many deposits are probably much thicker than the sections exposed. The greatest thickness is known from borings and standard penetration tests performed by the Foundation Company of Canada (Lea, 1952) on the islands at the mouth of Nicolet River, where approximately 100 feet of "soft grey clay becoming firm with depth" was encountered.

Typical Champlain Sea Clay

The typical off-shore sediment of the Champlain Sea is a uniform massive grey clay, silty clay, or silt (Pl. XXIIA) that has characteristic physical properties of water content, plasticity, thixotropy, and sensitivity, which produce in it a number of interesting phenomena. Much data are available on these properties, but for this report it is sufficient to state that the sediment is soft and slippery when wet, tough and highly fractured when dry, and subject to mud flow movements when disturbed that cause landslides in most of the area under study. Contrary to what one might conclude from the foregoing, both the massive and the stratified silts and clays commonly stand in nearly vertical faces when exposed by erosion (Pls. XXIIA, B).

Fresh surfaces of these sediments are commonly exposed because the sediments are subject to landslides that carry away weathered materials. Thus fresh, moist sediment in various shades of grey are the rule, and iron stained, leached clay banks are uncommon. Dried sufficiently, the powdery surface becomes a dazzling buff-white when seen in bright sunlight. Moist fresh surfaces in the clay have an anomalous bluish sheen, which presumably arises from diffraction of light in a film of water at its surface. It may be this phenomenon that has led to the name 'blue clay' (French, 'la glaise bleue') that is locally applied to this sediment.

Early concepts of composition of the marine clay and some fairly recent analyses (Peck *et al.*, 1951; Béland, 1956) suggested that it had an essentially quartz–feldspar composition. X-ray diffraction analyses (Karrow, 1957), however, showed that the clay fraction of the sediment contains chlorite, illite, amphibole, quartz, feldspar, and some calcite. The similarity of this composition to that of the clay fraction of the analyzed till of the area confirms the belief that the bulk of the silt and clay was derived from till or was of direct glaciomarine origin; Karrow suggested that some chlorite may have formed diagenetically in the marine basin. A clay-sized fraction from marine sediment at Ottawa, Ontario, has been analyzed by Eden and Crawford (1957); they reported

> that the clay is composed mainly of 'illite with a tendency toward mica, plagioclase feldspars, quartz and chlorite . . . with interstratification of the illite and chlorite minerals'. One laboratory reported small amounts of montmorillonite and kaolinite; the other reported none.

Black-mottled Facies

Freshly exposed surfaces of massive clay and silty clay in places contain jet-black patches and streaks of an oily or greasy appearance that seem to be due to concentrations of finely divided organic matter. Hollow black tubes of organic matter, probably remnants of roots, are common, and in a number of places shell moulds are found that appear to be

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PLATE XXII A. A 10-foot face of massive marine clay rises vertically above the talus slope. On the left, where the clay is wet by intermittent springs, it maintains its natural massive state; on the right, where the clay is dry, it shows initial development of a typical blocky fracture pattern. South bank of Bécancour River, north of St-Wenceslas.

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PLATE XXII B. Steep slope in typically thin-bedded stratified silty clay and sand of the Champlain Sea; section west side of Charest River 4 miles south of Rang-Ste-Anne.

those of *Portlandia* sp. Most such moulds are lined with a thin black film, which may often be lifted out of the mould in one piece. These linings appear to be the preserved remains of periostraca of the fossils about which the clay was moulded and whose carbonate shell remains have been destroyed. These clays have a pungent sulphurous odour when freshly exposed and effervesce with emission of sulphur dioxide and/or hydrogen sulphide when cold dilute hydrochloric acid is applied to them. Compounds producing these colours and odours are apparently unstable, because both the rich black colour and the sulphurous odour disappear after the clay has been cut and exposed to the air for a number of hours. Thus this facies of marine clay commonly has a uniform grey colour when seen in natural exposures.

In a few localities the writer observed that rusty bands on the surface mark the position of black bands in the fresh clay. In one place, about one-half mile northeast of Leclercville on the south shore of St. Lawrence River, the exposed surface was marked with alternate, 2-inch, rusty and light grey bands that corresponded to black and grey bands, respectively, in the freshly exposed material; the black bands gave place to rusty bands after 2 days of exposure to air and periodic washing by tidal waters of St. Lawrence River.

Although such phenomena as those described above may be formed in several ways—for instance, the black sulphurous clay might be produced in a near-shore environment—the black-mottled clays in this area commonly occur at or near the base of thick deposits of sediment. This might be interpreted as an indication of slow encroachment of the sea over the land, but most other evidence cited suggests that the Champlain Sea invasion took place immediately upon retreat of the last ice sheet, therefore at a time of maximum depression of the land surface. Hence, it is assumed that basal Champlain Sea clays were deposited in deep water, and it is also probably safe to assume that the black-mottled and black facies of Champlain Sea clay were formed in a deep basin under essentially anaerobic conditions. Furthermore, it is probable that in a glaciated area suddenly flooded by marine water, as this area undoubtedly was, small and large pockets may have existed on the sea floor, i.e., drowned glacial topography, in which normal circulation would not have taken place. Meltwaters from still active nearby glaciers would tend to enter the basin and flow along its bottom and accumulate in depressions; such water, because of its low temperature, might carry very little oxygen.

Such conditions would have permitted the formation of the black or black-mottled, carbonaceous, non-calcareous, and sulphurous sediments described above. As sedimentation continued and as the bottom of the marine basin filled with sediment, eliminating the local pockets or depressions on the sea floor, and perhaps also as the supply of frigid meltwater diminished, conditions would have changed to those favourable to the deposition of the typical grey, calcareous, and fossiliferous sediment of the basin.

Stratified Facies

Another common facies of the Champlain Sea clay is one in which fine and coarse material are regularly alternated, giving the general appearance of varving. Unlike varves these beds have no graded bedding; contacts between discrete layers are commonly sharp and distinct. The fine layers are typical Champlain Sea clay or clayey silt as described above, and the coarse layers are usually very well sorted fine- to medium-grained sand. Coarse sand and fine gravel with pebbles nearly an inch in diameter are found in a few places, but their occurrence is rare. In other places, however, the varve-like banding is caused by alternations of clay and silty clay; such beds closely resemble varves (Pl. XXIIIA) and well might be called pseudo-varves. The largest mass of banded marine sand and clay is found in the basal part of the Trois-Rivières delta (Pl. XXIIIB). Extensive exposures of banded

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PLATE XXIII A. Varve-like regular banding of alternate layers of clay and silty clay in marine sediment. Slump block in slide along bank of Salvail River, $1\frac{1}{2}$ miles northwest of St-Jude; photo taken day after slide occurred.

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PLATE XXIII B. Banded silt and sand in basal part of Trois-Rivières delta, 2 miles southwest of St-Boniface on east side of St-Maurice valley. Faulting and folding due to recent slumping.

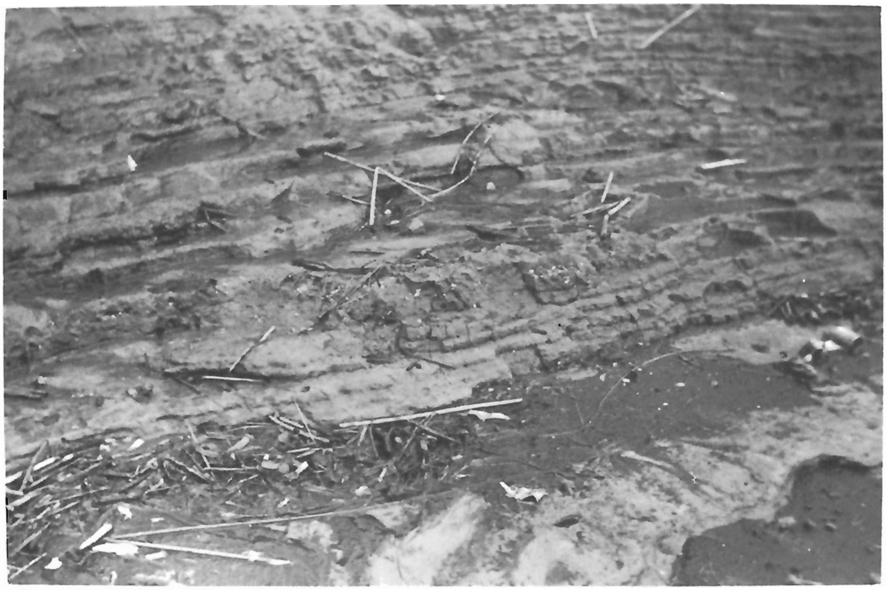

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PLATE XXIV A. Close-up of clay-sand strata on St. Lawrence River shore at Champlain. White spots in the sandy layer passing through the centre of the picture are the fossils *Portlandia arctica.*

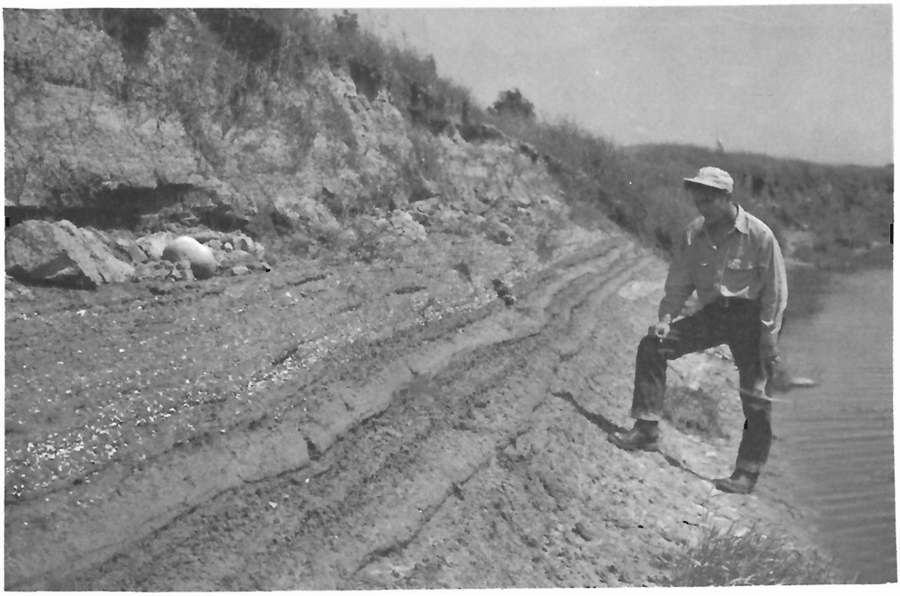

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PLATE XXIV B. Banded Champlain Sea sediments, containing much sand, overlie till and are overlain by alluvial sand. Abundant macrofossil fauna includes *Portlandia arctica*, *Mytilus edulis*, *Hiatella arctica*, *Mya arenarea*, and a few gastropods. Rivière Chibouet, 1¼ miles southwest of Ste-Hélène-de-Bagot.

clay and silty clay are also found along Yamaska and Salvail River valleys (Pl. XXIIIA), mainly upstream from the village of St-Aimé.

All offshore facies of the Champlain Sea at some places contain boulders. Most such boulders have faceted and striated surfaces, which indicate glacial erosion in some part of their history, and their composition is compatible with that of boulders in tills of the region. It is assumed that these boulders were dropped from icebergs and floating shore ice.

Some sections of the Champlain Sea offshore clays, silts, and sands have an abundant molluscan fauna. In general the massive clays contain only a few macrofossils, sparsely distributed; most commonly found is *Portlandia arctica*, with *Macoma balthica* second in abundance. The banded facies of the sediments contain a much more plentiful fauna, but the numbers of individuals seem to be directly related to coarseness of material. In banded clays with very thin sand partings (e.g., at the village of Champlain, north shore of St. Lawrence River, Pl. XXIVA) *Portlandia arctica* is present almost exclusively and is not common. In the more sandy strata (Pl. XXIVB) the fauna are much more abundant and varied. A fairly comprehensive list of fossils of the offshore environment of Champlain Sea collected in Grondines map-area (Karrow, 1957) is given in Table IV.

Microfossils, chiefly foraminifera, are plentiful in all facies of the offshore sediments. Many of the foraminifera are large enough to be observed without a microscope as white disks, and can be recognized by the arrangement of curved septae radiating from the centre of the disk. Some ostracods may also be observed with or without the aid of a hand lens. This enabled the writer to select samples for study of their microfossil content. Dr. Frank L. Staplin, now of Imperial Oil Enterprises, Ltd., Calgary, Alberta, identified the forms in four samples submitted to him in 1952 (Table V).

From Staplin's notes (pers. com., 1952) it appears that the fauna strongly suggest brackish-water conditions in the sedimentary environments, and that those sediments with marked stratification are from environments with the lowest salinity. In addition to this, macrofossils identified by Dr. Wagner (Table IV) from similar offshore sediments of the Champlain Sea are species known to thrive in a wide range of depth, salinity, and water temperature, and most of them could tolerate brackish-water to nearly freshwater conditions. The presence in the stratified sand–silt beds of *Cyprideis sorbyana*, which Staplin (pers. com., 1952) stated was indicative of brackish water, and of *Portlandia arctica*, which occurs abundantly in the glaciomarine environment at the toe of calving glaciers (Wright, 1937, p. 334), is strong evidence for the hypothesis that such regularly banded strata are due to glacial influence in the Champlain Sea basin.

Economics of the Champlain Sea Clays

Although Keele (1915) showed that the Champlain Sea clay in its natural state shrinks excessively for use in common brick, some pit operators find it may be used in limited quantities in certain mixtures or under special treatment procedures. Generally the procedures involve addition of sand to counteract shrinkage, and leaching to reduce free carbonate content. The clay has good moulding or pressing qualities which makes it desirable commercially if shrinkage can be controlled.

Clay within the soil zone in this region generally has at least a thin cover or admixture of sand. Thus the agricultural soils are commonly either loams or clay and silt loams. Drainage of these soils is difficult because vertical drainage is impeded by underlying impervious clays and therefore requires extensive systems of ditches. Thus in many parts of the area, e.g., west of Yamaska River in Upton map-area (31 H/15), natural drainage has been extended by a rectilinear system of ditches through the efforts of farmers and government agencies.

TABLE IV | *Fossils in Offshore Facies of Champlain Sea Sediments*[1]

FORAMINIFERA
Elphidium bartletti Cushman
E. clavatum Cushman
E. orbiculare (Brady)
E. subarcticum Cushman
Elphidium cf. *E. frigidum* Cushman
Bucella frigida (Cushman)
Cassidulina islandica Nørvang
C. norcrossi Cushman
C. teretis Tappan
Cibicides lobatulus (Walker and Jacob)

PORIFERA
Tethea logani Dawson

BRYOZOA
One unidentified specimen

PELECYPODA
Nucula tenuis (Montagu)
Nuculana pernula (Müller)
Nuculana cf. *N. tenuisculata* (Couthouy)
Yoldia arctica (Gray)[2]
Yoldia cf. *Y. limulata* (Say)
Volsella demissa (Dillwyn)
Mytilus edulis Linné
Lyonsia arenosa (Müller)
Thyasira gouldii (Philippi)
Macoma balthica (Linné)
Macoma calcarea (Gmelin)
Mya arenaria Linné
Mya truncata var. *uddevalensis* Forbes
Hiatella arctica (Linné)

GASTROPODA
Lepeta caeca (Müller)
Natica clausa (Broderip & Sowerby)
Polinices pallidus (Broderip & Sowerby)
Buccinum tenue Gray
B. undatum Linné
Neptunea despecta var. *tornata* (Gould)
Retusa obtusa (Montagu)

OSTRACODA
Cyprideis sorbyana (Jones)
Cytheridera papillosa Bosquet
C. punctillata Brady
Eucythere argus (Sars)

CIRRIPEDIA
Balanus crenatus Bruguière
B. hameri (Ascanius)

ECHINODERMATA
One unidentified ophiuroid

[1]From Karrow, 1957; fossil identifications by Frances J. E. Wagner, Geol. Surv. Can.
[2]Now *Portlandia arctica*; (*see* Wagner, 1967, 1971).

TABLE V | *Microfossils in Offshore Facies of Champlain Sea Sediments*[1]

Sample No.	Location and material	Forms present
2	Champlain, on north shore of St. Lawrence; stratified sand and silt	FORAMINIFERA: *Nonion* sp. (abundant) *Guttulina* sp. *Elphidium* sp. OSTRACODA: *Cyprideis sorbyana* (common) *Leptocythere* cf. *C. castanea* (common) *Cytheropteron* sp. one ostracod unidentified

TABLE V *(conc.)*

Sample No.	Location and material	Forms present
3	St. Lawrence River at Cap Lévrard; marine silt containing disseminated organic matter	FORAMINIFERA: *Nonion labradoricum* (Dawson) *Nonion* spp. *Elphidium* spp. *Ellipsolagena* sp. *Eponides* sp. (abundant) *Planulina ornata?* (D'Orbigny) *Virgulina* sp. *Guttulina* sp. OSTRACODA: *Cyprideis sorbyana* (fragments) *Cytheropteron* sp. *Kyphocythere*? sp. *Hemicythere* sp. *Cytheridea* sp.
7	Champlain River, 4½ miles southwest of St-Luc-de-Vincennes; massive grey marine clay	FORAMINIFERA: *Guttulina* sp. *Eponides* sp. (abundant) *Cassidulina* sp. *Elphidium* sp. (abundant) *Quinqueloculina* sp. *Nonion* sp. OSTRACODA: *Kyphocythere*? sp. *Cytheropteron* sp. *Cyprideis* sp. *Cytheridea* sp.
10	St. Pierre section; marine clay overlying varved silts	FORAMINIFERA: *Elphidium* spp. *Nonion* spp. abundant *Eponides* spp. *Astrononion* sp. *Guttulina* sp. *Ellipsolagena* sp. *Lagena* sp. OSTRACODA: None identified

[1]Identified by F. L. Staplin

Landslides in Champlain Sea Clay

Probably the greatest influence of the Champlain Sea clays is the adverse economic effect of the numerous landslides that occur in them. The marine clays described above in their various facies are all of a type classed by students of soil mechanics as extrasensitive. For the clays in this area this means that when material is disturbed by undercutting of a bank by a stream, by excavation with earth-moving equipment, by overloading with buildings or other forms of construction, or indeed possibly even by earthquake shock, and where the material has its natural water content, under appropriate conditions the material will be quickly transformed from a solid to a semi-liquid or fluid state. In this state the clay will flow as a slurry into whatever space is available, such as an excavation or a stream valley. Overlying clay, stiffer by virtue of desiccation, will break up into irregular linear blocks, drop into the crater so formed, and will be transported some distance, often as much as a half mile on the surface of the flowing fluid mass. Such flows are classified as 'earthflow' (Sharpe, 1938, pp. 50–53) and the term 'flow slide' is commonly used in Canadian literature (e.g., Meyerhoff, 1957; Leggett, 1962, p. 432). Perhaps the term 'flow slide' is prompted by the recognition of two types of phenomena: flow phenomena, i.e., liquefaction of the clay, and gravitational slide phenomena, to which overlying desiccated layers are subject.

Many small slides, which have gone unnoticed, are readily seen on air photographs of regions underlain by Champlain Sea clay both within and outside the areal limits of the present study. Many of the larger slides have caused great property damage; some have caused loss of life, and so have become the subject of particular note in the press and in scientific journals. The phenomenal flow at St-Alban (Laflamme, 1894), 40 miles west of Quebec City, accounted for removal by a single slide of 1,600 acres of land, an estimated 25,000,000 cubic yards of earth, and took four lives. Other less extensive flows have caused greater loss of life.[1]

The most notable landslide, in the area covered by this report, is the now famous Nicolet landslide (Béland, 1956; Bilodeau, 1957; Hurtubise and Rochette, 1957; Hurtubise, Gadd, and Meyerhoff, 1957) that occurred November 12, 1955. The scar of this slide is shown on the geologic map accompanying this report as a circular area of Champlain Sea clay within the village of Nicolet.

Stream banks are the main locus of development of earthflows. Both small and large earthflow craters have a variety of simple shapes ranging from narrow but more or less circular arcs of large radius, through semicircular, to bulbous or very nearly circular with a narrow 'bottleneck' outlet to the stream bank. All are concave towards the valley or other depression into which the flow has occurred; compound scars showing several stages of development are fairly common.

Most of these slides apparently occur as a result of breaching of a resistant desiccated layer of clay that forms a 'case-hardening' along the bank of the stream; it seems that any manner of breach will suffice so long as fresh, water-saturated clay is exposed in the process. Liquefied clay flows through the breach very rapidly, and the area affected by the flow expands radially and retrogressively from the point of initiation, thus causing a depression of the surface in the characteristic rounded or circular forms. As surface layers, including blocks of turf, are dropped into the depression by gravity sliding, they are carried out of the crater or distributed within the crater and ultimately form a series of concentric linear ridges. These ridges conform with the concavity of the slide scar inside the crater but have a convex form outside the crater that reflects the shape of the flow beyond the original bank or scarp position. These concentric surface patterns are distinctive and are one of the best means of distinguishing slides on air photographs. In time the ridges become flattened by erosion

[1]For tabular presentation of such losses in some well-known flows, *see* Crawford (1961), p. 204, Table II.

and vegetation occupies intervening swales so that the distinctive pattern gradually disappears; relative sharpness of the pattern is a measure of relative youth of the slide.

Where flow materials enter a stream or a river, depending on the size and activity of the body of water, they may be partly carried away as the flow is in progress, thus extending the period of active retrogressive development of the scar. Again, a valley may be completely filled with slide debris and the dam so produced causes temporary flooding as a side effect. Earth dams are eventually overtopped by the dammed waters, and are subsequently partly or wholly removed by erosion. Generally the stream relocates in a new channel on the distal side of the valley, but sometimes, when dislocation of the stream is minor and re-excavation of the channel is rapid, removal of the slide debris may cause the flow to be reactivated, and a further period of flow may occur.

The Champlain Sea clays of the region are thixotropic to the extent that within a period of hours or days after a slide, the material that has flowed recovers most of its strength and bearing capacity, in some cases even becomes stiffer than the original clay, and assumes physical characteristics very similar to those of the original clay. To distinguish between primary deposits of marine clay and bodies of clay that may have been redeposited by the mechanism of earthflow, one must take care to note in the reconsolidated slide debris evidence such as disoriented root casts, presence of modern organic matter in the body of the clay, and admixture of inorganic material, such as sand, from the strata overlying the clay in the original surface.

Root casts formed by concentration of carbonates and iron oxide around roots of modern or fossil plants form elongate tubular to spindle-shaped concretions, which in their natural state stand more or less vertically in the marine clays. These may be separated by erosion and are sometimes found lying at the foot of scarps cut in the clays. The presence of root casts in clays in other than vertical position indicates erosion and reconsolidation of the mass of clay that surrounds disoriented concretions. Because the clays are highly thixotropic, orientation of root casts and preserved rootlets may be one of the few clues to help distinguish between the initial deposit and a reconsolidated clay.

Although research is being conducted into the physical properties of the clays and the phenomena of landslides that occur in them, no effective means of predicting landslides or of controlling or preventing them is known. From available information, however, it is known that in areas underlain by Champlain Sea clay it is inadvisable to select promontories, such as river banks or other escarpments, in the siting of major structures. All such clay banks should be protected from erosion insofar as possible, the vegetal cover preserved, and any activity that would tend to steepen clay banks in the area should be studiously avoided. Construction activity, insofar as it contributes to saturation and disturbance of the clay, may be one of the most significant causative factors of some landslides.

Post-Champlain Sea Deposits

Large areas of sand are mapped separately from the 'Champlain Sea sand' because they are younger, non-marine sediments. One of the basic differences between the two sand map-units is that the Champlain Sea deposits commonly contain marine or brackish-water fossils, whereas the younger sediments generally lack fossils of any kind. This difference is not always a reliable one, however, because mulluscan fauna do not live or are not preserved in certain environments; therefore similar sands, deposited under essentially identical physical conditions, may have different faunas owing to differences in chemical factors such as salinity. For example, present-day shores of St. Lawrence River that are influenced daily by the same or similar tides and currents in the same bodies of water maintain two distinct molluscan fauna at widely separated places. The writer observed that for several miles upstream from Quebec City the shore sands and gravels contain a freshwater molluscan fauna, whereas similar sediments at Rivière-du-Loup contain a marine or brackish-water fauna comprising most of the genera of the Champlain Sea sands. Thus a single physical environment has two distinctly different ecological and faunal facies with a zone of transition somewhere between them. If we consider that the conditions observed today probably existed during the uplift following the maximum extent of the Champlain Sea, then we must expect to find that the zone of transition from fresh to salt or brackish-water conditions has migrated downstream. We should also expect to find that in the time after the passage downstream of such a transition zone, or simply after completion of the transition, all subsequent sediments and physical features should have been emplaced or formed under freshwater conditions. In the example cited the transition zone lies somewhere between Quebec City and Rivière-du-Loup. Thus at Rivière-du-Loup the sediments of all raised shorelines have been formed under marine, or brackish-water conditions and all contain a marine or brackish-water fauna. Upstream, however, only the upper abandoned shore features contain marine fauna; lower features were formed under freshwater conditions. Because leaching occurs rapidly in a freshwater environment, both marine and freshwater littoral fauna could have been destroyed by reworking. Therefore, even though perhaps initially deposited in a marine basin and containing a marine fauna, the sediments, subjected to a freshwater environment after the abovementioned transition, easily could become barren of calcareous fossil remains; in addition, freshwater mollusca do not have durable shells and are uncommon even in modern alluvium. The writer and his colleagues have found freshwater molluscan fauna preserved in the present shore sediments, but surface sediments in a zone between present water level and about the 300-foot contour level are apparently barren of molluscan fossil remains. Criteria other than the presence or absence of fossil remains must be applied to the classification of sediments in this zone as non-marine; these are described in a later section of this report dealing with "high terrace" and "low terrace" sands.

Aeolian Deposits

Wind-blown sand of uniformly fine grain in dune forms stabilized by vegetation constitute the bulk of sediment shown as map-unit 7 within the region. A few small active dunes are known in areas that have been stripped of vegetation by one means or another, chiefly through the activity of man. In a few places layers of wind-blown silt or loess, no more than a few inches thick, have been observed, but no mappable unit of the sediment has been found. Sand dunes are found chiefly within areas where high terrace sand and marine sand deposits are thick. The most prominent dune forms have been designated as crêtes de coq (Pl. III); their classification as dunes and the use of the local name for the ridges was proposed by the writer (Gadd, 1955) to supplant the hypothesis by Osborne (1950b) that the ridges were "marine crevasse fillings". Sediments from the crêtes de coq, described below, are typical of aeolian sands of the whole area studied.

The materials of the crêtes de coq comprise very well sorted medium- to fine-grained sand. No pebbles or larger materials were found in samples analyzed for this study (Fig. 9). From 61.1 per cent to 93.9 per cent of these sand grains are between $\frac{1}{4}$ mm and $\frac{1}{16}$ mm in diameter, and the modal class in the majority of analyses is the $\frac{1}{4}$ to $\frac{1}{8}$ mm class. Thus, the histograms of crêtes de coq samples have the modal distribution considered characteristic of aeolian sands by Krumbein and Sloss (1951) and generally have low percentages in the $\frac{1}{8}$ to $\frac{1}{16}$ mm class, a phenomenon also said to be characteristic of aeolian sediment (Pettijohn, 1949, pp. 43, 44, Fig. 18; Udden, 1914).

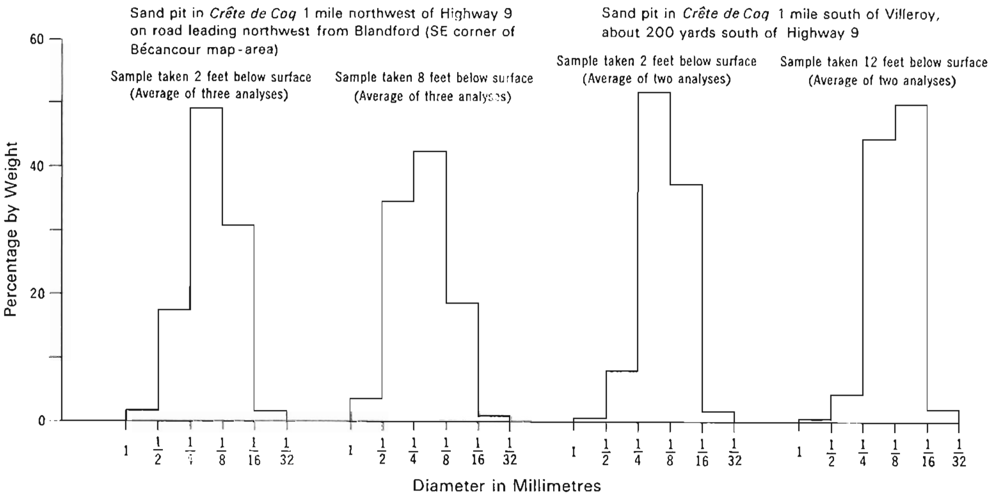

FIGURE 9. Histograms of grain sizes in crête de coq sands.

Frosting and rounding of grains of quartz, feldspar, and other mineral constituents of the sand can be observed with the aid of a hand lens. Microscopic examination (Pl. XXV) shows that rounding of some grains is well advanced. Other grains are subangular and translucent to transparent. As water-laid sands normally contain grains with smooth, clear surfaces, the presence of many such grains in this wind-blown sediment suggests that they were originally deposited in water and that the rounding and frosting was accomplished by a relatively short period of wind transport.

Although Osborne claimed to have found marine fossils in place within the crêtes de coq, the writer has observed that the sands of the crêtes de coq unconformably overlie fossiliferous beach gravel—Champlain Sea sand—at a number of places, and are therefore younger than these fossiliferous sediments.

These aeolian sands proved to be of considerable economic value during the construction of sections of the Trans-Canada Highway (No. 9) between Drummondville and Quebec, where sand from major crêtes de coq near the right-of-way provided a large volume of easily accessible and readily worked, cheap fill material.

High Terrace Sands

In general, high terrace sands show characteristics of current deposition and wave action, and represent environments such as deltas, abandoned shore features, and terraces formed in the major body of fresh water that succeeded Champlain Sea in the St. Lawrence Lowland. These sands are characteristically non-fossiliferous; they occur at levels below about 300 feet in this region and are considered to have been deposited in a freshwater environment.

Although the 300-foot contour in areas south of St. Lawrence River consistently seems to mark the boundary between marine sediments above it and freshwater sediments below it, Karrow (1957, 1959) included some sands above this contour level in the high terrace sands classification, thus implying a freshwater origin. This writer has insufficient field data to determine whether the sands mapped by Karrow at elevations above 300 feet were indeed non-marine and therefore an indication of differential uplift between the two sides

107547

PLATE XXV. Photomicrograph in reflected light of sand grains from sample 2 (Fig. 9) showing rounding and frosting of grains. Magnification 20X.

of the river, or whether they may be sparsely fossiliferous marine sediments. On the geological map accompanying this report they are classified according to Karrow's original interpretation.

The high terrace sand deposits range from a few feet to about 75 feet thick; thicker deposits may be present in places along the north-facing flank of Drummondville moraine. Sand of this type laid on flat terraces and less than 3 feet thick has been included with underlying older sediment on the geological map (Map 1197A) to emphasize the presence of subjacent material that is more significant on historical and cultural bases. Thus there is a fairly general cover of high terrace sand at levels below 300 feet throughout the map-area, but much of that area has been designated as terraced clay plains on Figure 4a or as Champlain Sea clay (map-unit 5) on the geological map accompanying this report.

Very few pebbles or coarse sand grains are found in the high terrace deposits (map-units 8, 8a), most of the unit being well-sorted fine- to medium-grained sand with some silty fine sand layers. Plate XXVIA shows sands typical of the area south of St. Lawrence River. In places along the north shore, where sands were probably laid down under glacial influence, high terrace sands include well-rounded gravel (Pl. XXVIB), but proximity to glacial sources is more commonly shown in the channel crossbedding structures in the sand, such as those in the northern part of the Trois-Rivières delta (Pl. XXVIIA).

Within the Trois-Rivières delta area there is a downward gradation from strata composed essentially of freshwater fluvial sand into horizontally bedded sand intercalated with fossiliferous silt (Pl. XXIIIA), and a lateral gradation southward towards the margin of the delta into finely crossbedded and ripple-marked fine sand, which has been reworked by wave action (Pl. XXVIIB). These relationships within the Trois-Rivières delta indicate that high terrace sands were the end members of a gradational series, with the high terrace sands, as top-sets, grading downward into stratified marine sand–silt strata and then to stratified marine basin sediments. As water levels dropped during the period of uplift, the Trois-Rivières delta was dissected by the ancestral St-Maurice River as new and longer distributaries built an almost continuous series of coalescent deltas that decreased in elevation and size down to the present delta at the mouth of the St-Maurice River. Silt is abundant in the higher level marine phases of the delta, but in younger, lower level phases the dominant sediment is sand. Bottom-set strata containing finer sediments may have been deposited in areas east and west of the sandy portion of the delta and in the part of the basin now occupied by St. Lawrence River. During the period of uplift, also, there was a redistribution of large volumes of sand downstream from the mouths of major streams along terraces parallel to St. Lawrence River.

The high terrace sands of the map-area are not known to contain fossil remains. In similar sands of the Montreal area, however, Elson (1960) found the freshwater pelecypod *Lampsilis siliquoidea* with a species of *Macoma* at 180 feet, and with "...other fresh water species (*Spaerium*; gastropods) characteristic of the modern St. Lawrence River" below about 160 feet. This indicated to Elson a transition from the marine Champlain Sea to a freshwater lake, which he named "Lampsilis Lake". Beach gravel about 200 feet above sea level in the Cornwall area of Ontario contains shells of *Lampsilis* sp. which "...shows that the Champlain Sea episode came to a close when the sea level receded to the present 225 foot elevation at Cornwall" (Terasmae, 1960b). Although the Montreal and Cornwall areas are many miles southwest from the area under consideration, the deposits described belong to the group of sediments that this author would call high terrace sands. Tenuous as this correlation may be, there remains a strong suggestion that freshwater conditions, elsewhere represented by freshwater molluscs, existed when large volumes of sand were distributed throughout the Ottawa–St. Lawrence drainage system at levels beginning some 200 feet, and in places within the area under study, as much as 300 feet above present river levels.

143270

PLATE XXVI A. Typical high terrace sand on south side of St. Lawrence River; fine-grained sand, some silty layers in gently dipping beds, with very few pebbles. Gully, 2 miles east of St-Pierre-les-Becquets, route 3.

152706

PLATE XXVI B. Well-rounded gravel, a rare occurrence in the high terrace sands of this region. Gravel pit in the edge of an abandoned high terrace scarp, about 2 miles east of Ste-Anne-de-la-Pérade.

201522

PLATE XXVII A. Stratified delta sands showing crossbedding and ripple-marks (at right). Trois-Rivières map-area, ½ mile northwest of St-Thomas-de-Caxton.

201524

PLATE XXVII B. Ripple-marks and crossbedding in high terrace sands; sand pit 2 miles west of Trois-Rivières.

Low Terrace Sands

The low terrace sands are alluvial sands that occupy terraces along the present drainage system and have been but recently abandoned by the present streams; modern alluvium is included in this classification. Most terraces occupied by these sediments are flooded at least partly by modern streams and rivers during occasional high-water stages, the most common time being during spring run-off floods. The position of highways parallel to St. Lawrence River in most places marks the limit of modern-day flooding, although some sections of the highways are still flooded from time to time. High river-trimmed scarps, which truncate major deposits of older sediments, limit the outcrop area of low terrace sands both north and south of St. Lawrence River. These scarps may be traced almost continuously from the western margin of the map-area along both sides of St. Lawrence River to where they merge with the modern shore cliffs near the eastern margin of the area. Riverward from the scarps the terraces are relatively flat and featureless and grade by stages in small vertical intervals to present water level. Minor scarps capped by sand ridges not commonly more than 5 feet high are the rule. Sand bars and levees are built along the margins of St. Lawrence River; these scarps and terraces are included in Goldthwait's Micmac shoreline and terrace (Goldthwait, 1911a).

Sediments of the low terrace sand areas are fine to medium sand with few pebbles. Silt is present in varying amounts from place to place; locally it occurs in segregated thin bands, but it is generally disseminated and in minor amounts. Commonly the sands are yellow-brown due to iron stain and the presence, in many places, of finely disseminated organic matter. Bronze-coloured mica flakes are abundant in the otherwise granular sediment and in places form discrete layers a few flakes thick.

143336

PLATE XXVIII A. Typical open muskeg becoming overgrown with sedges and with spruce encroaching from its margins. Southwest of intersection of highways 49 and 9.

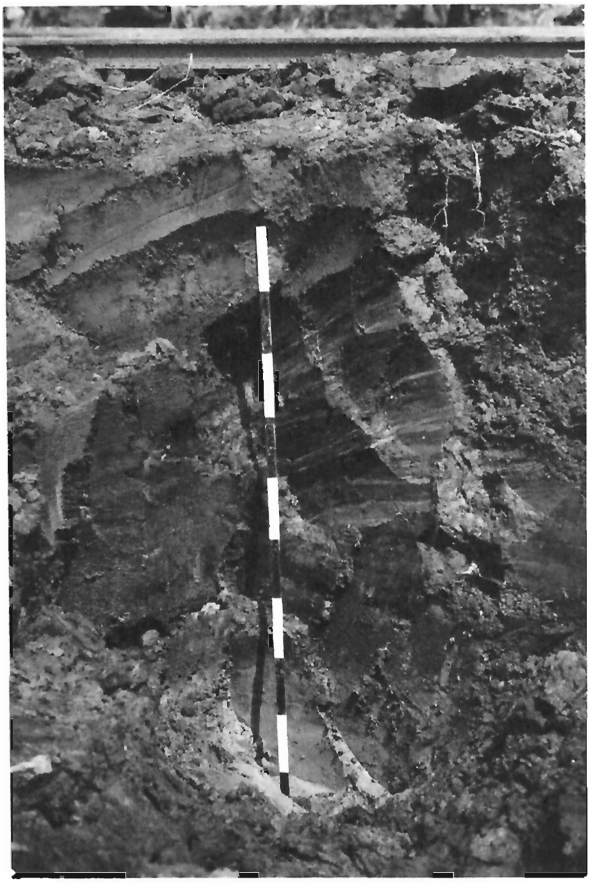

PLATE XXVIII B

Muck deposit approximately 5 feet thick in pits of Sherwin-Williams Company at Red Mill. The muck is gelatinous, black, and streaked with yellowish to light grey silty bands, and grades downward into gyttja (light grey at base of metre stick), which in turn overlies impervious massive marine clay.

143328

Bog Deposits

Much of the surface of the map-area is poorly drained, and as a result extensive bogs or muskegs (Pl. XXVIIIA) have developed. Their sediment is chiefly sphagnum peat, locally quite woody. Minor deposits of muck occur in a few places, but have not been shown separately from the peat on the geological map accompanying this report because the muck is not abundant, and being decomposed organic matter, it generally occurs at the bottom of bogs and is rarely exposed. One well-known exposure of muck in the area is in a bog approximately 4 miles northeast of the village of Red Mill. The southern part of the bog has been truncated by an abandoned river channel so that muck deposits lying on leached impervious clay are exposed or are near the surface (Pl. XXVIIIB). The writer believes that the production of muck and of iron oxides in this bog was accelerated by increased flow of groundwater and accelerated oxidation brought about when the bottom of the bog was exposed by the now abandoned river channel.

In this Red Mill deposit, black gelatinous muck streaked with yellowish to grey organic silt bands is charged with oxides and hydroxides of iron, and provides suitable material for

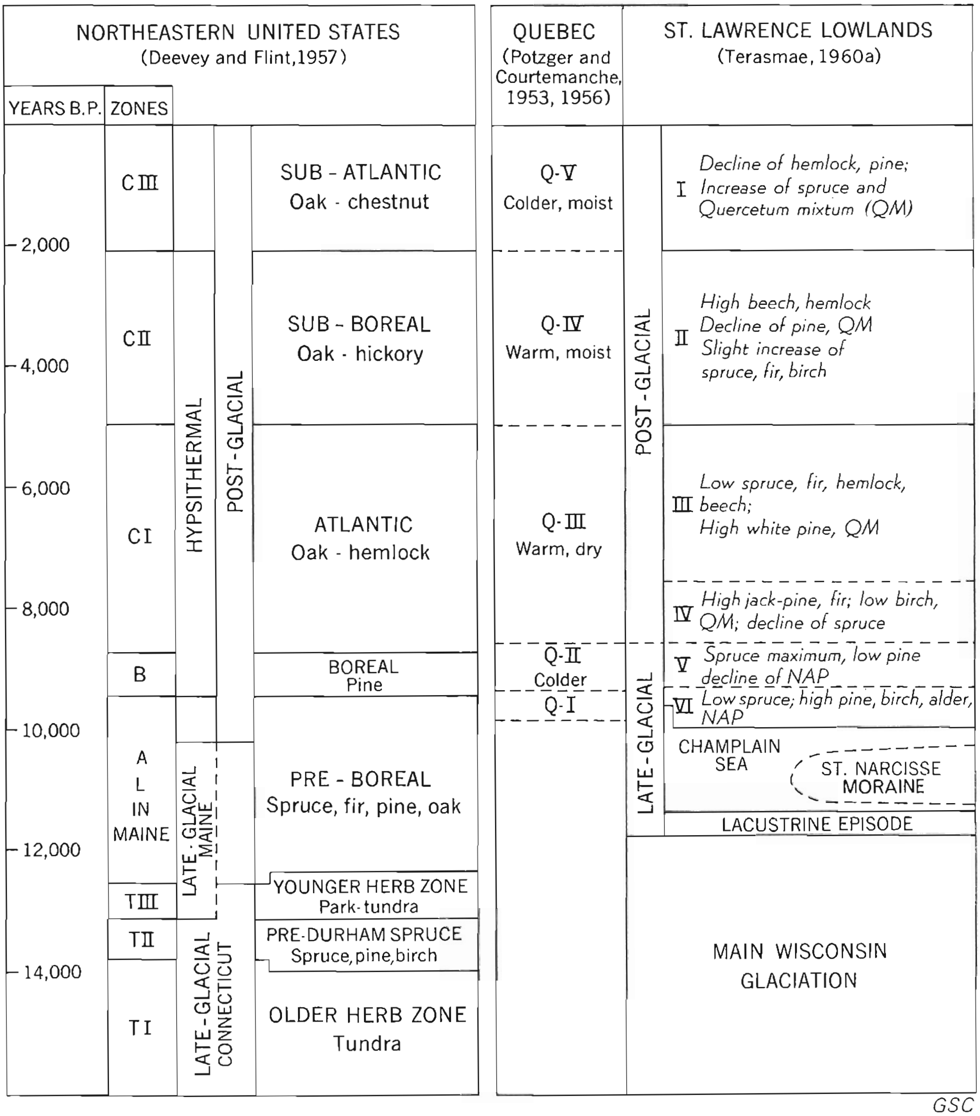

FIGURE 10. Pollen zones and late Wisconsin events in the St. Lawrence Lowland; QM, *quercetum mixtum;* NAP, nonarboreal pollen (after Terasmae, 1960a, p. 18).

a paint-pigment industry. The Sherwin-Williams Company of Canada, Limited, Montreal, derives its Canadian production of "mineral colours—red oxides of iron, umbers, siennas, rouge"—from the calcining of iron-rich muck in furnaces at the village of Red Mill, which apparently derives its name from the ever-present layer of red dust at and near the plant. Peat is exploited in several other bogs of the region for agricultural organic fertilizer, insulating material, and fuel.

Pollen studies of the muck deposits and younger peat beds in bogs of the region (Potzger, 1953; Potzger and Courtemanche, 1956; Terasmae, 1958, 1959) have been used to establish a chronology of climatic events since recession of Champlain Sea (Fig. 10), and radiocarbon dating of bog bottom samples has been used to establish the minimum age of Champlain Sea and of some more recent events (*see* Table III).

The small bog northwest of St. Germain de Grantham occupies a depression underlain by fossiliferous Champlain Sea sands and reworked glacial till. Samples from that bog gave a radiocarbon age of 9,500 years (Table III). Bogs above the marine limit within the area were sought for radiocarbon dating, but all were found to lack much of the pollen sequence. Northwest of St-Adelphe, in the northwestern part of Grondines map-area, bottom samples in a bog occupying an abandoned channel were dated at 8,480 years (Table III).

Four bogs in abandoned channels on the Trois-Rivières delta were examined by Terasmae (Gadd and Karrow, 1959), and it was shown that the pollen records in each were shorter than that of the St. Adelphe bog. These records, identical in their upper, recent parts, signify that the bogs began to form at different times, the bog with the shortest record being the most recent. The records from these bogs, which are at different elevations, also became progressively shorter with decreasing altitude. Thus it is possible to say that the levels of the delta occupied by these bogs were formed successively as water levels fell in post-last-glacial time, and that the Trois-Rivières delta diminished in size and elevation through time from the broad expanse of its highest levels down to the very small modern delta at the mouth of St-Maurice River.

Chapter IV

REVIEW OF GLACIAL AND POSTGLACIAL HISTORY AND RELATED STRATIGRAPHIC PROBLEMS

Pre-Pleistocene Time

Pre-Pleistocene sediments younger than Paleozoic are as yet unknown in the St. Lawrence Lowland. It is generally assumed (e.g., Dresser and Denis, 1944, p. 487) that the area was continental and was subject to subaerial erosion for an extensive period before glaciation; consequently it had a mature landscape with a very well graded drainage system. Because the lowland is blanketed in most areas by glacial and marine sediments of Pleistocene age, however, the nature of the bedrock surface has not been established in sufficient detail to provide a clear picture of the preglacial topography.

The modern stream valleys contain the thickest known deposits of glacial and postglacial sediment, whereas interfluve areas generally have thinner overburden. Bedrock is exposed at many places in the beds of existing rivers and streams, but deeply filled depressions are known to exist at places along the bed of St. Lawrence River. Thus the modern St. Lawrence River is in the process of reoccupying a preglacial valley system and already has excavated much of it, although as yet undiscovered buried channels probably exist in its valley and elsewhere in the region.

Pleistocene Time

Bécancour Stade

First Glacial Lakes

All preglacial drainage of the region described in this report is assumed to have been northeastward to the sea via the ancestral St. Lawrence River. The earliest evidence of glacial activity in the region is found in red varved silts in the valley of St. Lawrence River and in the lower parts of a few tributary valleys, such as the St-François and the Nicolet. The limited area and the discontinuity of exposures of these sediments, which exist near and below present water levels or are known in borings, do not allow for a reconstruction of the basin in which they were deposited. It is speculative to suggest that all occurrences known belong to one basin, but their occurrence at similar elevations in what are now, and probably were earlier, interconnected valleys, would tend to support this as a reasonable hypothesis.

The first ice advance in the area, then, at least partly blocked or impeded the flow of the ancestral St. Lawrence River, forming one or more glacial lakes in which red varves accumulated during an unknown period of time. Formation of the glaciolacustrine environment locally marks the beginning of the Bécancour Stade. The lacustrine episode was closed by an ice sheet advancing over the valley, overriding the red varves.

First Regional Glacial Event

The oldest glacial deposit discovered to date in the area is the Bécancour till. A few striae in the Bécancour map-area suggest that the orientation of movement was southward to southwestward and the dominance of pebbles and boulders from Laurentian Shield areas attests to southward transport. Where the ice sheet encroached on a proglacial lake in St. Lawrence Valley, varved silts are overlain by till; some of these varves have been contorted during emplacement of the till. The wide distribution of Bécancour till and the apparent absence of terminal moraines associated with this till indicate that the early Wisconsin glaciation extended an unknown distance beyond the southern limit of the map-area.

Only a few sections along St-François and Nicolet Rivers show evidence of the recession of this ice sheet. In places a small number of varves of red silt overlie Bécancour till; these grade upward into a varved deposit that is generally grey, but in which some of the varves have brick-red winter layers. In one section about 4 miles upstream from the village of Bécancour on the bank of Bécancour River, outwash gravel, sand, and some silt with intercalated sheets of red till occur in what appears to be a ridge buried by marine sediment. This feature does not show at the surface, but has a wide range of materials in a chaotic arrangement of steeply dipping beds, channel structures, etc., in which there are rapid changes in size of materials; this probably constitutes part of a recessional moraine. Thus, some development of glacial lakes and moraines apparently took place at the close of the early Wisconsin glaciation, but evidence is so scant that no detailed history of the recession can be constructed.

St. Pierre Interval

A distinct non-glacial, freshwater interval occurred at the close of the Bécancour Stade. During this time a drainage system, perhaps the equivalent of the present St. Lawrence River system, was developed with its central stream near the now existing valley of the St. Lawrence and its tributaries in the vicinity of the modern St-Maurice, St-François, Nicolet, and Bécancour Rivers. The system apparently drained to the sea outside the map-area when the sea level was near or below present water levels, because no marine sediments have been discovered to date in the interstadial St. Pierre sediments of this region, which themselves, at their highest points, are only a few feet above modern water levels.

Organic remains belonging to the interstadial interval are preserved as highly compressed peat layers in abandoned channels of the drainage system and as disseminated organic matter in silty sand and silt deposits. The oldest of these organic remains examined by Terasmae (1958) record a subarctic climate. The presence of such non-glacial sediments in the valley indicates that by the time these first sediments accumulated, the margin of the early Wisconsin ice sheet had regressed and the main ice mass was necessarily somewhere north of St. Lawrence Valley. Within the sequence of peat layers the climatic record shows an amelioration to maximum conditions that were comparable to those of the modern boreal forest, and then a decline of average annual temperatures to the end of the period of peat deposition. Pollen data from the lower few feet of the overlying Lake Deschaillons varved silts show that temperatures continued to decline towards subarctic conditions. This evidence of cooling represents the beginning of the next glaciation, which is also signalled by the formation of glacial Lake Deschaillons.

St. Pierre sediments and overlying proglacial varves thus contain a nearly complete record of a single cycle of climatic change that took place during the time between the end of the early Wisconsin Glaciation and the beginning of the main Wisconsin Glaciation. There would appear to have been no opportunity for marine invasion, or of erosion sufficient to remove evidence of a submergence within or immediately following the St. Pierre Interval.

Gentilly Stade

Glacial Lake Deschaillons Phase

At the end of the St. Pierre interstadial time a broad basin within St. Lawrence Valley became occupied by glacial Lake Deschaillons (Karrow, 1957). The full extent of its sediments is unknown. Presumably the lake extended westward beyond the limits of the map-area; eastward its sediments are known as far downstream as the town of Donnacona. It would appear, from scant knowledge of the Quebec City area, that Lake Deschaillons did not extend that far east and that therefore an obstruction, presumably an ice front, blocked St. Lawrence Valley somewhere between Donnacona and Quebec City to form the eastern limit of the glacial lake. Duration of the lake is estimated, by varve count in the St. Pierre type section, at about 500 years. After this time the lake basin was glaciated and its upper sediments disturbed by the passage of an ice sheet and the deposition of till.

Glacial Phase

Dominantly sandy grey till, called the Gentilly till, was deposited on Lake Deschaillons sediments and older sediments by what appears to have been the second Laurentide ice sheet of the Wisconsin glaciation. Direction of movement of this ice sheet is poorly known, but on the basis of dominance of Laurentian rock material in the till, it is known to have had a dominantly southward component.

Although a single, relatively thin till represents the existence of a major ice sheet in this region, nonetheless the duration of the glaciation may have spanned 40,000 to 50,000 years (*see* section on correlations below). During this time the southern margin of the ice sheet probably lay beyond the southern limit of the present area in the Appalachian Highland region of southern Quebec or in the New England states, where fluctuations of the ice front produced a much more complex stratigraphic sequence than that recorded here. It would appear that the central St. Lawrence Lowland area was stable and unaffected by phenomena that are recorded outside the map-area and that represent events of early and middle Wisconsin time.

Two moraines or morainic systems were built in this region during the recession of the last ice sheet: the Drummondville moraine and the St. Narcisse moraine. Both of these, though modified in some degree by wave erosion and marine sedimentation during Champlain Sea time, are distinguishable in the map-area as obvious physiographic features. The Drummondville moraine is discussed here, but to preserve the chronological order St. Narcisse moraine is treated in later paragraphs.

The Drummondville moraine is believed to have formed under essentially glacial conditions, because no marine fossils are known to occur more than a few feet below the surface in its sediments. The presence of fossils in overlying marine and modified morainic deposits indicates that the ridges were modified by marine inundation and wave erosion after their formation. The Drummondville moraine is therefore the last essentially glacial feature built by Laurentide ice on the south side of St. Lawrence River within this map-area. Although the series of ridges comprising the morainic system can be recognized in a wide belt over a great distance through the lowland region, they are typically low, smooth ridges because of their modification, and in this respect their outward form belies their glacial origin. Throughout most of the area the Drummondville moraine appears to lie on or near a fault scarp in the buried bedrock that may have had some influence on localizing the moraine. The Drummondville moraine is considered to be a recessional feature of the Laurentide glaciation, occurring in Wisconsin time just before retreat of the ice margin permitted the sea to spread over that part of the region. It is correlated in time only very loosely with that event.

Paucity of glacial lake and outwash materials related to the Gentilly till suggests that the glaciation came to an abrupt close, insofar as it is concerned with this area, with the advent of marine conditions. A number of sections containing thin sequences of varved silts that grade directly into overlying marine sediments suggests further that the change, though abrupt, was transitional, hence the end of the glacial episode is very closely linked with the beginning of the marine episode, and an overlap is indicated by glaciomarine phenomena, particularly in the northern parts of the region.

Champlain Sea Episode

The Champlain Sea occupied the valley of St. Lawrence River, in places to present altitudes of about 600 feet at the close of the local events of the main Wisconsin Glaciation; at that time the whole area studied here was below sea level, with the exception of small areas of the Laurentian Highland. South-facing slopes of the Laurentian Highland are generally steep, are of granitic bedrock, and little or no glacial debris was deposited on them; these factors apparently made the highland inhospitable to shoreline development because no major beaches have been built at or near the assumed marine limit in this area. Most abandoned shore features found in softer materials within the area record the recessional stages of the sea. In consequence the writer can give no new information on maximum levels of marine occupation in St. Lawrence Valley, but deals mainly with features recorded in the sides and bottom of a marine basin during maximum occupation by the sea and in the erosional period since then. Gradational and intertonguing relationships between glacial and marine sediments indicate that there was a strong glacial influence on the sedimentary environments of the Champlain Sea basin. Many of these are related to the St. Narcisse moraine and show that it was built by ice whose margin stood in the sea. Thus the nature of sedimentary environments indicates persistence of glaciation after the formation of Champlain Sea. Carbon-14 dating of its fossils points to the fact that this marine phenomenon occurred while glaciation persisted in highland areas north of St. Lawrence River.

There is no evidence of an erosional interval between the Gentilly Stade and the beginning of the Champlain Sea episode, and there is a direct gradation in the sediments from apparently freshwater varves, younger than Gentilly till, into the stratified sediments of the Champlain Sea. The following hypothesis is thought to account for the observed phenomena.

The ice front receded northward from a position at or near the north-facing flank of the Appalachians, where it stood at altitudes greater than sea level of that time. As the retreat occurred, glacial lakes of the Lake Champlain basin and the upper part of St. Lawrence Valley merged, then expanded progressively northward. When a halt occurred, during which the Drummondville moraine was built, glaciolacustrine conditions still persisted in places over a broad area south of that moraine (Fig. 11). The eastern part of the Drummondville moraine trends easterly, and it is assumed that the ice front continued on that trend beyond the map-area and south of Quebec City to impinge on the Appalachian Highland at some point southeast of Quebec City near Chaudière Valley. This is assumed because in areas near the Drummondville moraine thin layers of varved sediments overlie Gentilly till, hence areas south of the Drummondville moraine were under fresh water. Apparently the sea was blocked out of the lowland by an ice barrier somewhere between Quebec City and Rivière-du-Loup. If ice-front positions east of Quebec retreated in a manner similar to those to the

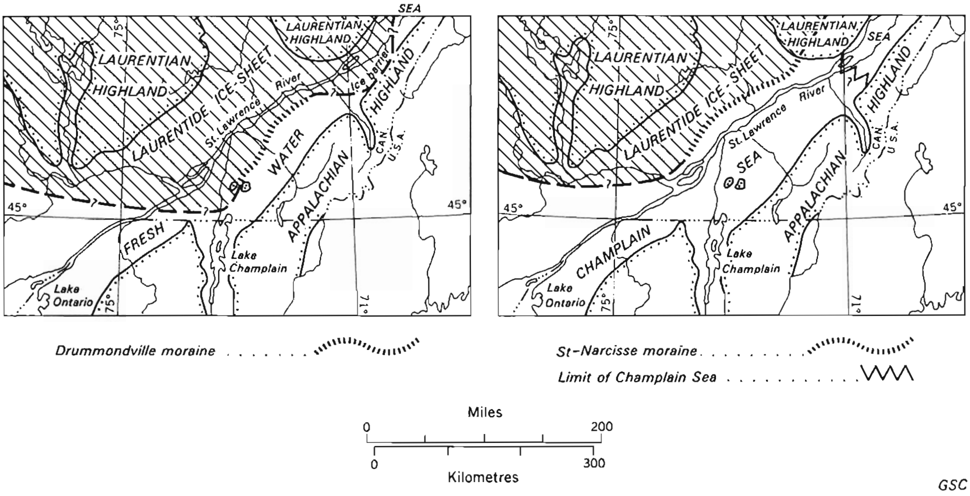

FIGURE 11. Hypothetical positions of ice margins at times of Drummondville and St. Narcisse moraines.

west, it is probable that sea water had come some distance up St. Lawrence Valley as a wedge-shaped body between the ice front and the highland, but had not reached inland as far as Quebec by the time of formation of the Drummondville moraine.

As mentioned above, the bodies of varved silt overlying Gentilly till at and near the Drummondville moraine formed during and shortly after the halt at the moraine; they are thin and grade upward into marine sediments, so it is assumed that the freshwater conditions suddenly ended only a short time after the Drummondville moraine was formed. This occurred when retreat of the ice front eliminated an ice barrier near Quebec City and allowed the fresh water in the west and the salt water in the east to merge and form a single body of brackish water. The rapid change in the character of the environment is reflected in the sediments as an abrupt, though gradational vertical transition from fresh- to brackish-water sediments and by the introduction of marine fauna.

Originally the name Champlain Sea was applied to a body of marine water that occupied the St. Lawrence Lowland and whose sediments were first described in the State of New York near Lake Champlain. Subsequent usage has extended the use of the name to include all post-last-glacial marine sediments and fauna of the St. Lawrence system, including those of the Gulf of St. Lawrence. It is apparent, if the mechanism of flooding of the St. Lawrence Lowland was as described, that marine sediments east of the ice barrier were deposited at the same time as some of the glaciolacustrine and glacial sediments in the same system west of the barrier. It has also been shown in the map-area discussed that marine water bodies ceased to exist in part of the St. Lawrence Lowland some 9,500 years ago. Therefore, non-marine sediments of the St. Lawrence Lowland areas described would be contemporaneous with marine sediments in areas downstream towards the Gulf of St. Lawrence and the sea.

To avoid confusion in stratigraphic work and unwarranted extrapolation of the name, it is deemed practical to confine the use of the name Champlain Sea to the area of the St. Lawrence Lowland west of Quebec City, or some place nearby when it becomes possible to define the position of the last remaining Laurentide ice-front barrier to the sea in that vicinity (*see also* Gadd, 1964, p. 1253).

The Champlain Sea expanded to its maximum areal extent as the margin of the last Laurentide ice retreated from the St. Lawrence and Ottawa Valleys. St. Narcisse moraine was built as a recessional moraine within the basin during that expansion (Fig. 11) and its crest was overtopped later by waters of the Champlain Sea that ultimately extended the full distance between the Appalachian and Laurentian Highlands. The writer assumes that the Champlain Sea stood at or near its maximum level during all these events.

The influence of nearby glaciers is in evidence throughout the suite of sediments of the Champlain Sea. Small closed basins with poor aeration and circulation may have been formed on the irregular valley floor where masses of debris were dumped from the wasting glacier or ice-rafted into place. It was probably in such basins that the formation took place of the known deposits of black-mottled silty clay high in carbonaceous matter, iron, and sulphur, but low in free carbonates. The combined influence of irregular sea floor and a ready supply of poorly aerated cold water from glacial sources may have created the anaerobic, reducing environment for such deposition. The black-mottled clays occur mainly in the lower parts of the thick sequences of marine clay, which suggests that as sedimentation continued the small basins were filled and circulation became generally good so that free carbonates were preserved and the clays came to have their normal, massive, blue-grey fossiliferous and calcareous character.

The north side of the basin, at least in this area, appears to have remained under glacial influence through much of Champlain Sea time, for there, particularly about the mouths of major rivers heading in the Laurentian Highlands, the marine sediments are typically laminated and have a regular alternation of coarse and fine sediments, similar to that of varves. The range of grain size is usually greater in these marine sediments than in typical glaciolacustrine varves. The best examples of these phenomena are in the so-called Trois-Rivières delta. Stratified sediments, ranging from sands in top-sets to clays in bottom-sets, occur both in the top-set beds of the delta as seen near Shawinigan Falls, and in the bottom-set beds that occur in terraced plains that spread east and west of the delta along the north shore of St. Lawrence River.

Ice-rafted boulders are found in places at virtually all levels through the marine sequence and in all facies of the sediment, thus suggesting a glacial influence, probably a nearby active glacier, through much of the period of existence of the Champlain Sea. However, other sources such as shore ice or sea ice cannot be eliminated as agents. Details of the St. Narcisse moraine show that the ice front lay in the marine basin at some time during the marine occupation of the St. Lawrence Lowland.

St. Narcisse Phase

The main part of St. Lawrence Valley within the map-area has been free of glacial ice since the beginning of the Champlain Sea episode. The St. Narcisse phase of the Gentilly Stade[1] took place entirely within the time of the Champlain Sea episode. At the central ridge of the St. Narcisse moraine, along Batiscan River, till lies on what appears to be either fossiliferous marine clay, stony marine clay, or fossiliferous water-laid clay-till (observations made during the summers of 1962 and 1966 showed the presence of marine foraminifera in the till and in clay throughout a 100-foot section); fossiliferous marine clays and sands overlap the flanks of the moraine.

[1]Glaciation related to formation of the St. Narcisse moraine is here considered to be part of the Gentilly Stade for want of sufficient evidence to distinguish it as a separate glaciation. Future work may well prove the existence of a widespread advance into the Champlain Sea that is younger than the Gentilly glaciation and part of the Champlain Sea episode, or that St. Narcisse moraine was built at a time significantly later than the Drummondville moraine. For the present, however, St. Narcisse is given a recessional moraine status within the Gentilly Stade.

It is assumed (from the complex interrelations of glacial and marine features, particularly on the north side of the moraine, and because of the wave-washed character of the crest of the moraine) that Champlain Sea was at or near its maximum height above present sea level when the ice front retreated northward from the St. Narcisse moraine into the Laurentians. Parts of this moraine, all of which was modified, are over 450 feet in altitude.

The St. Narcisse moraine, with its characteristically acid till (i.e., containing mostly pebbles and boulders of Laurentian origin where observed in this area), was deposited from ice centred on the Laurentian Highland and extending only a short distance south into the Champlain Sea basin. Although relationships are not clear, the St. Narcisse till is tentatively mapped as a facies of Gentilly till. The nearly linear form of the ridge and its parallelism with St. Lawrence Valley through this area suggest that calving into the sea was a major factor in localizing the moraine and in defining its shape.

Presumably the glacial activity that built the St. Narcisse moraine was the last pulse of the Wisconsin Laurentide glaciation to reach this part of the St. Lawrence Lowland. Relationships of the moraine to the Champlain Sea and evidence of glaciomarine conditions within the marine embayment establish the partial contemporaneity of the two events. This correlation indicates a probability that the unwatering of the St. Lawrence Lowland and development of the extensive system of deltas and river terraces may have begun in the St. Lawrence Lowland at a time when glaciers were still active in significant parts of northern Canada, for there is no evidence that Champlain Sea remained at its maximum for a long time. Rather the evidence demands a rapid uplift shortly after the inundation, so that glaciers might well have existed nearby while the Champlain Sea diminished.

Post-Champlain Sea Time

It is postulated that the thick sand deposits exemplified by high terrace sands and the upper layers of the Trois-Rivières delta are of freshwater origin. One principal criterion used by the author to distinguish such deposits from physically similar Champlain Sea sands is the absence of marine shells in situ in shore features below altitudes of about 300 feet. Such deposits, according to his hypothesis, have formed in a body of fresh water younger than Champlain Sea. It would be inaccurate to state that no marine shells occur at or near the surface in the vertical zone below 300 feet, for in many places fossiliferous marine beds have been exposed by erosion, and in these, shells commonly occur below the zone of leaching, whereas they have not been found even at depths of 10 to 12 feet, hence well below the zone of leaching, in sands considered to have a freshwater origin. Also, during the erosional process many shells characteristic of Champlain Sea have been carried and redeposited in high terrace sands by water currents, but they are included in the presumably freshwater deposits just as pebbles of similar size and weight are included; moreover, such marine shell 'pebbles' are not found in characteristic living attitudes, but rather are found mainly as single, water-worn valves lying with their long axes parallel to the bedding surface of the enclosing sand.

In addition, the thick sands of high terrace features, including the Trois-Rivières delta, are presumed to be genetically related to wastage of glaciers outside the map-area and to drainage through the St. Lawrence Valley of glacial lakes by such connections as the Fossmill Channel and the North Bay – Mattawa outlet.[1] This relationship, admittedly tenuous, may be sufficient evidence to postulate that a late-Wisconsin non-glacial episode is represented in this area by thick sand deposits between altitudes of about 300 and 100 feet. Within this

[1]Thick sand deposits of similar nature, thickness, altitude, and relationship to Champlain Sea strata have been noted near Petawawa, Ontario (Gadd, 1963b) and Ottawa, Ontario (Gadd, 1963a); these may belong to a system continuous with high terrace sand deposits of the region described in this report.

zone it may be noted that the thickness of sand deposits decreases with altitude, thus apparently registering the decline of systems originally providing the large volumes of sand. This is interpreted to mean that glaciers and glacial lakes in regions near St. Lawrence River declined and ultimately ceased to contribute large volumes of water and sand to the St. Lawrence River system. This involved a pronounced change in the regimen of the St. Lawrence River system when locally its role changed from basically depositional to basically erosional. This marked the end of any noticeable glacial influence on the region, hence the end of Wisconsin Glaciation locally.

Postglacial Time

Evidence of the change in regimen of the early stages of the St. Lawrence River system lies in the erosion of well-defined scarps on both sides of St. Lawrence River. These scarps are from 25 to 100 feet high within the map-area and probably are among the features that identified Goldthwait's Micmac shoreline (Goldthwait, 1911b). The scarps form the outside limit of broad terraces, only a few feet above present water levels, that are veneered by alluvium; some of these are flooded from time to time by the modern St. Lawrence River. These scarps and terraces constitute the physical evidence of postglacial erosion and uplift. Some uplift may still be in progress because the St. Lawrence continues to excavate its bed and remains a geomorphically youthful river. It would seem that until fairly recently St. Lawrence River occupied the valley delimited by the scarps separating the zone of high terrace sands from that of low terrace sands. A fairly recent and minor rejuvenation of the river in this part of the region could have resulted from removal by erosion of a plug of glacial debris from a narrow part of the pre-glacial channel of St. Lawrence River just outside the map-area, particularly that part between Leclercville and Quebec City.

Correlations

Local Considerations

Data from within the area give a basis for establishing broad limits within which correlations may be made and are reviewed here in the interest of future studies. It is not yet possible to give an exact age correlation of the events under study with glacial and postglacial events in the surrounding region.

The first known glaciation of this region pre-dates the St. Pierre Interval, and being older than the most widely accepted dates for that interval—viz. Gro-1766, 64,000 ± 1,000 years and Gro-1711, 67,000 ± 2,000 years (Dreimanis, 1960), is at least very early Wisconsin, or "post-Sangamon, pre-classical Wisconsin" (Flint, 1963). The Bécancour till may be pre-Wisconsin, but freshness of the till and lack of Sangamon soil above it argue against this. The dates and floral assemblage of the St. Pierre Interval (Terasmae, 1958) distinguish it from the Sangamon and establish it as early Wisconsin.

Sediments of Lake Deschaillons, interpreted as being proglacial deposits of the Gentilly glacial stade, contain a pollen spectrum that is continuous with that of the St. Pierre peat beds and indicates the approach of an ice front. The interstadial interval between early Wisconsin (Bécancour till) and main Wisconsin (Gentilly till) Glaciations seems to be perfectly bridged by organic remains in the St. Pierre and Lake Deschaillons sediments. At the other end of the scale, varve-like sediments grading upward into massive clays seem to bridge the time between main Wisconsin Glaciation and the Champlain Sea. This implies that the main Gentilly Stade began immediately at the end of St. Pierre interstadial early in Wisconsin

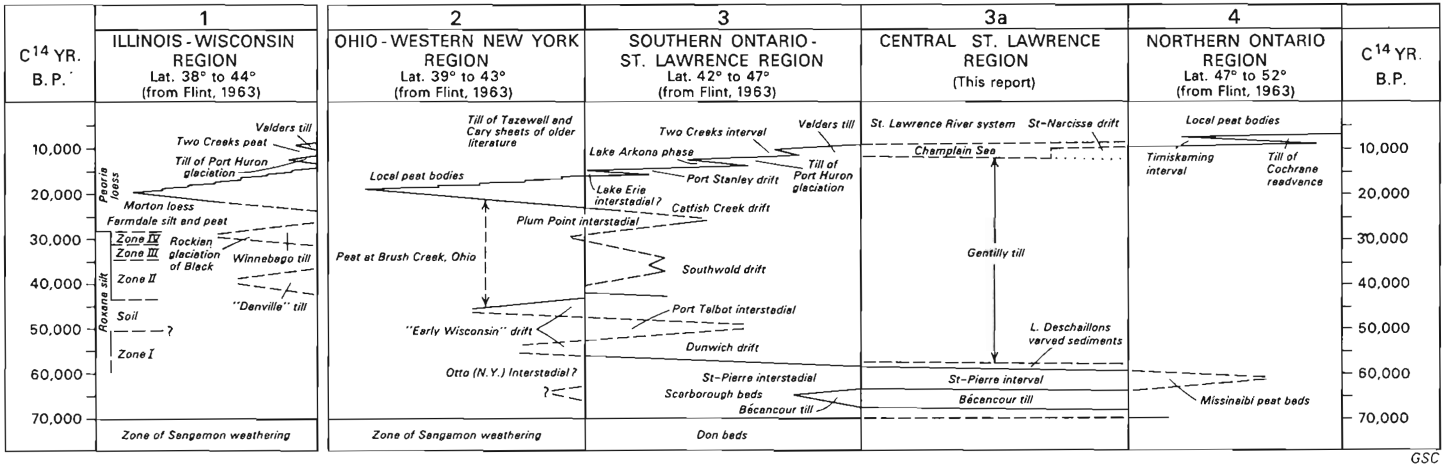

FIGURE 12. Chart showing regional stratigraphic relationships of Wisconsin Glaciation in central and eastern North America (after Flint, 1963, with additions).

time, and ended with invasion of the St. Lawrence Lowland by the Champlain Sea near the end of Wisconsin time. Other late-glacial and interstadial episodes of the mid-Wisconsin known in other regions are not recorded, or at least have not been recognized within the area under study in this report. For the central part of the St. Lawrence Lowland a single glaciation appears to have persisted through much of Wisconsin time. The period during which the valley was occupied continuously by main Wisconsin ice may have been some 45,000 to 50,000 years, i.e., between about 65,000 and 12,000 years B.P.

The age of the Champlain Sea cannot be determined from data taken within this region, but a limiting minimum age can be established if we consider only the one date obtained from a bog at St-Germain-de-Grantham, southwest of Drummondville (Olson and Broecker, 1961, p. 146). There marine shells occur in a beach on top of the Drummondville moraine at an elevation of about 300 feet. Freshwater bog deposits began to accumulate in a depression below this beach at least $9{,}500 \pm 300$ years B.P. (Table III, L–441C). Thus all areas above 300 feet elevation were free of the Champlain Sea some 10,000 years ago.

As we have seen, the bog vegetation itself is of a type representing freshwater conditions; therefore, the marine condition had ceased to exist at levels between 275 and 300 feet elevation at the beginning of peat deposition in St-Germain bog. Freshwater sediments in bars, spits, deltas, etc., only a few feet lower than the above-mentioned marine beach, appear either contemporaneous with or younger than the accumulation of peat in St-Germain bog, but could conceivably be somewhat older if there was some time lag in the beginning of peat accumulation after water levels dipped below 300 feet. Radiocarbon dating of the St-Germain bog, based on plant remains and supported by a pollen chronology, is considered reliable, and therefore rules out the possibility that the Champlain Sea may have existed in this area less than 9,500 years ago. In addition, it has been established that marine fossils do not occur at the surface as primary features at levels below the elevation of this bog.

The amount of time that the St. Lawrence Lowland was occupied by the sea has been confined within fairly narrow limits (viz., between about 12,000 and 9,500 years B.P.) by these considerations. The time available for development of modern drainage systems is correspondingly increased. Although St. Lawrence River is still in the process of re-excavating its channel, much time has been available for the very considerable amount of erosion involved in its partial re-occupation of pre-glacial channels, time equal to that required for the deglaciation and drainage of all of Canada north of the St. Lawrence and the Great Lakes.

Regional Considerations

Regional aspects of stratigraphic correlation are illustrated on Figure 12. The basis of the chart is one published by Flint (1963); it has been modified by the addition of a column (3a) representing data given in this report (*see also* Fig. 13, *in pocket*).

Dreimanis (1960, p. 116) suggested that the St. Lawrence Lowland must have been free of ice during the long, cool, mid-Wisconsin interstade, but the writer postulates here that no such interstade occurred in the area covered by this report. The hypothesis is that a single glacial episode, the Gentilly Stade, occupied a period of some 50,000 years between the St. Pierre Interval and the time of invasion of the lowland by the Champlain Sea. Admittedly this hypothesis is based on negative evidence, but several hundred vertical sections have been examined within the area and south of the St. Narcisse moraine as well as in adjacent areas, in none of which the writer or his colleagues have observed interstadial or glacial sediments that may be related to events other than those recorded. Further evidence, though again negative, is that there was only one marine invasion in this region, according to the writer's observations and interpretations, and it occurred after deposition of the main body of Gentilly till. If the St. Lawrence Lowland was free of ice at various times in the last 50,000 years, some record of marine invasion older than Gentilly till, or at least older than Champlain Sea, should be found. Despite what has been repeated many times in the literature, the writer finds no such record in the area considered in this report. Therefore, lacking freshwater or marine sediments that can be shown to belong to the period between 65,000 and 12,000 years B.P., and having a single till sheet to represent that time, it is reasonable to conclude that St. Lawrence Valley was occupied continuously by ice through most of the Wisconsin glaciation, and that ice front fluctuations recorded in areas west, south, and east of this region did not occur within or did not measureably affect the areas encompassed in this report.

Lee (1963) dates the Trois-Pistoles clay on the distal side of his St. Antonin moraine at 12,720 $\pm$ 170 years B.P. (GSC-102). Other dates from the distal side (GSC-70, 10,600 $\pm$ 170; GSC-63, 11,410 $\pm$ 150) are suggested as dates older than or contemporaneous with the St. Antonin ice lobe. The ages of marine sediments on the proximal side of the same moraine near Rivière-du-Loup are given by a series of dates ranging from 9,690 to 10,340 $\pm$ 130 years B.P. (GSC-69, GSC-68, GSC-61), which provides a minimum age for retreat of the ice-margin from the St. Antonin moraine. Thus, if the St. Antonin moraine marks the last ice stand south of St. Lawrence River prior to the Champlain Sea, as interpreted by Lee (1962, 1963), the earliest leads of the sea along the north side of the moraine must have occurred between 12,720 $\pm$ 170 years B.P. and 10,340 $\pm$ 130 years B.P. (dates GSC-102, GSC-61).

The age of post-Champlain Sea bogs in this central part of St. Lawrence Valley limits the occupation of the valley by an arm of the sea to the period between 12,000 and 9,500 years B.P., at least for the zone between altitudes 600 and 300 feet. As represented in primary deposits at the surface, the sea was therefore an event of some 2,000 to 2,500 years' duration well within glacial time; it is 'post-glacial', to use terminology of early writers, only in the sense of having occurred after the last glaciation of this region.

Building of the St. Narcisse moraine, evidence of strong glacial activity during the late Wisconsin, falls within the period of marine inundation. The possible correlation of this event with Valders till, as it may appear to be on Figure 12, is more apparent than real, because the St. Narcisse has been positioned arbitrarily within the Champlain Sea period for want of accurate dates to place it more precisely. Certainly the St. Narcisse moraine contains fossiliferous sediments including fossiliferous till and the moraine was modified by wave action of the Champlain Sea; therefore the whole glacial episode properly belongs within the short span of Champlain Sea time.

Research into the late glacial phenomena of the Appalachian region south of the area dealt with in this report will undoubtedly provide data on the late-glacial ice-margin fluctuations and on their relationships to stratigraphic successions available and being uncovered in critical areas such as New Brunswick, Maine, Vermont, and New York. Further work in the area under discussion should provide some insight into problems introduced in this report.[1]

[1]Since this manuscript was submitted for publication, several significant papers and maps have appeared. Many of them are summarized by McDonald and Shilts (1971) (*see* References).

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APPENDIX I

Sections Representative of Regional Glacial Stratigraphy

Thickness (feet)	Lithology	Cumulative thickness[1]
	Section 16	
	Location: 31 I/8 Bécancour River, north bank, ¼ mile east of bridge at south end of village of Bécancour. 46°20′30″N, 72°26′W, elev. ±30 feet above sea level.	
	POST-CHAMPLAIN SEA UNITS	
4	Medium- to coarse-grained buff alluvial sand	4
1	Buff gravel, alluvial	5
	GENTILLY STADE UNITS	
2	Stratified grey silt and silty sand, glaciofluvial or glaciolacustrine	7
3	Grey sandy till	10
1	Medium-grained buff sand with red shale pebbles	11
	BÉCANCOUR STADE UNITS	
12	Sandy red till	23

Section 17

Location: 31 I/8 Bécancour River, east bank, 1 mile upstream from bridge at south end of village of Bécancour. 46°20′N, 72°25′W, elev. ±50 feet above sea level.

	POST-CHAMPLAIN SEA UNITS	
4.5	Fine- to medium-grained alluvial sand, red due to abundance of Bécancour River shale; gravelly in lower 1 foot	4.5
	GENTILLY STADE UNITS	
11	Grey sandy silt till with sandy zone between 6 and 7 feet from top of layer	15.5
1	Coarse pebbly sand	16.5
	BÉCANCOUR STADE UNITS	
7	Sandy red till	23.5
	BEDROCK	
0.5	Brick-red shale and slate; Bécancour River Formation	24

[1]Measured from top of section.

Thickness (feet)	Lithology	Cumulative thickness

Section 20

Location: 31 I/8 Bécancour River, north bank, $1\frac{1}{4}$ miles upstream from bridge at south end of village of Bécancour. 46°20′N, 72°24′45″W, elev. ±60 feet above sea level.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
3	Buff gravelly alluvial sand	3
	CHAMPLAIN SEA UNITS	
2	Blue-grey marine clay, very soft	5
	GENTILLY STADE UNITS	
5	Sandy grey till	10
	BÉCANCOUR STADE UNITS	
20	Sandy red till	30
	BEDROCK	
20	Bécancour River Formation, red shale and sandstone	50

Section 21

Location: 31 I/8 Rivière Blanche (St-Wenceslas) at junction with Bécancour River. 46°17′30″N, 72°23′15″W, elev. ±134 feet (bar.) above sea level.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
3	Fine-grained buff sand	3
	GENTILLY STADE UNITS	
2	Sandy grey till	5
	BÉCANCOUR STADE UNITS	
20	Sandy brick-red till (Bécancour till type-section)	25
	BEDROCK	
41	Bécancour River Formation (type-section)	66

Section 23

Location: 31 I/8 Bécancour River, west bank, ±100 yards downstream from mouth of Rivière Blanche. 46°17′30″N, 72°23′15″W, elev. ±170 feet (bar.) above sea level.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
25	Horizontally stratified, uniform fine-grained buff sand with brownish buff silt bands; alluvial	25
	BÉCANCOUR STADE UNITS	
10	Red till in sheets and irregular masses with intercalated red outwash sand and gravel	35
9	Sand and silt with disturbed bedding	44

Thickness (feet)	Lithology	Cumulative thickness

Section 50

Location: 31 I/8 St. Lawrence River, south shore, ½ mile north (downstream) from mouth of Rivière aux Orignaux. 46°26′30″N, 72°13′30″W, elev. ±85 feet above sea level.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
8	Buff alluvial sand, some pebbles	8
	GENTILLY STADE UNITS	
15	Grey sandy till	23
	ST. PIERRE INTERVAL UNITS	
21	Medium- to coarse-grained, stratified and crossbedded alluvial sand	44
	BÉCANCOUR STADE UNITS	
25	Brick-red sandy till	69

Section 51

Location: 31 I/8 St. Lawrence River, south shore, 1 mile southwest of north edge of Bécancour map-area (31 I/8). 46°29′N, 72°12′30″W, elev. ±118 feet (bar.) above sea level.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
1	Medium sand, indurated and coloured by intergranular iron oxide cement	1
4.5	Buff-weathered medium-grained sand, some silt bands	5.5
2	Uniform fine- to medium-grained buff sand, water table at 7.5 feet	7.5
4.5	Stratified, fine- to medium-grained light grey sand	12
	GENTILLY STADE UNITS	
2	Calcareous, grey varved silts	14

Section 52

Location: 31 I/8 St. Lawrence River, south shore, approx. 1.65 miles southwest of north margin of Bécancour map-area. 46°28′35″N, 72°13′W, elev. 110 feet approx.

Thickness (feet)	Lithology	Cumulative thickness
	GENTILLY STADE UNITS	
30 (approx.)	Calcareous, sandy grey till	30
63 (approx.)	Surface of exposure covered with slumped till	93

Thickness (feet)	Lithology	Cumulative thickness
	Section 53	
Location:	31 I/8 St. Lawrence River, south shore, approx. 0.65 mile southwest of north margin of Bécancour map-area. 46°29′27″N, 72°12′45″W, elev. 110 feet approx.	
	POST-CHAMPLAIN SEA UNITS	
3	Buff sandy gravel	3
	GENTILLY STADE UNITS	
2	Grey calcareous till	5
15	Grey varved silts, crumpled and distorted in upper 5 feet	20
±70	Section covered by slump	±90
	Section 54	
Location:	31 I/8 St. Lawrence River, south shore, approx. 1.5 miles southwest of north margin of Bécancour map-area. 46°28′40″N, 72°13′W, elev. 110 feet approx.	
	POST-CHAMPLAIN SEA UNITS	
2	Coarse-grained buff sand	2
	CHAMPLAIN SEA UNITS	
8	Uniform fine-grained grey silt; fossiliferous	10
	GENTILLY STADE UNITS	
35	Strongly calcareous sandy silty grey till	45
	Section 55	
Location:	31 I/8 St. Lawrence River, south shore, approx. 1.1 miles southwest of north margin of Bécancour map-area. 46°29′N, 72°12′50″W, elev. 50 feet approx.	
	GENTILLY STADE UNITS	
10	Calcareous sandy grey till	10
	ST. PIERRE INTERVAL UNITS	
5	Fine-grained sand charged with disseminated organic matter	15
	Section 56	
Location:	31 I/8 St. Lawrence River, south shore, approx. 1.05 miles southwest of north margin of Bécancour map-area. 46°29′05″N, 72°12′50″W, elev. 110 feet approx.	
	GENTILLY STADE UNITS	
62	Strongly calcareous sandy grey till	62

Thickness (feet)	Lithology	Cumulative thickness
	ST. PIERRE INTERVAL UNITS	
18	Stratified fine- to medium-grained sand with silt bands, heavily charged with disseminated fragments of brown organic matter	80

Section 57

Location: 31 I/8 St. Lawrence River, south shore, ravine at 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 100 feet west of highway on right bank. 46°29′40″N, 72°12′15″W, elev. 100 feet approx.

	GENTILLY STADE UNITS	
82.5	Lake Deschaillons varved silts, grey, thin-bedded at base	82.5
	ST. PIERRE INTERVAL UNITS	
1	Fine-grained sand with abundant disseminated fragments of brown organic matter	83.5
12.5	Stratified uniformly fine- to medium-grained buff sand	96

Section 58

Location: 31 I/8 St. Lawrence River, south shore, ravine at 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.4 mile upstream (east and south) from highway on left bank of intermittent stream. Discovery and type section for St. Pierre interstadial sediments. 46°29′25″N, 72°12′W, elev. 121 feet (bar.).

	POST-CHAMPLAIN SEA UNITS	
3.5	Fine-grained buff alluvial sand	3.5
	CHAMPLAIN SEA UNITS	
5	Massive, soft, light grey silt	8.5
	GENTILLY STADE UNITS	
66.5	Approximately 500 varves of calcareous grey silt, thin-bedded at top and bottom of section	75
	ST. PIERRE INTERVAL UNITS	
1.5	Fine- to medium-grained sand heavily charged with disseminated fragments of organic matter; brown	76.5
1.75	Compressed peat with abundant wood as flattened stems, branches, twigs	78.25
3	Stratified medium- to fine-grained sand, some silt; alluvial	81.25
0.5	Compressed peat, some wood	81.75
1.5	Medium- and fine-grained sand, a few pebbles; alluvial	83.25
1.25	Compressed peat; beetle remains most common in this bed	84.5
3	Fine- to medium-grained sand and silty sand; alluvial	87.5

Thickness (feet)	Lithology	Cumulative thickness

Section 59

Location: 31 I/8 St. Lawrence River, south shore, ravine 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.2 mile upstream (east) from highway on left bank of intermittent stream. 46°29′32″N, 72°12′W, elev. 118 feet (bar.).

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
5	Stratified medium-grained buff alluvial sand	5
	CHAMPLAIN SEA UNITS	
2.5	Massive grey silt	7.5
	GENTILLY STADE UNITS	
52.5	Lake Deschaillons calcareous grey varved silts	60.0
	ST. PIERRE INTERVAL UNITS	
10	Rusty brown and greenish weathered indurated medium-grained sand; probably an iron-enriched zone of a buried soil profile	70.0
14	Stratified medium-grained sand and silty sand	84.0
	BÉCANCOUR STADE UNITS	
3	Sandy red till with lenses of red sand	87.0
4	Red varved silts	91.0

Section 60

Location: 31 I/8 St. Lawrence River, south shore, ravine 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.1 mile west of highway on right bank of ravine. 46°29′45″N, 72°12′20″W, elev. 100 feet approx.

Thickness (feet)	Lithology	Cumulative thickness
	CHAMPLAIN SEA UNITS	
60	Fine- to medium-grained buff sands, crossbedded and having a structure like delta fore-sets dipping towards the St. Lawrence; a few valves of *Macoma* present	60
15	Fossiliferous (*Portlandia*) blue-grey soft marine clay silt with black patches of disseminated organic matter, sulphurous odour	75
	BÉCANCOUR STADE UNITS	
10	Calcareous, brownish to reddish grey silty till	85
10	Brownish to reddish grey varved silt (lower 30 feet of section obtained by hand auger boring)	95

Section 63

Location: 31 I/8 St. Lawrence River, south shore, ravine 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.2 mile west of highway on right bank of ravine near St. Lawrence shore. 46°29′50″N, 72°12′20″W, elev. 113 feet (bar.).

Thickness (feet)	Lithology	Cumulative thickness
	CHAMPLAIN SEA UNITS	
5	Massive grey silt; assumed to be marine	5

Thickness (feet)	Lithology	Cumulative thickness
	GENTILLY STADE UNITS	
70	Grey varved silt, $1\frac{1}{2}$ to 2 inches per varve pair at top, 3 varves to the inch in lower 10 feet of section	75
10	Slumped varves	85
2	Grey varves in place as above	87
	BÉCANCOUR STADE UNITS	
4	Sandy brick-red till	91

Section 65

Location: 31 I/9 St. Lawrence River, south shore, Cap Lévrard, 2.4 miles downstream from Roman Catholic church at St-Pierre-les-Becquets. 46°32′N, 72°10′W, elev. 100 feet approx.

	POST-CHAMPLAIN SEA UNITS	
3	Alluvial sand	3
	CHAMPLAIN SEA UNITS	
12	Stratified silts, marine	15
	GENTILLY STADE UNITS	
1	Medium gravel	16
2	Buff sand	18
4	Calcareous grey sandy till	22
20	Stratified, crossbedded medium sand	42
3	Calcareous grey sandy till	45
10	Stratified, crossbedded medium sand	55
	BÉCANCOUR STADE UNITS	
5	Very sandy brick-red till	60
5	Reddish grey and red varved silts	65

Section 98

Location: 31 I/2 St-François River, northeast bank, 1.6 miles upstream from bridge on highway 3; the Pierreville section. 46°03′N, 72°47′20″W, elev. 100 feet approx.

	GENTILLY STADE UNITS	
7.5	Brownish grey calcareous sandy till	7.5
	ST. PIERRE INTERVAL UNITS	
17.5	Stratified, fine-grained buff to brown sand, becoming silty in lower 5 feet	25
1	Compressed peat with some wood	26
9	Stratified fine-grained sand and silty sand grading downward into subjacent silt	35
	BÉCANCOUR STADE UNITS	
16.5	Grey to brownish grey varved silt (in lower part of section beds are repeated by slumping; some contacts apparently are fault contacts)	51.5
25.5	Section covered by slump debris	77

Thickness (feet)	Lithology	Cumulative thickness
	GENTILLY STADE UNITS	
3	Brownish grey calcareous sandy till	80
	ST. PIERRE INTERVAL UNITS	
2	Stratified fine-grained buff sand	82
1	Compressed peat with some wood. (This peat bed was reported by Joseph Keele, 1916.)	83
	BÉCANCOUR STADE UNITS	
7	Grey and brownish grey varved silt	90

Section 99

Location: 31 I/2 St-François River, east bank, 3 miles upstream from highway 3. 46°02′10″N, 72°46′W, elev. 80 feet approx.

	CHAMPLAIN SEA UNITS	
5	Massive grey marine clay	5
	GENTILLY STADE UNITS	
5	Grey to reddish grey sandy till	10
	ST. PIERRE INTERVAL UNITS	
3	Fine-grained brown and grey-brown silt and fine sand, thin bedded	13
14	Crossbedded coarse sand	27
	BÉCANCOUR STADE UNITS	
12	Glaciolacustrine silt, varved, grey "summer" layers and red "winter" layers	39
10.5	Sandy red till	49.5
	BEDROCK	
5.5	Red sandstone of Bécancour River Formation	55

Section 100

Location: 31 I/2 St-François River, east bank, 4.5 miles upstream from highway 3. 46°02′N, 72°44′25″W, elev. 100 feet approx.

	POST-CHAMPLAIN SEA UNITS	
2	Medium-grained alluvial sand	2
	CHAMPLAIN SEA UNITS	
33	Massive grey marine silt and silty clay, fossiliferous; very tough near weathered surface	35
	BÉCANCOUR STADE UNITS	
40	Coarse, bouldery, sandy red till	75
	BEDROCK	
4	Variegated red and green sandstone of Bécancour River Formation	79

Thickness (feet)	Lithology	Cumulative thickness

Section 101

Location: 31 I/2 St-François River, east bank, 5.7 miles upstream from highway 3. 46°01′25″N, 72°43′W, elev. 120 feet approx.

Thickness (feet)	Lithology	Cumulative thickness
	CHAMPLAIN SEA UNITS	
32	Soft, grey, massive marine clay; fossiliferous	32
	GENTILLY STADE UNITS	
16	Strongly calcareous, grey, silty till	48
	ST. PIERRE INTERVAL UNITS	
32	Fine-grained grey to grey-brown sandy silt, regularly laminated	80
12	Coarse, flaggy gravel, crossbedded; river gravel derived from local bedrock source upstream	92
	BÉCANCOUR STADE UNITS	
6	Strongly calcareous, red sandy till	98

Section 109

Location: 31 I/2 St-François River, west bank, at mouth of Rivière aux Vaches, 3 miles upstream from highway 3. 46°01′45″N, 72°46′25″W, elev. 100 feet approx.

Thickness (feet)	Lithology	Cumulative thickness
	POST-CHAMPLAIN SEA UNITS	
0.5	Medium-grained alluvial sand	0.5
	CHAMPLAIN SEA UNITS	
21	Light grey, stratified, calcareous and fossiliferous marine silt	21.5
2.5	Grey to brown-grey sandy silt, varve-like stratification, fossiliferous, grading upward into grey marine silt	24
	GENTILLY STADE UNITS	
1.5	Stratified, apparently varved red and grey silt, non-fossiliferous, grading upward into fossiliferous varve-like strata	25.5
8	Sandy reddish grey till	33.5
3	Stratified, crossbedded, buff medium-grained sand	36.5
	BÉCANCOUR STADE UNITS	
13.5	Regularly alternating varve-like thin strata of fine-grained sand and silt; grey, weathering buff; grade downward into grey silt varves	50
16	Grey varved silt, thin bedded near base and with red "winter" layers in lower 4 feet	66
16	Coarse, sandy brick-red till	82
	BEDROCK	
2	Red shale of Bécancour River Formation	84

Thickness (feet)	Lithology	Cumulative thickness

Section 110

Location: 31 I/2 St-François River, west bank, 5.5 miles upstream from highway 3 bridge. 46°01′15″N, 72°43′15″W, elev. 125 feet approx.

	POST-CHAMPLAIN SEA UNITS	
22	Crossbedded, coarse-grained sand	22
	GENTILLY STADE OR ST. PIERRE INTERVAL UNITS	
61	Varve-like, fine-grained, thin-bedded sand and silt; strata with red and grey coloration	83
17	Section covered by slump	100
	BÉCANCOUR STADE UNITS	
2.5	Red varved silt	102.5
2.5	Sandy red till	105
10	Section covered by slump	115

Section 115

Location: 31 I/2 Nicolet River, east bank, landslide scar in ravine 2½ miles upstream from railway bridge at Nicolet village. 46°12′N, 72°34′W, elev. 100 feet approx.

	CHAMPLAIN SEA UNITS	
20	Regularly stratified silt in alternately light and dark grey bands from ½ inch to 2 inches thick; sandy near surface	20
52	Massive, dark grey, fossiliferous marine silt	72

Section 117

Location: 31 I/2 Nicolet River, east bank, 1 mile upstream from Ste-Monique-de-Nicolet. 46°09′N, 72°31′W, elev. 125 feet approx.

	CHAMPLAIN SEA UNITS	
72	Stratified grey marine silt, fossiliferous; massive in lower 20 feet	72
23	Mottled reddish brown and grey-brown silty sand; microfossils	95
5	Black, sulphurous, non-calcareous silty sand, with casts of macrofossils; much fine black organic matter	100

Section 118

Location: 31 I/2 Nicolet River, east bank, escarpment east of bridge at south end of village of Ste-Monique-de-Nicolet. 46°09′15″N, 72°32′W, elev. 150 feet approx.

	CHAMPLAIN SEA UNITS	
18	Fine-grained calcareous, fossiliferous, grey marine silt	18
16	Mottled grey to brownish grey, very fine grained silty sand with microfossils and casts of macrofossils; organic content increases in lower 4 feet	34

Thickness (feet)	Lithology	Cumulative thickness
	GENTILLY STADE UNITS	
1	Varved silt and fine sand above 3 inches of gravel	35
21	Coarse-grained calcareous dark grey till with red lenses at top grading to brick-red till at base	56
	BEDROCK	
14	Red and green sandstone strata presumably of the Bécancour River Formation	70

Section 122

Location: 31 I/2 Nicolet River, west bank, 1½ miles downstream from Ste-Monique-de-Nicolet. 46°09′50″N, 72°33′50″W, elev. 75 feet approx.

	CHAMPLAIN SEA UNITS	
10	Massive, soft grey marine silt	10
	ST. PIERRE INTERVAL UNITS	
2	Horizontally stratified brownish buff sand and silty sand	12
	BÉCANCOUR STADE UNITS	
21	2-inch layer of red sand overlying very sandy brick-red till	33

Section 123

Location: 31 I/2 Rivière Nicolet Sud-Ouest, 3½ miles upstream from confluence with Nicolet River. 46°09′50″N, 72°35′W, elev. 100 feet approx.

	CHAMPLAIN SEA UNITS	
50	Mainly massive, light grey marine silty clay, grading to fossiliferous silty fine-grained sand in lower 12 feet	50
	GENTILLY STADE UNITS	
2	Red gravel and sand with grey-brown silt bands	52
8	Dark reddish grey till with lenses of red till; grey dominant colour	60
	ST. PIERRE INTERVAL UNITS	
4	Fine-grained sand and silty sand, thin bands of finely disseminated organic matter	64
10	Fine-grained buff sand; alluvial. (Section 100 yards downstream has coarse gravel in lower 10 feet of section.)	74

Section 128

Location: 31 I/2 Rivière Nicolet Sud-Ouest, west bank, ½ mile upstream from bridge at La Visitation. 46°07′25″N, 72°35′40″W, elev. 150 feet approx.

	CHAMPLAIN SEA UNITS	
30 (approx.)	Section covered by slump, but assumed to be mainly massive marine clay	30

Thickness (feet)	Lithology	Cumulative thickness
	GENTILLY STADE UNITS	
22	Grey and pinkish grey sandy till irregularly interstratified with fine- to coarse-grained sand, some gravel	52
10	Massive grey calcareous sandy till	62

Section 129

Location: 31 I/2 Rivière Nicolet Sud-Ouest, west bank, ⅞ mile upstream from La Visitation bridge. 46°07′05″N, 72°35′15″W, elev. 150 feet approx.

	CHAMPLAIN SEA UNITS	
16	Massive grey marine clayey silt; somewhat siltier and brownish in lower 3 to 5 feet	16
	GENTILLY STADE UNITS	
0.5	Pebbly medium-grained sand; possibly outwash	16.5
0.5	Fine-grained silty sand stratified in alternately buff and brown varve-like layers; strongly calcareous	17.0
2	Pebbly coarse- and medium-grained sand grading downward into till	19
20	Coarse, tough, compact, sandy grey till; strongly calcareous	39

Section 130

Location: 31 I/2 Rivière Nicolet Sud-Ouest, west bank, 1½ miles (airline) upstream from bridge at La Visitation. 46°06′45″N, 72°34′40″W, elev. 150 feet approx.

	CHAMPLAIN SEA UNITS	
16	Massive, grey marine silty clay; brown mottled and charged with organic matter in basal 5 feet	16
	GENTILLY STADE UNITS	
3	Stratified medium- and coarse-grained sand with thin beds of brown silt; calcareous	19
5	Reddish grey and dark grey massive sandy calcareous till	24
5	Silt-pebble conglomerate of broken and distorted grey-brown varved silt	29
11	Undisturbed, horizontally bedded grey-brown varved silt	40

Section 131

Location: 31 I/2 Rivière Nicolet Sud-Ouest, east bank, 2½ miles upstream from bridge at La Visitation. 46°06′20″N, 72°33′10″W, elev. 150 feet approx.

	CHAMPLAIN SEA UNITS	
15	Massive grey marine silty clay	15
	GENTILLY STADE UNITS	
15	Light grey, very sandy till; calcareous	30
12	Buff, medium-grained sand, silty near top and grading upward into overlying till	42
	BÉCANCOUR STADE UNITS	
17	Coarse, sandy, dark red till, calcareous	59

Selected Passages from

THE ST. LAWRENCE LOWLAND

by

J. W. Goldthwait

An unpublished manuscript submitted to the Geological Survey of Canada about 1933

Technical Editor's Introduction

On the following pages are published for the first time descriptions and conclusions contained in the late Professor J. W. Goldthwait's manuscript, which reveal clearly his geological foresight and understanding of the glacial events in the St. Lawrence Lowland. Though many of his ideas were at variance with those of his contemporaries at the time (about 1933), they are in close agreement with currently held geological concepts, as expressed by N. R. Gadd in this report. His ideas were therefore well ahead of their time, and it is most appropriate that they be appended to this report, that the significance of his contributions can at last be formally recognized. Goldthwait's original manuscript was edited sometime after its submission to the Geological Survey, and some additional changes were made in the 1950's by his son, Richard P. Goldthwait. The following passages have been selected by N. R. Gadd from the edited copy; he has attempted in his selection to preserve Goldthwait's meaning and style, and to present a clear picture of his facts and interpretations. The complete table of contents of Goldthwait's manuscript is included to show the scope of his report. Chapter and section headings are those of Goldthwait; comments in italics are those of Gadd. A copy of the complete text is housed in the library of the Geological Survey of Canada.

The following comments (dated November 9, 1964) were submitted by Professor Goldthwait's son, Professor Richard P. Goldthwait, Department of Geology, Ohio State University, for inclusion in this introduction.

> In 1934 the director of the Geological Survey wrote my father, J. W. Goldthwait, to say "I think that when we received your report 'Physiography of the St. Lawrence Region' you were advised that publication would have to be deferred indefinitely". He concluded, "On the other hand it holds information that should, if possible, be made available to geologists". Both have proved abundantly true.
>
> In the summers of 1925, 1926, and 1927 J. W. Goldthwait took trains from town to town and tramped the length of St. Lawrence Valley forming a careful and penetrating analysis of the late-glacial events. Typical of that day many miles were covered slowly but attention to Pleistocene stratigraphy lacked meaningful detail. Not until 1952 did a new crop of Canadian Pleistocene geologists do very detailed systematic studies in smaller critical areas. Publications are appearing since 1960. With the extension and intensifying of studies in St. Lawrence Valley, the need for this earlier background work has increased.
>
> It is a great pleasure that part of this early discerning study can now be presented together with one modern study. In the thirty years vastly improved detailed maps show better expression. Techniques have changed so the advent of radiocarbon dating and pebble fabrics have solved some of the questions which perplexed my father. These events can now be fitted into a much more precise timetable of late-glacial chronology so that his contribution becomes even more significant.

THE ST. LAWRENCE LOWLAND

James Walter Goldthwait

CONTENTS

Illustrations

[1]Numbers following entry are reference numbers to files of negatives in the Photographic Division, Geological Survey of Canada.

Chapter 1

THE LOWLAND AND ITS PROBLEMS

The introductory pages review some physiographic and geographic notes by early explorers of Canada including Cartier and Champlain. They also include a philosophical treatment of the work of early geologists as follows:

Discoveries in the realm of geological science, likewise, have made this St. Lawrence Lowland a classic field. Shell-bearing sands and clays from Beauport and Portneuf collected by Captain Bayfield a century ago, and their close association with raised beaches, terraces, and ice-shoved boulders, drew the attention of Sir Charles Lyell to this great river and the coast of Maritime Canada and Newfoundland as the modern theatre of action of that "drift agency", which British and American geologists of his time preferred to the preposterous "ice-sheets" of Louis Agassiz. Here, up and down the St. Lawrence, Sir William Dawson gathered the data with which he earnestly supported Lyell and his drift theory, confident from what he saw current-driven ice doing along the estuary that this was a true miniature picture of the drift phenomena of earlier ages. Meanwhile, one by one, Dawson's contemporaries, unaccustomed to a St. Lawrence environment, renounced the drift theory and became converts to Agassiz. Today all investigators agree that the records, far and wide, are those of a vast ice-sheet. Yet, as we come back to the St. Lawrence we find it necessary to consider again the possible role that drifting ice has played.

As successive observers have pushed farther and farther into the obscure and ever widening interior of geological records, following one clue or another in search of fuller and clearer evidence, the better understanding of some of the original problems has brought with it recognition of new problems as difficult as those that Lyell faced. Just as the exploration of Canada's great river by Champlain led him and his successors up its several branches, to north, west, and south, that they might learn the truth on every side, so today we must proceed as best we may, now following those traditional currents of thought that seem safest and most direct, and now coming unexpectedly upon uncharted places that call for caution or perhaps for bold choice. To pass some of these figurative rapids and shoals without going utterly astray, to make the portage when circumstances require it, and to return with a somewhat clearer yet incomplete picture of the past, is the most that anyone may hope to do. The field for future explorers is a rich one. . . . .

So, because of the diversity of its appeals, the St. Lawrence Lowland ranks high among Canadian physiographic provinces. The purpose of this memoir is to trace its successive landscape forms, starting far back in geological time, to follow the region through long eras of land sculpture, and then to analyse the changes that began with the uncovering of its surface by the ice-sheet, continued with the emergence from the sea, and ended with the establishment of the river in the path where we now find it.

Chapter II

THE DEVELOPMENT OF THE ROCK STRUCTURE

This chapter comprises a description of bedrock geology of the St. Lawrence Lowland with considerable local detail drawn from published reports and the author's personal observation. It is summarized as follows:

Summary

The invasion of the St. Lawrence Lowland by Palaeozoic seas, which began early in that era and continued almost to its close, left an accumulation of more than 3,000 feet of muds, sands, and limestones. Possibly the seas, at one time or another, reached far north and south of the area, but their extent and outline from period to period cannot be determined because evidence is fragmentary and varied.

Toward the close of the era, or perhaps at a much later date, large bodies of hot magma, possibly in the pipes of volcanoes, or perhaps wholly subterranean, were injected upward into the strata, to crystallize into the hard igneous masses of the modern Monteregian Hills. Small scraps of Devonian seafloor material, rich in fossils, miraculously preserved and exposed on St. Helen's Island, are of immeasurable value in working out the closing stages of Palaeozoic history.

Upheaval of the earth's crust, at times accompanied by cracking and displacement, has elevated the strata high above their original position without tilting them strongly anywhere, and without any folding or mashing such as characterizes the Appalachian region to the south.

From the time the rock structure emerged from the sea, at the close of the Palaeozoic era, until after the Glacial epoch, the surface of this region has been exposed, perhaps continuously, to erosion.

Chapter III

THE WEARING DOWN OF THE LOWLAND BEFORE THE GLACIAL PERIOD

General Statement

Erosion of the surface of the St. Lawrence Lowland must have commenced as soon as the Palaeozoic strata came above the sea, probably near the close of that era, and perhaps after the incursion of the Monteregian intrusions. During the two long eras that followed—the Mesozoic and the Cenozoic—this province seems to have remained always a land surface, exposed to subaerial decay; for it shows no signs of the younger strata. But it is uncertain how many times upwarping or faulting interrupted the wearing down of the land toward sea-level before the area became a low 'peneplain', in mid-Tertiary time.

This old plain now stands from 150 to 450 feet above the sea. When it was first raised from its original position, at the beginning of the Pliocene epoch, it was somewhat higher than today; for the deep valley which was cut by the river at that time reaches a point at Quebec 100 to 150 feet below present sea-level. During the Glacial period the great ice-sheet and the Champlain Sea modified the lowland surface by spreading deposits widely over it, but did not deface nor hide all of the older features.

Reconstruction of the Lowland

The contour map* shows only the broad features of the lowland. It was prepared as follows: on a set of 'one-mile' sheets of the Department of National Defense, northeast–southwest lines were drawn 6 miles apart. These served as the centre lines of 'strip profiles'. The vertical scale used (1 inch to 200 feet) is 26.4 times the horizontal. Against each line were projected the highest points shown by contours within a mile on either side of it. Thus each of the profiles represents accurately the skyline of a strip 2 miles wide and 4 miles apart. When the strip profiles were placed directly above each other, the features on them were easily matched. Twenty-five profiles were thus prepared for the area between Quebec and Montreal, and partial profiles east and west of those limits. . . . .

When completed, these profiles were studied, one by one, and positions noted on each, where the average height of the lowland is 150, 200, 250, 300, 350, 400, and 450 feet above sea-level. These positions were then carefully plotted on a small-scale map—the 1/250,000 sheets, or 'four-mile' maps, of the Department of Interior. Contours for the 50-foot intervals were then drawn through the plotted points, and the representation of the general surface of the lowland was complete. . . . .

Of course, the method of construction nearly eliminates valley features from the picture, as was the intention, although in a few places a strip even 2 miles wide may chance to pass so close to a stream valley as to represent the surface below normal height . . . . This method supplies boundaries for the St. Lawrence Lowland based upon the broader characteristics instead of on a detail such as the limits of the late-Glacial sea. Inasmuch as the lowland originated far back in Tertiary time, whereas the Champlain submergence is only a late incident in its long history, with relatively delicate, often obscure shoreline, these more ancient boundaries are preferable.

General Form and Boundaries of the Lowland

This is a descriptive section.

Origin of the Broad Undulations

Under this heading discussion of some irregularities of the Lowland plain led to a statement of possible Pliocene movements and Pleistocene glacial influences on topography:

. . . . If Pliocene displacements disturbed the continuity of the plain itself, these were comparatively slight, and their scarps seem to have been so reduced by later weathering and glacial scour, or so hidden by Pleistocene deposits, that they cannot be identified. Warpings during the Ice Age may have occurred not only once but several times. We have a clear record here of only the final emergence from the Champlain Sea, after the ice had withdrawn. This movement is assumed to have been caused by recovery from ice load; but it has not

**This is the map referred to in the Table of Contents. It is filed with the other illustrations at the Geological Survey of Canada (Editor).*

been proved. Even if it is the case, it seems unlikely that the upwarp would be wholly free from local anomalies; it could hardly restore all parts of the area to the same positions they held before the ice-load was applied.

Development of Rock Gorges and Channels

A discussion of the trace of the preglacial channel of the St. Lawrence River as seen by several authors reveals that many parts are poorly known and that:

. . . . the modern St. Lawrence River, on the surface of the drift plain, is nowhere directly over the deepest place in the buried rock floor.

Further:

At Quebec, the St. Lawrence occupies a deep valley which it seems surely to have cut in rock before the Glacial period. Its floor is now about 100 feet below sea-level (150 feet, for a short distance, directly opposite the city), and nearly 500 feet below the lowland surface, which stands here at an elevation of about 350 feet. From this it appears that the late-Tertiary uplifts elevated the lowland surface at Quebec at least 500 feet, so that it stood at least 100 feet higher than now, while the river excavated the deep gorge in its rocky floor. During the last glaciation, there can have been no pronounced overdeepening of this gorge by glacial erosion, for ice movement was transverse to it. Nor have we any reason to suppose it during any earlier glacial epoch. How much glacial till was spread in the gorge we do not know. Just north of Quebec city, and connected with the St. Lawrence Valley at both ends, is a valley occupied by St. Charles River, with a wide, flat floor that stands from 50 to 100 feet above present sea-level, and so only 200 feet higher than the other. There is no obvious relation between these two valleys, so far as can be judged from their present floors; but as the bedrock topography in both places is largely hidden by drift, and not disclosed by borings or well records, their relationship is a mere matter of speculation. One thing alone seems reasonably sure: that the Quebec gorge antedates the Ice Age. It is not possible to say whether the river originally flowed eastward or westward through it.

According to Johnston and other writers, an old, pre-Glacial valley of Ottawa River is cut in rock west of the city of Ottawa. The river, still occupying its preglacial path, in spite of minor irregularities from glacial scour and deposits, from Pembroke down to the foot of Lake Deschênes, turns there from its old course, where the rock valley is blocked by drift, and flows northeastward in a shallow channel across ledges at Deschênes and Chaudière rapids and past the city of Ottawa, till it comes to the old valley of the Gatineau, which it follows thence to Montreal (Cooke, 1929, p. 116). The abrupt change of direction and of cross-section of the Ottawa, where it leaves Lake Deschênes, the presence of rapids, and the low clay-covered tract in line with the lake, southeast of Lake Deschênes, all favour this interpretation; but we lack direct proof of it, such as well records. What course the buried valley pursues from here is a matter of speculation. In any case, if we must judge from surface contours, it is wide and has gentle side slopes, and it is not at all gorge-like.

Other Inequalities on the Rock Floor

Consideration of the thickness of glacial and marine sediments in parts of the Lowland region, in particular of the Ottawa area, and consideration of the author's observations near the St. Lawrence where Champlain Sea had its maximum level at 331 feet a.s.l., led to an interpretation of this region as one . . . . where the Champlain Sea was shallow and short lived . . . . *and where* . . . . The surface lies between 350 and 450 feet, too high, it seems, to receive deposits of the Champlain Sea, whose highest beach, with shells at Maitland, is 331 feet. . . .

For this same area, although bedrock surfaces, where exposed, exhibit some irregularities:

. . . . Swells and sags in the rock floor slope gently in all directions as if they registered almost complete reduction of the surfaces in preglacial time; followed by light or very moderate glacial scour . . . The eastern part of the St. Lawrence Lowland, as far as Quebec, is so uniformly smoothed off by surface deposits, up to the very border of the Appalachian Highlands, that little can be said about the rock surface. Rivers and their branches, all through this district, have cut trench-like valleys 10, 20, or 30 feet deep through silts, and clays, into till, and more rarely to the rock itself. The contours over the lowland seem nowhere to express influence of rock beneath.

Inliers of Precambrian Rock

With reference to Rigaud Mountain (700 feet) 10 miles farther west (*of Montreal*), *Goldthwait wrote*: . . . It seems more probable that this inlier is a residual mountain that stood well above the peneplain of early Palaeozoic time, when the sea advanced and spread its sediments on and around it; so that after the lowland area had been raised and the soft strata were stripped away from its summit and sides the old mountain was once more revealed. Glaciation has left only a thin mantle of drift on its scrubbed slopes, and the Champlain Sea has built a most extraordinary series of cobblestone beach ridges high up on its north side, called the Devil's Garden. . . .

The Monteregian Hills

This is a descriptive passage.

Summary

The flatness of the St. Lawrence Lowland, as contrasted with the relief of the adjoining regions, is to be attributed to several circumstances. The strata that compose it, originally laid down nearly horizontally, on the floor of the Palaeozoic seas, seem to have emerged, at the end of that era, without any extensive folding or block-faulting . . . .

. . . On the whole, the spread of ground moraine by the ice-sheet, and in lesser amount the deposition of clays and sands by the late-Glacial sea, has tended to smooth the lowland area. Of all the processes that have contributed to make this region flat, however, the part played by the late-Glacial sea must be reckoned small, with effects seen only in certain districts, particularly on the plains around Montreal and Ottawa.

Chapter IV

OCCUPATION OF THE LOWLAND BY THE ICE-SHEET

Introduction

The St. Lawrence Lowland lies halfway between the Quebec centre of the last ice-sheet and its terminal moraine on Long Island and Nantucket, trending almost straight across the path taken by ice currents. Movement here was approximately southward on a wide front. The records of it come chiefly from the Laurentian and Appalachian Highlands, north and south of the St. Lawrence Lowland; for the lowland rocks are generally hidden by glacial deposits, and even where exposed are too soft either to bear good glacial scratches and grooves or to furnish detritus whose sources and paths can be determined. At the close of the Glacial period, when the edge of the ice-sheet was melting northward, a wide lobe developed west of Montreal, toward Lake Ontario. But the flow of ice over the lowland in general was much more uniform than in the Appalachian Highlands to the south, where two directions are indicated (MacKay, 1921, pp. 51–56) . . . .

The presence of many sure signs of marine submergence, in close association with the marks of ice, made the St. Lawrence Valley an area where the drift theory of Lyell (1842, pp. 135–144) found earnest advocates. But we can no longer accept the view of Sir William Dawson (1893) that transported boulders, till, and grooved ledges indicate wholesale submergence of eastern Canada by the sea, and current-driven ice grinding the seafloor and transporting debris while the land slowly sank and rose again. The upper limits of submergence have been found, hardly 600 feet above the sea, and many positive evidences of land-ice have been fully recognized above that. Nor can we agree with Robert Chalmers (1898, pp. 25–54), that a Laurentian ice-sheet moved into this St. Lawrence Lowland from the north and an Appalachian ice-sheet from the south, toward the close of the Glacial period. Modern field studies, almost without exception, disclose one great movement from the Quebec centre southward and southeastward across New England, and none in the opposite direction (MacKay, 1921, pp. 55–56).

Though always expecting to find evidence of glacial epochs earlier than the last one, in this part of North America, to duplicate those in the Upper Mississippi Valley and Great Lakes regions, investigators in Canada and New England thus far have been unsuccessful. There are scant signs, if any, of more than one occupation of this region by the ice. All suspected records of earlier glaciation and of interglacial epochs seem more satisfactorily accounted for by oscillations of the ice border during final retreat. Eastern Canada and New England may have been occupied continuously by the ice while the Great Lakes region experienced two or more glaciations.

Glacial Erosion

In the St. Lawrence Lowland it is particularly hard to discover whether glacial erosion was severe or light. Smooth slopes and weak rocks afforded easy movement without that wholesale plucking of blocks and scrubbing of ledges that marked the rougher highlands to north and south. The residual soils that accumulated during pre-Glacial time seem to have been picked up and swept away pretty generally here as through New England. But there is little to indicate whether the ice wore down the underlying fresh rock deeply . . . .

. . . Vigorous ice movement against Mount Royal appears to have steepened the eastern slope, stripping away the limestone from around that flank of the hard volcanic plug, while sparing it on the more protected western side. . . . Somewhat similar asymmetry appears on other Monteregian Hills . . . .

Scratches and grooves alone do not indicate whether the ice moved one way or the opposite. This partly accounts for Chalmers' idea of a northward moving Appalachian ice-sheet. But where ledges show good contrast between strongly scrubbed surfaces that opposed the ice and less scoured, rougher surfaces that slope away from it or lie in the shelter of projections of the ledge, the record is clear. Dawson (1893, p. 198) found features of this sort at Mile End quarry, where hard dykes of trap protected the limestone from scour on their southwest sides.

In general the courses of striae over this St. Lawrence Lowland imply a rather orderly advance of ice currents on a wide front, from the Quebec centre of glaciation, east or southeast of James Bay, southward into New England and New York. Discordant sets of scratches, common in the Appalachian Highlands, are open to more than one interpretation. It seems probable that the most abundantly registered movements are those of the closing stages of glaciation, when the edge of the ice-sheet was melting back across the lowland though the mass still had active motion. That it was not stagnant in this closing stage is suggested by the records of an active lobe in the Ontario basin, and by many instances of overridden lake beds in northern New England and the Chaudière valley (Antevs, 1928, pp. 119–127; MacKay, 1921, p. 54).

Somewhat earlier, during the climax of glaciation, the ice may have stood stagnant over the St. Lawrence region, moving only in the peripheral zone, in New England and Nova Scotia, . . . when the ice border at last retired, with oscillations, northward across the lowland, movement was evidently resumed and most earlier records were probably wiped out. As the last movement south and east of Quebec may have been southeastward (MacKay, 1921, pp. 51–56), while in the Montreal district the ice moved strongly toward the southwest, and in the intermediate district around Sherbrooke toward the south, there is indication of a broad lobe occupying this part of the lowland, with its axis about midway between Montreal and Quebec. Here seems to be the district where final removal of the ice barrier allowed the late-glacial sea to invade Champlain Valley and the upper St. Lawrence. And here is the place where the reconstructed waterplane of this sea, upwarped into a broad dome, reaches its summit altitude. As topographic influence can scarcely be thought to have caused this divergent movement, it may have come in response to localization of snowfall, at this stage, around a centre that lay somewhat back of the margin of the ice-sheet, and northeast of Montreal.

Finally, when the ice-sheet had retired and the sea had occupied the lowland, there was free movement of icebergs and pack ice up or down the estuary. The complex criss-cross striae noted by Dawson (1893, pp. 43–44) and Chalmers (1898, pp. 51–52) at Montreal, Murray Bay, and other places probably represent the changeable movements of floating ice.

Dispersion of Stones

. . . In order to discover how rapidly the percentage of Laurentian rocks in the drift falls off with increasing distance from the source, counts were made of these pebbles in gravel deposits at twenty-five or thirty localities . . . .

. . . the falling off in Precambrian percentage is fairly uniform and very rapid. From 100 per cent at the source, it drops to about 10 per cent in the first 10 or 12 miles, and 5 per cent at about 20 miles, beyond which, to the southern or distal border of the lowland, the percentage of stones from the Laurentians remains virtually unchanged, commonly from 2 to 5 per cent. This is rather surprising, in view of the fact that these stones are much more resistant than the rocks across which they travelled. Comparatively few stones appear to have moved more than a few miles from their sources before they were deposited or were worn and crushed to rock flour, or diluted by the accession of stony material of the lowland types of rock all along the way.

Fragments of volcanic rocks from the igneous mass of Mount Royal and the other Monteregian Hills are found at points southwest of their sources, according to Dawson (1893, p. 198). But it is not easy to work out the dispersion of these stones in detail, for they are scarce, and the till is generally concealed by marine clay. Moreover, dykes of similar rock occur at considerable distances from the volcanic plugs, and it is doubtful whether even a careful assembling of available information would show distinct fan-shaped areas of dispersion or 'boulder trains' from the several sources.

The Ground Moraine

The mantle of boulder clay or till that the ice-sheet spread over the bedrock almost everywhere is a compact, tough mixture of silt, clay, and stones. The finer part or matrix that encloses the stones consists chiefly of particles of fresh rock or 'rock flour', produced by the crushing and grinding of fragments against one another and against ledges, as they were dragged along in the glacier. . . . . Silt predominates over both sand and clay; but the texture of the matrix varies a good deal according to the kind of rock in the district from which the till has been derived, or on which it lies. Crystalline rocks and stones make rather sandy till, whereas limestones and shales afford a fair amount of clay. The stones are of all sizes and shapes, including many that seem to be merely broken fragments of ledge unaltered by transportation unless by splitting, and many that seem to have been rounded by water wear before the ice finally picked them up. A few only possess that curious subangular form, with partly rounded edges and corners but well planed and striated sides, that registers ice wear. The best in this respect are compact, fine-textured rocks such as the harder limestones, fine quartzites, and trap. Cobbles, blocks, and boulders may be abundant in the till near areas of massive rocks that split only into large pieces too strong to break again during transportation. They are commonly as plentiful underground as are the fieldstones at the surface. From the stone counts discussed above, it is evident that the great bulk of the till moved only 5 or 10 miles from its source before it was laid down. . . . .

An extraordinarily uniform, thin mantle of till occupies the western part of the St. Lawrence Lowland, between Ottawa, Smith's Falls, Merrickville, and Brockville. For many square miles the rock shows in roadside ditches less than 2 feet deep, and continuously mile after mile. It seems incredible that the continental glacier could have moved hundreds of miles across the Laurentian Highlands and over this district, for any considerable length of time, without laying down a thicker mantle of till than this. Perhaps we have overestimated the depth of glacial scour in the Laurentian area, whose rolling surface may be almost wholly that of the old paleoplain of Cambrian time. In that case, the ice perhaps did not bring much debris into the lowland from that region. Or, perhaps, ice movement at all stages was confined to a marginal zone, so that drift accumulation and transportation were not more long continued in the central areas of the glaciated region than in the outermost parts. In any case it seems certain that the ice slipped easily forward across this flat limestone floor, and that it was relatively clean.

Weathering in this region has struck down into the till only 1 or 2 feet,—much less than in southwestern Ontario. Probably this is due to the lingering of the great Ontario ice lobe on the lowland long after it had uncovered the higher ground to the south, and to the subsequent submergence by the waters of the glacial lakes and the Champlain Sea, for a period of several thousand years (Keele and Cole, 1922, pp. 24–25).

Locally, in this region, the till consists in part of seafloor material reworked by the ice, as if during oscillations of the ice border in the Champlain Sea, during its withdrawal. Lyell, Dawson, Spencer, DeGeer, Coleman, Johnston, Stansfield, and others have noted signs like these at widely separate localities, but all within the Champlain Sea area. Masses of stratified clays and sands included in the till near Ottawa, for example, are thought to have been incorporated while frozen to the ice-sheet (Johnston, 1917, pp. 13–14)*. Abundant shell fragments in the till of Montreal, Murray Bay, and other places on the lower St. Lawrence gave Dawson support for his view that drifting, floating ice, rather than glacial land-ice, had operated here

**Johnston, however, did not infer that the sediments were marine; indeed in the same reference (Johnston, 1917, pp. 13–14) at p. 14, line 14–16, he stated: The mode of origin of the till as ground moraine explains the absence of stratification and the lack of marine fossils (N. R. Gadd).*

(Dawson, 1893, p. 38). Sections showing till on top of crumpled deposits of marine or lacustrine origin still further support the view that the border of the last ice-sheet was oscillating back and forth on the old seafloor, in the St. Lawrence Lowland, when it withdrew.[1]. . . .

Drumlins

The southwestern part of the lowland, around Brockville, Prescott, and Cornwall, is characterized by elongated ridges of till and shorter, more symmetrical hills of elliptical form, which are typical drumlins. Their axes run in the direction of flow of the Ontario ice-lobe, from northeast to southwest. . . . This kind of landscape continues far southward in New York state past Canton, but seems to fade away east of Cornwall, around Lake St. Francis. As in other drumlin regions, the conditions that favoured growth seem to include: (a) rather a smooth floor; (b) till, rather rich in clay; (c) a nicely adjusted forward motion of the ice and downward pressure, allowing both for the accumulation of the till and the formation of the drumlins.

Moraines

East of Hawkesbury, along the line of the Canadian Pacific Railway, is a belt of knobs and hollows of glacial drift that resembles a moraine. It has been described as continuing southwesterly across Ontario past Alexandria to Cornwall (Johnston, 1916, p. 3). . . .

Summary

The Quebec ice-sheet still covered the St. Lawrence Lowland after it had retired from New England and the Great Lakes region. All records found in the St. Lawrence Lowland may date from this very late stage in the Glacial period. When most extensive, this ice had been at least 7,000 feet thick at Montreal. If it spread and retreated more than once, there is no proof of it either here or in New England. Glacial grooves and striae generally fall into one set, or can be referred to floating ice on the late-Glacial sea or St. Lawrence River. Dispersion of stones tells the same story. Oscillations of the ice border, registered in northern Vermont and Chaudière Valley, occurred here also, churning up shell-bearing seafloor clays and mixing them with the till. . . .

Chapter V

THE CHAMPLAIN SEA

Introduction

The withdrawal of the edge of the ice-sheet from northern New England and New York toward the St. Lawrence Lowland was probably slow, and attended by repeated halts and readvances (Antevs, 1928, p. 127; MacKay, 1921, p. 55; Taylor, 1924). Broad lobes that developed over the Ontario and Champlain basins as the ice thinned left poor records on the St. Lawrence Lowland, but built several moraines on the northwest side of the Adirondacks and account for ice border drainage channels and cobble deposits on the northeast side.

[1]Coleman (1932) has insisted that the marine deposits of the St. Lawrence are wholly interglacial; but since through the region very generally the marine strata overlie the till, and beaches and offshore deposits retain their delicate details of form, as fresh as the original, this view seems to me unworthy of serious consideration.

South of these Ontarian and Champlain lobes, as they withdrew, were lakes that drained southward: Lake Iroquois on the west discharging past Rome down Mohawk Valley, and Lake Vermont on the east with outlet at Coveville directly into the Hudson. Lake Iroquois expanded northeastward with ice retreat around the corner of the Adirondack highlands, where deltas now mark a constant level, until overflow came through a broad saddle south of Covey Hill on the Canadian Boundary. The lowering effect of this new outlet on the level of the lake was perhaps only slight (Fairchild, 1916, p. 242). At any rate, the stage was probably not long lived, for another half-mile of marginal retreat exposed the northern slope of Covey Hill and the lowland beyond, and allowed the Iroquois waters to escape at lower and lower levels to the Vermont side and permit the lake level to drop about 300 feet. Stratified sands without beach form, at altitudes around 740 feet on the northeast and northwest sides of Covey Hill, match strong wave-built beaches farther south in both basins, and mark this stage of the combined Ontario–Champlain waters, called glacial Lake St. Lawrence.

Meanwhile, in Champlain Valley, glacial Lake Vermont had been expanding northward, with the ice-sheet serving as a dam on the highlands to the northeast and preventing connection with sea-level waters that were working up St. Lawrence Valley past Quebec. While Vermont and Iroquois waters united to form Lake St. Lawrence, this dam still held. Indeed, freshwater conditions were maintained until the ice margin in the western district had retired to the line of Ottawa River between Renfrew and Montreal (Antevs, 1925, pp. 64–65; 1928, pp. 137–164; 1931, p. 12). Northeastward, escape of Lake St. Lawrence came later, when irregular ice retreat north of the Vermont line uncovered Sutton and Richmond. The waters slowly dropped to sea-level, becoming marine as soon as the lower ground was cleared. This was the "Champlain Sea".

All this time, according to studies of Chapman (1933), the St. Lawrence region had stood immovable. But after sea-level had been attained and clearly registered by shore features, widespread uplift occurred, warping the parallel (and hitherto horizontal) waterplanes of Lakes Vermont and St. Lawrence and the Champlain Sea into southward slanting positions. Their present parallelism can only be interpreted in that way.

Later stages of crustal stability, of long duration, alternating with short intervals of renewed uplifting, are registered both around Lake Champlain and in the St. Lawrence Lowland by watermarks whose strength calls for considerable lapse of time, and whose inclinations are gentler than those of the earlier upwarped planes. There seem to be at least three of these lower stages registered in our area. Though hard to reconcile with widely favoured doctrines of isostacy, the presence of these water planes cannot easily be doubted. Uplift of the St. Lawrence region seems to have been markedly intermittent.

Glacial Lake St. Lawrence

Following the rule of priority, the name Lake St. Lawrence will be used here for that body of fresh water that occupied the Ontario basin, the Champlain basin, and adjoining parts of the St. Lawrence Lowland after the lowering of Lake Iroquois but before the marine invasion. The name Lake Frontenac, recently employed by Antevs, seems to us inappropriate.[1]

[1]As first used, "Lake Frontenac" meant the post-Iroquois waters in the Ontario basin, with escape around the northern corner of the Adirondacks near Covey Hill to glacial Lake Vermont near West Chazy (Taylor, F. B., 1915, pp. 325, 445). But this stage on the Ontario side had already been called "Lake Emmons" by Fairchild (Chadwick, 1923, p. 504). Taylor chose the name Frontenac for this supposedly short stage because the ice border at that time "rested upon the Frontenac axis of Precambrian rocks" (Taylor, 1915, p. 445). Taylor seems not to have considered the later spread far to the east and north. Lake St. Lawrence was first named and defined by Upham, in 1895 (Upham, 1895, p. 178). Later, it was called "Lake Vermont–New York" (Fairchild, H. L.), "expanded Lake Vermont" (Chadwick, 1923, pp. 504, 506), and Antevs used the name "Frontenac" in a slightly different sense from Taylor and the name "Frontenac–Vermont" for this later and more extensive lake, the Lake St. Lawrence of Upham (Antevs, 1928, p. 97), as if to distinguish the later stage from the earlier one in the Ontario basin.

On the western side of the Adirondacks, shorelines have been traced interruptedly, and without securing accurate altitudes, from Covey Hill and the Canadian Boundary down to Watertown, Oswego, and Rome, New York. Authorities disagree as regards their identity and correlation, the slant of the waterplanes, and their relations to outlets.[1] It is uncertain, even, which shoreline marks the westward extension of the Champlain Sea toward Lake Ontario. But on the eastern side of the Adirondacks, Chapman has recently made and plotted many measurements by which he correlates the stage that we here call Lake St. Lawrence with his Fort Ann stage of glacial Lake Vermont. This shoreline is strong on both sides of Lake Champlain, but weak northwest of it, where it swings around Covey Hill near 740 feet elevation (Chapman, 1933). Fairchild (1916, pp. 240, 241; 1918, pp. 55 et seq.), and Taylor (1924, fig. 1; p. 666), thought that it marked the upper limit of invasion by the Champlain Sea; but the writer's tracing of the marine limit up the St. Lawrence Valley from Gaspé and Quebec to Lake Champlain (Goldthwait, 1913, pp. 122–126 and Plate A 10), and Chapman's recent work there, support the opinion that the marine records reach up only to 523 feet at Covey Hill and that all higher records are of fresh water. Chapman's studies indicate that the drop from the Fort Ann stage of Lake St. Lawrence to the Champlain marine stage came after a long interval of crustal stability; for the two tilted planes, as well as the higher Ft. Edward waterplane, are parallel with each other and to the still earlier Coveville stage of Lake Vermont.

All observers have commented on the weakness of the 740-foot watermark on Covey Hill, as contrasted with the very strong beaches from 523 feet down (Woodworth, 1905, p. 174; Goldthwait, 1913, pp. 124, 125; Fairchild, 1916, pp. 240–241, and 1918, pp. 19, 55–56). Fairchild's explanation of this is not satisfactory. Conditions on the long slope of till north of Covey Hill seem as favourable for a good record at 740 feet as at 523 feet. The greater strength of record on the 740-foot waterplane farther south, in glacial Lake Champlain, is consistent with Chapman's view that this Fort Ann stage began when the ice border stood near Cadyville, New York and Milton, Vermont, 25 or 30 miles south of Covey Hill, while, at the same time, the weakness of the 740-foot shoreline at Covey Hill suggests that the lowering of Lake St. Lawrence to sea-level came very soon after the ice border had retired north of the International Boundary (Chapman, 1933).

This view is strengthened by discovery of the position of the ice edge at the close of Lake St. Lawrence, ingeniously reconstructed by studies of fresh and marine sediments between Ottawa and Montreal (Antevs, 1925, pp. 64–66 and Plate 27; 1928, pp. 96–102, 137). Typical varved clays are taken to represent fresh proglacial lakes such as Lake St. Lawrence, massive un-laminated clays, with or without seashells, to represent seafloor deposits, and clays of intermediate characteristics, sometimes carrying stunted forms of shellfish, to represent brackish water deposits during transition from lake to sea, or, in proper situations, sea-level waters half-freshened by meltwater from the ice-sheet. By noting which sort of deposit was laid first, on the floor of rock or till, at each place, and which sort lies above it, Antevs has been able to follow the record of Lake St. Lawrence northward, and to locate the line where the ice edge stood at the close of that stage, when the sea replaced it. Unfortunately, the number of localities where such sections have been found is rather limited. Also, as Antevs has pointed out, it is not everywhere possible to say whether brackish water means a mingling of the incoming sea with the subsiding lake or a meltwater influence below sea-level. As most of the localities of brackish water deposits lie well out in the centre of the broad basin, and their relationships to the other types are such as to reduce the probability of meltwater influence, Antevs' line for the position of the ice border at the beginning of the marine stage is

[1]Cf. Fairchild, (1916) Plate. 11, and (1918) Plate 11, with G. H. Chadwick, (1920) pp. 50–51 and (1923) pp. 503–504, also, Taylor, 1915, p. 445.

rather definitely fixed. It runs approximately through Renfew, Quyon, Ottawa, Hawkesbury, and at least 8 miles south of Montreal. The reconstruction is supported also by the fact that this ice border runs nearly east and west, whereas the striae follow a general southerly course. The line could have been drawn farther south of Montreal and nearer Covey Hill, as the only record in that district, a clay section at Delson, indicates merely that the sea had already reached that point when the ice first uncovered it (Antevs, 1928, p. 137). We have drawn the line farther south than Antevs had it, east of Hawkesbury, partly because this is consistent with the weakness of the 740-foot shoreline at Covey Hill, but more especially because the strongly southwestward ice movement at Montreal seems to call for a curve in the ice border. Farther east, the line as we have drawn it departs widely from the line shown by Antevs, partly to conform better with striae requirements, and partly to keep the ice border down on ground low enough to allow the sea in along the line of the marine limit, which we have traced from Gaspé past Quebec to the head of Lake Champlain. As already mentioned (p. 46 MS) striae imply that, instead of a straight east–west ice border, a broad, active lobe occupied the district from Montreal around through Sherbrooke and Chaudière Valley to Quebec city during the closing stage of ice recession. The sea could hardly invade Champlain Valley from this side until this lobe, in its retreat, had uncovered that part of the Appalachian Highlands which stands near the marine limit, with present altitude of 500 to 600 feet.[1] There is no evidence of marine invasion as early as the time when the ice border stood along the Canadian Pacific railway east of Sherbrooke, where Antevs (1925, Plate 27, pp. 64–66; and 1928, p. 96) placed it.[2]

Spillway channels or other records of the escaping waters of Lake St. Lawrence, where they passed around or broke through the ice barrier northeast of the Champlain Valley, would be expected. Rapid reconnaissance of this district by Woodworth (1905, p. 198) and the writer (1914, p. 357) were without definite result. Chapman points out that most of the valleys and saddles between St. Albans and Lake Magog on the one hand and Brome Lake and Yamaska River on the other are too high to afford escape for waters at the Fort Ann (Lake St. Lawrence) level. His search for outlet channels in the uneven slate country bordering St. Lawrence Valley between Fort Ann and marine waterplanes was without positive result. But in the pass that lies nearest to Lake Champlain and lowest, Missisquoi Valley between St. Albans and Richford, on the International Boundary, he reports kames and other ice contact deposits and clays as occurring abundantly up to the marine level though absent above it. His conclusion is, that while ice still occupied Missisquoi Valley, Lake St. Lawrence fell, discharging first perhaps through fissured and rotten ice rather than by means of normal river channels. The lowering of level more than 200 feet seems to have been slow and interrupted, judging from transitional beaches in the zone between the two planes (Chapman, 1932).

Evidence of oscillations of the ice border in Chaudière Valley, in northern Vermont and the eastern townships, and at scattered points in St. Lawrence Valley have already been reviewed (p. 46 MS). The probability of similar, later readvances of the ice edge during the Lake St. Lawrence and Champlain marine stages cannot be overlooked, and involves serious consequences. This was long ago sensed though rejected, by Woodworth (1905, p. 202). A second Lake St. Lawrence and a second Champlain Sea might be produced by readvance and later recession in the critical zone between Montreal and the Vermont highlands, or as many more stages as there were readvances there. However, neither the shoreline features of the

[1]Though he had much less detailed evidence, Upham used the same argument nearly 40 years ago. He thought, however, that this barrier broke near Quebec, and that a seperate Appalachian ice field remained south of the estuary (Upham, 1895, pp. 16–18 and Plate 1).

[2]To account for marine invasion past Quebec at much higher levels than our marine limit, Antevs covers the unwatermarked surface with thin ice, and connects eastward with alleged shorelines near Gaspé peninsula far above our marine limit. The "beach" at Ste. Flavie (Coleman, 1922a, p. 12; Antevs, 1925, p. 66) is no beach at all, but merely the upper limit of Laurentian boulders.

Covey Hill district and the district northeast of Lake Champlain nor the sections of sediment on the lowland thus far seen require complications of this sort. At first glance, the very complex record of submergence in the Ottawa district, interpreted by Antevs (1928, pp. 97–102; and 1931, pp. 10–11) to include two stages of Champlain marine submergence separated by one of emergence—the "Ottawa land stage"—makes the idea of a glacial readvance in the eastern region seem attractive; but although this would account for two marine stages, it would fail to account for the LOWERED WATER LEVEL of the intervening, Ottawa land stage. Rather, the stage between the two marine stages would be a second Lake St. Lawrence with HIGHER water level. The idea of readvances, therefore, not only lacks support from field evidence but fails to serve present needs.

If Antevs has correctly interpreted the bottommost sediments of the Ottawa region, Lake St. Lawrence followed the receding ice front beyond Ottawa and Hawkesbury, where varves show that fresh water stood for 50 to 100 years (Antevs, 1925, p. 64; 1928, pp. 96–102). This encourages the view that the lake reached the edge of the crystalline highlands north of Ottawa River, although probably not remaining long before the water dropped to sea-level. Is the water-plane of Lake St. Lawrence registered anywhere north of Ottawa? The 690-foot sand deposit north of Kingsmere, hitherto assumed to be marine because it is the highest and oldest watermark,[1] lies on or somewhat below the Lake St. Lawrence water-plane. It is a small, inconspicuous plain of sand, in a situation unfavourable for wave work; it lacks good topographic character; the absence of gravel in it suggests that it was formed in shallow water rather than at the water's edge; and the marine shells in sands and clays, down the slope, are not known to occur above 510 feet. On Rigaud Mountain, about 70 miles east of Ottawa, the problem is much the same. The strongly built cobble beaches at the Devil's Garden (370 to 550 feet) seem surely marine; but the small, isolated yet definite beach at 671 feet found by Johnston (1916, p. 6) may well be the mark of Lake St. Lawrence. That, at least, is the writer's preference, as it seems to accord better with the record of deep-water sediments.

Of all strange phenomena connected with Lake St. Lawrence, the whale bones discovered at Smith's Falls are the most disconcerting. These were found in 1882, in a deep sand pit in an outwash plain or kame plain some 100 yards out from its ice contact. Two vertebrae and a rib were recovered, and some associated marine shells. Its situation in a deposit built so close to the edge of the ice-sheet seems odd, but was not questioned at the time (Coleman, 1901, pp. 215–227). Curiosity was aroused in 1925, when it was realized that Smiths Falls lies in the district believed to have been occupied by Lake St. Lawrence when the ice front first uncovered it, and not to have been occupied by the Champlain Sea until the ice had retired some 25 miles farther north. The varved clays beneath the marine clays at Ottawa indicated that (Antevs, 1925, pp. 64–73, and Fig. 27). With this obvious contradiction in mind, a field conference was arranged with Antevs at Smith's Falls in 1926. Questions raised and yet not fully answered are: (1) Was this whale deposited in a marine beach that lies on top of the ice-contact deposit? What is left of the deposit after extensive excavations appears to deny this possibility. (2) Are the varved clays at the base of the Ottawa section Champlain seafloor clays freshened by meltwater, and not those of Lake St. Lawrence? Neither the situation at Ottawa in a central position in the lowland, nor the occurrence of typical saltwater clays in other places of similar situation supports such a view. (3) Were this whale skeleton and associated shells picked up by the ice-sheet while it was advancing on a seafloor (here or in the Hudson Bay region) during an earlier stage, and finally deposited by ice melting in Lake St. Lawrence? This opinion was expressed by J. W. Spencer in an unpublished manuscript entitled "New Discovery" (undated, seen in 1928). Quite independently it also occurred to Antevs and to the writer in

[1]DeGeer, 1892, p. 469; Johnston, 1916, pp. 5–6; Fairchild, 1918, p. 215; Antevs, 1928, p. 101.

1926 as an explanation. Before casting it away, we may observe that other ideas as speculative as this have occasionally turned out to be correct,—for example, Louis Agassiz's theory of continental ice-sheets.

Some of these problems of Lake St. Lawrence can no doubt be cleared by further study, but its beaches, both in New York state and Ontario, must first be traced.

The Champlain Sea

The outline of the Champlain Sea during its greatest transgression is worked out from observation of the beaches that it built at favourable places along its shoreline. But the distinction between these and the higher lake beaches is by no means simple. Tracing such a water-plane far seaward, as is done, for example, in following the 'highest marine' beach past Quebec to Gaspé, does not in itself guarantee marine origin, as is known from conspicuously high lake records on Cape Cod, Massachusetts, and Long Island Sound. Association of the beaches with clays of undoubted marine origin, judging from their massive, unlaminated structure, plasticity, and habit of breaking up into irregular fragments when dry, has little determinative value, because the clays occupy central, flat, deep-water areas, remote from both the marine and the freshwater beaches, which lie on higher ground and steeper slopes. Subarctic shells, indeed, prove certain beaches to be of late-Glacial marine origin; but this good evidence is rarely found in the earliest, uppermost beaches of the marine series, and by no means everywhere in the lower ones. Mere absence of shells is no sign of freshwater origin, for freshwater shells are nowhere found in the lake beaches. Only by accurately measuring the elevations of all beaches, by properly correlating and reconstructing the warped water-planes they mark, and by drawing such inferences as seem safe from the fossil record and the relation of the shorelines to open sea, on the one hand, or to deserted lake outlets on the other, may we separate the marine from those of lacustrine origin. Considerable uncertainty surrounds the identification of the highest marine shoreline west of Montreal, both up Ottawa River and toward Lake Ontario. From Montreal and Lake Champlain down the St. Lawrence to Quebec and Gaspé, the determination is more satisfactory and has been checked by various investigators since it was first made in 1912. . . . .

This rather lightly registered watermark of the St. Lawrence sector of the Champlain Sea compares favourably, at least, with those found along the Atlantic coast from New Brunswick and Nova Scotia down to eastern Massachusetts. There, watermarks are mysteriously absent in places where conditions would seem to be ideal, as for example on drumlin islands well offshore, and where recent studies almost force the conclusion that for a period of at least 2,000 years no crustal movement affected that coast.[1] . . . .

The Champlain Sea, thus reconstructed, reaches up the St. Lawrence as an estuary that is very narrow at Quebec but widens rapidly to a maximum of 75 miles, near Montreal, where it connects southward with the marine area mapped by Chapman around Lake Champlain. Thence westward it extends up the St. Lawrence almost but not quite to Lake Ontario, and northwestward up the Ottawa to Renfrew and Pembroke. The failure of this late-Glacial sea to enter the Ontario basin is inferred partly from the position and westward slant of the reconstructed water-plane and partly from the well known change, near Brockville, from typical marine clays to typically laminated freshwater clays beyond. The upper limit of marine submergence is least well determined up Ottawa River. . . . .

What rise of sea-level, if any, took place during the first marine stage, before upwarping and emergence began, is a question on which we have as yet no direct evidence. Shrinkage of

[1] R. J. Lougee's study of Connecticut Valley water-planes, as yet unpublished, seems to require long stability of the Maine coast before its emergence.

the ice-sheet was attended by return of meltwater to the sea in amounts which, from first to last, may have raised the sea-level some 200 or 300 feet (Antevs, 1928, pp. 81–82). Half of the ice-sheet had perhaps already gone by the time the Champlain Sea entered the St. Lawrence, and thus half of the rise of sea-level had perhaps been attained. The distance to which the ice margin retired, north of the St. Lawrence, before upwarping took place is not known. Tracing of the marine plane northward has been difficult and problematical. The delicacy of watermarks at the marine limit suggests that sea-level rose very little at this time,—not enough to develop cliffs and strong beaches such as those commonly encountered at later, lower stages. This contrast, however, is due in large part to the fact that, at the lower levels, shore agencies were generally working on more favourable slopes and in looser materials. Also, differences in duration of successive marine stages—that is, in length of successive periods of crustal stability,—may have counted more strongly than any rise of sea-level.

The Marine Limit between Gaspé and Quebec

Observations and measurements made mostly in 1910, 1911, and 1926 were taken principally along the south side of the St. Lawrence, for a distance of about 250 miles (Figure 3). They show a slow, steady rise of the upwarped plane of the late-Glacial sea, from altitudes of approximately 250 feet at Little Metis to nearly 600 feet at Quebec. . . . .

. . . . Subarctic marine shells, common enough at lower levels, are found near the extreme upper limit of submergence at only one place, Rivière du Loup.[1] Nowhere does a seacliff seem to mark this old water-plane; and even the beaches seem rather delicate. This led to the opinion that emergence was already in progress when ice retreat just uncovered the coast. . .

The manner in which the ice uncovered this region is not wholly clear. It seems to have been thin, even when at its height, in the Gaspé region, surrounding the high tableland there without overtopping it, and receiving tributary valley glaciers from that source (Coleman, 1922, pp. 12–14). Glacial grooves, *roches moutonnées*, and other features north and south of the St. Lawrence, between Gaspé and Quebec, particularly those on higher ground, suggest withdrawal of the ice border across the estuary toward the northwest, without any noticeable deflection of ice currents down the valley.[2] It is true that scour along the shores of the estuary during much later stages of submergence, by pack ice, was registered at several places (Chalmers, 1898, pp. 51–52). Nor was there a vast cap of ice left over the Appalachian Highlands, south of the St. Lawrence, so far as recent investigations indicate (MacKay, 1921, pp. 51–56). If, then, the St. Lawrence estuary east of Quebec was freed from ice almost simultaneously, as the glacial records lead us to think, the highest beach registers one and the same stage of marine submergence at all localities. The harmonious manner in which twenty independent measurements of the marine limit in this region fall upon a single upwarped water-plane supports the view that uplift came after the ice had uncovered and the sea had submerged the entire area. If movements had been in progress during an irregular and diagonal retirement of the ice-front across the valley, we would expect greater discordance in the figures, between stretches of shore that carried watermarks of different dates.

The likelihood of so simple a solution is supported by the recent discovery that while the ice-front was retreating from the southern part of Champlain Valley, during the early Coveville stage of Lake Vermont, uplifts ceased, and from that time on until after sea-level waters had entered the Champlain basin there was stability (Chapman, 1933). This long period would seem to include the time when the ice was uncovering the St. Lawrence estuary below Quebec,

[1]Goldthwait, 1912, p. 359, shells at 340 feet, beach at 372 feet; 1913, pp. 66–67.

[2]A statement to the contrary by H. C. Cooke, 1930, p. 64, seems to be without support from published observations.

according to the reconstruction of the ice-front on the map (see Fig. 2). Furthermore, it has been found that before the uplifts of Coveville time stability had reigned over southern Maine, New Hampshire, and southern New England for a period of some 4,000 or 5,000 years, while the ice-front was receding from Middletown, Connecticut to Littleton, New Hampshire (Lougee, MS). With such prolonged stages of crustal stability, opportunity for correlation of beaches at the marine limit ON COASTS THAT THE ICE UNCOVERED AT APPROXIMATELY THE SAME TIME is better than under the theory formerly held in this region (Goldthwait, 1911, p. 223) and still held in northern Europe.

Results in full agreement with these were obtained by MacKay in 1921 (pp. 56–58), along a line running south from the city of Quebec up Chaudière Valley some 50 miles. Several deltas there show a rise northward of the water-plane of about 35 feet in 20 miles. So it appears that the marine plane rises from the southeast as well as from the northeast, toward Quebec. Comparing the foregoing data with the isobases drawn by Chapman on the tilted water-planes of the Champlain Valley (Figure 3), one finds that this upwarping created a dome over Montreal and Quebec. Taylor (1915, Fig. 14; 1913, Fig. 10) and more recently Cooke (1930, Fig. 4) have used the writer's measurements for construction of isobases, but in these cases, as well as in the map published in 1924 by the present writer (Fig. 17), correlation is implied between the lower St. Lawrence and other districts whose marine water-planes differ from these in age by some few thousands of years, and in level, due to meltwater, by scores of feet; and so they should not even approximately match.

Data from the north side of the St. Lawrence estuary are more scattered and less definite in character. Although supporting the conclusions reached in the foregoing paragraphs, they do not satisfactorily indicate the exact course of isobases across the St. Lawrence, and the direction of slant of the upwarped plane. Mawdsley, in his study of the Gouffre Valley (1927, p. 40), 60 miles east of Quebec, found terraces and other records of the upper marine limit at about 500 feet elevation. These conform to the writer's plane.

The Marine Limit between Quebec and Montreal

From Quebec to Montreal and Lake Champlain the record again is fairly definite, though in some respects less satisfactory than farther east. Closely approaching, but nowhere quite reaching 600 feet elevation around Quebec, the marine limit declines somewhat westward, though still above 550 feet as far as Granby. From there southward to Champlain Valley it drops rather steadily as if to meet the 523-foot beach at Covey Hill. Chapman has traced this water-plane southward from that point and St. Albans almost to Whitehall. . . . .

On the north side of the river, owing to lack of good contour maps and difficult terrain, little exploratory work has been done. Only one district has been thoroughly worked,—that west and north of Shawinigan Falls. . . . . the upper limit of submergence was easily found and measured at several points around St. Elie, where ice-contact washplains and associated kames and eskers are beautifully developed. Though 50 miles away from the localities on the opposite side of the St. Lawrence, this seems to establish the position of the marine plane here at 590 feet, near the top of the dome of uplift, and to indicate little or no difference in its altitude from Quebec to Lake St. Peter. No records were found, though searched for, between there and Montreal.

The upper marine limit at Montreal, the earliest studied and most visited of all places in the St. Lawrence – Champlain embayment, is perhaps also the most disputed. Sir William Dawson (1893, p. 201) put the limit of submergence over the summit of the mountain because Laurentian boulders occur to the very top of it. DeGeer (1892) selected a certain terrace and bluff at the rear of the Protestant cemetery, at 585 feet (corrected from barometric measurement), as the high-water mark. Chalmers (1898, p. 69J) accepted DeGeer's figure. Woodworth (1905, p. 209, and pp. 215–216), though unable to find the locality, adopted the highest reported shell locality of Lyell and Dawson at 560 feet as the marine limit on Mount Royal. Fairchild (1914, p. 239; 1918, p. 215), extending his "theoretic marine plane" from New York state across Vermont and St. Lawrence Valley, placed sea-level at Montreal at 830 feet, or about 70 feet above the top of the mountain. The writer adopted the highest of the beach ridges seen by Dawson, below the park ranger's house, at 568 feet, as a limit of marine submergence, as the gravel in it contains *Saxicava* shells, and no signs of wave wash appear on the gentle slopes behind it. . . . .

At Covey Hill, 40 miles south of Montreal on the New York border, the position of the upper limit of marine submergence has long been disputed.[1] Fairchild placed it at 740 feet on the water-plane that is here called Lake St. Lawrence. This is not registered by any wave-built features on the well exposed north slope of the hill, where conditions seem almost ideal (see p. 64 MS); but well built beaches at corresponding levels occur both southeast and southwest of Covey Hill, on and south of the boundary. Associated with this water-plane on the Champlain side from Cannon Corners, near Covey Hill, southward to West Chazy and Peru, are abundant records of ice-front drainage from west to east, but all these features are as readily referred to a glacial Lake St. Lawrence with ice dam east of St. Albans as to the Champlain Sea. And since Chapman, by field study and accurate measurements, has matched them with those of the Fort Ann stage of glacial Lake Vermont, which he traces southward to its outlet, and since the corresponding shoreline cannot be followed northeastward beyond St. Albans, and since it is weak at its northerly limits, as our theory of Lake St. Lawrence requires, we consider it unlikely to be the marine shoreline.

The lower and stronger beach at Covey Hill, at 523 feet, matches the water-plane traced from Gaspé past Quebec to Champlain Valley, and is the topmost member of an extraordinarily strong series of wide vertical range, which can be followed into both the Champlain and Ontario basins (Chapman, 1933; Fairchild, 1919, Pl. 5; Chadwick, 1920, p. 50). This, it appears, is the highest beach of the Champlain Sea (Goldthwait, 1913b, pp. 122–126). Fairchild calls this group the "Franklin Center series". It was studied simultaneously but independently, in 1911–12, by Fairchild and the writer when for the first time new precise levels run by the topographers of the Department of Militia for their contour sheets afforded accurate altitudes. Previously this 523-foot beach at Covey Hill, discovered by Gilbert and later adopted by Woodworth as the marine limit, had been given the elevation of 450 feet, owing to a poor barometric determination of altitude. This error of nearly 75 feet in a point used by Woodworth (1905, pp. 236–239) as a vertical control for plotting the profile of the tilted marine plane and estimating the amount of time occupied by the tilting, destroys the value of those computations.

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[1]Woodworth, 1905, pp. 173, 201–204; Fairchild, 1916, pp. 240–241; and Goldthwait, 1913b, pp. 122–126 and Plate A 10.

The corresponding series of beaches at Sciota, first described by Woodworth (1904, pp. 39–41; 1905), was visited and measured with a wye level in 1911 by the writer (1913; 1914, p. 358) and found to reach an elevation of 486 feet. Chapman's observations and measurements carry the plane down the lake almost to its south end, with best records as follows:

New York Localities

	Feet
West Chazy	467
W. Beekmantown	440–430
Saranac	425
Schuyler Falls	400–398
Au Sable	380
Port Douglas	360–300
Essex	305–290
Westport	260

Vermont Localities

	Feet
St. Albans	440
Georgia	400
Cobble Hill	359
Winooski	325

This marine water-plane appears to intersect the level of modern Lake Champlain 5 or 10 miles north of Whitehall. Other marine water-planes, of later date and lower altitude, slant less steeply toward the south, converge with it, and like it are drowned by Lake Champlain toward its south end.

The Marine Limit West of Montreal

The orderly relation of beach elevations that seems to prevail east and south of Montreal, where the Champlain marine limit seems to lie between 525 and 575 feet, vanishes as one goes northward into the crystalline highland or westward up Ottawa Valley. . . .

At St. Joseph du Lac on the Oka Mountains, 20 miles west of Montreal, a long vertical series of well built gravelly beaches reaches its upper limit at 525 feet; but behind and above these there is so little ground where waves could leave their marks that the 525-foot figure cannot be accepted as an actual marine limit . . . on Rigaud Mountain, the record is better, although even there steep rocky slopes and forest cover make precise determination of the limit no easy matter. The highest member of the great series of cobblestone beaches that runs from Devil's Garden southward across the mountain road stands at 550 feet. This harmonizes so well with figures for Covey Hill and Montreal that it seems reasonable to accept it as the high-water mark of the Champlain Sea. The ground behind it for some distance displays no beaches, and the small, solitary beach at 671 feet at the back of the mountain, as has been explained (page 70), is interpreted as the record of Lake St. Lawrence. . . .

Westward along the north side of Ottawa River, a few beaches and many conspicuous river terraces, in valleys like the Gatineau, indicate marine submergence to approximately 500 feet. One richly fossiliferous gravel ridge, half a mile north of Old Chelsea, stands at 470 feet; and another, 2 miles north of Aylmer, at 450 feet. Marine shells have been found at Kingsmere at 465 feet. Lacking better evidence, and in view of the likelihood that the highest watermark near Ottawa is not that of the Champlain Sea but of Lake St. Lawrence (see p. 69 MS), the writer assumes that the 690-foot sand plain at Kingsmere marks fresh water.

Slopes on the grounds of the Ottawa Ski Club suggest wave work at about 585 feet, but they are not convincing. Back of Quyon and 25 miles west of Ottawa, a well built beach stands at 540 feet, and terraces described by Wilson (1924, p. 16) reach up to about 570 feet. At Kazabazua, 40 miles up the Gatineau, north of Ottawa, conspicuous outwash plains, almost surely marine, register a water-plane at 600 feet. Records comparable to these, including particularly a distinct upper limit of submergence on the hill north of Renfrew at 560 feet, seem to carry the Champlain water-plane far up Ottawa Valley to Pembroke and beyond without serious discordance. But, as Antevs has pointed out (1928, pp. 137–140), upwarping while this zone was being uncovered by the ice may have to be taken into account, so the figures may not match.

Interpretation of these scattered and rather conflicting records is made doubly difficult by the apparent "disconformity" or "erosion surface" in the marine clays at several places near Ottawa, which led Antevs to distinguish three stages of late Glacial time in that district: (a) the first deepwater marine stage; (b) the stage of emergence or "Ottawa land stage"; and (c) the second marine stage.[1] If, as Antevs thinks, this disconformity is of subaerial origin, and if both the upper and the lower marine clays are of late Glacial date, then it is hard to escape the conclusion that Antevs came to—that upwarping and emergence from the Champlain Sea were followed by reversal, which sunk the land at least 200 feet before a second upwarping brought the seafloor finally out of water and established the modern river conditions. CRUSTAL OSCILLATIONS OF THIS SORT ARE NOT EASY TO ACCEPT. Little or no sign of them has been found in the Great Lakes region to the west, or in the lower St. Lawrence to the east. More particularly, they are in direct conflict with conclusions of Lougee and Chapman regarding the character of uplifts of northern New England. Nowhere outside of the Ottawa district has a record of two, late Glacial marine stages been seen. In view of this, it seems well to consider other possible explanations of the Ottawa "erosion surface".

Two explanations at least deserve attention. Coleman (1927, 1932) has suggested that the marine clays are inter-Glacial. Among the reasons given are: (a) the well known presence of marine shells, more or less broken, in the till; (b) the presence in the clays of nine extinct species of animals, including insects, sponges, shellfish, fishes, and a mammal; and (c) the inability of "experienced field geologists such as Johnston, Goldthwait and Antevs . . . to follow the highest sealevels with any certainty." These beaches, he argues, have been largely or wholly erased by the last glaciation. In answer to the three points, it may be said that: (a) seafloor deposits incorporated in till or overridden by it are no more an indication of interglacial conditions than of oscillations of the ice border during late Glacial recession, with the ice edge standing deep in the sea; (b) that extinct southern species, such as the oyster, may and probably did live as far north as this, even in post-Glacial time, especially during the late stage of occupancy of the lowland by the sea, as records of many kinds, in New England and elsewhere, imply warmer climate in late post-Glacial time than today; and (c) that although continuous tracing of a marine limit is not everywhere to be expected, in limited time and on a terrain as difficult as this, the data presented in this memoir make it clear that since the final retreat of the ice, beaches with marine shells have been built at altitudes between 500 and 600 feet at Montreal and Ottawa. Without following Coleman so far as to adopt an inter-Glacial date for ALL the Leda clay," and all the higher deposits whether sand or clay", it seems well to consider whether the LOWER marine clay may not be inter-Glacial and the upper one late Glacial. It is true that there is no till sheet between them, but neither is there a weathered zone on the surface of the lower clay. So far as this is actually

[1]Johnston, 1916, pp. 9–14; 1917, pp. 18–33; Antevs, 1925, pp. 66–73; 1928, pp. 97–102; 1931, pp. 5, 10–11.

an "erosion surface", we may suppose that it registers river or wave wear just prior to the last marine submergence, which removed part of the earlier deposit. Similarity of composition and density of the two clay deposits can hardly be taken as full proof that they are both late Glacial, though they look so. If the lower clay and the varved clays beneath it are inter-Glacial, then the inferences drawn by Antevs in reconstructing the position of the ice-front at the beginning of the Champlain marine stage—which the writer has followed in Figure 2 and on page 69 (MS)—must be abandoned. Although admitting the possibility, he does not think this to be necessary.

The second explanation accepts both upper and lower marine clays as late Glacial, but assumes that the disconformity between them, instead of resulting from subaerial erosion, is due to seafloor scour, maybe to readvances of land ice, or to icebergs, or by strong melt-water currents issuing from a returning ice border during local readvances in the Champlain Sea. Lack of mashing and contortion of the clays and of patches of stony submarine till are arguments against ice as the eroding agency; but currents of meltwater seem not impossible. In one instance, at Brennan (Antevs, 1928, p. 100) the erosion surface is overlain by a few feet of cobbly gravel.

Until more complete proof is found, therefore, there seems to be no compulsion for belief in an Ottawa land stage, nor in the reversing crustal movements that it involves . . . .

The position of the marine water-plane at Brockville and westward toward Kingston is a question of considerable importance, as it carries with it the question of invasion of the Ontario basin by the Champlain Sea. That this took place has been assumed by all those working in southern Ontario and northern New York ever since Gilbert (1897, pp. 58–59) suggested the marine origin of a certain shoreline that lay below the Iroquois plane (*see* Gilbert, 1898, p. 73). But there has never been good evidence that the "Oswego beach" or any other in the Ontario basin is of marine origin. Fairchild's "Gilbert Gulf" beach (1905, pp. 712–718; 1918, Pls. 9–10) certainly has a plane high above the 350-foot watermark at Brockville, for it is said to reach Covey Hill at 740 feet, far above our 523-foot marine limit. Taylor (1915, p. 445), however, follows Fairchild and Coleman in the assumption that the sea entered Lake Ontario through a strait 25 or 30 miles wide, for a short time. The writer cannot confirm his view. If the marine limit is taken at 550 feet on Rigaud Mountain and 350 feet at Brockville, then the westward slant of the water-plane carries it down to the level of Lake Ontario (245 feet) between Gananoque and Kingston. If the marine limit at Rigaud is at 670 feet instead of 550 feet (as Johnston and others have supposed), then the westward slant of the plane is still steeper, and its failure to reach Lake Ontario is still more certain. And if the marine plane at Brockville stands at 331 feet instead of 350—which seems entirely possible—the same thing is true. Moreover, it is reasonable to suppose that the south-westward slant of the plane in the region west of Brockville is stronger than that between Rigaud and Brockville because the latter district lies near the central dome of upwarp. This consideration makes marine invasion of the Ontario basin doubly unlikely.

The conclusion thus reached by reconstruction of the Champlain water-plane is supported by the observation of an abrupt change in character of the clays, along St. Lawrence Valley, as one passes Brockville and approaches Gananoque. The clays at Brockville, like those everywhere to the east, are massive, without varved structure, sticky, and contain *Macoma* shells. Only a few miles farther west at Lyn, clays exposed in sections along the motor highway past Mallorytown and both east and west of Gananoque show perfect varved structure. In some cases these clays rest directly on bedrock. In one place (Lyn) a 15-foot sheet of till covers the varved deposits, showing readvance of the ice across the lake floor; but in the other sections undisturbed varves reach up to the very surface of the clay plains. This contrast east and west of Brockville has been recognized by most observers and interpreted as evidence of freshwater conditions in the Ontario basin and saltwater farther east (Wright, 1923, pp. 43–44). Coleman (1922a, p. 55) first sought to explain the freshwater character by the inflow of Niagara River, and later by meltwater from the ice; but the marine gulf he pictures expands widely eastward into the Champlain Sea, instead of connecting through a narrow gateway. Varved clays like these do not prevail in a similarly situated gulf of Ottawa Valley. Massive marine clays like those east of Brockville are found, instead. Coleman's explanation, in the writer's opinion, is untenable. Even if the Champlain Sea had reached into Lake Ontario through a narrow passage, the contrast between the two types of clay would hardly be so strong, nor would it come so abruptly, in so short a distance, where the valley is so wide. Wright saw the implication of this evidence, though he did not deny the possibility of a short marine invasion.

Summary

When first uncovered by the ice-sheet, the western part of the St. Lawrence Lowland, west of Montreal, seems to have been occupied by a lake. Ice over the highlands between Quebec and Sherbrooke prevented the eastward escape of these waters, and invasion by the sea, until the ice edge had retired to the line of Ottawa River. The last and greatest stage of this lake, when waters of the Ontario and Champlain basins merged, is called Lake St. Lawrence. Though its shorelines are only partly traced, its extension northward into the Ottawa region is indicated by the freshwater clays at the base of the late Glacial series. Some of the highest watermarks in that part of our area—for example, the high beaches at Kingsmere and Rigaud—hitherto accepted as marine—are thought more likely to belong to Lake St. Lawrence.

The record of marine submergence in the Ottawa region is exceedingly difficult to interpret; for on the one hand the watermarks are liable to be confused with those of Lake St. Lawrence, and on the other, the deep-water marine clays include a so-called disconformity that has been adopted as evidence of vertical oscillation of the region in late Glacial time, with two marine stages separated by an "Ottawa land stage". The writer is not ready to accept this explanation.

Marine submergence in the district from Montreal and Lake Champlain eastward to Quebec is more satisfactorily deciphered; for here the upper limit of submergence is more strongly marked, and observations and measurements by different observers show good agreement. In particular, the studies of MacKay in Chaudière Valley and of Chapman in Champlain Valley confirm the identification of this uppermost water-plane of the Champlain Sea, which has been upwarped to a position nearly 600 feet above sea-level near Quebec and Three Rivers, and only slightly less at Montreal, but which slants strongly southward and southeastward toward New England. Up Ottawa Valley the writer's observations seem to carry the limit of marine submergence as far as Renfrew and Pembroke with little departure from elevations of 550 to 570 feet. The whole problem, however, is complex, and very detailed studies will be necessary to find the correct solution.

As regards the westward extension of the Champlain Sea toward Lake Ontario, evidence is still too fragmentary to justify positive statement; but there seems to be little or no ground for the view, so long entertained, that the sea reached the Ontario basin in late Glacial time. Again, critical study and plenty of accurate measurements are needed, to settle the question.

Chapter VI

EMERGENCE OF THE LOWLAND FROM THE SEA

Introduction

When the Champlain Sea first occupied the St. Lawrence Valley no warping was in progress (see p. 61 MS). If sea-level rose because of meltwater at this stage the amount of the rise was probably small, for the time that the water stood at the marine limit appears to have been rather short. Upwarping, when it did come, was either interrupted by many halts, or was so slow that severe storms left successive marks; for only by one of these explanations or the other, or by their combination, can we account for the closely packed series of beach ridges that occupies the vertical zone of 225 feet at Covey Hill, 176 feet at Rigaud, and 280 feet at Oka Mountains, and comparable records at other places where the terrain was less favourable for a full record. None of these beaches has outstanding strength; and there is not a wave-cut shelf or seacliff among them. If there were halts, therefore, during the first few hundred feet of upwarping, they were of short duration.

Below this unbroken series of beaches is a shoreline so distinct and so uniform in elevation at ten widely separated localities that it seems to mark a more definite stand of sea-level. It lies at an elevation of 210 to 215 feet in the Montreal district, where it is most plainly seen; but it seems to reach up the valley to Rigaud Mountain and down the valley past Quebec and southward into the Champlain basin, with little change of elevation. The discovery of this feature in 1925 was a surprise, requiring old views to be abandoned (Goldthwait, 1910, p. 228) in favour of the opinion that one or more periods of stability interrupted the upwarping. Subsequently Lougee's careful work in Connecticut Valley and Chapman's around Lake Champlain led more positively to the same opinion. The 210- to 215-foot waterplane seems to be the first of two or three stages of halt between successive regional uplifts.

Emergence of the lowland was not accompanied by simple withdrawal of the sea from the far western corners of the lowland eastward to the estuary at Quebec, and the steady extension of St. Lawrence and Ottawa Rivers in that direction. Broad, basin-like portions of the lowland, detached from the marine waters one by one, became freshwater lakes, through which the river pursued its new course . . .

For each stage of emergence there is, consequently, the problem of distinguishing between truly marine watermarks, estuarine records in which tides and river discharge are combined in complex slopes, and true supramarine river features, which are complex because of highly variable seasonal discharge and extremely variable width of the river channel.

The records seem to indicate that simple marine conditions reached inland as far as Montreal until after the waters had dropped below 100 feet, and that estuarine conditions involving down-valley gradient of the water-plane became well established below Montreal before the Micmac or 20-foot stage of the lower St. Lawrence. . . .

The 210-foot Stage

Although no particular search was made for records at this elevation, prominent features were noted at ten localities. The westernmost is on the northeast side of Rigaud Mountain, where a sharp bluff cut in till with a shelf at 207 feet connects with a gravelly beach at 212 to 215 feet. Up the Ottawa, the altitude of the valley floor rises, and higher ground on both sides closes in so much that the sea at this stage could scarcely have passed Chutes à Blondeau and reached Hawkesbury. Features above that point, though close enough to the 210-foot mark to be mistaken for records of that stage, are clearly river-carved channels of later date, and will be described as such on later pages (pp. 106–107 MS). . . .

River Channels West of Hawkesbury

The regional upwarping that inaugurated the 210-foot stage of the Montreal district seems to have been accompanied by the retirement of the sea from the Ottawa Valley to a point east of Hawkesbury. Shoals coming up out of water-made barriers divided the Ottawa embayment into segments that were first brackish and then fresh, as sea changed to lake and lake to river. Among the first of these barriers, probably, was the wide belt of upland just east of Hawkesbury, which can be traced southwestward and westward on the map, to where it merges with the upland north of Prescott. The clay-mantled basin of the Ottawa to the north is scarred by channels that disclose the early history of the river.

The lowest sag in the encircling rim was near Chutes à Blondeau. Though its original surface has been cut away, it appears to have been somewhat under 200 feet at the lowest point. During the stand of the sea at 210 feet, a passage here scarcely $1\frac{1}{2}$ miles wide gave access westward to the lowland near Hawkesbury, where a wide lake or estuary stretched across Caledonia and Alfred townships, narrowing and branching toward Rockport and Ottawa. The soft clays across which this primitive Ottawa flowed allowed the cutting of an elaborate system of branching, interlocking channels, with steep current-trimmed bluffs that run straight and unbroken for many miles, and with smooth floors that slope almost imperceptibly downvalley (Johnston, 1917, pp. 9–10). Reconstruction of these channels, from field studies and contour maps, indicates that near the city of Ottawa, at a level now about 230 feet, the river split: one wide branch, the northern one, following the present line of the river and the other flowing through three parallel gateways into a single channel near Mer Bleue Bog, and thence roughly parallel to the modern Ottawa, but about 10 miles south of it, converging finally and joining it near Hawkesbury. At least three diagonal cross channels were cut from the northern route to the southern one. Their steep bluffs and flat floors resemble closely the modern features of the Ottawa at Green's Creek, and the water-surface altitudes indicated at their upstream and downstream ends harmonize with the view that all are parts of one great river, which formed a network of channels around islands, while it commenced to cut down through the clay plain to rock. The pattern is much like that of the modern St. Lawrence River at Montreal, both in design and scale. At Montreal, the river splits into three channels, enclosing two islands, and descends thus over broken gradients about 50 feet in 30 miles. The ancient Ottawa split into five channels around four islands, and dropped about 40 feet in 40 miles. There is, however, at least one striking difference between these two cases: the old channels of the Ottawa, cut through soft clays, are wide and shallow, rather like parts of Lake St. Francis, whereas the Rivière des Prairies and Rivière des Milles Iles around Montreal run in narrower, steeper channels on floors of rock and till. At Alfred, where the main channel was 6 miles wide, the water in midstream was 30 feet deep . . .

Lake Ottawa

West of the city of Ottawa, on both sides of Lake Deschênes, beaches and current-trimmed bluffs distinctly mark a waterplane which Johnston (1916, pp. 7–9; 1917, p. 24) named "Lake Ottawa". Eight measurements of elevation of the shore features indicate a definite southeastward slope of the waterplane downvalley, from 264 feet near Breckenridge to less than 250 feet at Deschênes. This is perhaps an initial slope of the expanded river, rather than a slope created by subsequent upwarping. The lake probably discharged through the narrower channel east of the city of Ottawa and into the network of channels at Hawthorne and Mer Bleue Bog, already described, . . .

The 110-foot Stage

. . . Although more elaborate field study and more data are needed to establish the reality of a 110-foot marine stage around Montreal, distinct from current-trimmed channel bluffs, the extension of the 110-foot marine waterplane inland, horizontally, from the Island of Orleans into and through the narrows at Portneuf, and the watermarks noted at Gentilly, Three Rivers, and Montreal at approximately 110 feet, seem to support the opinion that this was a stage when crustal upwarping ceased for a time, as it had before and did again.

The 50-foot Stage of Lake St. Peter, and the Decline of Terraces Downvalley toward Quebec

. . . The conspicuous records of this 50-foot stage around Lake St. Peter are not matched by any watermarks whatever at 50 feet in the Quebec district, nor between Quebec and Gaspé. There seems to have been no stand of the sea at that position or near it. Sharp current-cut bluffs and benches along the river below Lake St. Peter register watermarks that decline eastward toward Quebec, not at a steady rate, to be sure, for in some places they are due to local influence of ledges or resistant till surfaces, but leading down to the level of the Micmac or 20-foot marine shoreline of the lower St. Lawrence . . .

. . . Obviously it is the shoreline of an ancestral Lake St. Peter that stood some 20 feet higher than the modern lake. The fact that the bluff has been cut in sediments that overlie the till, that it is fresh and steep, that it stands so close above high water of today, and that the lake at the present level has failed to cut a new shoreline comparable to the former one—these all suggest the abandonment of the shoreline at no very remote date . . .

Summary

Emergence of the lowland from the sea seems to have been interrupted by halts, first when the waters stood near an altitude of 210 feet and later at about 110 feet. Evidence of this consists of bluffs and beaches seen especially in the Montreal district, but noted also sparingly as far east as Quebec. Accurate measurements of watermarks in critical places, notably in the narrowest sector of the valley near Portneuf, support the view that even at the 110-foot stage the marine estuary and broad inner embayment had one horizontal waterplane without seaward slant. Terraces and other watermarks below 110 feet, particularly the conspicuous 50-foot shoreline around Lake St. Peter, seem in some cases to mark expansions of the river, such as Lake St. Peter today, and in other cases to register downvalley scour by the seaward flowing river, which in its later stages was seeking sea-level of the Micmac or 20-foot stage.

The Ottawa River, between Ottawa and Hawkesbury, and the St. Lawrence just below Montreal cut elaborate branching channels in the clay plains that emerged from time to time. Some of these can easily be distinguished from the records of static water; others can not, without more study. Full analysis of the problem with all its local manifestations calls for a vast amount of field work . . .

Chapter VII

THE MICMAC STAGE

Introduction

The Micmac shoreline is an outstanding feature of the coast of the St. Lawrence estuary from Gaspé to Quebec. The cliffs that rise so steeply in the city and on the opposite shore, at Lévis, are not—save for short distances—bathed by the tidal river, as one expects a shore cliff to be; instead, there is a shelf or platform below, never covered by even the highest tides . . .

This extraordinary feature reaches down the south side of the St. Lawrence for about 300 miles. Old villages lie more on the shelf than on higher slopes . . .

. . . Sir William Dawson made passing reference to it in 1893, but gave no hint of its bold form and continuity. Daly (1920a, pp. 246–247) in 1899 appears to have been the first to observe it and treat it as a noteworthy feature, though, because he had no opportunity to examine the shoreline at close range, he postponed announcement until 1920. Meanwhile, in 1910, the 20-foot terrace and bluff had been seen by the present writer, who called it the Micmac shelf (Goldthwait, 1911, pp. 229–232; 1911a, pp. 291–317; 1913, pp. 50–51, 77–79).

Characteristics of the Micmac Which Demand Explanation

. . . Cut either in till or in the shaly Paleozoic slates that generally occupy the coast of the lower St. Lawrence, the cliff ranges in height from 20 or 30 feet to 100 or more, according to the height of the ground into which the sea has cut. The emerged upper part of the old shelf is commonly a few hundred yards wide, but in extreme cases more than a mile . . . Where the gently sloping terrace drops below present sea-level, there may be a low cliff; but more commonly salt marshes merge with the upland grass along an otherwise indistinguishable high-water line. From there, the terrace reaches out far beyond low-tide mark as a drowned platform, in most places from 1 to 5 miles wide . . .

Such sharp outline and such large dimensions would not be so hard to explain if they were characteristic alone of the lower estuary, where strong wave and current action are to be expected. But, as noted during 1910, the Micmac is fully as bold in places so sheltered from surf that an appeal to the usual cliff-cutting agencies—waves, undertow, and shore currents—fails to meet the facts (Goldthwait, 1912, p. 297; 1913, p. 51). A field conference with D. W. Johnson, in November 1910, led to a theory for this aspect of the problem which shall presently be reviewed. It regards the terrace as a plain of subaerial erosion, much older than the shoreline.

Another perplexing feature of the Micmac shoreline has been its close approach to horizontality. Even in the region where the marine limit is differentially upwarped so as to slant 2 feet to the mile down the estuary, this lower Micmac terrace does not measurably depart from a horizontal water-plane, 20 feet above present sea-level . . . no net rise of level of the shoreline is found in the 300 miles between Gaspé Peninsula and the city of Quebec. This invited the theory that the final emergence of 20 feet was due to a lowering of sea-level rather than to uplift of land. If so, the Micmac shoreline should be more or less easily traceable from the estuary out around the Gulf and Nova Scotia to New England and other coasts the world over. It was a disappointment in 1911 to find that the Micmac cliff and terrace vanished before it got around the corner of the Gaspé peninsula (Goldthwait, 1912, pp. 300, 301). Subsequently, Coleman (1922, pp. 14–23) corroborated this report . . .

If then the final 20-foot emergence was an uplift, registered in the Quebec–Gaspé region but not elsewhere to the east and south, shall we associate it with the well known seismic activity of this district? . . .

In 1925, Johnson (1925, pp. 216–234), after a close scrutiny of coast charts and brief studies in the field at selected places on the lower St. Lawrence, presented the view that the broad Micmac shelf is not so much a record of waves and shore currents of recent date as it is a series of wide terraces or plains of subaerial origin and pre-Glacial date that slant gently down the estuary. Where the sea in Micmac time intersected any one of these plains diagonally, covering it for 20 or 30 miles, cliff cutting was easy, and a sharp bluff and bench was quickly etched out to look like part of the broader feature. Johnson called attention to river-worn plains of different altitudes at various points along the south side of the river, but particularly near Rivière du Loup and between Green Island and Bic. At both of those places the Micmac cliff and shelf are conspicuous. Though rather smooth in places, the plains are more or less uneven, with low parallel undulations such as result from slight contrasts in resistance of lowland rocks to weathering and stream erosion. One of the plains was found to slant northeastward about 2 feet to the mile, extending far down the river as a submerged platform to depths of 60 feet or more. As the drowned outer part of the terrace widened, that part between high tide and the Micmac bluff narrowed proportionately. During the Micmac stage, while the sea overlapped long stretches of terrace like this, it is supposed to have shaved away whatever soft mantle of till and sea floor deposits covered it, so as to develop a sharp Micmac bluff not only in these unconsolidated deposits but locally, where recession went far enough, in the shale slopes beyond the inner edge of the plain. Three wide plains or terraces of this kind were reported at Rivière du Loup, implying that a sufficient number of them, slanting seaward, might intersect the Micmac water-plane, one by one, and facilitate the development of abnormally wide marine platforms.

Thus Johnson accounted for the lack of a good Micmac record around Gaspé, on the one hand, where stronger wave action might have removed old river terraces, and for the abnormally strong development of the shelf in the protected upper end of the estuary, just east of Quebec, where waves could hardly be supposed to have worked well at any level, but where old valley floors might be best preserved . . .

Re-examination in 1926

With Johnson's suggestions particularly in mind, the district from Quebec eastward about 80 miles to Kamouraska was revisited in 1926. The Micmac bluff and terrace were followed almost continuously for 40 miles from Kamouraska to Montmagny, and measurements were made of the elevation of the terrace. Glimpses only were had of it between Montmagny and Quebec, where the highway lies inland and far above the Micmac level. But time was spent along the north shore, and on the Island of Orleans, following the bluff through its course and measuring the altitude of the terrace at the foot of it.

Almost everywhere, in this 80-mile stretch, the Micmac is cut in shales or slates . . .

Conclusions Reached in 1926

There is no other strong shelf and bluff comparable to the Micmac between Quebec and Gaspé, nor any wave-built beaches at all equal to it as a record of the attack of the sea on these gentle slopes. If the sea had stood long at the present level, as it did when it cut the Micmac shelf, then we ought to find a modern seacliff comparable to the Micmac along each stretch of coast that lies between the drowned and tilted plains where Johnson assumes that the Micmac runs out to the present shoreline. Instead of this, the Micmac appears to intersect moderate slopes as well as gentler ones and to be missing only where rocks much harder than shale discouraged cliff cutting. There seem to be no such long gaps in zones between successive slanting plains of denudation as Johnson's theory would require.

The wide shelf between Green's Island and Bic was found by Johnson (1925, pp. 223–226) to slant down the estuary at the rate of 2 feet to the mile. That indeed was given as one of the reasons for calling the terrace a river-worn plain with a seaward slope. But present reconstruction of the UPWARPED MARINE LIMIT gives the late-Glacial uplift THAT VERY MEASURE—2 FEET TO THE MILE—in the same direction. The drowned terrace, therefore, would seem to have been nearly horizontal before late-Glacial upwarping, while it was still covered by the ice-sheet. Of course, plains of denudation developed in the St. Lawrence Lowland in Tertiary time might have slanted in various directions with various gradients. These would have been modified by all the ups and downs and local irregularities of successive late-Tertiary crustal movements, not to mention Pleistocene movements due to ice load or otherwise. There are unlimited possibilities. But among them the least likely would seem to be that of a pre-Glacial valley floor composed of a series of broad terraces so nearly horizontal that after all Tertiary movements and at the close of the Ice Age, while still covered by the ice-sheet, IT STOOD PARALLEL TO THE THEN SEA-LEVEL. In any analysis of these old subaerial plains, it would seem wise first of all to take full account of all the last deformation that they have suffered, as recorded in the upwarped waterplane of the Champlain Sea, and to see where the features would stand if that last upwarping were eliminated.[1]

Having adopted the view that the Micmac registers a time interval much longer than that of any shoreline above or below it, we may observe next that the Micmac stage DOES NOT SEEM TO HAVE BEEN A TIME OF RISING SEA-LEVEL OR SINKING LAND, because large rivers as well as small streams that cross the terrace have cut only the shallowest of channels through its shale floor. If the terrace and cliff cutting had begun when the sea stood at a level lower than the Micmac, vigorous rivers like Rivière du Sud at Montmagny and Rimouski River at Rimouski should have cut their channel floors down faster than the seacliffs were worn back, and the rising of the water level should have flooded these channels farther upstream than the cliffs receded. So, since the river mouths on the Micmac are not drowned, it appears probable that the Micmac marks a long halt, or period of almost perfect stability of land and sea before the final 20-foot emergence. More particularly, it follows that the late-Glacial rise of sea-level caused by meltwater from the waning ice-sheets had probably ceased before the Micmac stage. It does not seem likely that any previous pause in melting of ice and rising of sea lasted long enough to make this strong a record; and it is equally probable that slow and uniform crustal uplift here exactly kept pace with slow rise of sea-level due to meltwater, to produce a fictitious record of stability. So the shallow river channels, like the fresh appearance of the Micmac bluff, its low elevation, and the lack of a good wave and current record at modern sea-level, make the final emergence appear to be a very recent event.

The Sawing of Cliffs and Platforms by Batture Ice

A natural agency at work along the St. Lawrence may explain the strength of the Micmac cliff and terrace, particularly in sheltered situations where good wave action is impossible. It is the sawing action of pack-ice or "batture ice" drifted up and down the estuary by strong tides and river currents. The attention of the writer was called to it by E. A. Hodson, Seismol-

[1]This principle applies very well to the analysis of peneplains or "erosion levels" in western Massachusetts and Vermont, by Meyerhoff and other students of Johnson.

ogist of the Dominion Observatory, in 1926. Since Dawson's time little thought has been given to this agency; and even the literature of his day stresses the movement of boulders and fine sediment rather than the abrasion of banks and floor.[1]

. . . Strong tidal currents then, as now, strengthened at times by high-water discharge in the narrower parts of the river, and dragging thick blocks of ice with them so vigorously as to move 10-foot boulders, could hardly fail to act also as a horizontal saw, plucking, tearing, grinding, and cutting the soft flaky shale, and causing the cliffs to retreat while planing down the submerged terrace. A cliff and shelf of that origin would be hard to distinguish from an ordinary wave-cut one. Ice-worn ledges, with striae running up and down the river and shapes that imply movement in both directions, are numerous along the edge of the lower St. Lawrence between high and low tide, as several observers have noted. Similar records of scour are not unknown on the Micmac terrace . . .

The Nature of the Final Emergence

The question of the nature of the recent 20-foot emergence of the lower St. Lawrence must be left unsettled, awaiting data sufficient for critical study. Certain considerations, however, are worth notice.

The very general lack of 20-foot shorelines bordering the ocean throughout the world so far outweighs the minute fragments of evidence noted and tabulated by Daly (1920, 1920a) that the theory of a recent world-wide sinking of the sea-level need not be considered. Study of the unmarked slopes of New Brunswick, Nova Scotia, and New England at the 20-foot level should be sufficient to show that the Micmac shoreline is restricted to the St. Lawrence. We conclude that the last emergence was an uplift of land and not a lowering of the sea.

In line with . . . the evidence here presented for halts at a 210-foot and a 110-foot stage in our region, it seems most likely that the Micmac stage was another interval of crustal stability interrupting the upwarping. Judging from the extraordinary topographic strength of the feature AS COMPARED WITH HIGHER SHORELINES AT THE SAME LOCALITIES the Micmac halt was by far the longest of all that came during or after the Champlain marine submergence; and judging from the failure of the sea to register a distinct watermark below the Micmac, at present high tide, the latest rise of this coast to the 20-foot position has been in progress up to the present time, or until very recently . . .

Summary

The Micmac shelf and seacliff register a long stage of crustal stability, during which it is thought BATTURE ice played a very important role in cutting a watermark. No other stage, from the earliest retreat of the ice-sheet to the present, compares with this in the strength of its record, and by inference in the lapse of time it represents.

That the Micmac was a stage of coastal stability rather than of slow subsidence (from sinking of land or rising of sea) seems to be indicated by rock-floored tributary valleys, which are shallow to their very mouths on the old Micmac shelf.

The complete absence of a 20-foot shelf or of distinct 20-foot beaches outside of the St. Lawrence estuary, in New Brunswick, Nova Scotia, and along the New England coast—and generally throughout the world—argues against this being the record of a 20-foot lowering of sea-level. It seems, rather, to register a 20-foot uplift, confined more or less to the Quebec–Gaspé district.

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[1]See quotations from Bayfield, Lyell, Logan, and Dawson, and discussion of modern action of pack-ice, on pp. 160–164 MS.

That this uplift was very recent is indicated by the very fresh, faintly watermarked present shore. That emergence of the St. Lawrence estuary is still going on, and that it finds partial expression in the severe earthquakes of the last three centuries, is regarded with favour, though it calls for full and critical study.

Chapter VIII

THE PRESENT RIVER

The St. Lawrence from Brockville to Montreal
The Ottawa from Arnprior to Montreal
The St. Lawrence from Montreal to Lake St. Peter

The St. Lawrence from Lake St. Peter to Quebec

This last section includes extensive quotations of discussions on the action of ice in transport of boulders and in stream bed erosion by: Logan (1842, pp. 766–770), Lyell (1842, pp. 135–141; 1850, p. 223), and Dawson (1893, p. 192, pp. 63, 64).

Although Bayfield, Lyell, Logan, and Dawson recognized batture ice as a powerful transporting agency, none of them seems to have appreciated the fact that such a process might involve the cutting of cliffs and the planing of platforms. But geologists of that day were not particularly interested in geomorphology. With the profiles of these shelves and with Logan's vivid account before us, it is easy to imagine that blocks of batture ice, floating swiftly down the river, turning with eddying currents, grounding on bottom when the tide falls, and lifting and moving off when it rises, are well able to cut a sloping floor of shale, within the zone between high and low water, crushing the rock into thin flakes or grinding it to mud, which even the river current can remove. This action, we suspect, accounts not only for the battures and bordering cliffs of the present river, but also for the extraordinary platforms associated with the Micmac or 20-foot shoreline. (See pages 135–137.)...

Chapter IX

DESCRIPTION OF LOCALITIES

Manuscript pages 167–186 locate and describe in some detail marine records that have been used to reconstruct the limits of the Champlain Sea and the Micmac shoreline.

Comments on details of the observations at each site as well as on their relationship to earlier observations and other significant notes are included in this chapter. No doubt such notes would be of great value in further research on the limits of the Champlain Sea, but unfortunately they are too voluminous for publication here.

Chapter X

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Entries marked by an asterisk (*) are from an unpublished manuscript by J. W. Goldthwait from which the author has quoted selected passages.

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