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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 71-47

DEGLACIATION OF SOUTHERN QUEBEC

(Report, Map 10-1971, 1 table and 4 figures)

N. R. Gadd, B. C. McDonald, W. W. Shilts

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ABSTRACT

A compilation of morainic features, eskers, glacial striations, and radiocarbon dates relating to final deglaciation is presented for the Appalachian Mountains and St. Lawrence Lowlands areas of southern Quebec. The data have been obtained largely by Geological Survey of Canada mapping since 1950. An active ice-front retreated northward and northwestward down the topographic gradient in the Appalachian region and deposited a series of discontinuous moraines, largely composed of ice-contact stratified drift, in the glacial lakes at the ice-front. The Highland Front moraine system was deposited along the northwest flank of the Appalachians about 12,500 B. P. Deglaciation may have begun near the Quebec-Maine border as early as 14,900 B. P. and, except for an area near Thetford Mines where active outflow persisted for a time, the Appalachian region was ice free by 12,000 B. P. when the Champlain Sea flooded the St. Lawrence Lowlands. Retreat northwestward across the lowlands continued, and the St. Narcisse Moraine was deposited between 11,100 and 11,600 B. P. as the ice front stood in the sea. The Champlain Sea episode ended gradually in the lowlands about 9,500 B. P. by which time the level of the freshening water body had fallen below 300 feet a. s. l.

RÉSUMÉ

La présente étude constitue une compilation du modelé morainique, des eskers, des stries glaciaires et des dates établies au radio-carbone, relatifs à la dernière déglaciation survenue dans les régions des Appalaches et des basses-terres du Saint-Laurent, dans le sud du Québec. Les données ont été recueillies en majorité au cours des travaux de cartographie réalisés par la Commission géologique du Canada depuis 1950. Un front de glace actif a régressé vers le nord et vers le nord-ouest, le long du gradient topographique, dans la région des Appalaches et a déposé une série de moraines discontinués, composées en grande partie de matériaux de contact stratifiés, dans les lacs glaciaires à l'endroit du front. Le système de moraines du front Highland s'est déposé le long du versant nord-ouest des Appalaches il y a environ 12,500 ans B. P. Il reste possible que la déglaciation ait commencé près de la frontière entre le Québec et le Maine il y a 14,900 ans B. P. et, sauf une région proche de Thetford Mines, où la coulée active a persisté un certain temps, la région des Appalaches était libre de glace lorsque la mer de Champlain a inondé les basses-terres du Saint-Laurent, il y a environ 12,000 ans B. P. La régression s'est poursuivie sur les basses-terres vers le nord-ouest et la moraine de Saint-Narcisse s'est déposée entre 11,100 et 11,600 ans B. P., lorsque le front de glace a atteint la mer. L'épisode de la mer Champlain s'est terminé progressivement dans les basses-terres il y a environ 9,500 ans B. P. ; à cette époque, cette mer se transformait en une étendue d'eau douce dont le niveau s'était abaissé à moins de 300 pieds au-dessus du niveau de la mer.

DEGLACIATION OF SOUTHERN QUEBEC

INTRODUCTION

The accompanying map is a compilation of data relating to Late-Wisconsin glacial flow and ice-marginal positions in southern Quebec. The general configurations of ice margins and locations of moraines were anticipated in some degree by earlier writers (cf. Chalmers, 1898; Goldthwait, ca. 1933; Antevs, 1925; MacLean, 1944). Parts of the data on which this report is based have been published by the authors individually (Gadd, 1959, 1960a, 1960b, 1960c, 1964a, 1964b; Gadd and Karrow, 1960; McDonald, 1966, 1967, 1968, 1969; Shilts, 1970, 1971) and the map also draws on data published by other authors (see references). An inset on Map 16-1971 shows the areas where the surficial geology has been mapped in detail. This includes the Chaudière and the middle St. Francis river valleys, and the large parts of the St. Lawrence Lowlands. Interpretation of glacial phenomena outside principal areas of study are based on airphoto interpretation, and on both airborne and ground reconnaissance. Correlations across the Chaudière-St. Francis interfluve are tentative; they must await solution of an interesting regional problem discovered by Lamarche (1971).

GLACIAL FEATURES

Two basic factors had considerable influence on the sediment and landform record of deglaciation: (1) the ice-margin retreated down the present topographic slope in most parts of the map-area from the height of land at the International Boundary to the St. Lawrence Lowlands; and (2) the ice sheet was not stagnant, and ice continued to flow towards the glacier terminus during the retreat of that terminus. Consequently, features relating to ice-margin retreat in southern Quebec are in sharp contrast to those of neighbouring areas of New England, where regions of kettled, ice-contact stratified drift have led to current hypotheses of the stagnation of ice masses (Borns, 1970; Stewart and MacClintock, 1969, p. 44-45), and where the ice margin retreated up-slope from the sea coast to the height of land.

Striations

Glacial striations and streamline features, known from the work of the authors and other published sources, are shown on the map. In cases where former workers did not discuss the basis for assigning flow directions, arrows have been omitted from the figure. In some reports authors assigned arrows on the basis of criteria that are no longer considered valid; in others, editorial errors have been made. [1]

[1] Although some symbols are shown indicating northward flow in the Beauceville map-area (Gadd, 1964b), these were unintentional and represent an editorial oversight on the part of the author.

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Where it was possible to determine ice-flow direction, the symbol carries a directional arrow. The common criterion is the miniature crag-and-tail feature; crystals of pyrite and other minerals in slate and schist were relatively resistant to glacial abrasion and protected an elongate tail or ridge of host rock on their lee sides. Tails also have been observed down-glacier from quartz veins, resistant clasts in agglomerate and coarse-grained sedimentary rocks, and relatively resistant grains in igneous rocks. Lengths of such tails vary directly with the diameter and hardness of the clast or crystal. Where two directions of ice flow are preserved, it is common to find short, triangular tails on the lee sides of resistant material, with the two sides of the triangle parallel to the two principal flow directions. Most striations recorded are interpreted as having been inscribed during the last glaciation.

Striated quartz veins in some places protect a tail of host rock on the downstream side but, more commonly, where differential erosion has removed the striated surface of the host-rock, the striated surface of quartz veins is the only source of ice-flow information (fine striations on the highly polished surfaces of the veins are seen readily in reflected light or where the surface is rubbed with a soft lead pencil).

Detailed mapping (McDonald, 1966, 1967, 1969; McDonald and Shilts, 1971; Shilts, 1970, 1971) has shown that till fabrics, till provenance, paleo-currents, and distribution of proglacial sediments with respect to ice fronts in the middle St. Francis and upper Chaudière valleys all confirm a regional ice-flow direction from northwest to southeast. Striations observed in several parts of the area record flow at significant angles to the regional flow trend and appear to be associated with two phenomena: (1) late movements of the retreating lobate glacier margin that were controlled to some extent by northeast trending valleys while the ice margin was calving into proglacial lakes; and (2) late-glacial rejuvenation of an area of ice dispersal located on the interfluve between the Chaudière and St. Francis rivers (see discussion under Deglaciation).

Delineation of Ice-front Positions

The present drainage of southern Quebec is generally north or north-westward to the St. Lawrence River. Retreat of the main ice front north-westward was, therefore, down the regional slope. Consequently, as long as the ice front stood against Appalachian slopes south of the St. Lawrence Lowlands, meltwater was ponded at or near the ice front in lakes that spilled southward or eastward into the St. John, Kennebec, Connecticut, and Hudson River drainage basins. Below about 1,500 feet, sediments that accumulated near ice fronts comprise more glaciofluvial and glaciolacustrine deposits than till; above 1,500 feet, the reverse is true. All accumulations that owe their linear continuity, their locally abnormal thickness, and their topo-graphic expression to formation at an ice front are included in the genetic landform term "moraine". Whether sediment in the moraine is stratified or not is largely a function of the availability of water to sort the sediment and of basins in which to deposit it. Below 1,500 feet, the ice front stood in glacial lakes along much of its length. It is thought that this greatly influenced the sorting and deposition of material at the ice front and led to the predominance below 1,500 feet, and in valleys, of stratified sediment in the moraines.

Ice-front positions shown on the map are based on locations of moraines and ice-marginal drainage channels. Those features are linked into systems on the basis of altitude, direction of glacier flow, and occurrence of glaciolacustrine features relative to possible lake outlets. A significant problem in correlation of ice-marginal features in southern Quebec, besides the fact that large areas are as yet unmapped, is that lobes of the ice margin, extended up valleys, produced loop moraines there over a period of time, but produced no clearly correlative separate features around highland barriers and promontories; thus, several valley moraines might correlate with only one in the vicinity of high ground.

Only locally is there stratigraphic evidence compatible with minor readvance of the glacier margin during deglaciation. With particular reference to the Drummondville and St. Narcisse moraines, Gadd denies any intent on his part to show these features as other than recessional moraines. There are no stratigraphic data that prove any significant readvance associated with these features. This does not, of course, preclude the presentation of such proof at some time in the future.

DEGLACIATION

For the sake of convenience, interpretation of the deglaciation of southern Quebec is divided into two parts: (1) deglaciation of the Appalachian region; and (2) deglaciation of the St. Lawrence Lowlands.

Deglaciation of the Appalachian Region Between the International Boundary and the Highland Front Moraine

Northwestward retreat of an active ice front

From Sherbrooke eastward to Megantic, in a 20-mile-wide belt adjacent to the International Boundary, regional ice flow was consistently toward the south and southeast. Ice-flow direction is based on abundant crag-and-tail features, till fabrics, and on mineral, trace-element, and rock-dispersal data (McDonald and Shilts, 1971; Shilts, 1970, 1971). Glacial retreat from the International Boundary northward through the Lake Megantic basin in the upper Chaudière valley, and northwestward from New Hamphire to Sherbrooke and then down the middle St. Francis valley to Drummondville was characterized by backwasting of an active ice margin. Several end moraines were constructed during this phase of deglaciation.

The Frontier Moraine in the upper Chaudière valley (Shilts, 1970) is the oldest known moraine in Quebec. It occurs between 1,500 and 1,800 feet altitude on the north and northwest facing flanks of the height of land that forms the International Boundary between Quebec and Maine-New Hampshire. It consists of a series of discontinuous gravel and till ridges up to 100 feet in height. The ridges are associated with well-developed meltwater channels, either parallel to or leading away from the former ice front. The Frontier Moraine represents the first end moraine to be formed west and north of the Maine-New Hampshire highlands.

Lake-bottom organic sediment from Unknown Pond, Maine, a few hundred yards east of the International Boundary and east of the Frontier Moraine, gave a radiocarbon date of 14,900 ± 220 years (GSC-1339; see Table 1), and

a compatible date of 12,700 ± 280 years (GSC-1404) on organic matter 10 cm above the base of the core. Thus, south-trending drainage systems in Maine were free of ice as early as 12,700 years B.P. and possibly as early as 14,900 years B.P. The older date should be interpreted with caution because it is almost 2,000 years older than any other date in the region and therefore may be anomalous.

The Woburn Moraine marks the next younger recognizable ice-front position in the upper Chaudière valley. It is composed mostly of ice-contact stratified drift and merges with the Frontier system in the highlands east and west of the Lake Megantic-Spider Lake (Lac-aux-Araignées) basin. At the time of formation of the Woburn Moraine, a small lake, draining through a col with a present altitude of about 1,400 feet a.s.l., was ponded in Mud Brook valley. The altitude of this outlet requires free drainage below 1,400 feet through the Maine highlands to the sea while ice was retreating from the Chaudière basin. As the ice front retreated north and northwest, the lake expanded and filled the Chaudière valley and its eastern tributaries until the ice front had retreated at least as far north as St. Gédéon.

The Ditchfield Moraine is the most strongly developed complex of ice-front features in the Chaudière Valley. It consists of morainic ridges of till and gravel, an ice-contact delta, and hummocky outwash deposits connected by deep meltwater channels cut in rock. It is traceable along a northeast-trending line from Mount Megantic to the headwaters of the Nebnellis River where it apparently merges with the Woburn-Frontier system.

During the formation of the Ditchfield Moraine, ice thinned over Mounts Ste. Cécile and St. Sébastien to the point that southeastward flow of ice into both the Lake Megantic basin and the Chaudière Valley was impeded. A broad lobe developed, flowing southwest up the Chaudière Valley, and its east side coincided with the portion of the Ditchfield Moraine east of Lake Megantic. Its western margin followed an arc from the mouth of Victoria River to the south end of Mount Ste. Cécile.

Late retreat positions of the ice front are not well marked in the Chaudière Valley. A belt of till and ice-contact stratified drift features which pass through the town of Lac-Mégantic has been named the Megantic Moraine Complex and best serves to illustrate the relationship of the Chaudière Valley lobe to ice lying to the west (Fig. 1). Retreat of the lobe was apparently rapid; moraines are poorly developed and deposits of the above-mentioned 1,400-foot lake are rare. Neither the full extent of the 1,400-foot lake nor the configuration of the ice front at the time of lake lowering have been established. Deltaic deposits at 1,425 feet a.s.l. in the vicinity of Portage Lake suggest that the lake extended north at least to 46° 00' latitude along the east side of the Chaudière Valley lobe.

In and near the middle St. Francis River valley, and simultaneously with retreat in the upper Chaudière Valley, retreat of ice northwestward from the International Boundary toward Sherbrooke was accompanied by the formation of many small moraines of till and/or gravel, and by the incision of meltwater channels along the ice front (McDonald, 1969). Large volumes of sandy "ablation" till, ice-contact gravel, and hummocky terrain in a 5-mile-wide patch southeast of Bury, has been interpreted as the product of melting of a small ice mass stranded on the down-ice side of the small interfluve separating the St. Francis and North rivers.

As the retreating glaciers thinned, lobes were diverted around each end of the Stoke Mountains. The lobes coalesced south of the mountain, and

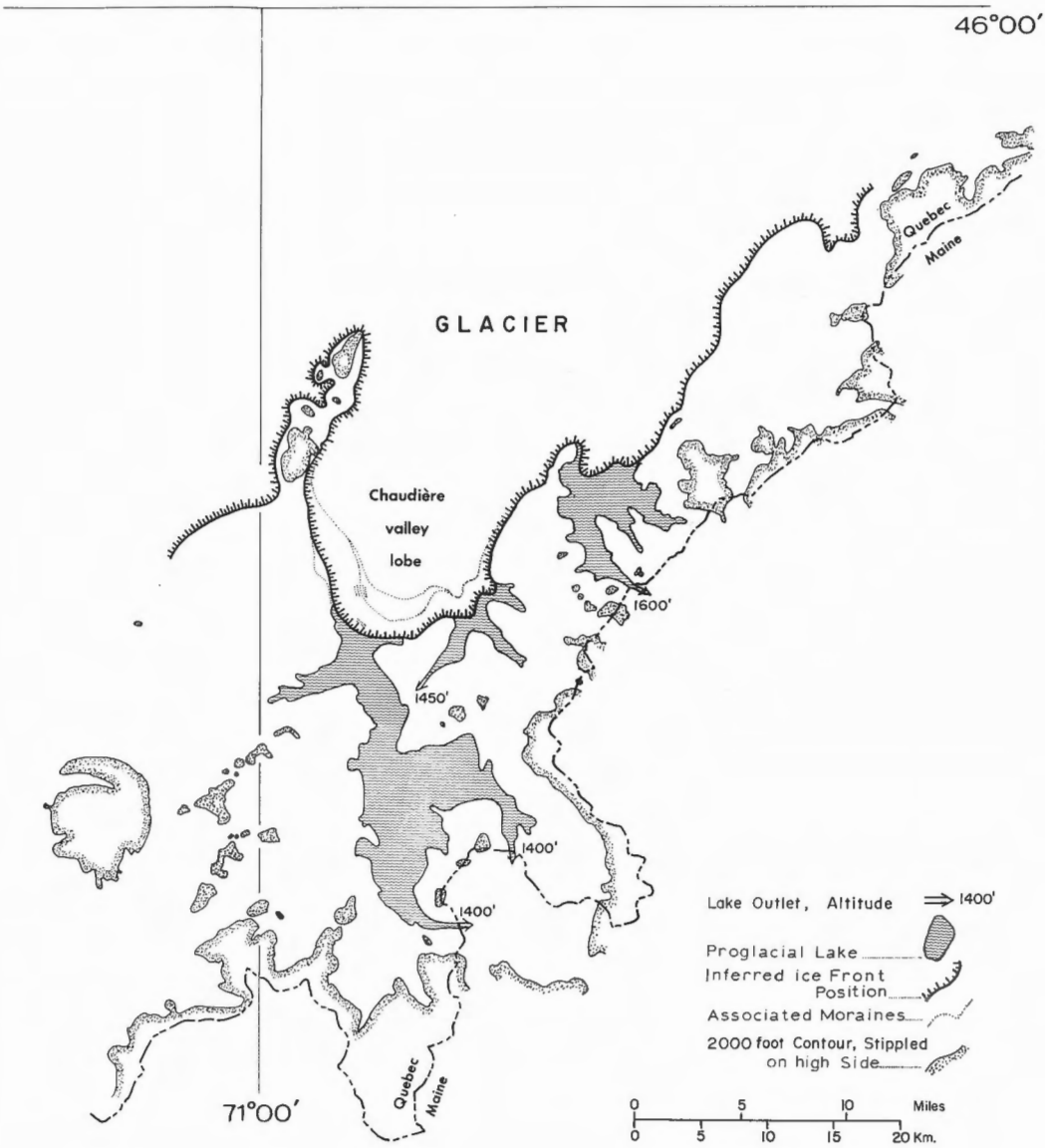

Figure 1. Ice-front configuration during formation of Megantic Moraine Complex, showing relationship of 1400-foot and higher-level lakes to Chaudiere Valley lobe.

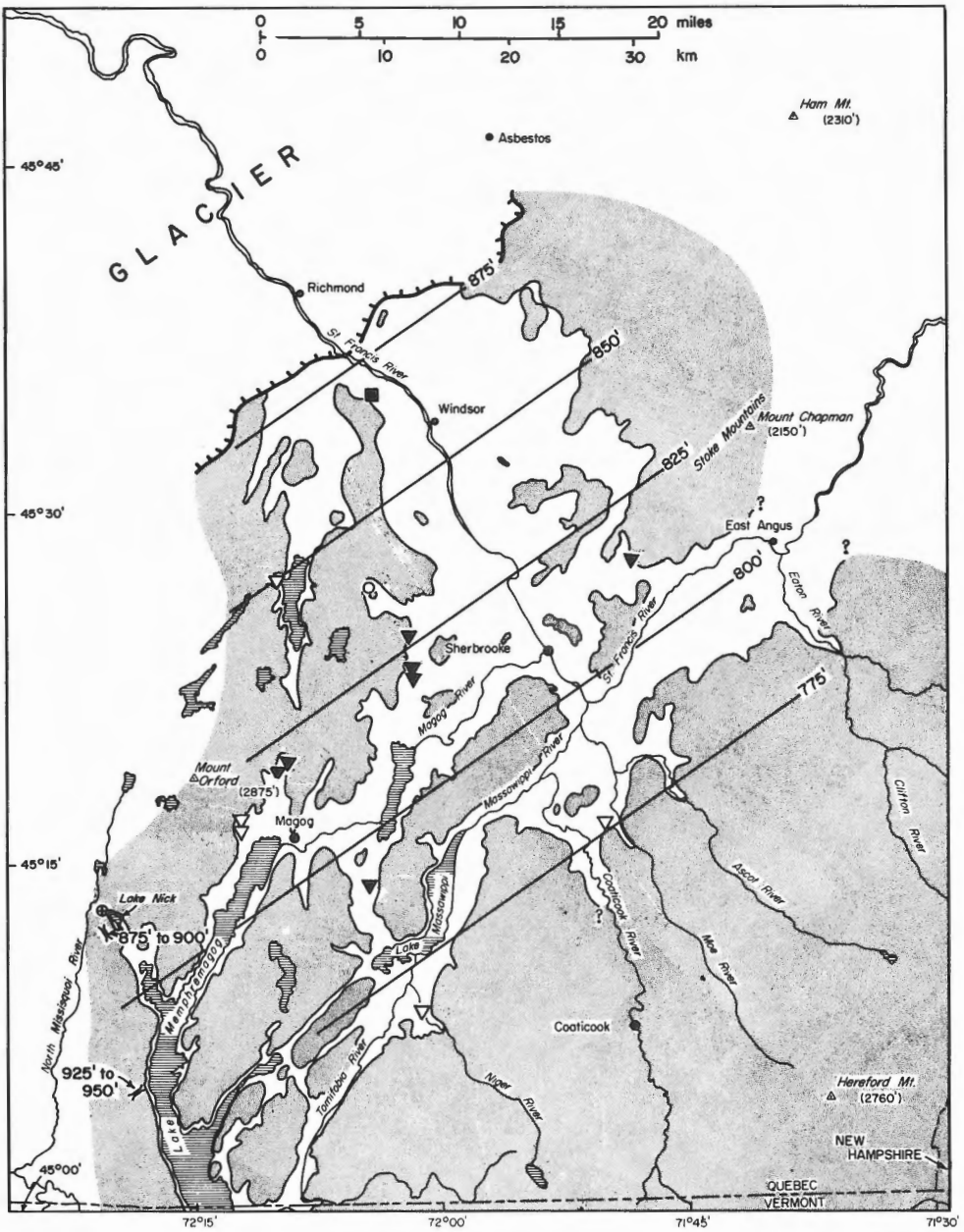

Figure 2. Extent of Sherbrooke phase of Glacial Lake Memphremagog after formation of Cherry River Moraine, showing isobases (feet a.s.l.) on the former water plane.

the prominent Stoke Mountain Interlobate Moraine was built in the recess where the two lobes came into contact. The moraine is composed of ice-contact gravel and sand and is continuous for 12 miles from Martinville north to the Stoke Mountains. Water flowed south along the axis of the moraine due to the presence of ice on both sides. The retreating lobes finally separated at the north end of the moraine; one lobe retreated northwestward, the other northeastward. During this general retreat, glacial lakes at the ice front first drained southward into the Connecticut River valley, later southwestward toward the Lake Champlain basin, and dropped to lower and lower levels as new outlets were uncovered.

The last well-defined moraine to be built south of the northwest flank of the Appalachian Highlands was the Cherry River Moraine (McDonald, 1968). It has been traced from the west side of the Sutton Mountains near Lake Brompton, southward around a major lobe occupying the Magog and St. Francis Valleys, through Sherbrooke and to the western flank of the Stoke Mountains. Throughout this distance, the moraine is composed mostly of large, discontinuous accumulations of ice-contact stratified drift. Stratigraphic evidence indicates either that the ice readvanced at least three miles to the moraine, or that there was a fluctuating ice front for at least three miles behind the moraine. The lake that existed at the ice front in the St. Francis River valley during formation of the Cherry River Moraine has been named the Sherbrooke phase of Glacial Lake Memphremagog (Fig. 2; McDonald, 1968). It drained westward into the Missisquoi River system and thence to the Lake Champlain basin. The water plane defined by near-shore features has been tilted to the northwest at 3.8 feet per mile. This lake drained when ice retreated northwestward from the bedrock ridge between Windsor and Richmond.

Late-glacial area of ice dispersal near Thetford Mines

Evidence from north-trending crag-and-tail features (Lamarche, 1971), many of which are minute, clearly indicates that, during the general thinning of the ice sheet over the southern Quebec Appalachians, a mass of ice persisted in a large area in the vicinity of Thetford Mines. This remnant ice mass apparently acted as a dispersal centre from which ice flowed radially outward (Fig. 3). The northward component of this flow is recorded north of a line approximately between St-Gérard (southeast of Lac Aylmer) and St-Martin-de-Beauce. South of this line, ice-flow phenomena record only southward and southeastward ice flow and it is difficult to determine whether particular striations resulted from the main regional flow or from later outflow from the local centre. The authors, in conjunction with Lamarche, have extended the observations of north-trending striations eastward as far as Beauceville. It appears likely that the whole set of striations oriented north-south in this area on the map is associated with this northward flow. North-trending striations exist on the bottoms of grooves that trend east-southeast; thus the local northward-flow event postdated regional southeastward flow.

Although little is known about this ice dispersal area, speculations can be made about its formation and regional influence:

(1) It is tempting to relate its location on the Chaudière-St. Francis interfluve to a substantial volume of ice having been "stranded" in the lee of the high Appalachian bedrock ridge northwest of Thetford Mines, as the main ice sheet thinned over the ridge during deglaciation;

TABLE 1: RADIOCARBON DATES

Group I: Lake-and bog-bottom dates south of the St. Lawrence and above or near marine limit

Lab No.	Date (years B.P.)	Altitude (in feet)	Material	Location	Collector and/or Reference
GSC-1339	14,900±220	1604	Moss and calcareous gyttja at base of organic core	Unknown Pond	Shilts & Mott (unpub.)
GSC-1404	12,700±280	1604	Non-calcareous gyttja 10 cm above GSC-1339	Unknown Pond	Shilts & Mott (unpub.)
*GSC-1344	13,000±290	414	Non-calcareous gyttja at base of organic core	Mt. St. Bruno	LaSalle & Mott (unpub.)
GSC-312	12,640±190	1325	Non-calcareous gyttja at base of organic core	Petit Lac Terrien (St. Nazaire-de-Buckland)	Gadd, 1964a
*GSC-419	12,570±220	850	Non-calcareous plant detritus in silt at base of organic core	Mt. St. Hilaire	LaSalle, 1966
GSC-1248	11,200±200	1978	Non-calcareous gyttja at base of organic core	Boundary Pond	Shilts & Mott (unpub.)
GSC-1294	11,200±160	2124	Non-calcareous gyttja at base of organic core	Lac Dufresne	Shilts & Mott (unpub.)
GSC-420	11,020±330	1360	Non-calcareous gyttja at base of organic core	Barnston Lake	McDonald, 1968
GSC-1289	11,000±240	1875	Non-calcareous gyttja at base of organic core	Trout Lake	Shilts & Mott (unpub.)
GSC-1353	10,700±310	1333	Non-calcareous gyttja at base of organic core	Lac-aux-Araignées	Shilts & Mott (unpub.)
GSC-248	9,130±150	1545	Non-calcareous gyttja from base of organic core	St. Benjamin bog	Dyck *et al.*, 1965
GSC-627	9,130±150	650	Non-calcareous gyttja from base of organic core	Valcourt bog	Lowdon *et al.*, 1967

* Dates outside the map area

Group II: Dates on shells from marine sediment in lower St. Lawrence River, east of Quebec City

Lab No.	Date (years B.P.)	Altitude (in feet)	Material	Location	Collector and/or Reference
*GSC-102	12,720±170	550	*Yoldia arctica*	Trois Pistoles, P.Q.	Lee, 1963

* Dates outside the map area.

Group III: Dates on Champlain Sea marine shells in marine sediment

Lab No.	Date (year B.P.)	Altitude (in feet)	Material	Location	Collector and/or Reference
GSC-936 (50% leach)	12,000±230	400	Mixed species	L,Avenir, P.Q.	McDonald, 1968
GSC-505 (10% leach)	11,880±180	400	Mixes species	L,Avenir, P.Q.	McDonald, 1968
GSC-475 (10% leach)	11,530±160	475	Mixed species	Ste. Christine, P.Q.	McDonald, 1968
GSC-475-2 (50% leach)	11,500±160				
GSC-187 (10% leach)	11,410±150	400	Mixed species	Kingsey Falls, P.Q.	Gadd, 1964a
*GSC-842	11,600±150	557	Mixed species	Meach Lake, P.Q.	Buckley, 1968
*GSC-1013	11,800±210	340	Mixed species	Maitland, Ont.	Henderson, 1969
GSC-1444	10,100±150	450	Hiatella arctica Macoma balthica	Charette, P.Q.	Gadd (unpub.)
GSC-1451	10,000±150	210	Hemithyris psittacea?	St. Nicholas, P.Q.	Gadd (unpub.)
GSC-1508	9,960±150	210	Mytilus edulis	St. Nicholas, P.Q.	Gadd (unpub.)

* Dates outside the map area.

Group IV: Dates on marine shells from ice-contact deposits in St. Narcisse Moraine and presumed equivalents

Lab No.	Date (years B.P.)	Altitude (in feet)	Mineral	Location	Collector and/or Reference
GSC-1235	11,600±160	582	Shells from glacio-marine sediment	Notre-Dame-des Laurentides	LaSalle (unpub.)
GSC-1232	11,100±160	350	Marine shell fragments from till	Beauport, P.Q.	LaSalle (unpub.)
GSC-1526	11,500±630	300	Foraminifera from till in core of St. Narcisse Moraine	Barrage St. Narcisse, P.Q.	Gadd (unpub.)

Group V: Dates on bog bottoms below Champlain Sea limit in St. Lawrence Lowlands

Lab No.	Date (years B.P.)	Altitude (in feet)	Mineral	Location	Collector and/or Reference
L-441 C	9,500±300	300	Non-calcareous gyttja from base of organic core	St. Germain bog	Terasmae (1960)
Gro-1922	8,480±80	425	Bog-bottom organic sediment	St. Adelphe	Gadd (1960a)

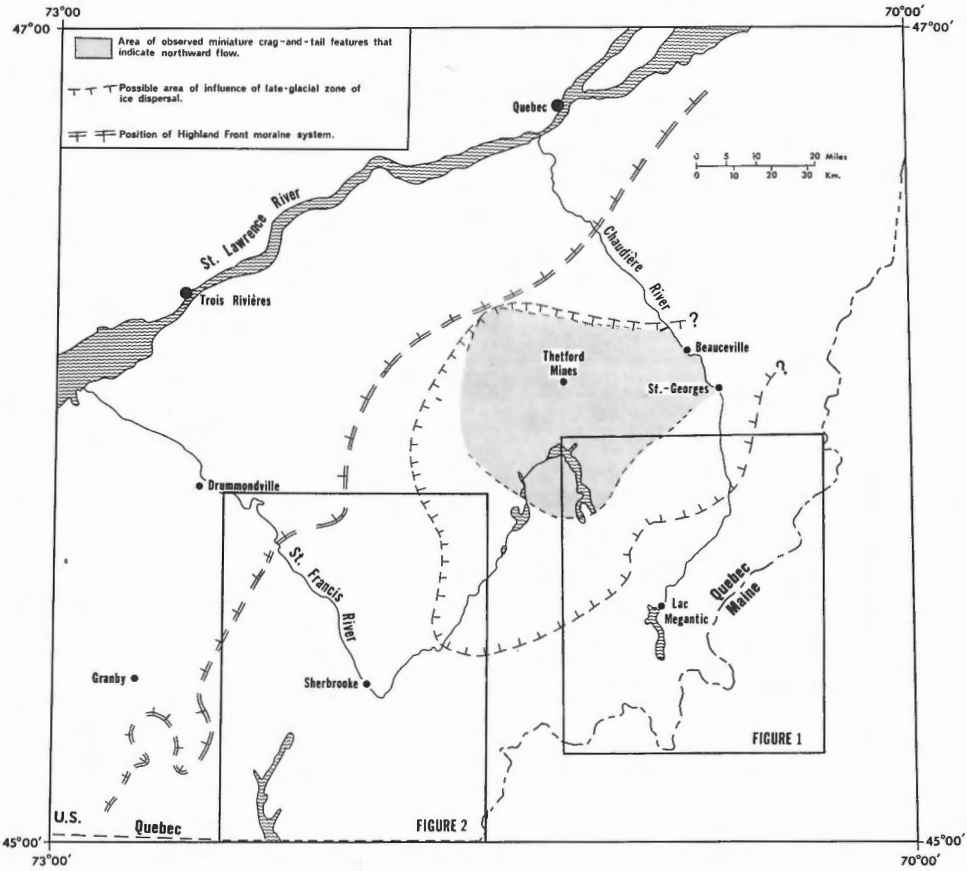

Figure 3. Possible area of influence of late-glacial zone of ice dispersal, showing area in which miniature crag-and-tail features indicate northward flow of ice. Also shown are position of Highland Front morainic system, and areas shown in Figures 1 and 2.

(2) Flow northward may have been in response to one, or more, of the following factors: (i) the stranding process envisaged above would have isolated a mass of ice several hundred feet thick, thick enough to flow radially outward for a short time under its own weight; (ii) northward flow may have resulted in part from drawdown into proglacial lakes or marine water; or (iii) the stranded mass of ice may have been nourished by precipitation derived from Glacial Lake Memphremagog (see above) or from the extensive late-glacial water bodies in the St. Lawrence Lowlands;
(3) A rigorous climate associated with the large ice mass might have delayed the introduction of plant life to the region and thereby might explain the many relatively young radiocarbon dates (9,000 to 11,200 years B.P.; Table 1; map) on bog-bottom and lake-bottom plant remains. Rigorous climate might also explain occasional occurrences of fossil ice-wedge casts near Sherbrooke and Thetford Mines (Dionne, 1969);
(4) It is possible that the ice that retreated northeastward from the east flank of the Stoke Mountain Interlobate Moraine was flowing under the influence of this dispersal centre. After retreat from this moraine, a glacial lobe flowed southwestward down the St. Francis River valley east of the Stoke Mountains and terminated at a moraine across the valley at East Angus. The moraine at East Angus is composed of till in which most of the clasts are angular and sheared masses of "varved" silt and clay. This is interpreted as evidence of readvance of the ice over lake sediments. This moraine, tentatively correlated with the Cherry River Moraine (McDonald, 1968), may also be an indication of readvance nourished from the local dispersal area;
(5) The northward-flow event provides a regional framework compatible with observations by Cooke (1937) that certain asbestos-bearing boulders had apparently been glacially displaced 5 miles northward near Thetford Mines. It could also account for north-northeastward displacement of granodioritic boulders some 12 miles from the Winslow stock near the south end of Lake St. Francis (Shilts, 1970; McDonald and Shilts, 1971); and
(6) With north-trending striations traced east as far as Beauceville, it is likely that this late-glacial dispersal area covered the central part of the Chaudière River valley. This may account for the lack of well developed morainic and glaciolacustrine features in this part of the valley.

It will be necessary to investigate the interfacial relationships between the retreating main continental glacier and ice of the local dispersal area, and the influence of north-flowing ice on the Highland Front Moraine. A considerable body of data is also required on the areal extent of the north-trending striations, on the occurrence of northward dispersal of materials from their sources, and on the distribution of and paleocurrents in late-glacial stratified sediment bodies. Limits on the areal extent of this dispersal centre on Figure 3 are based on the present availability of these types of data.

Deglaciation of the St. Lawrence Lowlands

When the margin of the main ice sheet had retreated to the sharply defined front of the Appalachian highlands in the area of Richmond-Asbestos-Victoriaville - St. Sylvestre, general southeasterly flow maintained the ice in contact with the hills while the glacier surface was lowered by melting several hundred feet of thickness (a similar situation existed during formation of the Frontier Moraine against the Boundary Mountains). In the Chaudière Valley, meanwhile, a deep lobe retreated from Vallée-Jonction to

St. Anselme. Eastward from there and parallel to Appalachian bedrock structure, several ice-marginal positions are marked by large accumulations of ice-contact gravel and sand in the vicinity of St. Philémon, St. Nazaire-de-Buckland, and the position between St. Anselme and St. Raphael that appears to be correlative with the St. Antonin Moraine (Lee, 1962) of the Rivière-du-Loup region (northeast of the map-area covered by this report). The complex of moraine features produced during this phase has been named the Highland Front moraine system (Gadd, 1964a). Southwestward from the St. Francis River the Highland Front moraine system is composed of large, although separate, accumulations of ice-contact gravel and sand. A low mass of hummocky ice-contact gravel in the vicinity of Dunham, about 8 miles north of the Vermont border, is the most southerly part of the moraine recognized in Quebec. A large accumulation of gravel south of Frelighsburg (one mile north of Vermont), may be part of the Highland Front system but more detailed local work would be necessary to substantiate this. In the New York State portion of the Lake Champlain basin, Denny (1966) has described a "mountain-front morainic system" that he correlated tentatively with the Highland Front system.

Along the entire length of the Highland Front moraine, only two exposures of till over stratified sediments have been seen that are compatible with, but that do not require, readvance of about 3 miles to the location of the moraine. Elsewhere the moraine appears to be simply a halt in the general recession.

A number of moraines and ice-marginal positions, particularly those formed by major lobes in areas of low topographic gradient such as in the Lake Champlain basin, may correlate with the Highland Front system because of the time-span necessary to reduce the bulk of the ice sheet by some 600 to 800 feet of thickness along the critical zone between Lake Champlain and Quebec City. During this time, ice-marginal drainage grew from minor local drainages of isolated basins into an integrated drainage system connecting the Lake Champlain basin to the Gulf of St. Lawrence and releasing northward waters that were ponded in major valleys, such as the St. Francis and Chaudière, and that had previously drained eastward and southward as outlined above.

The Highland Front moraine system, therefore, is considered to represent an important phase in the history of ice margin recession in Quebec. The wasting of ice in the St. Lawrence Lowlands after construction of the moraine was the key control factor in the northward expansion of glacial lakes in the Lake Champlain basin and also during the inland migration of salt water of the Champlain Sea. In this paper, the Champlain Sea is considered a late-glacial body of brackish to salt water that existed in the St. Lawrence Valley upstream from Quebec City (Gadd, 1964a). Lee (1963) has shown that the sea was in the vicinity of Trois Pistoles, Quebec, at least 12,720±170 years B.P. (GSC-102); the shells dated were from marine clay (550 feet a.s.l.) lying on the distal side of the St. Antonin Moraine, which we correlate with the Highland Front moraine system. Lee has interpreted this as a maximum date for formation of the St. Antonin Moraine because the clay underlies marine deltaic sand derived from outwash in pre-St. Antonin time. This interpretation is supported by the age of lake-bottom gyttja

12,640±190, GSC-312; map) from Petit Lac Terrien, in the vicinity of St. Nazaire-de-Buckland, south of parts of the moraine system. A minimum date for retreat of the ice from the Highland Front position is provided from the oldest known date on shells from the Champlain Sea (12,000±230, GSC-936, L'Avenir, Que.). A bog-bottom sample above the Champlain Sea marine limit on Mont St. Hilaire, about 30 miles northwest of the Highland Front moraine system, has been dated at 12,570 ± 220 B.P. (GSC-419; LaSalle, 1966; Terasmae and LaSalle, 1968). The Mont St. Hilaire and Lac Terrien dates may indicate that by about 12,500 years B.P. the Appalachian region of southern Quebec was ice free and Highland Front moraine system had formed.[1]

During retreat of the ice margin to the vicinity of Drummondville, ice continued to block incursion of the sea into the lowlands, thereby maintaining freshwater conditions in the St. Lawrence Lowlands. Evidence for this lies in non-fossiliferous rhythmites occurring at the base of Champlain Sea fossiliferous sedimentary sequences that post-date the Drummondville Moraine. In addition, there are no marine or glacio-marine features in the core of the Drummondville Moraine. The moraine has been shown on the map with a cross hatch pattern to indicate the belt or zone within which discontinuous isolated masses and ridges of morainic material may be found. These have been so modified by post-depositional action of waves and currents that they commonly appear at the surface as masses of marine beach material. However, the glacial and glaciofluvial nature of exposed core materials in this belt allows its identification as a moraine. Dispersal of materials by post-glacial processes leaves doubt in some cases as to the exact location of the remnant of the original material and therefore causes the feature to be given a map distribution that far exceeds its significance as a glacial feature. Nonetheless, its relationship to probable glacial-lake sediments that predate marine sediments suggests northward expansion of glacial lakes of the Lake Champlain basin into a broad area along the south side of the St. Lawrence Lowlands, prior to invasion of the lowlands by the sea. The only age inference for the Drummondville Moraine is that it pre-dates the Champlain Sea and would therefore be slightly older than 12,000 years B.P.

The youngest major moraine shown on the map is the St. Narcisse Moraine (Osborne, 1950; Karrow, 1959). Several writers have traced the moraine east and west of the area shown on the map, and it has been variously interpreted as to age. Lack of evidence of till overlying marine or other non-glacial deposits at places north of the moraine itself suggests that ice may not have readvanced to the position of the moraine, but rather that the moraine represents a halt in the recession. Minor fluctuation of the ice margin may have taken place during the building of the moraine. The core of the St. Narcisse Moraine in its type section contains clayey, till-like material that contains abundant foraminifera, a few shells of Portlandia sp., and minute shell fragments that may be Mytilus sp. About 3.7 grams of foraminifera collected from this material gave a radiocarbon age of 11,500±630 years B.P. (GSC-1526, Table 1). This indicates that the moraine was

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[1]A bog-bottom date of 13,000 ± 290 (GSC-1344; Table I; P. LaSalle, per. comm., 1971) from Mont St. Bruno, near Mont St. Hilaire, suggests that the Highland Front moraine system was formed slightly earlier than 12,500 B.P.

built under glacio-marine conditions and is, therefore, at least in part contemporaneous with the Champlain Sea at a time when relative sea level was higher then 475 feet a. s. l. Two marine shell dates, from presumed extensions of the St. Narcisse Moraine near Quebec City (P. LaSalle, oral comm. 1971; Table I) have given radiocarbon ages of 11,100 and 11,600 years B. P. (GSC-1232, GSC-1235). Where best known, the moraine lies below supposed maximum levels of the Champlain Sea and is modified by wave action. Reworked materials of depths of as much as 15 feet, and spit-like extensions of 30 to 50 feet in thickness, contain typical shore-facies shells of the Champlain Sea (including Balanus crenatus, Hiatella arctica, Macoma balthica, Mya truncata, Mya arenaria, Mytilus edulis, etc.). Such material resting on the crest of the moraine near the village of Charette, elevation ca. 450 ft. a. s. l., has a radiocarbon age of 10,100±150 years B. P. (GSC-1444) thus providing a minimum age for the moraine as well as a suggested date for the position of sea level at approximately 450 feet a. s. l. in that area; uplift was rapid following retreat of ice from St. Narcisse Moraine.

CHRONOLOGY OF GALCIAL RECESSION IN SOUTHERN QUEBEC

Figure 4 depicts schematically the spatial and temporal relationships of the events discussed in this paper. One problem that is evident from study of Table 1 and Figure 4 is that the "Group I" lake- and bog-bottom dates, that should give an indication of the minimum date of deglaciation, lag 1,000 to 2,000 years behind dates of deglaciation deduced from other evidence. For example, the Champlain Sea is thought to have been present in the St. Lawrence Lowlands as early as 12,000 years B. P. However, dates from the bottoms of organic accumulations in lakes and bogs located deep in the Appalachian Highlands (at localities where deglaciation clearly preceded the Champlain Sea episode) commonly range from 9,000 to 11,200 years B. P. (see Table 1, GSC-1248, 1294, -420, -1289, -1353, -248, and -627). These dates appear to be anomalously young and suggest that deposition of organic material was delayed at most sites, possibly by a severely cold climate related to the local glacier dispersal area discussed above. Most cored lakes and bogs are in bedrock basins which should have held water as soon as they were ice free. Some cores do, however, yield "old" dates. The oldest date obtained on post-glacial material in Quebec is 14,900±220 years B. P. (GSC-1339) and, although the sample was thoroughly leached before dating, it may reflect contamination by calcareous material that was deposited with the gyttja and mosses that were dated. A date of 12,700±280 years (GSC-1404) obtained on non-calcareous gyttja 10 cm above GSC-1339 tends to support the apparent antiquity of the latter date.

The above discussion assumes that marine shell dates are comparable to dates on terrestrial plant material. Dates on shells from high-level beaches and sediments throughout the Champlain Sea basin are internally consistent (see Table I) but may possibly be reflecting some constant contamination inherent in carbonates formed in a marine environment. Although such contamination has been suggested by many workers, marine shell and terrestrial plant material from the same sand lamination in the District of Keewatin have given ages of 4,900±140 and 4,950±140 B. P., respectively (GSC-1121, GSC-1150; B. C. McDonald and R. G. Skinner, oral comm.). Seaweed in a bed between shell layers near Ottawa, Ontario, has a date of 10,800±150 years B. P. (GSC-570) that is compatible with those of the shells above and below (10,620±200, GSC-587, and 10,880±160, GSC-588, respectively; Mott, 1968).

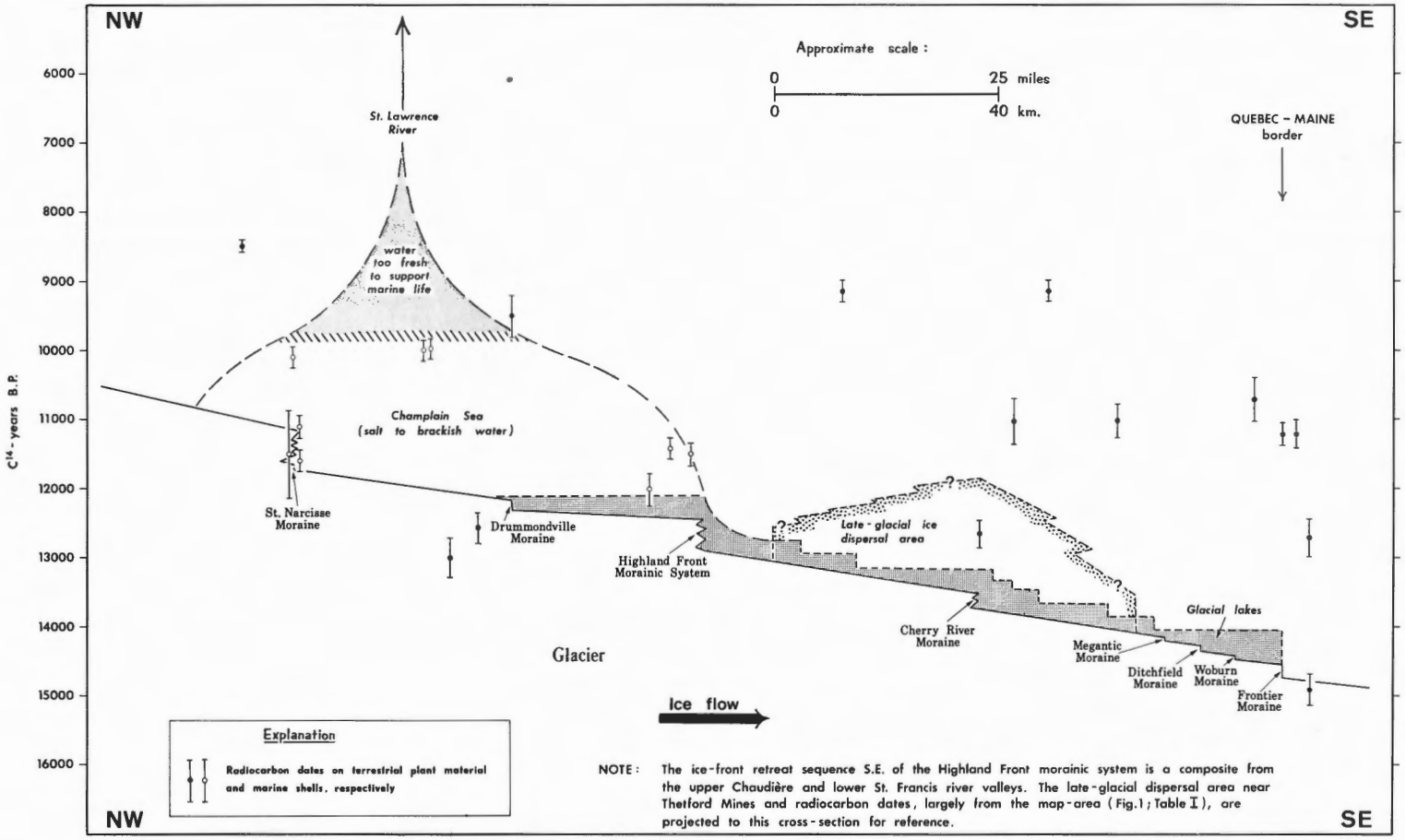

Figure 4. Schematic representation of deglacial events and chronology in Southern Quebec.

From the data presented in the preceding sections, and from radiocarbon dates listed in Table 1, temporal relationships of events that took place during deglaciation may be summarized as follows:

1) Deglaciation of the area between the Frontier Moraine and the St. Narcisse Moraine may have taken as long as 3,500 years between about 15,000 C^{14} years B.P. and 11,500 C^{14} years B.P. This time span is suggested by limiting dates a) 14,900±220 (GSC-1339) for material from the base of a core from Unknown Pond, Maine (the pond is on the distal side of the Frontier Moraine) and b) dates of 11,600 to 11,100 B.P. (Table I) from shell fragments and foraminifera found in till and glaciomarine sediments associated with the St. Narcisse Moraine.

2) From the time of formation of the Frontier Moraine, the Dead-Kennebec River systems, that cut through the highlands of central Maine, must have been ice free below 1,400 feet; the major glacial lake impounded in Quebec was in contact with the glacier at ice-front positions younger than the Frontier and drained eastward through central Maine via the 1,400-foot col east of Woburn. The concept that central Maine should have been ice free as early as about 15,000 years ago is in conflict with concepts of deglaciation proposed by Borns (1967; pers. comm., 1970) who contends that ice was actively building moraines along the east coast of Maine 1,500 to 2,000 years after this date.

3) During deglaciation, a large mass of ice that persisted in the vicinity of Thetford Mines was a glacier dispersal area and supported radial outward flow for perhaps as long as 2,000 years.

4) The Highland Front moraine system was formed about 12,500 B.P., or slightly earlier.

5) The Champlain Sea episode had begun by 12,000 years B.P. (GSC-936) suggesting that the glacier had retreated from the Drummondville Moraine position shortly before that time, freeing the narrows at Quebec City and allowing salt water to flood the region between the ice front and the Appalachian Highlands.

6) Ice stood at the St. Narcisse Moraine about 11,500 years B.P.

7) By 9,500±300 years B.P. (L-44IC) the level of the Champlain Sea had fallen below 300 feet a.s.l.

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