Correlation of Wisconsin glacial events between the Eastern Great Lakes and the St. Lawrence Lowlands

Corrélation entre les événements glaciaires wisconsinien de l'est des Grands Lacs et des basses terres du Saint-Laurent

A. Dreimanis

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Résumé de l'article

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CORRELATION OF WISCONSIN GLACIAL EVENTS BETWEEN THE EASTERN GREAT LAKES AND THE ST. LAWRENCE LOWLANDS

A. DREIMANIS, Geology Department, University of Western Ontario, London, Ontario N6A 5B7.

ABSTRACT The interrelationship of the Wisconsin glaciogenic events among the Upper St. Lawrence Lowland and the eastern Great Lakes, particularly the Lake Ontario basin is controlled mainly by 3 factors: 1) presence or absence of a glacial dam across the St. Lawrence Lowland; 2) isostatic lowering or rise of the outlet of Lake Ontario, related mainly to glacial loading or unloading in the Upper St. Lawrence Lowland; 3) shifting in the regional direction of glacial movement through the Upper St. Lawrence Lowland, upglacier from it, and in the Lake Ontario basin. Changes in the above conditions result in detectable changes in lake levels, and in compositional changes of tills in the Lake Ontario basin. Crosschecking of the above relationships supports the relative sequence already proposed. However, the chronology of the events which are older than reliable finite ^{14}C dates, may be reinterpreted by a comparison with oceanic stratigraphies. A possible re-interpretation of some late-glacial Late Wisconsin glacial fluctuations depends greatly upon the reliability of ^{14}C dates on shells and correct interpretation of till-like deposits. For those glacial fluctuations in the St. Lawrence Lowlands which lack ^{14}C dates, it is tempting to apply correlations with the ^{14}C dated stratigraphic units of the Great Lakes Region, but we have to consider also possible regional differences in glacial dynamics.

RÉSUMÉ *Corrélation entre les événements glaciaires wisconsinien de l'est des Grands Lacs et des basses terres du Saint-Laurent.* Ces rapports sont régis principalement par les conditions suivantes: 1) Présence ou absence d'un barrage glaciaire à travers les basses terres du Saint-Laurent. 2) Affaissement ou relèvement isostatique du déversoir du lac Ontario en fonction principalement de la surcharge ou de l'allègement glaciaire des basses terres du Saint-Laurent supérieur. 3) Changement de la direction régionale du mouvement glaciaire: traversée des basses terres du Saint-Laurent supérieur, remontée de celles-ci et entrée dans le bassin du lac Ontario. Selon les variations de ces conditions, des changements apparaissent dans le niveau du lac ainsi que dans la composition des tills du bassin du lac Ontario. Une vérification par recoupements de toutes ces interactions confirme la séquence des principaux événements de glaciation et de déglaciation déjà proposée. Toutefois, la chronologie des événements antérieurs aux dates déterminées avec certitude par le ^{14}C peut être réinterprétée au moyen d'une comparaison avec des stratigraphies océaniques. Une réinterprétation possible de certaines fluctuations tardiglaciaires dépend en grande partie de l'exactitude des datations au ^{14}C des coquillages et la justesse de l'interprétation de dépôts semblables aux tills dans les séquences océaniques.

РЕЗЮМЕ ВЗАИМОЗАВИСИМОСТЬ ВИСКОНСИНСКИХ ЛЕДНИКОВЫХ ЯВЛЕНИЙ В РАЙОНЕ МЕЖДУ ВОСТОЧНОЙ ЧАСТЬЮ ВЕЛИКИХ ОЗЕР И НИЗМЕННОСТЕЙ ВДОЛЬ РЕКИ СВ. ЛАВРЕНТИЯ. Взаимосвязь висконсинских ледниковых явлений в районах низменности верхней части долины реки Св.Лаврентия и восточной части Великих озер, особенно в бассейне озера Онтарио, регулировалось главным образом тремя факторами: 1) наличие или отсутствие гляциальной дамбы, перерезающей низменность реки Св.Лаврентия; 2) изостатическое понижение или повышение выхода из озера Онтарио, связанное главным образом с ледниковой нагрузкой и выгрузкой в низменности расположенной в верхней части долины реки Св.Лаврентия; 3) смещение в направлении вышеупомянутого района ледникового движения вдоль низменности верхней части долины реки Св.Лаврентия, поверх этой низменности и в бассейне озера Онтарио. Изменения в этих факторах дают о себе знать в способных к обнаружению изменениях уровней озерных вод и в изменениях состава тиллей в бассейне озера Онтарио. Перекрестная проверка вышеупомянутых связей подтверждает уже предложенную относительно последовательность. Однако, хронология явлений которые более старые чем надежная конечная датировка радиоуглеродным методом, может быть реинтерпретирована с помощью сравнения с океанскими стратиграфиями. Возможная реинтерпретация некоторых поздне-ледниковых, поздневисконсинских гляциальных колебаний зависит очень от надежности радиоуглеродной датировки раковин и правильной интерпретации похожих на тилли отложений. Что касается тех ледников, находившихся в низменности реки Св. Лаврентия, которые проявили колебания, то для них не существует радиоуглеродная датировка раковин. Желательно применить корреляции с колебаниями с радиоуглеродными стратиграфическими подразделениями но мы должны иметь в виду возможные районные различия в ледниковой динамике.

INTRODUCTION

The late Pleistocene events of St. Lawrence Lowlands (for their outline see Fig. 8-1 in BIRD, 1972) and the eastern Great Lakes (Fig. 1) are closely interrelated during both the glacial and nonglacial episodes. Thus, presently, and whenever St. Lawrence Lowlands have been free of glacial cover, they serve as the lowest outlet for the Eastern Great Lakes of North America and as their biologic connection with the Atlantic Ocean. The role of the Lowlands has been reversed when they were occupied by glacial ice: the glacial plug raised the lake levels in the area to the east, forcing the lakes to find other alternative higher outlets. Also, during the expansion of the late Pleistocene glaciers, St. Lawrence Lowlands channeled ice from the Laurentide ice sheet, into the topographic depression of Lake Ontario.

This paper will deal mainly with the interrelationship of the Upper St. Lawrence Lowland (west of Montreal) and the eastern Great Lakes, particularly Lake Ontario. The factors which may have influenced their geologic development during late Pleistocene will be discussed first, and the brief review of the presently generally accepted Wisconsin stratigraphy of the above areas will be expanded by suggesting — for discussions — some tentative correlations of late glacial events (14,000 – 10,000 years BP).

THE DRAINAGE OF EASTERN GREAT LAKES VIA ST. LAWRENCE LOWLANDS

During the non-glacial and partially glacial episodes, the drainage of eastern Great Lakes via St. Lawrence Lowlands was influenced by several factors which will be discussed briefly, as they are important for stratigraphic correlations of both above areas.

1) If the St. Lawrence Valley is free of glacial ice, the level of Lake Ontario is determined by the highest portion of the St. Lawrence River in the Frontenac Arch area (Fig. 1), which presently holds the lake level about 75 m above the sea. Besides minor meteorologically determined variations, this water level will undergo major changes under following conditions.

a) The isostatic uplift of the outlet area, supplemented by possible tectonic movements, particularly in the Frontenac Arch area, may slowly raise the Lake Ontario level. This has occurred, for instance, during the second half of the last or Sangamon Interglacial, when the Lake Coleman level rose from below the present lake level to at least 103.5 m above it at Toronto (KARROW, 1969). Even presently the Lake Ontario outlet is probably undergoing a slow uplift, as during the historical times, Prescott, Ontario (Fig. 1) has been rising about 0.35 m per 100 years, if compared to Hamilton, Ontario, which is at the west end of Lake Ontario (PRICE, 1954).

FIGURE 1. Location map. Double arrows: relatively low outlets of proglacial lakes; single arrows: higher outlets not discussed here.

Carte de localisation. Flèches doubles: déversoirs inférieurs des lacs proglaciaires; flèches simples: déversoirs supérieurs non décrits dans le texte.

b) The deepening of the St. Lawrence River by stream erosion may lower the Lake Ontario level, but it could have been significant only shortly after glacial episodes, while the erosion removed unconsolidated glacial or their meltwater deposits. Under the present or similar past situations, when the St. Lawrence River flows through a bedrock valley in its upstream portion, its downward erosion is insignificant. The deepening by glacial erosion, however, may account for some of the Lake Ontario level differences between various non-glacial episodes, which have been separated by glaciations.

c) Greatest lowering of the lake level in the Ontario basin occurred shortly after any complete removal of glacial load and glacial dams from the St. Lawrence Valley, while the Lowlands were still isostatically depressed and the ocean level was low. For instance, the early Lake Ontario Admiralty phase began with a lake level 11 m below the present sea level, or 86 m below the present Lake Ontario level (SLY and LEWIS, 1972).

A similar low-water phase must have existed in the Ontario basin at the beginning of Sangamon Interglacial, and later, during the Early Wisconsin, at the beginning of St. Pierre Interstadial, when deep valleys were cut in the Scarborough and Don Formations at Toronto, some of them extending below the present Lake Ontario level (KARROW, 1967, 1969, and references therein). Some of the buried valleys encountered by LEWIS and SLY (1971) off-shore at Toronto, may be of similar ages. No such valleys have been eroded in the mid-Wisconsin interstadial beds in the same Toronto area, suggesting that St. Lawrence Lowlands did not

become entirely ice-free during the middle Wisconsin interstadials.

d) Following the discharge of Great Lakes via Lake Ontario towards St. Lawrence Lowlands, another set of relatively low outlets of Great Lakes developed along the retreating and oscillating margin of the Laurentide ice sheet through the area between Georgian Bay — Lake Nipissing — Petawawa (Fig. 1). The outlets were particularly significant for draining the Great Lakes during the post-Algonquin time, beginning with about 10,400 years BP (KARROW *et al.*, 1975) and ending before 5000 years BP (LEWIS, 1968). For the various interpretations of the history of these outlets see PREST (1970), HARRISON (1972), CHAPMAN (1975) and the references therein. The post-Algonquin outlets were at their isostatically depressed lowest absolute elevations shortly after the ice sheet retreated from them; for instance, the resulting lake level of the Lake Hough phase in Georgian Bay was about 147 m below the present Georgian Bay level (or 30 m above the present sea level).

It is possible that similar relatively low level connections between the Huron-Georgian Bay basin and the Atlantic Ocean via St. Lawrence Lowlands existed also some time prior to the post-Algonquin time. The reason for such a belief is because of the findings of the remains of walrus and large whales in the beach deposits of Glacial Lakes Arkona and Whittlesey in eastern Michigan (HANDLEY, 1953; FARRAND and ESCHMAN, 1974; HARRINGTON, 1977). FARRAND and ESCHMAN (*ibid.*) propose that an eastern outlet for Lake Huron (via the St. Lawrence or Mohawk routes) existed during the Cary-Port Huron interval (= Mackinaw Interstadial of DREIMANIS and KARROW, 1972). HARRINGTON (*ibid.*) proposes that such a connection was present during the 13,000 — 12,000 years BP period. However, HANDLEY (1953) notes, that the walrus specimens show signs of human working. Further investigation of these remains of marine mammals is still required to determine whether the 'signs of human working' might not be caused by glacial abrasion. As the whale specimens have been submitted for radiocarbon dating HARRINGTON, *ibid.*, further speculation about their age may be postponed.

e) The competition between the isostatic uplift of St. Lawrence Lowlands and the postglacial eustatic rise of the sea level, followed by a subsequent differential uplift of the shore lines of various ages complicates the interpretation of the marine record of St. Lawrence Lowlands and its correlation with the time- and space-related hydrographic events in the adjoining areas. In spite of several former suggestions, that late Wisconsin Champlain Sea had entered the Lake Ontario basin, in the form of FAIRCHILD's (1907) 'Gilbert Gulf',

HOUGH's (1958) 'St. Lawrence marine embayment', or as a short period invasion by the Champlain Sea (COLEMAN, 1941; CHAPMAN and PUTNAM, 1966), no brackish water sediments or any other unequivocal evidence has been found that Champlain Sea had extended into the Ontario basin. PREST (1970) contends that the maximum westward extent of Champlain Sea has been as far as Brockville, Ontario (Fig. 1: 80 km short of Lake Ontario) up the St. Lawrence River, and to Petawawa up the Ottawa River. Admittedly, bones of walrus and narwhale have been found in the late Wisconsin beaches of the Ontario basin (COLEMAN, 1901; HARRINGTON, 1977), but these beach deposits contain also other bones, such as those of giant beaver and peccary, which, according to COLEMAN (1941) may be reworked from some older interglacial deposits. A glacially re-deposited walrus tusk, still bearing glacial striae and polish, and found in the London area, Ontario, has been shown to me by Mr. B. Deller.

f) Evidence of very high lake levels in the Ontario basin, particularly if they represent either an abrupt rise of the lake level, or if they follow a glacial retreat from this lake basin, suggest blocking of St. Lawrence Lowlands by a glacial dam. If the lake level in the Ontario basin was similar to that of late glacial Lake Iroquois, a complete blocking of St. Lawrence Lowlands has been concluded, and the most probable outlet was in the Rome area of northern New York, via the Mohawk River valley towards the Hudson River (Fig. 1). According to HOUGH (1958), the zero isobase of Lake Iroquois is estimated at about 100.5 m above sea level, south of Buffalo, N.Y. Around Lake Ontario, the Lake Iroquois shore line has been uplifted isostatically, with a strong tilting northeastward: from 110 m at the southwestern corner of the basin to 314 m above the sea level at its most northeasterly point (HOUGH, 1958).

In the Lake Ontario basin, lake levels similar to that of Lake Iroquois have been deduced from the Early Wisconsin (the Scarborough delta) and middle Wisconsin deposits (the Thorncliffe Formation) in the Toronto area (KARROW, 1967 and 1969; DREIMANIS, 1969; MÖRNER, 1971; BERTI, 1975). Some of these lake levels were even higher than that of Lake Iroquois. Explanations of the higher lake levels will not be discussed here, as they apply to outlets other than through St. Lawrence Lowlands. It may be mentioned that the top of the Scarborough beds is about 15 m below the Iroquois level in the Scarborough bluffs at Toronto (KARROW, 1967), but this elevation represents an erosional contact between the Scarborough Formation and the overlying Sunnybrook Till, rather than the original top of the Scarborough delta.

g) The comparison of ancient lake levels with the Iroquois level in the Ontario basin reveals also a partial

lowering of the ice dam in the central and lower parts of St. Lawrence Lowlands, resulting in dropping of the lake levels below that of the Iroquois. Thus successive short-lived lake phases, lower than Lake Iroquois, but higher than early Lake Ontario, are suggested by the shore lines of intermediate levels and intermediate ages between the above two, in the following sequence: Iroquois — Frontenac — Sydney — Belleville — Trenton — Admiralty phases, the latter marking the beginning of early Lake Ontario (MIRYNECH, 1967; PREST, 1970).

Similar intermediate lake phases probably existed also during the St. Pierre Interstadial, at its beginning and its end. However, no records on levels lower than Lake Iroquois have been found for Middle Wisconsin, nor for the Erie or Mackinaw Interstadials.

GENERAL GLACIAL CONDITIONS DURING THE WISCONSIN GLACIATION

A glance at any glacial map of Northeastern America, e.g. Fig. 15 in PREST, 1970, or Fig. 18-R in FLINT, 1971, shows that St. Lawrence Lowland is closer to the initial centres of glacial outflow in Labrador and in the Appalachian Mountains, than is the Great Lakes Region. Therefore it is not surprising to observe differences in the glacial records among both areas, for instance in Figures 2 and 3. Thus the Early Wisconsin glacial advance during the Nicolet Stadial or Bécancour Stade (Fig. 3), which invaded St. Lawrence Lowlands, did not extend into Lake Ontario. Later, during the mid-Wisconsin Port Talbot and Plum Point Interstadials, the Laurentide ice sheet retreated from eastern Great Lakes

FIGURE 2. Time-space diagram with the "short scale chronology" after DREIMANIS and KARROW (1972, Fig. 2). In the columns of the Lake Erie and Ontario basins and the St. Lawrence Lowland, glacial deposits are shown by slanted letters; nonglacial events, deposits and lake phases by vertical letters; radiocarbon dates as heavy dots with standard deviation as vertical lines, and the glacial margin as heavy line. Time-stratigraphic divisions are listed in the two right-side columns.

Diagramme spatio temporel selon la "chronologie courte" de DREIMANIS et KARROW (1972, fig. 2). Dans les colonnes des bassins des lacs Érié et Ontario, et dans celle des basses terres du Saint-Laurent, on désigne les dépôts glaciaires en italique, les événements non glaciaires, les dépôts et les phases lacustres en romain, les dates au radiocarbène par des points traversés par une verticale indiquant l'écart-type, et la marge glaciaire par une ligne grasse. Les divisions chronostratigraphiques sont inscrites dans les deux dernières colonnes.

FIGURE 3. Correlation between the eastern Great Lakes Region, the St. Lawrence Lowland and the southeastern Québec Upland, with a "longscale chronology" (after DREIMANIS and RAUKAS, 1975) applied to all three columns.

Corrélation entre la région est des Grands Lacs, les basses terres du Saint-Laurent et les hautes terres du sud-est du Québec selon la "chronologie longue" de DREIMANIS et RAUKAS (1975).

or oscillated in them. All this time the St. Lawrence Lowlands remained ice covered, although some areas on its south side, such as the Chaudière River Valley, were ice-free for a time more than 20,000 years BP (MCDONALD and SHILTS, 1971).

Judging from the lithology and fabric of tills, and also striae in the Upper St. Lawrence Lowland and the Ontario basin, both areas have been directly affected by the Laurentide ice sheet only, even though the ice flow directions did change during the Wisconsin glaciation because of shifting of the areas of glacial outflow (for local details see HOLMES, 1952; MacCLINTOCK, 1958; DREIMANIS, 1960; PECKOVER, 1961; MacCLINTOCK and STEWART, 1963; MacCLINTOCK and DREIMANIS, 1964; TERASMAE, 1965; HENDERSON, 1967, 1968; RICHARD, 1975, and the discussion in this paper).

Absence of typical Adirondack rocks in the tills of the Upper St. Lawrence Lowland suggests that the Adirondack glaciers did not extend into these Lowlands during the last glaciation. The Appalachian glaciers will not be discussed here, as they did not affect the Upper St. Lawrence Lowland. However, their indirect climatic influence, and their possible participation in the glacial

blocking of the lower portion of the Lowland is considered, when discussing the meltwater lakes and the glacial dynamics of the upper Lowland.

The absence of St. Pierre and Mid-Wisconsin organic deposits from the Upper St. Lawrence Lowland, while the St. Pierre Interstadial is well represented in the central Lowland, suggests that all the presently known glacial deposits of the upper Lowland are of Late Wisconsin age. If this assumption is true (not proven yet conclusively as pre-Late Wisconsin absolute dates are lacking), then the above absence of pre-Late Wisconsin deposits also indicates a more vigorous Late Wisconsin glacial erosion in the upper, than in the central St. Lawrence Lowland. This difference in glacial dynamics between the upper and the central Lowland areas is quite significant for stratigraphic correlations.

RADIOCARBON DATES

Though the carbon isotopes are discussed in detail by HILLAIRE-MARCEL (1977), a few brief comments pertinent to this region, may be mentioned here.

The finite radiocarbon age determinations are reported by many laboratories for the time span up to 50,000 yr BP, by a few — up to 70,000 yr BP, including also some St. Pierre interstadial dates (VOGEL and WATERBOLK, 1972: GrN-1711 and GrN-1799). However, the older is the materials dated, the more can the date be affected by natural contamination of the sample. Because of this, some stratigraphers do not trust those age determinations which are older than 32,000 years BP, e.g. MÖRNER (1972). Others, e.g. DREIMANIS and GOLDTHWAIT (1973), are considering those dates in the forty thousands relatively trustworthy if they have been determined on carefully sampled plant material, preferably wood, and if these dates cluster in groups, for the samples taken from stratigraphically well controlled sections.

KARROW and ANDERSON (1975, p. 1811) have recently discussed the "old carbonate errors in the dating of many materials, particularly marl, shells, gyttja, and aqueous plant material", and they also "regard with suspicion bog bottom dates as minimum dates for deglaciation" as some kettle lobes "have been occupied by residual ice masses for perhaps 2000 to 3000 years". In addition, MANGERUD and GULLIKSEN (1975) have found that the apparent radiocarbon ages of living marine shells in cold seas are 440-750 years older than their real age. This discrepancy has been caused by higher apparent ages for the waters where the shells lived (see also HILLAIRE-MARCEL, 1977). This difference between the 'apparent' and 'real' radiocarbon ages applies also to marine plants. As one of the

reasons for the old apparent dates may be the addition of 'old' meltwater from glaciers, the St. Lawrence Lowland dates from marine deposits may be suspected as being several centuries too old, and this possibility will be considered particularly when discussing the Champlain Sea dates.

GENERAL STRATIGRAPHY OF THE WISCONSIN GLACIATION

A threefold time-stratigraphic division of the Wisconsin Stage into the early, middle (or mid-) and late Wisconsin Substages, had originated in the eastern Great Lakes-Ohio River basin region (see DREIMANIS and GOLDTHWAIT, 1973, for a historic review), and has been generally accepted for both the eastern Great Lakes and the St. Lawrence Lowlands regions, because of their close interrelationship (see DREIMANIS and GOLDTHWAIT, 1973; DREIMANIS and KARROW, 1972, also Fig. 2 of this report; FLINT, 1971; GADD, 1976; McDONALD, 1971; PREST, 1970). However, some differences exist in the concept of middle Wisconsin. While those authors cited above who have worked in the eastern Great Lakes and Ohio River basin region, consider lengthy interstadial retreats as main characteristic of Middle Wisconsin, e.g. in Figures 2 and 3, the middle Wisconsin of GADD (1976, p. 43) is based upon "the concept of a single glaciation of the 'central Lowland' region during most of the Wisconsin" spanning "all the Wisconsin between at least 66,000 years BP and approximately 13,000 years BP". Consequently, GADD (*ibid.*) adds main glacial episodes of the Early and Late Wisconsin of other authors (see above) to the original Middle Wisconsin. The above difference in the middle Wisconsin concept has arisen from different locations of both areas in respect (a) to the glacial margins, (b) to the glacial outflow areas, and (c) to the differences in glacial dynamics.

The radiocarbon age determinations have dominated, and are still dominating the chronology of Late and Middle Wisconsin, though presently with a more critical approach than in the past. Therefore the 'short scale chronology' of the Wisconsin Stage (Fig. 2), that considered the St. Pierre Interstadial dates as absolute ages, was commonly accepted up to about 1972 (PREST, 1970; FLINT, 1971; GADD, 1971; DREIMANIS and KARROW, 1972; DREIMANIS and GOLDTHWAIT, 1973). MÖRNER (1972) because of his mistrust in the radiocarbon dates beyond 32,000 BP preferred the theoretical astronomic chronology for 'world climate dating during the last 130,000 years'. According to him (*ibid.*), the Sunnybrook Till (Fig. 2) was deposited during the Early Wisconsin about 60,500-72,000 BP, and he placed the St. Pierre Interstadial and the preceding glacial events into a new time-stratigraphic unit calling it the

Earliest Wisconsin (72,000-94,000 BP). After a comparison of the terrestrial and the ocean stratigraphics of northern hemisphere, DREIMANIS and RAUKAS (1975) and TERASMAE and DREIMANIS (1976) came to similar conclusions and lowered the glacial maximum of the Early Wisconsin Guildwood Stadial (during which the Sunnybrook Till was deposited) slightly before 70,000 BP, but did not use the term, 'Earliest Wisconsin' of MÖRNER (1972) for the preceding events. This 'long chronologic scale' is used for Figure 3 in this report.

Discussions of the general terminology of the Wisconsin Stage may be concluded with brief remarks about the term 'classical Wisconsin'. In 1957 (p. 341) FLINT introduced the term 'classical Wisconsin drift' as a provisional term, to distinguish the strata less than 25,000 years old from the older Wisconsin deposits, "then mostly without names". In 1971 he retracted this term by stating that "the provisional term proved useful, but being no longer needed, it is not used in the present volume" (FLINT, 1971, p. 560). Instead he (*ibid.*) used 'Late-Wisconsin', defining it in terms of radiocarbon dates as being 25,000 to 10,000 years BP. In order to reduce the multitude of terms, it is suggested here to follow this FLINT's (1971) advice.

EARLY AND MIDDLE WISCONSIN

Our present knowledge on Early and Middle Wisconsin glacial and nonglacial deposits and their interpretations from the Lake Ontario basin and the central St. Lawrence Lowlands are discussed either in the general reviews or regional and topical papers of BERTI (1975), DREIMANIS (1969), DREIMANIS and KARROW (1972), DREIMANIS and GOLDTHWAIT (1973), GADD (1971, 1976), KARROW (1967, 1969, 1974), McDONALD (1971), PREST (1970), TERASMAE (1958), TERASMAE and DREIMANIS (1976) and not much can be added here.

The Upper St. Lawrence Lowland which lies between the above two areas has not preserved any deposits that can be identified with certainty as of Early or Middle Wisconsin age. Once I suggested (DREIMANIS, 1960), that the Malone Till of MacCLINTOCK (1958) might be Early Wisconsin, but subsequent stratigraphic investigations in company of P. MacClintock convinced me that this till was deposited most probably during Late Wisconsin (DREIMANIS and KARROW, 1972).

The central St. Lawrence Lowland and the adjoining Appalachian region have produced two kinds of independent evidence, that the Laurentide ice sheet which entered this area during the Nicolet Stadial, did not become very thick. 1) The Johnville Till (Fig. 3) that was deposited by this ice sheet on the highland slopes

southeast of the Lowland, has been reported from areas below the 300 m elevation only (McDONALD and SHILTS, 1971). 2) No marine deposits have been found in the next youngest, St. Pierre Interstadial sequences, in the central Lowland (GADD, 1971, 1976), thus suggesting minor isostatic depression of that area by the thin ice sheet of the preceding Nicolet Stadial. Whether this thin ice sheet ever reached the present Lake Ontario, or whether the ice-dammed Lake Scarborough (Fig. 2) extended into the Upper St. Lawrence Lowland, is not known.

Indirect evidence about the glacial conditions in the Upper St. Lawrence Lowland region may be deduced from the lithologic investigations of tills from the down-glacier sections, particularly the Toronto area (DREIMANIS, 1960; DREIMANIS and KARROW, 1965; KARROW, 1967). During the major glacial advance of Guildwood Stadial, which deposited the Sunnybrook Till at Toronto (Fig. 2) the regional glacial movement over the Upper St. Lawrence Lowland was from that part of the Precambrian Grenville Province between Ottawa and Montréal, which is rich in purple garnets (DREIMANIS *et al.*, 1957; GWYN, 1971), then it proceeded over the dolostone-rich bedrock of the St. Lawrence Valley, and on the way to Toronto incorporated clay- and silt-rich lacustrine deposits. This portion of the Laurentide ice sheet must have been vigorous, as it eroded any pre-Guildwood deposits from the Upper Lowland, and also deposited tills of the above provenance as far as the Lake Erie basin (DREIMANIS *et al.*, 1966: upper Bradville till) and central Ohio (DREIMANIS, 1960).

Even over the Lower St. Lawrence Lowland and in the adjoining Appalachian region, the early glacial movements during the beginning of the deposition of the Gentilly Till (GADD, 1971, p. 36: striae at Rivière du Moulin, Qué.) and the deposition of the lower Chaudière Till (SHILTS, 1973), was from northeast towards southwest. This suggests a possibility of participation of the Appalachian ice masses, merging with the granite-rich Laurentide ice sheet (GADD 1971, p. 35), and flowing up-valley as far as the central St. Lawrence Lowland, even though GADD (1976) considers the Laurentide ice sheet in this advance only. Later on, the glacial movement in the central Lowland changed to north-to-south (GADD, 1971, p. 35: till fabric in the Bécancour map area) and even turned southeastward in the Mégantic region, adjoining to the southeast (SHILTS, 1973, p. 196). This change implies, that by this time, the Laurentide ice sheet in the Lower Lowland was no longer diverted by the Appalachian glacial complex nor by the Appalachian highland. The absence of any vigorous erosion of the St. Pierre sediments in Central Lowland suggests that the Lowland portion around Trois Rivières, Qué., may have developed into some sort of a

glacial divide between a southwestern flow in the Upper Lowland, and the southeastern flow in the Lower Lowland. When this change in the ice-flow patterns occurred, is not known, but it was definitely prior to the deposition of the Gayhurst Formation (Fig. 3), possibly during the beginning of Middle Wisconsin.

Returning to the Lake Ontario basin, it may be concluded from the garnet lithology of the Middle Wisconsin Seminary and Meadowdrift Tills of the Toronto area (DREIMANIS and KARROW, 1965; KARROW, 1967) that they were deposited by a more westerly portion of the Laurentide ice sheet: in comparison with the Guildwood Stadial: now the regional ice flow was from the red-garnet rich portion of the Grenville Province west of Ottawa into the Ontario basin. This also implies a dynamically less active Laurentide ice sheet in the central and upper St. Lawrence Lowlands during the Middle Wisconsin. A thinning of the Laurentide ice sheet was experienced also over the Lower St. Lawrence Lowland, during the Middle Wisconsin, judging from the glacial retreat during the deposition of the Gayhurst Formation (McDONALD and SHILTS, 1971).

In summary, the thickness and dynamics of the Laurentide ice sheet and the Appalachian glacial complex were not the same during all the glacial episodes of the Early and Middle Wisconsin, even though the present information is fragmental. Further regional, and local investigations, will eventually lead to the deciphering of the sequential changes during this lengthy time interval of the Wisconsin Glaciation. The above implied changes, though presently having poor absolute chronological control, suggest a stronger glacial activity during the beginning of the deposition of the Gentilly and the Chaudière Tills (Guildwood Stadial?) than during the subsequent time including the glacial retreats while the Gayhurst Formation (of Middle Wisconsin) was deposited.

LATE WISCONSIN

MISSOURI AND PORT BRUCE STADIALS

Late Wisconsin is characterized by the maximum extent of the glacial advances of last glaciation throughout most of the areas south of the St. Lawrence Lowlands. Most extensive glacial advances have been recorded from the Great Lakes Region and the Lake Champlain-Hudson River lobe (DREIMANIS, 1977). The Laurentide ice sheet must have sent vigorous glacial flows through the Upper St. Lawrence Lowland, judging from the erosion of the pre-Late Wisconsin deposits, an activity similar to that of the Guildwood Stadial. Major erosion marks (striae, flutings in bedrock, etc.) trend southwestward parallel to the Upper St. Lawrence River, and the same direction of glacial movement is suggested also by the fabric and lithology of the

lower Malone Till and the other unnamed oldest tills in contact with bedrock throughout the Lowland between Montréal and Lake Ontario (DREIMANIS *et al.*, 1957; MacCLINTOCK, 1958; DREIMANIS, 1960; PECKOWER, 1961; MacCLINTOCK and STEWART, 1963; MacCLINTOCK and DREIMANIS, 1964; TERASMAE, 1965; HENDERSON, 1967, 1968). This southwestward glacial movement may be contemporaneous with the similar regional movement of the Laurentide ice sheet over the Adirondack Mountains (BUDDINGTON, 1953; CRAFT, 1976), thus implying a considerable thickness of the Laurentide ice sheet. Some contribution of the Adirondack rock materials to the tills of the south-eastern part of the Ontario basin is suggested by a greater abundance of hypersthene in the tills and Lake Ontario sediments of that area (SELLEK, 1974; compare with GWYN, 1971).

The vigorous glacial flow discussed above must have been reduced later when the centre of glacial outflow existed in the Lake Ontario basin (HOLMES, 1952): at that time the glacial flow radiated out of a lowland centre over the lake basin except for the upglacier supply area between the middle of the north shore of Lake Ontario and the St. Lawrence Valley. Judging from the pattern of the drumlins and moraines around Lake Ontario (FLINT *et al.*, 1959), this local centre could have existed during the Pt. Bruce Stadial, though absolute radiocarbon dates are lacking.

MACKINAW INTERSTADIAL, PORT HURON STADIAL, TWO CREEKS INTERSTADIAL

When the regional climatic improvement of the Mackinaw Interstadial resulted in the overall thinning of glacial lobes and their rapid retreats in the entire Great Lakes region (EVENSON and DREIMANIS, 1976; DREIMANIS, 1977), the already thinned ice of the upper Lowland began to turn into an ice shelf, with an oscillating margin in a local proglacial lake. The glacial movement was still from the northeast, and the resulting deposits, the upper Malone drift of MacCLINTOCK and STEWART (1963) consisted of basal and waterlain tills interstratified with glacio-lacustrine sediments. No fossils and hence no radiocarbon dates have been recorded but MacCLINTOCK and STEWART (1963) correlate the upper Malone event with the Cary-Port Huron interval, later re-named the Mackinaw Interstadial by DREIMANIS and KARROW (1972). Because of the re-arrangement of the areas of glacial outflow after the Mackinaw retreat, the subsequent Fort Covington glacial re-advance (Fig. 5), usually correlated with the Port Huron, entered the upper Lowland from the north-north-west, partly eroding or re-orienting the Malone drift: (MacCLINTOCK and STEWART, 1963; MacCLINTOCK and DREIMANIS 1964; TERASMAE 1965).

A further remoulding of the drumlins by a post-Fort Covington readvance from the north was suggested by TERASMAE (1965), but without indicating any overriding of proglacial deposits. Hence there may have been merely shifting of the direction of glacial movement during a slow retreat from the Fort Covington terminal position during the Two Creeks Interval.

By about 12,500 BP, "the ice sheet had thinned sufficiently to expose the Monteregian Hills as islands or nunataks above the surface of the glacier" and "the Monteregian Hills were colonized by plants by 'island hopping'" (TERASMAE and LASALLE, 1968, p. 257). At the same time the Ontario lobe was gradually replaced, in the Lake Ontario basin, by Lake Iroquois. If low-water phases existed in the Michigan and Huron basins at the end of the Two Creeks interval, about 11,850 yr. BP (BROECKER and FARRAND, 1963) the ice must have retreated north of the Kirkfield outlet (Fig. 1), so that the Michigan-Huron basin lakes could have drained into Lake Iroquois (KARROW *et al.*, 1975).

GREATLAKEAN READVANCE

The Greatlakean (EVENSON *et al.*, 1977) readvance, culminating about 11,800 years BP and formerly called the Valders or Valderan, is well documented in the Lake Michigan lobe area, but it has not been identified with certainty in the eastern Great Lakes region, nor in St. Lawrence Lowlands, though, from time to time, some minor readvances or still stands of the retreating margin of the Laurentide ice sheet have been suggested as possible correlatives of the 'Valders'. Thus TERASMAE (1965, p. 36) proposed the already mentioned (p. 23) post-Fort Covington readvance in the Prescott area as possibly belonging "in the Valders substage". RICHARD (1975) expanded this readvance over the Prescott-Cornwall area, suggesting that the 'Newington ice lobe' advanced into the Champlain Sea 11,200 years BP and incorporated marine shells in the "till adjacent to deformed beds of fossiliferous beach gravels" (*ibid.*, p. 113). However, following considerations makes this readvance of Richard and its age doubtful: 1) Its radiocarbon date of $11,200 \pm 100$ years BP (GSC-2108) has been obtained on shells collected supposedly from till, while other geologists who are familiar with that area, e.g. H. Gwyn (pers. comm.) have failed to find in that area a till containing marine shells. It could be a wave-reworked and slumped exposure of the Fort Covington Till, containing marine shells admixed from the younger fossiliferous beach gravels. 2) The above radiocarbon age of 11,200 BP is younger than several of the radiocarbon dates from glacially undisturbed Champlain Sea deposits upglacier from Newington (see Fig. 1 in RICHARD, 1975). Though, according to RICHARD (*ibid.*,

p. 115-116), "it is further suggested that this event may correlate with the St. Narcisse readvance and both would then belong in the Valders substage", the radiocarbon dates of these events disagree among themselves: the 'Valders' readvance in the Lake Michigan lobe area occurred 11,800 yr. BP, the Richard's (*ibid*) shell date is 11,200 yr. BP, and the St. Narcisse moraine is most probably younger than 11,000 yr. BP¹).

For the area north of Lake Ontario, KARROW *et al.* (1975) propose that the Lake Simcoe moraine (Fig. 4) which according to DEANE (1950) marked a pause in glacial retreat, or a slight readvance, may have "extended down to the north shore of Lake Ontario, although the configuration of the ice front in the somewhat irregular terrain remains uncertain. The readvance may be the Ontario equivalent of the 'Valders'". GRAVENOR (1957, p. 42-43) however, concludes that the Lake Simcoe moraine which is less than 10 km long, "marks a local halt in the retreat of the Lake Simcoe ice lobe, and that there was no comparable halt or pause in the Lindsay-Peterborough area. The only halt in the retreat of the Lake Simcoe lobe in the Lindsay-Peterborough area is marked by the Dummer moraine." This moraine is a 10-30 km wide complex of stagnant ice landforms (CHAPMAN and PUTNAM, 1966, Map 2226), extending east-west for about 150 km (Fig. 4). MIRYNECH (1967, p. 196) concludes about the formation of the Dummer moraine, that "it is obvious that the retreat of the ice decreased owing to a temporary return to colder climatic conditions." Although neither GRAVENOR (1957) nor MIRYNECH (1967) correlate the Dummer moraine with any named glacial substage, MIRYNECH (1967) and HENDERSON (1970) relate its formation approximately to the termination of Lake Iroquois. If the KARROW's *et al.* (1975) estimate of the draining of Lake Iroquois shortly after 12,000 yr. BP is correct, then the Dummer moraine is contemporaneous with the 11,800 yr. old Greatlakean (formerly 'Valders') advance.

As the Upper St. Lawrence Lowland, to the northeast of the east end of the Dummer moraine, is topographically lower than the area of the moraine, the absence of an eastward continuation of the moraine may be due to calving of the glacial margin in Lake Iroquois and in the short-lived post-Iroquois lake phases (Frontenac-Sydney-Belleville-Trenton Admiralty: see MIRYNECH, 1967, and PREST, 1970), followed by the Champlain Sea invasion northeast of Brockville (see p. 28). However, evidence of glacial readvance into

proglacial lake exists in the area between the eastern ends of the Dummer Moraine and Lake Ontario (Fig. 4): in several highway 401 cuts between Napanee and Kingston, Ontario, the northeast-southwest trending bedrock flutings are covered by two tills. — A coarse textured till preserved in the grooves is overlain by a clayey till rich in incorporated lacustrine clays and silts. The bedrock flutes or ridges are covered by the clayey till only, and north-south trending striae and stoss-and-lee features on them suggest that the clayey till was deposited by a glacial readvance from the north into a proglacial lake. This readvance, at the southeasterly extension of the Dummer Moraine, is probably contemporaneous with this moraine.

In the region farther northeast, it is possible, that the stillstand of the Laurentide ice sheet at the Covey Hill (Fig. 1), permitting Lake Iroquois to last longer than the subsequent very brief lake phases in the Ontario basin, was due to the same temporary climatic cooling which resulted in the formation of the Dummer moraine. Another glacial halt in southern Québec, in line with Covey Hill, is the Drummondville moraine (Fig. 4) which was formed prior to the invasion of the Champlain Sea (GADD *et al.*, 1972).

Though the above proposal that the Ontario-southern Québec equivalent of the Greatlakean readvance in the Lake Michigan lobe area (EVENSON *et al.*, 1977) is marked by a glacial halt or even a minor readvance along the line Dummer moraine-Covey Hill-Drummondville moraine is hypothetical, without any supporting absolute dates, its time-relationship to the more or less accurately dated proglacial lake phases makes this correlation worth considering as a working hypothesis for further investigations.

CHAMPLAIN SEA

Following the glacial retreat northward from the St. Lawrence Lowland, accompanied by dropping of the proglacial lake levels (see a discussion in PREST, 1970, p. 727) the Champlain Sea invaded the Upper St. Lawrence Lowland "as early as 12,000 years BP" (GADD *et al.*, 1972) or, more probably some time between 12,000 and 11,000 years BP (KARROW *et al.*, 1975), considering the possibility that the radiocarbon dates "on fossil plants and animals from the Champlain Sea are too old by a few hundred years" (KARROW *et al.*, 1975, p. 83; see also the discussion on radiocarbon dates in this paper, and in HILLAIRE-MARCEL, 1977). Therefore arrows, indicating the direction of age correction, but not the amount of correction, are added to the radiocarbon dates from Champlain Sea in Figure 5. For the environmental conditions and other details on Champlain Sea see CRONIN (1976, 1977) and references therein.

1. After the submission of the manuscript of this paper, GADD (1977) has published a discussion of Richard's postulation of a glacial readvance 11,200 years BP. GADD (*ibid.*) notes that no evidence has been found by him, nor his colleagues of such a glacial readvance in the Ottawa Valley and southwest of the city of Ottawa.

FIGURE 4. Tentative correlations of Late Wisconsin ice-marginal positions (after DREIMANIS, 1977, with modifications).

Essai de corrélation entre les positions marginales des glaces au Wisconsinien supérieur, d'après DREIMANIS, 1977, avec modifications.

NORTH BAY INTERSTADIAL

The interval between the Greatlakean glacial advance or an ice-marginal stillstand (called the 'Valders phase' in DREIMANIS and KARROW, 1972) and the Driftwood Stadial, has been named the North Bay Interstadial for the Eastern Great Lakes-St. Lawrence Region by DREIMANIS and KARROW (1972). Here only its early half, from 11,500 up to the beginning of Holocene, 10,000 years BP (HAGEMAN, 1971) will be discussed. Though this interval is characterized by a dominance of glacial retreat, this retreat was interrupted by a slow-down or even minor readvances during the Algonquin phase 11,000-10,500 years BP (Figs. 4 and 5). The Algonquin phase was first suggested as the Algonquin Stadial and estimated to have been 11,000-10,100+ yr BP by SAARNISTO (1974), and was later re-defined by DREIMANIS (1977) as a glacial phase occurring 11,000-10,500 yr BP. It is based principally upon evidence of slowing of glacial retreat throughout the area from Lake Superior to the Ottawa River Valley. SAARNISTO (1974) correlates it with the younger Dryas cold phase

of northern Europe. CRONIN (1976) has described an arctic-subarctic foraminiferal fauna from Kars, Ontario, about 30 km south of Ottawa, with an apparent radiocarbon age on *Hiattella arctica* shells as $10,900 \pm 100$ yr. BP, which is probably slightly too old. "The presence of cold water conditions in Ontario at this time can be attributed to the proximity of the post-Valders Laurentide ice sheet" (CRONIN, 1976, p. 1682), probably during the Algonquin phase (Fig. 4).

To the northeast, a minor glacial readvance about the same time is recorded along the 500 km long St. Narcisse moraine, (LASALLE and ELSON, 1975) along the north-western side of the St. Lawrence Lowlands. The age estimates of this moraine have ranged from 11,500 years BP (GADD *et al.*, 1972) to 10,600-11,000 years BP (OCCHIETTI, 1976). As these age determinations are based upon radiocarbon dates on marine shells, the true age of the moraine may be slightly younger, still correlating well with the Algonquin phase (DREIMANIS, 1977), and not with the 'Valders' as it has been suggested often in the past.

4) Broad regional and local climatic changes.

SUMMARY

While discussing the interrelationship of the Wisconsin events among the Upper St. Lawrence Lowland

Major glacial and non-glacial events of the Wisconsin Stage generally agree with those already concluded by GADD (1971) and DREIMANIS and KARROW (1972). The absolute time scale for the interval prior to 50,000 yr. BP may be expanded following DREIMANIS and RAUKAS (1975) as suggested in Figure 3.

As more details are available for the late glacial time of Late Wisconsin (14,000-10,000 yr. BP), several tentative correlations are evaluated or proposed for this interval, particularly the Port Huron, Greatlakean and Algonquin glacial readvances or slow-downs during general glacial retreat. Some problems exist in this absolute chronology in the eastern Great Lakes-Upper St. Lawrence Region, either because of absence of radiocarbon dates (for the Port Huron Stadial), or the possibility that the dates from marine fossil remains are slightly too old (in the Champlain Sea). Tentative correlations are suggested, considering the interrelationships of glacial, glacio-lacustrine and glacio-marine events, and assuming that major glacial fluctuations are more or less time-parallel in the Great Lakes — St. Lawrence Region. However, because of the differences in the glacial dynamics between the St. Lawrence Lowlands, and the Great Lakes Region, discussed particularly for the Middle Wisconsin, some chronologic differences may have existed during the late glacial deglaciation sequences.

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QUESTIONS AND COMMENTS

G. SAMSON:

"Concerning the St. Pierre Interstadial, do you have pertinent information relating to paleo-environmental conditions (climate, vegetation, fauna, amount of territory deglaciated) in the perspective of hypothetical human occupation?"

A. DREIMANIS:

"Though I am unaware of any evidence of human occupation in Eastern North America during the St. Pierre Interstadial, extensive non-glaciated areas were available for such an occupation, for instance in the Great Lakes Region, the St. Lawrence Lowlands and the Atlantic Provinces of Canada. The climate was cool, but the vegetation may be deduced from the palynologic a. o. investigations (for further details see: Grant, *Geol. Surv. Can. Paper* 75 1B, p. 109-110, 1975; Muller, *Am. Sci.*, vol. 262, p. 461-478, 1964; Prest, *Geol. Surv. Can. Econ. Geol. Rept.* 1, 5th ed., p. 675-764, 1970; Terasmae, *Geol. Surv. Can. Bull.* 46, p. 13-34, 1958)."

C. HILLAIRES-MARCEL:

"I would like to point that it is not necessary to correct ^{14}C shell dates of the St. Narcisse glacio-marine sediments for Mangerud's effect: because you compare ^{14}C shell dates and ^{14}C wood dates with different biological fractionation. In fact, without correcting that fractionation effect, the difference in ages due to Mangerud's effect varies between 0 and 300 years. But your correlation between St. Narcisse and Saarnisto or Algonquin phase is in agreement with the age suggested by Occhietti in the field trip guide-book for St. Narcisse moraine: 10,900 to 10,600 ^{14}C yrs."

A. DREIMANIS:

"Mangerud and Gulliksen (1975) and Mangerud (1972) have drawn attention to several factors which cause apparent radiocarbon ages which can vary from 200 to 300 yrs to more than 2,500 yrs (Mangerud and Gulliksen, 1975, p. 263), but I did not have time to discuss all these factors, nor did I use the term 'Mangerud's effect'. I just wanted to draw the attention to the

possibility that the radiocarbon dates obtained on shells from the Champlain Sea and Goldthwait Sea may be older than their true radiocarbon age. The marine organisms dated had obtained their carbon in part from old water, e.g. glacial meltwater, or even from the bicarbonates dissolved in the marine and glacial waters. If the amount of the admixed old carbon was small, the apparent shell dates may be very close to their true radiocarbon age, but considerable admixture of old carbon may make the dates older — how much, it is difficult to tell, as we do not know the composition of the water where the shell-forming organisms lived, and it varied from place to place."

J. GRAY:

"Your map showing tentative correlations of late Wisconsin ice marginal positions suggests the possible correlation of the Northern Ontario Cartier morainic belt with the St. Narcisse moraine. Do you have ^{14}C evidence from the Cartier moraine belt to back up this suggested correlation?"

A. DREIMANIS:

"No radiocarbon dates are available from the Cartier moraine, but its age has been concluded from correlations with the proglacial lake phases by Saarnisto (*Quaternary Research*, Vol. 4, p. 316-339, 1974)."