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The Middle Wisconsinan History of the Laurentide Ice Sheet
Évolution de la calotte glaciaire laurentidienne au Wisconsinien moyen
Geschichte der laurentischen Eisdecke im mittleren glazialen Wisconsin

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Résumé de l'article

Les indices sur les limites glaciaires et les climats du Wisconsinien moyen proviennent d'endroits situés en bordure de la calotte glaciaire laurentidienne et des basses terres de la baie d'Hudson. Les interprétations se fondent sur la datation du bois, de la tourbe, des coquilles et des sédiments, sur les indicateurs biologiques de climat et sur les séquences stratigraphiques des unités glaciaires et non glaciaires. Les meilleurs indices proviennent des Prairies et des Grands Lacs; ils révèlent un recul marqué de la glace à partir des limites méridionales antérieures et des climats frais de type boréal ou de toundra. L'ouest de l'Arctique a peut-être initialement connu une période chaude, mais cette région, les plaines du nord-ouest et les Maritimes seraient par la suite devenues des zones d'accumulation de glace. Trois cartes montrent les diverses limites glaciaires proposées. Dans la première, la couverture glaciaire est très étendue dans l'Arctique et moins étendue dans les Prairies et les Grands Lacs; on y voit de grandes calottes glaciaires maritimes dans le sud-est et dans l'île de Baffin. Cette répartition de la glace pourrait résulter du déplacement des masses d'air et des courants océaniques au cours du Wisconsinien moyen. Un autre modèle, légèrement différent, résout certains problèmes associés aux basses terres de la baie d'Hudson; la baie de vêlage, qui s'avance jusqu'au centre de l'inlandsis, est le produit de l'instabilité dynamique de la masse glaciaire marine dans la baie d'Hudson. Un troisième modèle fait voir une déglaciation étendue provoquée par des changements climatiques; la glace laurentidienne persiste uniquement à certains endroits dans le nord-ouest, dans la région du Labrador et de l'Ungava et dans la zone appalachienne atlantique.

THE MIDDLE WISCONSINAN HISTORY OF THE LAURENTIDE ICE SHEET*

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ABSTRACT Evidence for Middle Wisconsinan ice limits and climates comes from sites scattered around the periphery of the Laurentide Ice domain and from the Hudson Bay Lowlands. Interpretations are based on dated wood, peat, shell and sediment; biological climate indicators (chiefly cool-climate indicators); and stratigraphic sequences of both glacial and nonglacial units. The best evidence comes from the prairie provinces and the Great Lakes areas, both of which indicate substantial ice retreat from earlier southern glacial limits, and cool, boreal-tundra climates. The western arctic may have experienced an early warm period but both the western arctic — northwestern plains and eastern maritime areas may later have become ice accumulation areas. Three maps portray various possible ice limits. The first shows substantial ice cover in the arctic, but reduced ice cover in the prairies and Great Lakes, and expanded maritime ice caps (rather than Laurentide Ice) in the southeast and on Baffin Island. This ice mass distribution may reflect Middle Wisconsinan shifts in air masses and ocean currents. Ice volumes generated by this model are in accord with the marine oxygen isotope record and perceived global sea level changes. A modification to this model, which resolves some of the controversy in the Hudson Bay Lowlands, shows a calving bay penetrating into the heart of the ice sheet, induced by dynamic instability of the marine-based ice mass in Hudson Bay during relatively high glacial isostatic and eustatic seas. A third reconstruction portrays extensive climatically induced deglaciation and retains Laurentide ice only in parts of the northwest and Labrador-Ungava, with local ice in the Appalachian-Atlantic region. This model is based on alternative genetic interpretations of lithologic units and reassessment of age assignments.

RÉSUMÉ *Évolution de la calotte glaciaire laurentidienne au Wisconsinien moyen.* Les indices sur les limites glaciaires et les climats du Wisconsinien moyen proviennent d'endroits situés en bordure de la calotte glaciaire laurentidienne et des basses terres de la baie d'Hudson. Les interprétations se fondent sur la datation du bois, de la tourbe, des coquilles et des sédiments, sur les indicateurs biologiques de climat et sur les séquences stratigraphiques des unités glaciaires et non glaciaires. Les meilleurs indices proviennent des Prairies et des Grands Lacs; ils révèlent un recul marqué de la glace à partir des limites méridionales antérieures et des climats frais de type boréal ou de toundra. L'ouest de l'Arctique a peut-être initialement connu une période chaude, mais cette région, les plaines du nord-ouest et les Maritimes seraient par la suite devenues des zones d'accumulation de glace. Trois cartes montrent les diverses limites glaciaires proposées. Dans la première, la couverture glaciaire est très étendue dans l'Arctique et moins étendue dans les Prairies et les Grands Lacs; on y voit de grandes calottes glaciaires maritimes dans le sud-est et dans l'île de Baffin. Cette répartition de la glace pourrait résulter du déplacement des masses d'air et des courants océaniques au cours du Wisconsinien moyen. Un autre modèle, légèrement différent, résout certains problèmes associés aux basses terres de la baie d'Hudson; la baie de vêlage, qui s'avance jusqu'au centre de l'inlandsis, est le produit de l'instabilité dynamique de la masse glaciaire marine dans la baie d'Hudson. Un troisième modèle fait voir une déglaciation étendue provoquée par des changements climatiques; la glace laurentidienne persiste uniquement à certains endroits dans le nord-ouest, dans la région du Labrador et de l'Ungava et dans la zone appalachienne atlantique.

ZUSAMMENFASSUNG *Geschichte der laurentischen Eisdecke im mittleren glazialen Wisconsin.* Anhaltspunkte für Eisgrenzen und Klima im mittleren glazialen Wisconsin ergeben sich aus Plätzen, die um die Peripherie des von der laurentischen Eisdecke bedeckten Gebiets verstreut sind, sowie aus dem Tiefland der Hudson Bay. Die Interpretationen gründen sich auf datiertes Holz, Torf, Muscheln und Sedimente, biologische Klima-Indikatoren und die stratigraphischen Abfolgen sowohl glazialer als auch nichtglazialer Einheiten. Die besten Zeugnisse stammen aus den Prärie-Provinzen und dem Gebiet der Großen Seen. Aus beiden Regionen zeigt sich ein bedeutender Eis-Rückgang von den früheren südlichen Eisgrenzen und kühles nördliches Tundra-Klima. In der westlichen Arktik mag wohl eine frühe warme Periode aufgetreten sein, aber sowohl die westarktischen Ebenen als auch die östlichen Meeres-Gebiete sind wohl später Gebiete starker Vereisung geworden. Drei Karten illustrieren verschiedene mögliche Eisdecken. Die erste zeigt eine beträchtliche Eisdecke in der Arktis, jedoch in den Prärien und dem Großen Seen-Gebiet eine geringere Eisdecke und im Südosten und auf der Baffin-Insel ausgedehnte Meeres-Eiskappen. Diese Verteilung der Eismasse mag die Folge von Verschiebungen von Luftbewegungen und ozeanischen Strömungen sein. Eine Abweichung von diesem Modell, welche einige der Kontroversen im Hudson-Bay Tiefland klärt, zeigt eine Kalbungs-Bucht, welche in den Kern der Eisdecke vordringt. Diese Bucht wurde durch die dynamische Instabilität der marinen Eismasse in der Hudson-Bay während relativ hoher glazial-isostatischer und eustatischer Gezeiten hervorgerufen. Ein drittes Modell beschreibt ausgedehnte klimatisch bedingte Enteisung und zeigt laurentisches Eis nur in Teilen des Nordwestens und von Labrador-Ungava mit örtlich begrenztem Eis im Gebiet der Atlantik-Appalachen.

INTRODUCTION

The Middle Wisconsinan Substage has long been regarded as a period of glacial recession between the two periods of Laurentide ice expansion which encompass the last glaciation. However, the extent of ice recession and ice volume reduction, the timing of onset of ice recession and of later glacier reexpansion, the degree of synchrony of events along the Laurentide ice margin, and the climatic character of the mid-Wisconsin are poorly understood. This paper addresses these issues by summarizing the data at dated sites, and by evaluating them in a regional context. In many cases, interpretations developed in one area conflict with those resulting from work in adjacent regions. These problems involve not only the extent of marginal retreat, but also whether the Middle Wisconsinan was a time of partial marginal ice recession, or a time when the core area of the Laurentide Ice Sheet was ice free. This paper does not resolve such major problems, but at least brings them to the attention of the reader, and in this capacity, serves as a document for discussion and a basis for further research.

The terms 'Early, Middle, and Late Wisconsinan' incorporate the entire interval between the last (*i.e.* Sangamon) interglaciation and the Holocene interglaciation (FORSYTH, 1956; DREIMANIS, 1957; GOLDTHWAIT, 1958; FLINT, 1963; DREIMANIS and KARROW, 1972). The Middle Wisconsinan Substage refers to a major period of ice recession between two major glacial periods of the Wisconsin Glaciation. The Middle Wisconsinan Substage as used here, corresponds to the period between about 65 ka and 23 ka (DREIMANIS and RAUKAS, 1975; FULTON, 1984). It thus encompasses stage 3 and possibly the early part of stage 2 of the marine oxygen isotope record, depending on the ocean core chosen. The 65 ka boundary corresponds to a time of rapid world-wide temperature rise and reduction in ice volume. The 23 ka boundary is more arbitrary, but corresponds roughly to the youngest radiocarbon ages from buried organic deposits. The end of the Middle Wisconsinan occurs during a decline in temperature which culminated in the last re-expansion of the Laurentide Ice Sheet. In practice, deposits spanning the Middle Wisconsinan time boundaries are difficult to identify in the field; hence, it is difficult to determine what events occurred at these time limits. The lower time boundary is beyond the limit of ^{14}C dating. The upper boundary commonly either occurs in till, which is generally undatable, or in deposits which have been subsequently eroded away by ice advances.

The assignment of deposits to the Middle Wisconsinan Substage is based on lithostratigraphic sequences, climatic interpretation of inter-till units, and 'absolute' geochronology, but the identification of Middle Wisconsinan materials has proven difficult in many cases. Because till sheets can rarely be dated directly, most information comes from areas beyond the ice margins — ice extent is therefore delimited by establishing where it isn't. Where Middle Wisconsinan materials have been identified, the stratigraphic record commonly consists of sequences of tills separated by terrestrial or marine nonglacial sediments. Because dateable materials are commonly absent, stratigraphers have tacitly assumed that the

first major 'warm climate' terrestrial or marine deposits represent an interglaciation, specifically the Sangamon; whereas any nonglacial deposits above these units, are of mid-Wisconsin age, particularly if biotic remains indicate climates cooler than present. These assumptions presuppose that sub-till deposits indicating a climate as warm as present must predate the Wisconsinan and that deposits indicating a cooler climate must be interstadial. The possibilities for incorrect age assignments using these criteria are obviously enormous. Some sections have organic-bearing beds which have yielded finite radiocarbon dates, but many of these should be considered to be minimum dates. The limit of reliable ^{14}C dating is roughly 20 ka for shells, and 35-50 ka for wood and well-cleaned bone (LOWDON, 1985). These limits can be extended in some cases using particularly good samples and high pressure techniques. Dates on soils and disseminated organics have lower reliability than wood, peat and shell due to the possibility of contamination by younger or older organic components. In any case, many radiocarbon ages on suspected Middle Wisconsinan materials are non-finite and may therefore belong either to Middle Wisconsinan or to earlier periods. U/Th, amino acid, thermoluminescence and oxygen-isotope dating methods have generated Middle Wisconsinan dates on both organic and inorganic sediment. Although these methods have proven influential in the interpretation of stratigraphic records in some places, they are still in their developmental stages; in a number of instances the age obtained has had to be extensively manipulated to fit other chronostratigraphic information. The best Middle Wisconsinan sequences should be those whose upper parts are well-controlled by multiple, reliable, finite ^{14}C dates, and whose lower parts systematically become older. Such sequences are rarely found.

WESTERN ARCTIC ISLANDS

Radiocarbon dates from peat and wood, and amino acid racemization ratios from shells, give some indication of Middle Wisconsinan events in the western Arctic. Evidence comes largely from terrestrial and marine deposits on Banks, western Victoria and Melville Islands, near the limits of Late and Early Wisconsinan Laurentide ice. Much of the data can be assigned either to the Middle Wisconsinan, or to other time intervals, depending on the age interpretation and correlation of adjacent till sheets. Those data which might pertain to the mid-Wisconsin are summarized below.

BANKS ISLAND

Surface marine shells on eastern Banks Island, found between 36 m and 120 m a.s.l., have total amino acid ratios between 0.04 (AAL-895A) and 0.09 (AAL-895C), and corresponding free ratios between 0.41 and 0.51. Since these values suggest a younger age than those from the Sangamon Interglaciation (total 0.19) and an age older than those from Late Wisconsinan marine deposits (total 0.02), they are assigned a Middle Wisconsinan age (VINCENT, 1983). The existence of a high sea at that time implies that the coast was isostatically depressed, either as a residual effect from Early Wisconsinan glacial loading (VINCENT, 1983) or from a nearby Middle Wisconsinan ice mass. The shells give no

information about subsequent events but presumably, during the Middle Wisconsinan the ice margin at one time lay behind the Late Wisconsinan ice limit (as shown by VINCENT, 1984), since the Late Wisconsinan was a time of readvance. If VINCENT's (1984) Late Wisconsinan limits are correctly shown then there was substantial ice recession in the western Arctic during the Middle Wisconsinan.

Or northern Banks Island (1)[1], mosses from an organic layer associated with glacially deformed silt and sand in the Kaerosk River valley gave an age of > 41 000 BP (GSC-1088), and peat from fluvial terrace sands at another site (Dissection River; 2) at 50 m gave ages of > 39 000 (GSC-2819) and 49 100 ± 980 (GSC-2375-2) (VINCENT, 1983). VINCENT (1984) tentatively assigned a Middle Wisconsinan age to these units on the basis of the dates and their association with higher base (sea) levels; it is possible, however, that the nonglacial materials are Sangamonian, particularly since arthropod remains in the peat indicate climate warmer than present.

VICTORIA ISLAND

At Graveyard Bay (3), Victoria Island, FYLES (1963) and VINCENT (1984) described intertill organic deposits containing wood (willow), dated at > 32 400 (GSC-388), > 37 000 (GSC-3613) and > 38 000 (GSC-3592). Macrofloral and arthropod remains indicate climatic conditions similar to present. These may either be mid-Wisconsin interstadial deposits, or older deposits, depending on the interpretation of the tills which enclose them. VINCENT (1984) suggested that they might be Middle Wisconsinan, particularly since they lie just within his limit of Late Wisconsin glacier readvance. SHARPE (1984), however, has suggested that Late Wisconsinan ice cover was thicker and more extensive than Vincent has indicated. If so, then the nonglacial deposits developed during a time of substantial ice retreat and are more likely to be Sangamonian; the area could have been ice covered since the last interglaciation (i.e. throughout the Middle Wisconsinan).

MELVILLE ISLAND

Shield erratics scattered over the surface of Melville Island indicate that it was glaciated at some time by continental ice. Shells on the surface of assumed Early Wisconsinan tills lying a few kilometres beyond the Late Wisconsinan ice limit (14) gave radiocarbon ages of > 33 000 (GSC-727) and 42 400 ± 1900 (GSC-787 at 85 m), a value that should be regarded as a minimum (HODGSON et al., 1984). Those authors point out that the samples may date a marine event post dating deposition of the underlying till (i.e. mid-Wisconsin marine event), or they may have been glacially transported from marine deposits equivalent in age or older than the till. Shells from the Late Wisconsinan Winter Harbour Till, deposited by an ice shelf which impinged on southern Melville Island, date at 27 790 ± 480 (GSC-667), implying that Viscount Melville Sound was ice free at that time.

SOMERSET ISLAND AND BOOTHIA PENINSULA

Evidence from Somerset Island (DYKE, 1983) indicates that glacial recession occurred prior to the last glaciation, which may either have been limited to Late Wisconsinan or have spanned a longer time. Driftwood from a raised glaciomarine delta at 160 m, north of Creswell Bay (5), yielded a non-finite age of > 38 000 (GSC-2542). The occurrence of driftwood implies regional ice-free conditions, but the height of the delta suggests that the sea invaded an isostatically depressed area (i.e. a large ice load was nearby or recently removed?). Shells, both in beach sediments and in the surface till above the Holocene marine limit, are thought to be older than Late Wisconsinan on the basis of their amino acid ratios. Holocene total ratios lie between 0.02 and 0.04, whereas shells from a raised glaciomarine delta at 145 m yielded free ratios of 0.13 and 0.17, and total ratios of 0.05 (AA1-410). Surface tills yielded free values of 0.17 to 0.72 and total values of 0.02 to 0.10. DYKE (1983) indicates that it is difficult to suggest an age for the shells because of the uncertainty of age assignments in calibration sections at Cape Broughton, Baffin Island, and because of uncertainty of the thermal history of the area. If the Cape Broughton "interstade" is Middle Wisconsinan (cf. MILLER et al., 1977), then these shells on Somerset Island could also belong to a Middle Wisconsinan nonglacial interval.

In the Pasley River area of Boothia Peninsula (5A), however, where there are good sections, there is only one till overlying deposits that are assumed to belong to the Sangamon interglaciation because they indicate climate warmer than present and are radiocarbon dated at > 55 ka. If the shell fragments on surface tills on Somerset Island date from this same nonglacial period, as DYKE and MATTHEWS (in press) suggest, then the central Arctic may have remained ice covered throughout the Middle and Late Wisconsinan.

BEAUFORT SHELF

Fibrous freshwater plant remains, including spruce and birch pollen, from submerged deltaic deposits (5) on the Beaufort shelf indicate that sea level was 140 m below present about 27 380 ± 470 BP (B-5069; HILL et al., 1985). Drowned river valleys, channel levees, and well defined submerged shorelines further attest to lowered sea levels at some time. Other deltaic deposits in cores (6) date 21 620 ± 630 (B-6276) at − 120 m, and 28 360 ± 630 at about − 160 m indicating gradually rising sea levels. HILL et al. (1985) attribute 35 m of the sea level rise to subsidence and consolidation. The remaining 105 m was attributed to the presence of a forebulge associated with ice and the onset of glaciation towards the end of the Middle Wisconsinan interval. This implies that the area was within 180 km of major ice load. However, their explanation should account for only 20 m of the remaining 105 m. One alternative explanation is that the area was "far away" from any glacier ice, and that the Middle Wisconsinan deltaic deposits reflect low global sea levels associated with ice accretion in other parts of the continent (see Fig. 2). Another and more likely possibility is that the dated 'peats' used in this study contain allochthonous detrital materials, specifically

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1. Number in bracket refers to site location on Figure 1.

Tertiary coal, and that the lowering of sea level actually occurred during the Late Wisconsinan.

SUMMARY

In summary, data from western and central Arctic presents conflicting interpretations of ice extent. Sites with potential information about Middle Wisconsinan events are scattered over a very large area; they are also only poorly controlled with absolute chronology. The authors believe that most of the shell and peaty organic material reported here as probably Middle Wisconsinan, are more likely Sangamonian. Both HILL et al. (1985) and VINCENT (1983) invoke glacial loading in the western Arctic during the Middle Wisconsinan — one to explain very low sea levels, the other to explain high ones. If Vincent's high seas are due to low global ice volumes, rather than residual isostatic depression from Early Wisconsinan ice, and if his Late Wisconsinan ice limit for the western Arctic is correct, then ice may have receded more than 200 km behind its Early Wisconsinan limit during the Middle Wisconsinan. Some of the paleoecological data suggest climates as warm as present. Numerous sections in the Queen Elizabeth Islands farther north contain shells with finite dates in the 20-50 ka range, indicating limited ice cover in these areas as well. On the other hand, if the high seas are due to nearby glacier loading and SHARPE's (1984) and DYKE and PREST's (1987) interpretation of more extensive Late Wisconsinan ice cover is correct, then it is possible that the western Arctic was essentially ice covered throughout both the Middle and Late Wisconsinan, although there was minor recession along the northernmost margin in Viscount Melville Sound. The Beaufort Shelf may have remained well beyond the ice limit. A study of landscapes in the western Arctic may shed some light on Middle Wisconsinan events and the extent of glacier recession. If there were substantial climatic warmings and extensive ice recession then the terrain beyond the Early Wisconsinan ice limit, as mapped by VINCENT (1983), the terrain between the Early and Late Wisconsinan limits, and behind the Late Wisconsinan limit should show differences in maturity, drainage pattern, and soil development.

NORTHERN AND CENTRAL PLAINS

Some of the best dated, but in some cases still controversial, sequences relating to Middle Wisconsinan events are found on the Interior Plains. The mature terranes of the extreme northwest and southwest have probably remained ice free during and since Middle Wisconsinan time. Throughout the central and southeastern parts of the prairie provinces there is evidence of substantial ice retreat between Early and Late Wisconsinan glaciation. The best evidence for this is from sub-till organics, particularly beds containing wood and peat, that have Middle Wisconsinan radiocarbon dates. Other, less reliable evidence comes from humus dates on paleosols which rest between tills younger than the last major interglaciation. Some paleosols are not directly dated but are assumed to belong to the Middle Wisconsinan because they are formed on tills which are correlated with Early Wisconsinan tills from other parts of the region. Still other units are assigned to Middle Wisconsinan time because they are the first nonglacial

beds lying below till in this region. No till units have been assigned to the Middle Wisconsinan. North of the central Plains, however, the Quaternary stratigraphic record consists only of till sheets, and in many places only one till is recognized. These areas are presumed to have been ice covered during the Middle Wisconsinan; however, the limit of nonglacial deposits corresponds to the edge of the Canadian Shield, and it is possible that unrecorded nonglacial events occurred in this region. Evidence for such events could have been destroyed by succeeding glaciers in these areas of extensive erosion and thin till cover.

ARCTIC COASTAL PLAIN AND NORTHERN YUKON

Evidence suggests that the Mackenzie Delta area of the Arctic Coastal Plain remained ice free throughout the Middle Wisconsinan, but that Laurentide glaciers readvanced into other parts of the Mackenzie valley during late Middle Wisconsinan.

There are marine shells in raised nearshore sediments in the Mackenzie delta (7) dating > 35 000 (GSC-562) and > 37 000 (GSC-690). Farther east, autochthonous wood from terraces on "Bathurst" Peninsula (8) were dated at 33 800 ± 880 BP (GSC-1974). Autochthonous plant remains in a pond on glacial deposits on the Yukon Coastal Plain date at 22 400 ± 240 (GSC-1262; RAMPTON, 1982). Similarly, on the unglaciated Coastal Plain west of Herschel Island (9), plant and moss remains from terraces date 34 600 ± 1480 (GSC-1900). These dates indicate that the northern plains were ice free since the latter part of the Middle Wisconsinan, and may have been ice free earlier.

Radiocarbon dates of > 38 000 (e.g. GSC-204) were obtained from wood and organic detritus from silt overlying till along the Rat River (10) (eastern Yukon). These deposits are not overlain by till. HUGHES (1972) assigned a Middle Wisconsinan age to these on the assumption that the till below is Early Wisconsinan. SCHWEGER and MATTHEWS (1985), however suggest that the underlying till belongs to an earlier event, on the basis of tephrachronology; if their interpretation is correct, then the organics could instead be Sangamonian. Recent finite dates on these deposits (e.g. 21 300 ± 270; GSC-3371; CATTO, 1986) tend to confirm Hughes' interpretation.

Old Crow area (11) lies beyond the limit of Quaternary glaciation. A date of 32 400 ± 770 (GSC-952; McALLISTER and HARINGTON, 1969) on molluscs and ostracodes indicates that sediments were being deposited in fluvial and lacustrine environments during the Middle Wisconsinan. Glaciolacustrine deposits overlying these sediments indicate that Laurentide ice readvanced to the eastern edge of the Richardson Mountains somewhat later, although THORSON and DIXON (1983) suggest a glacial lake formed as early as 39 ka.

HUGHES et al. (1981) reported a wood date of 36 900 ± 300 (GSC-2422) from deltaic and glaciofluvial sands which are overlain by Late Wisconsinan till at Hungry Creek (12) in the eastern Yukon. Macro plant remains and insects from these beds indicate climatic conditions similar to, or warmer than, today. The sediment record at this site suggests that

this area, and perhaps others near the western periphery of Laurentide ice, remained ice free from the Sangamon interglaciation until the Late Wisconsinan. In many sections east of the Richardson Mountains, there are two Laurentide tills that are separated by stratified sediments (HUGHES, 1972) which may also be Middle Wisconsinan in age.

BURIED ORGANIC SITES OF THE CENTRAL PLAINS

Several sites on the central Interior Plains either have been dated as Middle Wisconsinan or overlie materials thought to be Early Wisconsinan. These sites each indicate nonglacial conditions. An important site containing sub-till organics is situated near Watino Alberta (13). The nonglacial part of the Middle Wisconsinan is represented by 6 m of fine-grained fossiliferous fluvial sediments (WESTGATE et al., 1972) containing molluscs, ostracodes, insects, pollen and plants. These are capped by laminated proglacial silts and clays. Dates on wood and peat indicate that sediment deposition began before 43 500 ± 670 (GSC-1020). A date of 27 400 ± 580 (GSC-2034) for tooth apatite and another of 27 400 ± 850 (I-4878) on wood indicate a considerable period of deglaciation. Microfossils suggest a temperate boreal climate similar to present.

To the west, in the Fort St. John (14) area, MATHEWS (1978) recognized two Laurentide till sheets separated by glaciolacustrine deposits, and valley fill sequences. He assigned both types of sediment to the Middle Wisconsinan on the evidence of ice-free conditions at Watino to the east, and other evidence for glacial recession in the Cordillera (14A) to the west. This means that an uninterrupted ice-free corridor extended south from the Yukon and Alaska during the Middle Wisconsinan. Ice free conditions in this region may have extended at least as far east as Fort Assiniboine (15), where a date of > 52 000 (GSC-1019-2) was obtained from wood in glaciofluvial gravel lying between two tills, the lower of which is likely Early Wisconsinan (ST-ONGE, 1972).

In the Medicine Hat area (16) of southwestern Alberta, radiocarbon dates indicate an ice free interval between 24 and 38 ka BP. Up to 45 m of alluvium and lacustrine deposits lie between two tills (STALKER and CHURCHER, 1982). The sediments include quiet water clays, partly varved, and the Evil Smelling Band, which is interpreted as a combination of slide, solifluction, and vegetation debris laid down under periglacial conditions (STALKER, 1983). Dates of 24 490 ± 200 (GSC-205) and 28 680 ± 800 (GSC-578) were obtained on plant fragments in periglacial deposits near the top of the unit. Dates of 37 900 ± 1100 (GSC-1442) and 38 700 ± 1100 (GSC-1442-2) were from lower in the unit at a nearby exposure. These deposits directly(?) overlie a clayey silt band containing a well developed vertebrate fauna including ground sloth, rabbit, prairie dog, squirrel, skunk, coyote, lynx, mammoth, horse, camel, pronghorn and woodland muskox (STALKER and CHURCHER, 1982). The fauna are similar to Sangamon assemblages and could be either Sangamonian or Middle Wisconsinan in age. The deposits near Taber Alberta which yielded the Taber child appear to be equivalent (STALKER et al., in press). The bone assemblage suggests a climate that was "not overly cold", while the organics above suggest a later cool period which culminated in periglacial conditions.

If the bone unit and overlying organic bearing beds form a continuous sequence, then either nonglacial conditions prevailed from the Sangamon interglaciation to sometime after the Middle Wisconsinan, or else a temperate climate animal population thrived during the earlier part of the Middle Wisconsinan.

A number of sites in Saskatchewan have yielded finite dates ranging from 38 ka to 18 ka. Dates of 27 750 ± 1200 (S-96) from Outram (17), and 38 000 ± 560 (GSC-1041) from Kenaston (18) are on wood and gyttja in sands between tills of the Battleford (Late Wisconsinan) and Floral (Early Wisconsinan) formations (CHRISTIANSEN, 1971). Six other dates on humus and carbonaceous silt in a paleosol under the Battleford till from Leader (19), Marsden (20) and Alvina (21) gave dates ranging from 18 000 ± 450 (S-2282) to 33 000 ± 2000 (S-267) (DAVID, 1966; CHRISTIANSEN, 1971), and thereby suggest that nonglacial conditions extended at least throughout the latter part of the Middle Wisconsinan and into Late Wisconsinan time. Christiansen also described other sites with a weathering zone on top of the Floral Formation (Early Wisconsinan till) and he attributed this alteration to Middle Wisconsinan weathering. FULLERTON and COLTON (1986), in contrast, assign an Illinoian age to the Floral Formation, on the basis of intraformational vertebrate fauna, and a Sangamonian to Middle Wisconsinan age to the weathering.

In Manitoba, a Middle Wisconsinan nonglacial interval is recorded by sediment at the Zelena section (22) (KLASSEN, 1972, 1979). The dates obtained are 23 700 ± 290 (GSC-1279) and 37 700 ± 1500 (GSC-653) on charcoal and 28 220 ± 380 (GSC-711) on marl. The sediments of the Vita Formation (23), farther south, have been correlated with the Middle Wisconsinan because they are the first nonglacial units underlying "Late Wisconsinan" tills (FENTON, 1984). The unit contains periglacially deformed gravels overlain by floodplain deposits containing wood and vertebrate and invertebrate fossils indicating climate cooler and drier than present. Radiocarbon dates on wood there are > 41 000 (GSC-1663) and > 43 000 (GSC-1081; FENTON, 1974). Organic detritus and wood fragments in silt between two tills nearby at Roseau River (24) yielded a date of 22 200 ± 1000 (GX-3530).

EVIDENCE FROM SURFACE FEATURES
IN THE CENTRAL PLAINS

Conflicting physiographic interpretations on the Late Wisconsinan limit in the western Plains bears upon ice extent during the Middle Wisconsinan. STALKER (1977) noted that the terrain south and west of the Lethbridge moraine was more mature than that to the east, that major valleys were more incised, and that ice flow markings were discordant with those east of the moraine. He therefore considered the Lethbridge moraine to be the Late Wisconsinan ice limit and that terrain to the west was deglaciated during and since the Middle Wisconsinan. FULLERTON and COLTON (1986) challenged this interpretation, claiming that the terrain south of Lethbridge was similar to areas of Montana that were covered by Late Wisconsinan ice and that therefore, this terrain does not date from the Middle Wisconsinan.

In the Saddle Hills area of central Alberta (25), also near the western margin of Laurentide ice, WHITE et al. (1979) dated organics from a core at Boone Lake on the summit of Saddle Hills (827 m a.s.l.). The lower two dates were 17 750 ± 650 (WAT-406) and > 30 000 (WAT-361). These dates have been used to suggest that the Saddle Hills were ice free during and since the Middle Wisconsinan. RUTTER (1984), however, believes that the oldest and lowermost date is contaminated with "fine grained old carbon" and that these hills were covered with Late Wisconsinan ice. The Saddle Hills is thus another problem area.

CONCLUSIONS

Evidence from the Plains indicates that there was either substantial ice retreat or continuation of an earlier (Sangamonian) nonglacial interval during the Middle Wisconsinan. Nonglacial conditions began sometime prior to 49 ka and ended 18 to 20 ka BP. Since this was also a time of either some ice retreat (RUTTER, 1984; STALKER et al., in press) or almost total deglaciation (FULTON et al., 1984) in the Cordillera, an ice-free corridor extended from the Arctic Coastal Plain to the central Plains during the Middle Wisconsinan substage. The distribution of dated sites and nonglacial deposits in the southern Prairie Provinces indicate that the Laurentide ice margin retracted at least 400 km north of its former limits. It may have retreated even further onto the Canadian Shield, but we have no record for that area. The northern Plains may have experienced less retreat (Fig. 1).

The lithostratigraphy of some sections (e.g. Hungry Creek, Mackenzie Delta, Medicine Hat) indicates that nonglacial conditions may have persisted from the Sangamon Interglaciation to the end of the Middle Wisconsinan. These sites all lie near the maximum limits of Laurentide ice. Other sites well within the limit apparently have a till unit between Sangamonian and Middle Wisconsin nonglacial beds. Assuming that the till has been correctly assigned to the Early Wisconsinan, the beginning of the Middle Wisconsinan could have been a time of substantial ice cover. At these sites, the preserved Middle Wisconsinan deposits indicate cool, humid conditions. Radiocarbon dates indicate that southern areas were ice free at least by 43 ka, but there is no indication as to when deglaciation started. We do know that southern Alberta first experienced cool humid nonglacial conditons by 34 ka, and by 33 ka farther north. Deglaciation in some parts of the Arctic Coastal Plain was underway at least by 37 ka.

The end of the Middle Wisconsinan marks the onset of the re-glaciation, which appears to have occurred over a period of about 3 ka in the central Plains. Events were not synchronous in all areas; the ice did not readvance into northern Alberta until after 27.4 ka, and into the south until about 24.4 ka (date on organics in periglacial deposits). If the dates on paleosols in Saskatchewan are correct, however, reglaciation there occurred after 18 ka. (We suspect that the paleosol dates are incorrect.) Central Manitoba was glacierized after 23.7 ka and southern Manitoba after 22.2 ka. This indicates rapid ice advance, because the Late Wisconsinan ice reached its maximum limit by 20 ka. Glaciers apparently were approaching their Late Wisconsinan limit in the northern plains

before they advanced onto the central Plains. The readvancing Laurentide Ice Sheet may have forced meltwater to flow westward into the Old Crow area as early as 30 or even 40 ka BP.

There is little climate information pertaining directly to the early part of the Middle Wisconsinan interval. Bone and plant remains on dated Middle Wisconsinan deposits from the Yukon and southern Alberta, indicate that the climate at the beginning of the Middle Wisconsinan was cool, but not glacial; by 38 ka it was 'not overly cold' and then gradually cooled to periglacial conditions by 24 ka, corresponding to the onset of Late Wisconsinan glaciation. In southern Manitoba, the deformed lower part of the Middle Wisconsinan nonglacial beds indicate periglacial conditions while the overlying fossiliferous floodplain deposits suggest a slightly moist grassland or tundra environment adjacent to a coniferous forest; i.e. the climate was cooler and moister than present. In Saskatchewan, the climate was warm enough to form a paleosol, but little more information is available. However, in northern Alberta in the Yukon, western Arctic, and Beringia, pollen and microfossils suggest climates similar to or warmer than present; the Watino area, for instance experienced temperate boreal conditions (LICHTI-FEDEROVICH, 1975).

Most areas show a cooling at the end of the Middle Wisconsinan, accompanied by drainage blockages, indicating the onset of the Late Wisconsinan glaciation.

GREAT LAKES AREA

Evidence from the Great Lakes area suggests that the Middle Wisconsinan Substage was a time of substantial glacial retreat, possibly punctuated by minor readvances. The readvances appear to have occurred at different times in various parts of the region, suggesting that the glacier margin followed the same type of lobate configurations as in Late Wisconsinan time.

MICHIGAN LOBE

The Wisconsinan Stage stratigraphy in Illinois and Wisconsin, as described by FRYE and WILLMAN (1960), WILLMAN and FRYE (1970), JOHNSON (1976) and BLACK (1976) consists of sequences of tills, loess deposits and paleosols. The loess units in Illinois indicate glacial meltwater drainage through the Mississippi valley due to blockage of northward and eastward drainage by an ice margin, whereas soils indicate cessation of loess deposition and climatic conditions favouring vegetation growth. In Illinois radiocarbon dates of 31 to 40 ka from shells and soils, and one date of 40 ka on wood (26), all from the Roxana Loess (FRYE and WILLMAN, 1960; MACKAY, 1979; FOLLMER et al., 1979) imply glacier activity during the Middle Wisconsinan. TL ages of 46 and 47 ka from loess underlying Late Wisconsinan sediments in Iowa support a slightly greater age (NORTON and BRADFORD, 1985). The Roxana Loess is overlain by the Farmdale Soil which developed about 25 to 28 ka according to FOLLMER (1983). Deposition of Roxana Loess may correlate with Middle Wisconsinan ice advances reported on the basis of sediments at Toronto and at Port Talbot, Ontario.

The Farmdale Soil corresponds in age to subsequent interstadial conditions in both the Great Lakes and Plains.

There is some debate as to whether glaciers actually advanced into the southern part of the area. The Capron Till in northern Illinois may date to about 33 ka (KRUMM and BERG, 1985), thereby indicating a readvance of the Michigan lobe during the Middle Wisconsinan. Otherwise, the record indicates a presumed advance based on loess deposition followed by an episode of soil formation.

HURON, ERIE, AND ONTARIO LOBES

Evidence for Middle Wisconsinan nonglacial conditions in southern Ontario comes from a number of sites, the best and most intensely studied being in the Port Talbot area on Lake Erie, and the Toronto area on Lake Ontario.

At Port Talbot (27), Late Wisconsinan tills overlie the Port Talbot beds (DREIMANIS et al., 1966). The lowermost beds consist of green clay which has been interpreted as an accretion
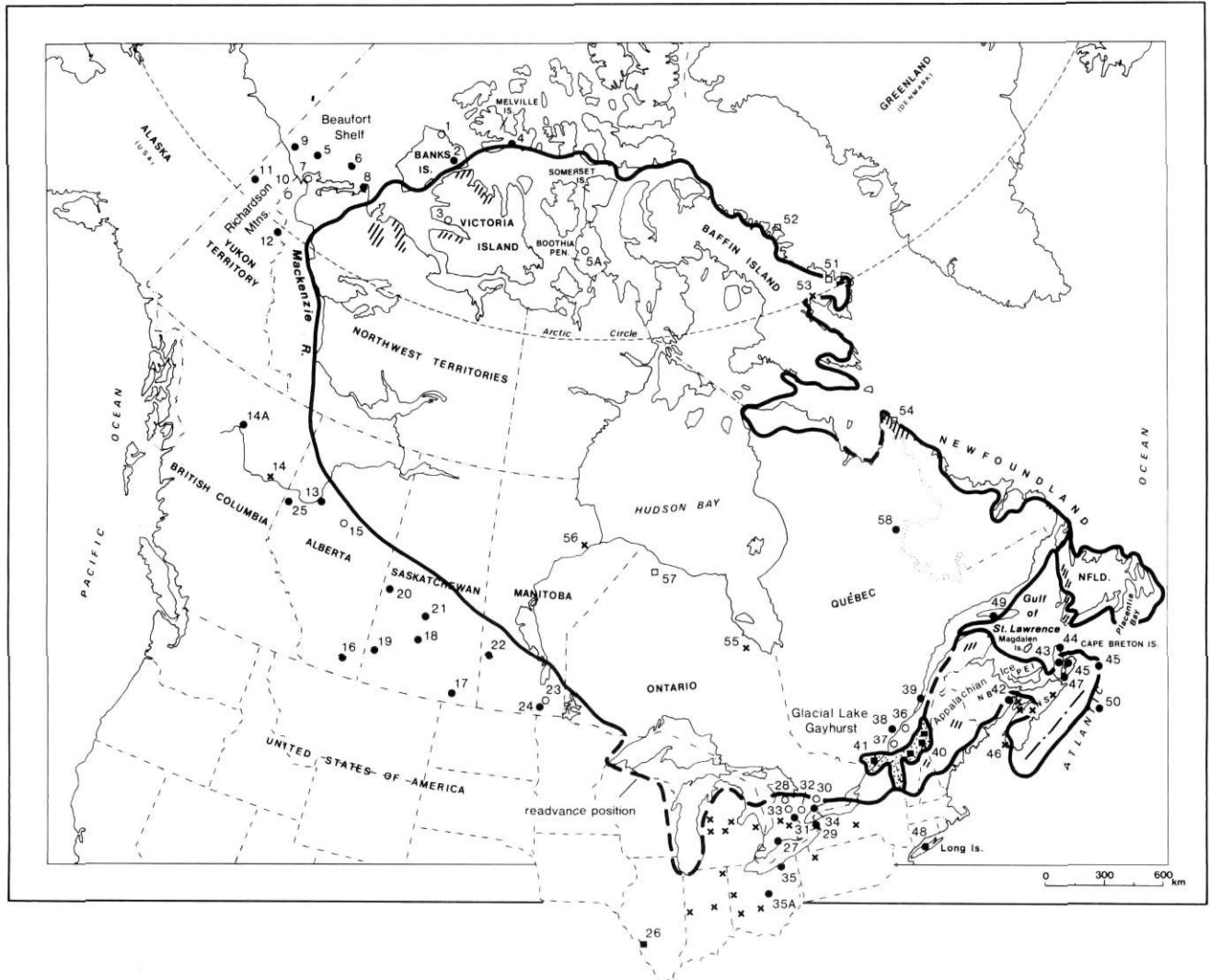

FIGURE 1. Middle Wisconsinan ice limits (Hypothesis I). Laurentide ice divides may be centred in the northern plains-western Arctic, central Québec, and possibly northwestern Ontario. Local caps possibly developed on Baffin Island, Newfoundland, New England, and Nova Scotia. Numbers refer to text citations. ● Finite ¹⁴C dates; ○ non finite ¹⁴C dates; □ amino acid ratios; ■ TL, U-series dates; X other sites. Cross-hatched areas were nunataks. Dash-dot line on the ice mass on the continental shelf indicated the location of a possible independant ice divide.

Limites glaciaires au Wisconsinien moyen (hypothèse I). Les lignes de partage de la glace laurentidienne ont pu être centrées dans la région des plaines du nord et de l'Arctique de l'ouest, dans la partie centrale du Québec et peut-être dans le nord-ouest de l'Ontario. Il pourrait y avoir eu formation, par endroits, de calottes glaciaires locales dans l'île de Baffin, à Terre-Neuve, en Nouvelle-Angleterre et en Nouvelle-Écosse. Les chiffres se rapportent au texte. ● Dates significatives (¹⁴C); ○ dates non significatives (¹⁴C); □ rapports des acides aminés; ■ dates TL ou des séries de l'U; X, autres sites. Les régions hachurées représentent des nunataks. La ligne en tirets-points sur le plateau continental donne la localisation possible d'une ligne de partage des glaces indépendante.

gley deposited during a lengthy period of weathering (QUIGLEY and DREIMANIS, 1972). A Sangamon interglacial age was rejected in favour of assignment to an early Middle Wisconsinan interstade (Port Talbot I, DREIMANIS et al., 1966) because of stratigraphic position, lithologic associations, and the pollen assemblage of pine, spruce, oak, and non-arboreal species, which suggests a climate cooler than present. Overlying varves suggested a brief ice advance into the Erie Basin. The upper beds consist of gyttja and lacustrine silt and rhythmites. Most radiocarbon dates on gyttja, wood and peat range between 40 and 47 ka (e.g. 47 690 ± 1200; GSC-217), and define the mid-Middle Wisconsinan Port Talbot II Interstade. The materials indicate low water levels and cool climate, as do peat balls found along the lake shore, presumably from a submerged peat bed. Wood ages of 25 to 30 ka (e.g. 27 470 ± 130; GrN-2625) from the base of the Catfish Creek till, which overlies the nonglacial sediments, date the youngest part of the Middle Wisconsinan nonglacial interval, called the Plum Point Interstade. The Port Talbot section in total is interpreted to represent a long period of deglaciation characterized by cool-climate, forest-tundra vegetation. The earlier part of the interstade may have been somewhat warmer than the latter, as indicated by the presence of oak. Varved silts, as well as the cool climate indicators, suggest that glaciers may not have retreated far to the north, and that the margins of the Huron and Georgian Bay ice lobes fluctuated from time to time.

Other sites bearing peat beds and/or lacustrine silts assigned to the Middle Wisconsinan are scattered across southern Ontario, the farthest north being along Georgian Bay (28) (KARROW, 1984). All of these have cool-climate affinities, and most have non-finite radiocarbon dates. Exceptions are the wood detritus in sand at St. David's Gorge (19), dated at 22 800 ± 450 (GSC-816; HOBSON and TERASMAE, 1969), peat beds in gravel at Amber (30) north of Toronto dated between 25 and 34 ka (in KARROW, 1984), and the Waterloo site (31) (KARROW and WARNER, 1984), dated by accelerator to 40 ka. These sites are thought to represent Middle Wisconsinan interstades, chiefly on the basis of their cool-climate biotic affinities rather than on strict chronologic or lithostratigraphic control. Sites at Guelph (32) (KARROW et al., 1982), Glen Allen (33) (KARROW, 1984) and Toronto (34) (WATT, 1954; DREIMANIS and TERASMAE, 1958) contain paleosols. If these deposits all formed during the Middle Wisconsinan, rather than during a cool peat-forming period of the Sangamon interglaciation or other nonglacial interval, then they suggest that the ice margin lay slightly north of Georgian Bay.

The Middle Wisconsinan units at Toronto (34) are known as the Thorncliffe Formation (KARROW, 1967), which consists of a lower member of lacustrine deposits containing detrital plant remains dated 39, 49 and > 53 ka, a middle member between Seminary and Meadowcliffe "tills", and an upper member of stratified silt, sand and clay with well preserved, fragile organic detritus dated at 28 300 ± 600 and 32 000 ± 690 ka (GSC-1082 and 1221; BERTI, 1971, 1975; KARROW, 1984). The silts of the upper member have a TL date of 36 ka (BERGER, 1984). The Thorncliffe Formation rests on the Sunnybrook Till, considered by DREIMANIS and TERASMAE (1958) to be Early Wisconsinan, and is overlain by Late Wisconsinan Halton Till. Contacts between members of the Thorncliffe Formation and with the underlying Sunnybrook Till, are gradational in some places. The origin of the Meadowcliffe, Seminary, and Sunnybrook units has been a point of contention. MORNER (1971), DREIMANIS and KARROW (1972), KARROW (1974 and 1984), DREIMANIS (1977), and KARROW et al. (1978) believed these units were deposited by a glacier (Ontario lobe) and that the Sunnybrook advance extended as far south as the central Erie basin. KARROW et al. (1978), BROOKFIELD et al. (1982) and MARTINI et al. (1984) have identified correlative till units east of Toronto. EYLES and EYLES (1983), however, found no evidence of grounded ice or depositional breaks between the Thorncliffe Formation and underlying units in the section they examined, so they concluded that all deposits preceding the Late Wisconsinan till could represent continuous lacustrine sedimentation. Their lithogenetic interpretations however, still require ice in the general area to block drainage into the St. Lawrence Valley and sustain a high level lake, and to account for diamictons, and rapid sedimentation inferred from dish structures (indicating rapid dewatering) and climbing ripples (indicating underflow currents). An extensive sedimentologic reinterpretation is that if the entire sequence was rapidly deposited, if the dated organics were reworked from older materials, and if the TL date is incorrect, then the Sunnybrook/Thorncliffe sequence could have been deposited 20 to 30 ka ago during the approach of Late Wisconsinan ice. If this is the case, then most of the Middle Wisconsinan and the Early Wisconsinan are missing from the Toronto sections (CLARK and LEA, 1986).

Evidence for coeval interstadial conditions south of the Erie-Ontario basins includes the New Paris Silt in Indiana (GOODING, 1963), a possible correlative of Port Talbot I, the Garfield Heights site (35) in Ohio (WHITE, 1968), the Gahanna Ohio site (35A) (GOLDTHWAIT, 1958) where wood in gravels between two tills has been dated at 47 ka (GrN-3219) and a number of locations in Michigan (figured in DREIMANIS, 1982). The weakly developed Sidney Soil (nonglacial) may also have developed during this period (FORSYTH, 1965; FOLLMER, 1983). The Titusville Till in Pennsylvania (WHITE et al., 1969) has also been suggested as a continuation of the intra-Thorncliffe diamictons at Toronto, thereby implying a major readvance of the Ontario lobe. The age assignment of the Titusville till, however, is currently under review (e.g. FULLERTON, 1986).

SUMMARY

In summary, the Great Lakes record indicates a lengthy period of ice recession, possibly interspersed with ice advances. Radiocarbon dates from the Scarborough bluffs sequence imply prolonged glaciolacustrine sedimentation during the Middle Wisconsinan, with glacial blockage of the outlet of Lake Ontario into the St. Lawrence Valley creating high level lakes. The margin was probably lobate and the various lobes may have fluctuated diachronously; for instance, the soil record in midwest United States implies that loess deposition (glacial) was succeeded by soil formation (nonglacial); whereas the record in the eastern Great Lakes suggests two nonglacial

episodes separated by a minor ice advance. Paleoecologic indications suggest a climatic cooling from Port Talbot I time to Port Talbot II-Plum Point, which finally culminated in a very cool climate associated with the onset of Late Wisconsinan glaciation.

Conventional radiocarbon dates on peats and detrital organics, one accelerator date, and a TL date of 36 ka on the upper Thorncliffe sediments suggest that interstadial conditions persisted between at least 23 ka and 47 ka. Non-finite dates on organics and a TL date on silt (BERGER, 1984) suggest that the interstadial may have begun as early as 66 ka. This interpretation fits with the interpreted history of the central Plains area and southeastern Québec, but is in conflict with some interpretations of the U.S. record south of the Great Lakes. In most interpretations, repeated readvances, and the northern limit of interstadial sites suggest that the ice margin never receded much beyond the Shield boundary. One alternative for the Toronto area has been suggested in which the Great Lakes area was entirely beyond the influence of glacial ice. This hypothesis implies that the Middle Wisconsinan was a time of soil development and valley erosion.

ST. LAWRENCE LOWLANDS

Two sets of nonglacial deposits, in different stratigraphic positions, have yielded finite Middle Wisconsinan dates in the St. Lawrence valley and southeastern Québec: the St. Pierre Sediments and the Gayhurst Formation. Although the stratigraphic position of both sedimentary sequences is generally agreed upon, the ages of the formations are not. This is because various dating techniques, including traditional radiocarbon dates on wood and peat, and on carbonate concretions, thermoluminescence determinations on silts, and U/Th methods have produced differing results.

ST. PIERRE SEDIMENTS

This formation consists of beds of gravel, sand, clay, organic detritus and peat (36,37; GADD, 1971). All organic-bearing units in the St. Lawrence area, and the Massawippi Formation in SE Québec (MACDONALD and SHILTS, 1971; LASALLE et al., 1979) are thought to be correlative. Their widespread distribution suggests that fluvial, lacustrine and paludal conditions prevailed over a considerable part of the lowlands, and that water was free to drain through the St. Lawrence River system to the sea. Baselevel was 15 to 30 m above present (GADD, 1971). Pollen and macrofossil remains indicate that the climate was about 2°C below present when the peat formed, and that the area supported a cool boreal forest vegetation (TERASMAE, 1958). The pollen, stratigraphic position, early non-finite radiocarbon ages on wood and peat, combined with old finite ^{14}C dates ranging from 65 to 74 ka (reported in OCCHIETTI, in press) led to the assignment of the St. Pierre beds to the latter part of the Sangamonian (5a) and/or Early Wisconsinan (GADD, 1971, 1976; OCCHIETTI, 1983). The best radiocarbon date (37) is probably the 74 ka wood date of STUIVER et al. (1978). Some of the other wood dates in the 64 to 67 ka range (GADD, 1971) are now thought to have been contaminated in the laboratory (GROOTES, 1977).

It was assumed that the Gentilly Till, which overlies the St. Pierre beds, was laid down by Laurentide ice which continuously occupied the lowlands during the (part of Early?), Middle, and Late Wisconsinan.

Younger finite dates ranging from 28 to 38 ka have been obtained on wood and peat from units supposedly correlative with the St. Pierre at Vieilles-Forges (38) (OCCHIETTI, 1982) and Île aux Coudres (39) near Québec (BRODEUR and ALLARD, 1985). These include six dates run using the benzene method, which LASALLE (1984) considers to be suspect, and one date run by conventional ^{14}C techniques (28 170 ± 800; I-13549; BRODEUR and ALLARD, 1985). Subsequent dating of the Île aux Coudres material has provided a non-finite date and has led Allard (Dépt. de géographie, Université de Laval, personal communication, 1987) to conclude that all dates from this site probably should be considered as non-finite. If however, these dates are correct then the "St. Pierre" sediments represent either a very long period of time, or two different and possibly stratigraphically separate time intervals.

Concretions derived from the varved clays (Deschaillons Formation: KARROW, 1957; GADD, 1971) which directly overlie the St. Pierre beds, and which indicate the onset of the major glaciation which emplaced the Gentilly till, have been dated between 34 900 $^{+1625}_{-1350}$ (QC-559) and 37 500 $^{+2300}_{-1800}$ (QC-357) (HILLAIRE-MARCEL and PAGÉ, 1981). These authors believe the dates give a reliable indication of the time of deposition of the varved sediment. GADD (1971, 1980) and LASALLE (1984), however, question the reliability of radiocarbon dates on concretions and the contemporanity of sedimentation and concretion formation. In support of their views, LAMOTHE (1984) reported a TL age of 61 ka for the varves and LASALLE et al. (1986) reported a TL date of 56 ka.

If the finite dates on the St. Pierre Sediments and overlying varves are correct, and these units are correctly correlated across the lowlands then there was an ice free interval in the St. Lawrence lowlands that lasted 40 to 50 ka, from Sangamonian time through most of the Middle Wisconsinan. Not only was the St. Lawrence lowlands ice free, but Laurentide ice had receded sufficiently to allow free drainage through the St. Lawrence River system to a sea that was 15 to 30 m above present levels (OCCHIETTI, 1982). However, this is unlikely since: 1) the concretion dates and young radiocarbon ages are suspect and U/Th dates on the varves are as old as 135 km (LAMOTHE, 1984), 2) an extremely long nonglacial interval in this area conflicts with till sequences in Ontario (DREIMANIS and TERASMAE, 1958) which require southwestern ice flow across the St. Lawrence lowlands to emplace Early Wisconsinan tills and to maintain high level lakes in the Ontario Basin (Scarborough and Thorncliffe Formations), and 3) there are few indications of a long weathering interval. Consequently we feel, as do many others (LASALLE, 1984; OCCHIETTI, in press; KARROW, in press) that the St. Pierre Sediments and Deschaillons Formation are Sangamonian (oxygen isotope stage 5), possibly lapping into the Early Wisconsinan, and that the overlying Gentilly Till represents conti-

nuous Laurentide ice cover in the St. Lawrence valley throughout the Early, Middle and Late Wisconsinan.

GAYHURST FORMATION

The second unit in the general St. Lawrence Lowlands area that might be of Middle Wisconsinan age is the Gayhurst Formation of southeast Québec (40A-C), which locally consists of as many as 4000 glaciolacustrine rhythmites (GADD, 1971; MACDONALD and SHILTS, 1971). Possibly correlative units have been reported at Montréal (41) (PREST and HODE-KEYSER, 1977) and other parts of the eastern townships (CHAUVIN, 1979; LASALLE, 1981; PRICHONNET, 1984). These deposits are bracketed by tills, all of which lie stratigraphically above the St. Pierre Sediments. Dates on concretions in these sediments range between $20\,600 \pm 350$ (UQ-556) and $32\,900 \pm {}^{1450}_{1225}$ (QC-508) (HILLAIRE-MARCEL, 1979). The stratigraphic position of these deposits, as well as the dates, suggest that some ice recession occurred during the latter half of the Middle Wisconsinan, but that ice retreat was limited to parts of the eastern townships and the Montréal area. Since only 4000 varves are reported, the recessional interval probably was shorter than concretion dates indicate.

Laurentide ice blocked drainage through the St. Lawrence River, impounding the lake. The sequence of tills enclosing the sediments suggest that during the earlier part of the Middle Wisconsinan, Laurentide ice flowed southwards across the St. Lawrence valley and abutted Appalachian ice (LASALLE, 1984; OCCHIETTI, in press). The Laurentide Ice Sheet then overrode areas that had been covered by Wisconsinan age Appalachian ice in some areas. Towards the end of the Middle Wisconsinan, Laurentide ice receded from some of the valleys in southeastern Québec, and glacial lakes Gayhurst and Chateauguay (Montréal area) developed. Because it dammed the lower St. Lawrence Valley throughout the Middle Wisconsinan, Laurentide ice probably occupied all areas north of the St. Lawrence. Appalachian ice may have completely disappeared from much of southeast Québec but may have remained in upland regions.

THE ATLANTIC REGION

As discussed here, the Atlantic region comprises the area surrounding the Gulf of St. Lawrence, eastern US seaboard, and adjacent parts of the continental shelf. For terrestrial sites, deposits are assigned to the Middle Wisconsinan on the basis of a limited number of radiocarbon and U/Th dates on bone, wood and marine shells, and more commonly, by the correlation of tills stratigraphically overlying either a marine platform or organic deposits, both inferred to belong to the Sangamon Interglaciation. The offshore record is based on continuous seismic and acoustic profiles, core samples, and radiocarbon dates on total carbon in organic silt. The onshore and offshore records lead to conflicting ideas about Middle Wisconsinan sea levels and ice cover.

EVIDENCE FOR A NONGLACIAL INTERVAL

Evidence for a nonglacial Middle Wisconsinan interval comes from mastodon remains, peat and marine shells having finite ^{14}C ages, and from rusty zones interpreted as weathering horizons on tills overlying interglacial beds.

A number of mastodon remains have been reported from Nova Scotia and New Brunswick. The most interesting site is the sinkhole at Hillsborough, New Brunswick (42), where till overlies a complete skeleton. Coprolites from this animal yielded an age of $37\,300 \pm 1313$ years (GSC-2469; GRANT and KING, 1984). Another date on a bone, from modern alluvium, on Cape Breton (43) was $31\,900 \pm 630$ years old (GSC-1220). The existence of these remains indicates that at least parts of the area were deglaciated sufficiently for beasts to migrate into the region and survive there.

Two organic deposits on Cape Breton Island have yielded Middle Wisconsinan radiocarbon and U/Th ages (MOTT and GRANT, 1985). The organics at Bay St. Lawrence (44) lie between the marine interglacial platform and colluvium. Cool climate was indicated by pollen as well as colluvial sediments (DE VERNAL, 1983). The peat has provided ^{14}C ages of $44\,200 \pm 820$ BP (GSC-3636) and > 46 ka (GSC-3864) which are corroborated by a U/Th date of $47\,000 {}^{+4700}_{-4300}$ (UQT-178). Buried peat at the East Bay site (45) yielded a U/Th date of $58\,400 \pm 6000$ years (UQT-179). An interesting aspect of this site is that organics lower in the same unit yielded Sangamonian ages. This might suggest that these areas, which are geographically remote from proposed ice centres, could have remained ice free from that time until the Late Wisconsinan.

Oxidized zones between till sheets stratigraphically overlying the Sangamonian bench and interglacial organic deposits have been used to suggest that Middle Wisconsinan nonglacial conditions may have prevailed in central Nova Scotia, although there is the usual controversy over whether such weathered zones are true paleosols or the result of groundwater reactions at lithologic contacts. The possible truncated soil profiles on the lower (Early Wisconsinan) and middle tills may be Middle Wisconsinan in age, and possibly correspond to two warm intervals, separated by a cool period, in the shelf and seamount record. In Nova Scotia, oxidized zones in tills were noted both near the coast (GRANT and KING, 1984; Yarmouth (46)), and in the central part of the peninsula (STEA, 1983, 1984), where occasional patches of intertill sediment were also noted.

Finite Middle Wisconsinan dates on transported marine shells suggest ice free conditions offshore. These include shells from an esker (47) dated at $32\,100 \pm 900$ BP (GSC-1408) and shells from sand at Salmon River (46) dated $38\,600 \pm 130$ (GSC-1440). The Salmon River date has been corroborated by a U/Th determination of 40-45 ka (GRANT and KING, 1984). Despite these ages, Grant considers the shells and enclosing sediment, to be ice thrust Sangamon deposits. They contain the gastropod *Atractodon stoneii*, which indicates warm water conditions, and is thought to have been extinct since the Sangamonian. On Long Island, New York (48), other ice thrust marine sediments also yielded finite dates between 21 and 44 ka, and indicate warm climate temperate forest conditions onshore at that time (SIRKIN and STUCKENRATH, 1980). The date on *Atractodon* and other dates

from these sites are beyond the limit of reliable radio dating and should perhaps be regarded as minima.

Dates from glaciomarine deposits on Anticosti Island (49) indicate that the limit of grounded Middle Wisconsinan Laurentide ice lay along the south-central coast of that island (GRATTON et al., 1984), although results obtained are at the limit of credible ^{14}C dating of shells. Glaciomarine sediment containing shells dating at 36 000 ± 3500 (UQ-533) overlying deepwater deposits indicate the approach of glacier ice into a formerly ice-free area. Grounded ice subsequently reached part of the south coast, incorporating marine sediment with shells dating at 30 000 ± 1200 years (UQ-514 at 90 m), 29 060 ± 1050 years (UQ-510 at 113 m), and 28 100 ± 200 years (UQ-509). The absence of Late Wisconsinan till beyond these sections suggests that grounded ice did not extend beyond this area. The elevation of shelly debris, first incorporated into the till at 113 m a.s.l., suggests a substantial Middle Wisconsinan glacial isostatic load and local high sea level along the Québec North Shore. Marine regressive sequences directly above the glaciomarine units indicate that unloading occurred prior to Late Wisconsinan readvances. The presence of a single till sheet in the central and northern parts of the island, as well as over much of the Québec North Shore suggests that these areas remained ice covered during the Middle Wisconsinan.

EVIDENCE FOR MIDDLE WISCONSINAN GLACIERIZATION

Although evidence for one or two Middle Wisconsinan nonglacial intervals has been presented above, most of those sites lie in coastal areas, and it is possible that deglaciation was restricted to those areas. There is a considerable body of evidence that much of the Atlantic region was ice covered. The Anticosti record, and the lithostratigraphic record from adjacent parts of the north shore of the Gulf, indicate that the Laurentide ice margin lay along the northern part of the Gulf. Studies on the Labrador Shelf (reported in ROGERSON, 1981) indicate that the eastern limit of grounded Laurentide ice also lay near the coast of Labrador.

The available data from till sheets and ice flow data in Newfoundland (GRANT and KING, 1984) indicate that most of the province was covered by island-centred ice caps during the entire Wisconsinan stage. A possible exception is the Burin peninsula, which lies beyond the limit of Late (and possibly earlier) Wisconsin glaciation (TUCKER and McCANN, 1980). The highest summits along the west coast were also not overtopped. Onshore iceflow indicators in southern Newfoundland suggest that an ice cap had developed on the continental shelf in the basin now occupied by Placentia Bay or the Grand Banks. The record from the Newfoundland shelf (PIPER et al., 1978) indicates that the Atlantic coast was the limit of grounded ice.

The Wisconsin glacial record in Nova Scotia consists of three tills overlying the Sangamonian marine and organic beds. In most places there are no intertill sediments or paleosols. The lithologically distinct tills are linked to separate ice flow events and source areas. Although all tills were orig-

inally assigned to the Late Wisconsinan, according to the convention of the time (PREST and GRANT, 1969; PREST, 1977), studies on weathering zones (GRANT, 1977; BROOKES, 1982), and growing awareness of a longer time scale in other areas led the principal investigators to position events into a longer time framework. In this newer (and still unproven) context, the tills and striae indicate that ice flow shifted during the course of the Wisconsin glaciation and that local ice caps prevailed during the Middle and Late Wisconsinan (i.e. after the Early Wisconsinan Laurentide ice flood deposited the red till). Onshore flow is indicated near Yarmouth (46) (GRAVENOR, 1974) and eastern Cape Breton (GRANT and KING, 1984), suggesting that at least two ice caps developed on the continental shelf. These offshore caps necessitate low sea levels and emergent banks on which to form grounded ice masses.

Workers in Gaspé have reported a four-till sequence. There is evidence for a between-till weathering interval, overlain by a Laurentide till in the west and a local (ice cap) till in the east (LEBUIS and DAVID, 1977). DAVID and LEBUIS (1985) have assigned a Middle Wisconsinan age to the weathered horizon and a Late Wisconsinan age to the till. GRANT (in press) however believes that weathering there likely represents the Sangamon, and that the Laurentide till above was emplaced during the Early Wisconsinan, when Laurentide ice also reached into Nova Scotia. Similarly, deeply weathered horizons on the lower till of New England (KOTEFF and PESSL, 1985) and intertill sediments in Maine (BORNS and CALKIN, 1977) have also been tentatively assigned Middle Wisconsinan ages by some workers; others (OLDALE and ESKENASY, 1983) however, argue that the lower till is probably pre-Wisconsinan and that the weathering zone developed during the Sangamon.

The offshore record from the Scotian Shelf (KING, 1980; KING and FADER, 1985, 1986) suggests substantial Middle Wisconsinan ice cover in the Atlantic region, but of a different nature than that inferred from the terrestrial record. King's and Fader's interpretations are based on seismic and acoustic stratigraphy, sediment cores, and numerous radiocarbon dates on total organic carbon. The seismic profiles show distinct sediment units, the two principal glacial sediments being a subglacial melt-out deposit called the Scotian Shelf Drift, and an overlying glaciomarine rain-out deposit known as the Emerald Silt. KING (1980) initially assigned the main moraine complex, the Scotian Shelf end moraine complex, to Late Wisconsinan but later changed his chronology because of radiocarbon dates on disseminated organics in marine sediment. The data of King and Fader suggest that a major (Laurentide) grounded ice sheet extended from the land to the outer part of the continental shelf during the earliest part of the Middle Wisconsinan, but that it had substantially wasted by 50 ka BP, to the point where parts of the ice sheet lifted off and became an ice shelf, floating over deeper basins but grounded over banks. The grounding line had receded to the inner part of the shelf (50) by 30-38 ka and deposited a major grounding line moraine there (Scotian Shelf end moraine complex). Between 30 and 28 ka the ice retreated farther, but still lay beyond the coast. King thus considered the Middle Wisconsinan to be a period of thinning and retreat corre-

sponding to the climatic improvements in the early part of the Middle Wisconsinan reported in the deep cores. This implies the Middle Wisconsinan extension of the Laurentide Ice Sheet onto the shelf, and fairly high sea levels. His interpretations conflict with those of Grant, whose terrestrial stratigraphy indicates local and diverse ice movements, and includes ice flow onshore, a very limited ice load, and low sea levels. It is possible that King's stratigraphic interpretation is correct, but that the total organic carbon dates are wrong. It is also possible that Grant's offshore ice caps could well have developed at the onset of Late Wisconsinan glaciation, rather than during the Middle Wisconsinan.

RECORD FROM THE CONTINENTAL SLOPE SEAMOUNTS

Analyses of microfauna in cores from the continental slope give some indication of Middle Wisconsinan climate changes. Age control is based on ^{14}C dates on foram-nanno ooze. ALAM and PIPER (1977) identified three biostratigraphic units within the Middle Wisconsinan: zone B_4 (dated 50 to 45 ka) marks a distinct mild period. B_3 marks a frigid interval from 40 to 30 ka, which was even more severe than the Late Wisconsinan. B_2 marks a second warming from 25 to 20 ka.

CONCLUSION

The evidence presented here appears to indicate that the southern margin of Middle Wisconsinan Laurentide ice lay along Anticosti Island, and the eastern margin lay along the coast of Labrador; Newfoundland was glacierized by island ice; and grounded ice extended only as far as the Atlantic coast. Apart from sub-till oxidation zones, the terrestrial record for Nova Scotia and New Brunswick indicates that much of the land mass was covered by ice from local (Appalachian) ice caps, although some coastal areas may not have been glaciated. Ice caps may also have developed on exposed parts of the continental shelf and pushed ice onshore. Sea level was lower than present. The record from the Scotia shelf conflicts with the interpretation based on Terrestrial data and requires an ice sheet of major proportions (Laurentide) extending well out into the shelf. It is possible that King's profile interpretations are correct but that the organic carbon dates on which his chronology is based are wrong. It is also possible that Grant's offshore ice caps developed during the onset of Late Wisconsinan glaciation, rather than during the Middle Wisconsinan Substage. One alternative way of reconciling their two conflicting interpretations would be to have an essentially independent Middle Wisconsinan ice divide on the continental shelf, directly offshore from Nova Scotia, as shown in Figure 1.

EASTERN ARCTIC

Radiocarbon dates from shells and marine algae in subsurface sediments, as well as amino acid data, have been used to infer glacial and deglacial events in the eastern Arctic. Several radiocarbon dates ranging from 35-42 ka on shells from buried marine silts led BLAKE (1980) to conclude that a Middle Wisconsinan nonglacial episode affected Cape Storm,

Ellesmere Island. The radiocarbon data are supported by free amino acid ratios in the 0.13-0.18 range and totals between 0.021 and 0.03. Microfossils indicated frigid water conditions. Free amino acid ratios averaging about 0.15 (Løksland aminozone) have also been obtained on shells from raised marine deposits in Southern Baffin Island (51,52) (e.g. MILLER, 1985). By using an effective diagenetic temperature (EDT) of $-9°C$ and a calibration of 125 ka for the underlying Kogalu (last interglacial) aminozone, Miller calculated an age of about 44 ka for the Løksland aminozone. He inferred a cold, Middle Wisconsinan non-glacial interval from these results. DYKE et al. (1982) mapped numerous moraines intermediate in position between their Early and Late Wisconsinan limits (53). Unless all of the moraines are recessional from the Early Wisconsinan limit, then one or more Middle Wisconsinan moraines are present. They indicate that ice was more extensive during the Middle Wisconsinan than during the late Wisconsinan. IVES (1977) and CLARK (1982) report Middle Wisconsinan aged materials from the Torngat Mountains of northern Labrador (54). Shells in raised marine diamictons produced radiocarbon ages between 35 and 43 ka, and amino acid values similar to those of Baffin Island.

The presence of the marine fauna has been used to suggest that non-glacial ("interstadial") conditions prevailed in the eastern Arctic during the Middle Wisconsinan. It could also be argued, however, that the occurrence of these in transgressive raised marine and glaciomarine deposits implies that the land was glacial isostatically depressed at the time (i.e. that the area was still largely ice covered), or had been ice covered during an earlier part of the Middle Wisconsinan.

HUDSON BAY LOWLAND

The Hudson Bay Lowland, located south of Hudson Bay at the centre of the area once covered by the Laurentide Ice Sheet, is an appropriate area in which to determine the extent of ice retreat during nonglacial episodes that are recorded nearer the periphery of the ice sheet. Shell fragments in till, and in fine grained sediment and gravels between till units have been used to suggest that Hudson Bay may have been open at one or more times during the Wisconsin glaciation. There is considerable discussion among various people working in different parts of the Hudson Bay Lowland as to whether this interpretation is correct, and how many openings, if any, occurred during the Wisconsinan Stage.

As many as four till sheets, some separated by intertill deposits, overlie the peat beds and sediments of the Missinaibi Formation (SKINNER, 1973) (east) and correlative Nelson River Sediments (NIELSEN et al., 1986) and Gods River Sediments (KLASSEN, 1986) (west), which are assumed to belong to the Sangamon Interglaciation. The Wisconsin sequence consists of an upper brown clay till, overlying brown silty till and grey silty tills. All contain shell fragments. Intertill sediments are in the form of lenses of sand and gravel intercalated with till, massive or cross-bedded sand and gravel layers, and sandy diamictons with related varves.

In the eastern lowlands (Moose River basin; 55) SKINNER (1973) recognized two tills separated by cross-stratified sands and rhythmites (Friday Creek Sediments). He suggested that the inter till deposits were either of Holocene or of Middle Wisconsinan age. HARDY (1976), working in the James Bay Lowland of Québec demonstrated that the rhythmites were deposited in Holocene Lake Barlow-Ojibway and that the overlying till was deposited by surges and readvances into the lake; DREDGE and NIELSEN (1985) concluded that similar subtill sediments in Manitoba sections (56) were deposited into the correlative glacial Lake Agassiz. SHILTS (1984) and ANDREWS *et al.* (1983), however, preferred the Middle Wisconsin age interpretation for these sediments.

In the central Hudson Bay Lowland (*e.g.* 57) MACDONALD (1969, 1971, and Geological Survey of Canada field notes) identified intertill silt deposits under a brown till which was more compact than the till associated with the postglacial lakes, and interpreted these as Middle Wisconsinan interstadial deposits (equivalent to the Port Talbot of southern Ontario). He postulated that ice retreated from southern Ontario as far north as the Hudson Bay coast (*i.e.* an interstade of major proportions), but that ice remained in Hudson Bay, thus sustaining a glacial lake. ANDREWS *et al.* (1983) considered that the total amino acid ratios from shell fragments in the various tills, subtill sediments, and Holocene deposits formed clusters of values, and concluded that there had been two or three Wisconsinan openings of Hudson Bay postdating the deposition of the marine sediments (Bell Sea) that underlie the Missinaibi Formation, which was thought to be of Sangamonian age. At least one of these openings is indicated to have occurred during the Middle Wisconsinan (SHILTS, 1984). These data groupings, however, were not apparent in the same data as presented by SHILTS (1982), but rather appeared as a continuum of ages from Bell Sea time to present. Since then, additional surveys have yielded better lithostratigraphic definition of the various shelly till sheets. As a result, WYATT and THORLEIFSON (1986) have found that the amino acid ratios on shell fragments from the upper (brown) till are statistically lower than those in the underlying tills. If these lower ratios are due to age difference rather than to variations in racemization rates, then their results support the idea of a Middle Wisconsinan opening of at least part of Hudson Bay.

NIELSEN and DREDGE (1982) and DREDGE and NIELSEN (1985) reported similar lithologic records from the western Hudson Bay Lowlands, but reached different conclusions about events in Manitoba. They indicated that thin intertill (post-Sangamon) sand and gravel beds in Manitoba, interpreted as interstadial units by NETTERVILLE (1974), ANDREWS *et al.* (1983) and SHILTS (1984), were more likely to be subglacial deposits. Furthermore, amino acid results indicated a high degree of variability within a given till unit, and showed no systematic change from one till unit to another. On that basis, and the temperature assumptions that had to be made in assigning ages to the amino acid ratios, Dredge and Nielsen concluded that Hudson Bay could have remained ice covered during the entire Wisconsinan Stage, and that lithic differences in the tills indicated shifting ice flow patterns during the course of that glaciation. The lithostratigraphic record and dispersal

of erratics also suggests that most ice movement throughout the Wisconsinan was across, or out of, Hudson Bay, rather than being drawndown into an open bay during Middle Wisconsinan. Despite this, one TL date (Nielsen, Dredge and Berger, in prep.) from intertill sediments (56) did, however, yield an age of about 40 ka. The date was from sediments associated with a peat bed containing spruce branches and boreal pollen which would otherwise have been assigned a Sangamonian age. If this date is valid then conditions during the Middle Wisconsinan must have been similar to those of an interglaciation, with Hudson Bay not only ice free, but with temperate climate environments prevailing in the core area of the Laurentide ice sheet.

THE SHIELD

On the Shield there is evidence of multiple till units, which are generally unoxidized below the surface till. The simplest explanation is that the tills reflect shifting ice flow during a period of continuous Wisconsinan ice cover. Where weathering horizons are present in northern Ontario and Manitoba (DREDGE and COWAN, in press) and Saskatchewan and Keewatin (DYKE and DREDGE, in press), other evidence suggests that those tills are pre-Sangamonian. In central Labrador (58) a twig below till and glaciofluvial sediment, dated 24 250 ± 600 BP (GRANDBERG and KRISHNAN, 1984), may indicate massive deglaciation in Québec-Labrador, or a major shift in ice accumulation areas during the Middle Wisconsinan. Such a major shift is quite possible, since oceanic and atmospheric circulation patterns were different from interglacial and other glacial times. The date itself however is somewhat suspect because of the small specimen size and state of preservation.

LAURENTIDE ICE AND
THE OCEAN RECORD

Although the continental records of glacial events are commonly incomplete, cores representing a more complete sequence of events have been retrieved from deep ocean basins. If the $O^{18/16}$ ratios recorded in the deep ocean cores are a reflection of continental ice volume changes, as proposed by EMILIANI (1966) SHACKLETON and OPDYKE (1973), RUDDIMAN and McINTYRE (1981) and others, and if the Laurentide ice sheet accounts for most (at least 60 %) of the northern hemisphere's ice volumes, then the deep sea cores provide a record of growth and disintegration of the Laurentide ice sheet. Three cores are shown on Figure 2. On a broad scale the isotope record shows a gradual increase in ice volume during the Early and Middle Wisconsinan, culminating in a major Late Wisconsinan glaciation. When the Middle Wisconsinan record is resolved in greater detail, however, it indicates a number of ice volume fluctuations. The north Atlantic core, which is perhaps a more direct indicator of the Laurentide ice sheet than the more globally applicable Caribbean and Pacific cores, shows a number of oscillations in a trend of gradually increasing ice volumes to the Late Wisconsinan. The curves shown on Figure 2 suggests that Middle Wisconsinan ice volumes were commonly about 80 % of the
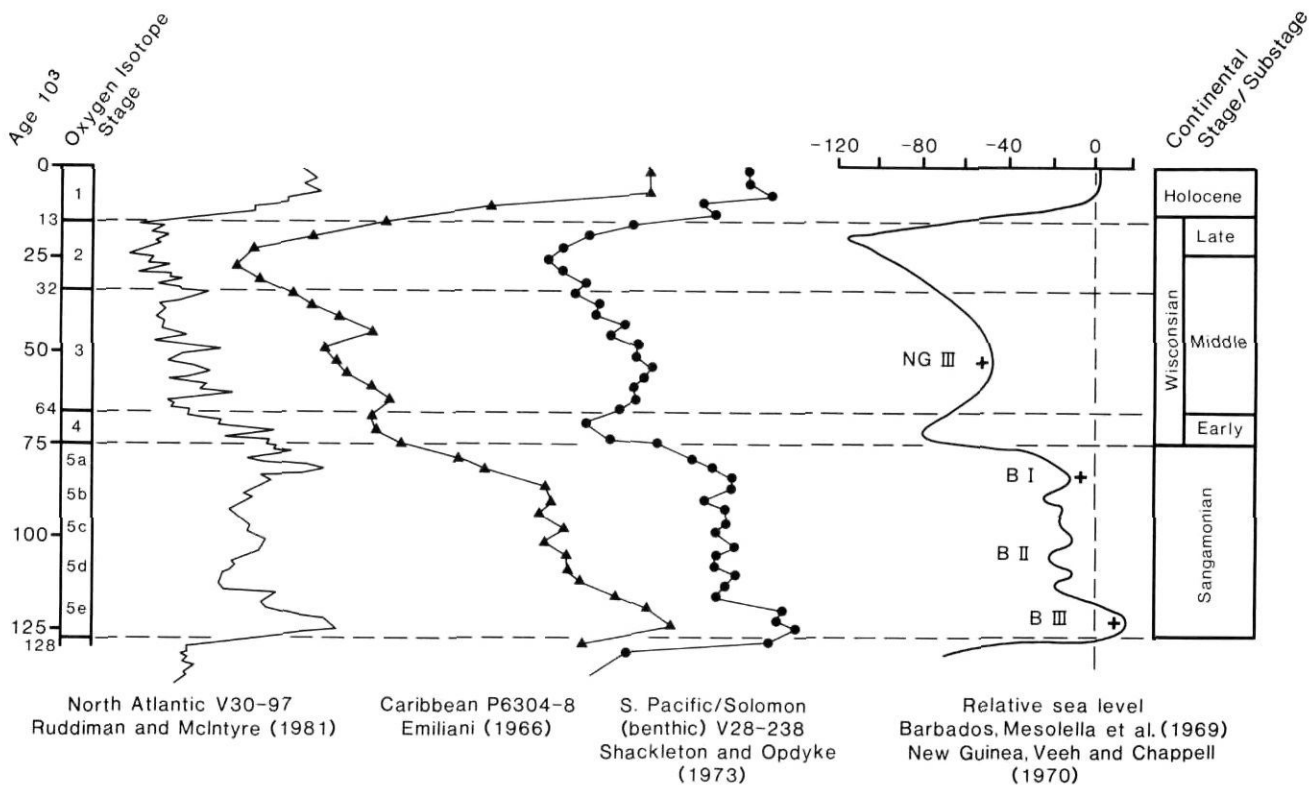
FIGURE 2. Oxygen isotope cuves and sea level changes   *Variation des isotopes de l'oxygène et du niveau de la mer.*

maximum Wisconsinan volume, but at times were as low as 60 %, particularly about 33 ka and 50-64 ka. If the seamount record from offshore Canada (ALAM and PIPER, 1977) is compared to the North Atlantic oxygen isotope record, then the Middle Wisconsinan periods of greatest ice growth indicated by the seamount record correspond with warm ocean temperatures, and the periods of ice recession with cooler intervals. Ice accretion thus seems to have occurred when warmer, water and more moist air extended northwards, and created a steep temperature gradient and moisture source. RUDDIMAN *et al.* (1980) also suggested this, based on other evidence.

The Caribbean curve shows a more general increase in ice volume during the Early and Middle Wisconsinan, but with two distinct intervals during which ice volumes declined to about 65 % of the Late Wisconsinan maximum. These intervals are out of phase with the Atlantic record. The Pacific benthonic core, regarded as the standard for the upper Pleistocene (SHACKLETON and OPDYKE, 1973) because of its long record and because isotopic changes due to temperature change are minimized in this area, suggests that Middle Wisconsinan ice volumes declined to about 55 % of their Early Wisconsinan value, and that Early Wisconsinan and Late Wisconsinan ice volumes were roughly the same. The Pacific core suggests a Middle Wisconsinan interstade, culminating about 50 ka, although ice volumes were still substantial. This interval apparently coincides with the time when global sea level rose from a low of perhaps −80 m during the Early

Wisconsinan, to about −50 m (New Guinea curve, VEEH and CHAPPELL, 1970).

The published oxygen isotope records and sea level curves shown here suggest that glaciers were prevalent during the Middle Wisconsinan, although there may have been a reduction of up to 55 % of the Early Wisconsinan ice volume. Using either a single ice dome model for the Laurentide Ice Sheet (as in PATTERSON, 1972), or a multidome model (*i.e.* less total ice volume), widespread Middle Wisconsinan deglaciation of the Plains, partial deglaciation in southern Ontario, replacement of extensive Laurentide ice in the Atlantic area with local Appalachian ice caps, and minor recession elsewhere is sufficient to produce the changes of sea and ice volume reported. THOM (1973) has indicated that sea level did not approach present levels during the Middle Wisconsinan but indicated that they might be higher than is shown on Figure 2. If sea levels were significantly higher than shown, or if growth of the Antarctic ice sheet greatly affected Middle Wisconsinan sea levels, then perhaps an argument for more substantial deglaciation of the Laurentide ice sheet is warranted.

The causes of Middle Wisconsinan ice volume reductions recorded both in the deep sea and terrestrial records remain uncertain. RUDDIMAN and McINTYRE (1981) claim the glaciations and deglaciations are driven by planetary phenomena, based on a 23 ka precessional cycle. JOHNSON (1982) relates glacial extremes to insolation minimum at times of low orbital eccentricity, and interstades to precessional insolation peaks.

SUMMARY AND CONCLUSION

SUMMARY

There are clearly a wide variety of opinions about the extent and activity of Laurentide glaciers during the Middle Wisconsinan substage. It must be stressed that most interpretations are based on units that lie near or beyond the limits of conventional dating methods. Radiocarbon dates on wood, peat, and well-cleaned bone are probably valid up to 50 ka, but shell dates are considered to be suspect beyond about 20 ka. Bulk organic dates may be contaminated by a variety of materials, and dates on carbonate concretions might not relate to the enclosing material. Amino acid, U/Th and thermoluminesence dating are still in developmental stages.

Commonly, ages derived from materials using more than one method are discordant. The assignment of materials to the Middle Wisconsinan and the interpretation of glacial events thus relies heavily on the stratigraphic position of units, particularly nonglacial deposits, above marker beds. Commonly major organic beds with warm climate indicators are assumed to be interglacial and of Sangamonian age, whereas inorganic material between tills is assumed to be interstadial and Middle Wisconsinan in age. In a number of cases the tills enclosing nonglacial sediments cannot even be positioned with certainty above known interglacial deposits; also some presumed interglacial organic beds could be older than Sangamon Interglaciation, or younger.

In the Plains area there is general agreement that Middle Wisconsinan glaciers receded at least 400 km north of their Early Wisconsinan limit, possibly to the edge of the Shield (which may have marked a significant change in glacial bed conditions). The timing of the initiation of this recession is not known, although it appears to have been underway by 43 ka. The ocean isotopic record suggests recession may have begun much earlier. Ice readvanced over the Plains about 27 ka in the north, crossed southern areas by 24 ka, and reached its most southern limit by 18-20 ka. Parts of the Interior Plains may not have been glaciated from the Sangamonian until the Late Wisconsinan. Since Cordilleran Ice either receded substantially or disappeared completely during the Middle Wisconsinan, there was an ice free area east of the Rocky Mountains, extending from the Yukon to Southern Canada. The southern Plains initially experienced periglacial climatic conditions, which was replaced by a tundra-grasslands environment, and finally culminated in a return to cold climate.

In the western Arctic, the Middle Wisconsinan record has been conventionally interpreted as a period of ice recession from more extensive Early Wisconsinan limits to somewhere inside the less extensive Late Wisconsinan boundary. Ice retreat, however could actually have been very slight. We believe that some of the materials and deposits postulated to be Middle Wisconsinan could actually be Sangamonian, especially since they indicate warm conditions and high sea levels, and they overlie undated tills. The Mackenzie Delta area could have been ice-free during the Middle Wisconsinan, or remained unglaciated since the Illinoian. The Beaufort Sea record indicates a low sea level, which implies that high ice

volumes were maintained on the continent, although not directly adjacent to the offshore. The northern Plains were glacierized as early as 30 to 40 ka ago, and Laurentide ice may not have retreated significantly from its earlier maximum during Middle Wisconsinan time. This suggests that Middle Wisconsinan ice accumulation areas were probably different from those of Late Wisconsinan possibly because the western Arctic areas experienced relatively warm climatic conditions. Radiocarbon dates on shells suggest that Viscount Melville Sound may have been ice free at the end of the Middle Wisconsinan and that there had been ice recession from some earlier more northerly limit. The record from Somerset Island and the adjacent mainland, however, indicates that these areas remained ice covered, i.e. that ice recession in the north was very slight. Amino acid chronology in the eastern Arctic suggests partial ice free conditions, although the location of some shell sites suggests glacial isostatic high level seas and generally more ice than during Late Wisconsinan time. Grounded Laurentide ice did not extend much beyond the Labrador coast; Laurentide ice did not reach the island of Newfoundland which supported local ice caps.

In the Maritimes local ice caps replaced the Early Wisconsinan massive Laurentide ice cover; therefore, Middle Wisconsinan ice volumes here may not have been great. Mastodons roamed the ice-free coastal plains. Sea level was lower than present and ice caps have developed on emerged parts of the Continental shelf. The interpretation of events based on the terrestrial record directly conflicts with that based on dated deposits on the Scotian Shelf, which shows progressive Middle Wisconsinan ice retreat of a major (Laurentide source?) ice mass, with several fluctuations. The New Brunswick record is similar to the Nova Scotia terrestrial record. The growth of maritime ice caps, like the persistence of Laurentide ice in the western arctic, may be related to the existence of warm atmospheric and oceanic masses.

Most of the Gaspé Peninsula was probably glacierized although an undated weathering zone has been taken previously to represent a Middle Wisconsinan nonglacial interval. Shell dates from ice contact deposits along the north shore of the Gulf of St. Lawrence show that the limit of grounded Middle Wisconsinan Laurentide ice lay along the southwest coast of Anticosti Island.

The reported record for southern Québec indicates initial Laurentide and Appalachian ice cover at the beginning of the Middle Wisconsinan, followed by limited recession of Laurentide ice on the south side of the St. Lawrence River. However, the correlation of lithostratigraphic units and the interpretation of events in this area may be more complex than has been suggested.

There is considerable uncertainty over the extent of Middle Wisconsinan ice recession in the Great Lakes. Some United States data implies that the ice margin stood south of the Great Lakes during at least part of the Middle Wisconsinan Substage. Loess and tills suggest a major advance of the Michigan lobe, followed by a substantial warming period during which soils formed. Much of the Canadian evidence indicates that the ice margin lay a short distance north of Lake Ontario

and that ice of the Huron-Georgian Bay and Erie-Ontario lobes occasionally advanced into the glacial Great Lakes. An initially cool climate gradually gave way to cold forest-tundra conditions. Recent speculations on key sections, however, suggest that the ice margin may have lain well north of the lakes, that the water bodies were not glacial lakes, and that there were no tills in the Middle Wisconsinan sequence. One worker had earlier proposed that Middle Wisconsinan ice retreated as far north as James Bay, and that extensive glacial lakes in northern Ontario were contained by an ice mass in Hudson Bay. We believe that most of the shield probably remained ice covered, although some sub-till weathered zones and organic remains could possibly be interpreted as signs of massive Middle Wisconsinan deglaciation.

Establishing the presence or absence of ice in the Hudson Bay Lowlands during the Middle Wisconsinan is especially important because the area lay in the heart of the Laurentide Ice Sheet. Disappearance and regrowth of glaciers here implies

rapid, massive ice volume changes and shifting ice divides. Some workers claim that most evidence points to almost continuous ice cover during the Middle Wisconsinan, while others suggest a single opening of Hudson Bay; still others postulate multiple openings and reglaciations, and the possibility that full interglacial climatic conditions were established over much of the landmass.

CONCLUSION

The data presented in this report can be interpreted in various ways to lead to very different conclusions about the extent of ice during the Middle Wisconsinan Substage. One possible configuration of Laurentide ice that assumes limited ice recession (Hypothesis I) is shown in Figure 1. This illustrates extensive ice recession from earlier limits in the southwest and recession along the southern margin to a position just north of the Great Lakes. This pattern may have resulted primarily from melting back of inherently unstable, thin, ice
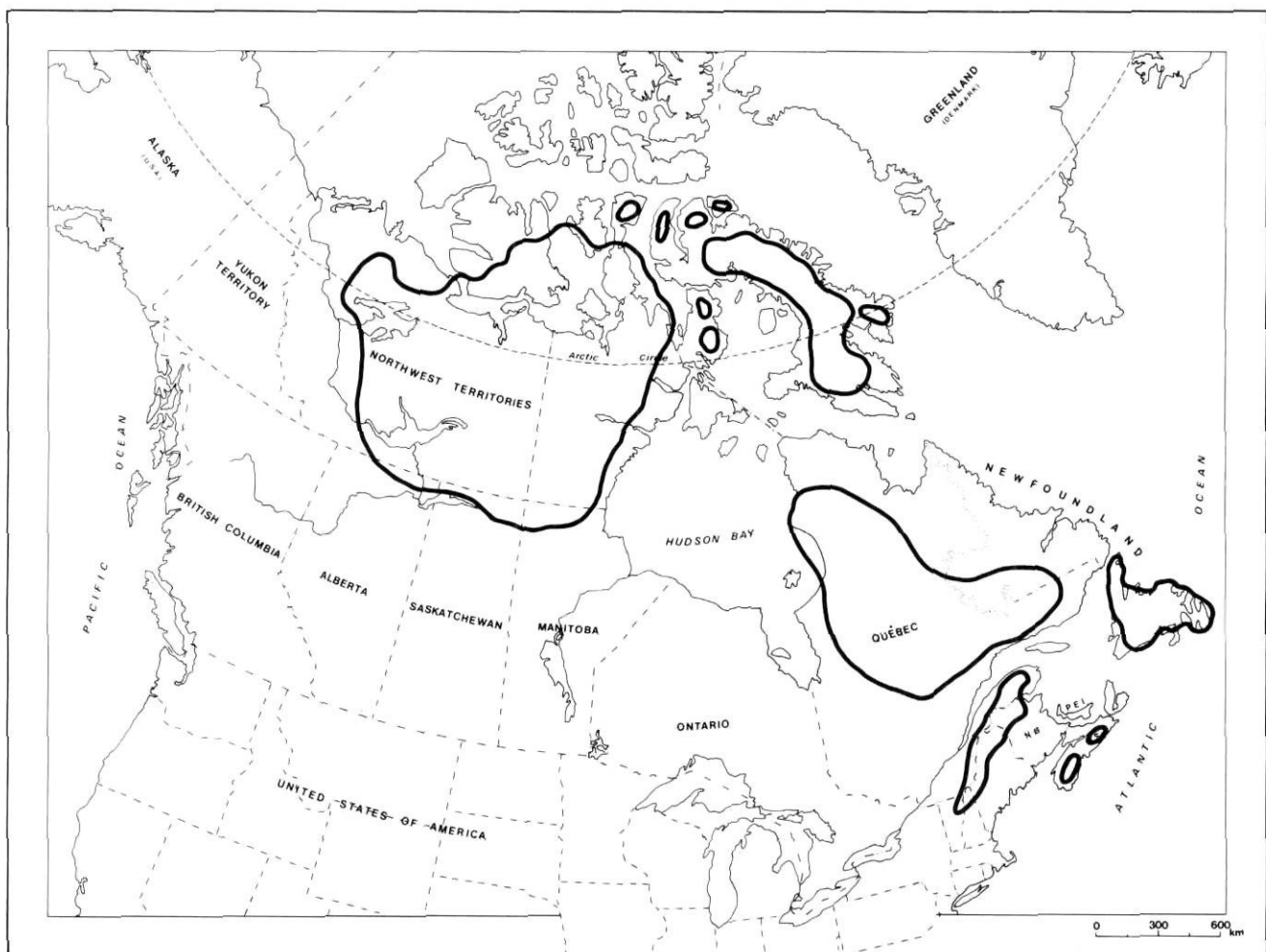

FIGURE 3.   Middle Wisconsinan ice limits resulting from extensive, climatically induced deglaciation (Hypothesis II).

Limites glaciaires au Wisconsinien moyen à la suite d'une importante déglaciation provoquée par des changements climatiques (hypothèse II).

masses which had been flowing over deformable beds or into water bodies. Large areas remained glaciated, or were reglaciated during the Middle Wisconsinan, suggesting that major Laurentide ice divides could have occupied the northwestern Plains as well as central Québec and possibly northwestern Ontario. In this model most of the Arctic remained ice covered, although there was some ice retreat in coastal areas in the western regions. Grounded Laurentide ice lay just offshore along the Labrador coast, and along Anticosti Island on the north shore of the Gulf of St. Lawrence. Most of the Shield and Hudson Bay remained ice covered. The maritimes areas were glacierized by local ice caps, although coastal zones in Nova Scotia and New Brunswick were ice free. Ice dispersal patterns and accretion centres were thus considerably different during the Middle Wisconsinan, compared to Late Wisconsinan patterns. The seamount record indicates that North Atlantic ocean temperatures were fairly warm during this interval. This situation would have produced a northward flow of warm moist air permitting ice caps to develop in the Maritimes while the south-central part of the continent was experiencing significant ice retreat. Since warm climate fauna and floral have been reported in the northwestern Arctic, a similar situation there may account for the proposed northwestern ice accretion area.

An alternative interpretation of both the genesis and age of deposits assigned to the Middle Wisconsinan, particularly those in southern Ontario and Hudson Bay Lowland, favours greatly enhanced, climatically induced ice recession (Hypothesis II; Fig. 3), to the point where the only Laurentide ice remaining may have been in the core dispersal areas of the Northwest Territories and central Québec, and parts of Baffin and adjacent slands. Separate ice caps may have developed in eastern maritime regions.

An intermediate interpretation, that could account for both marine fossil fragments in the Hudson Bay Lowland and
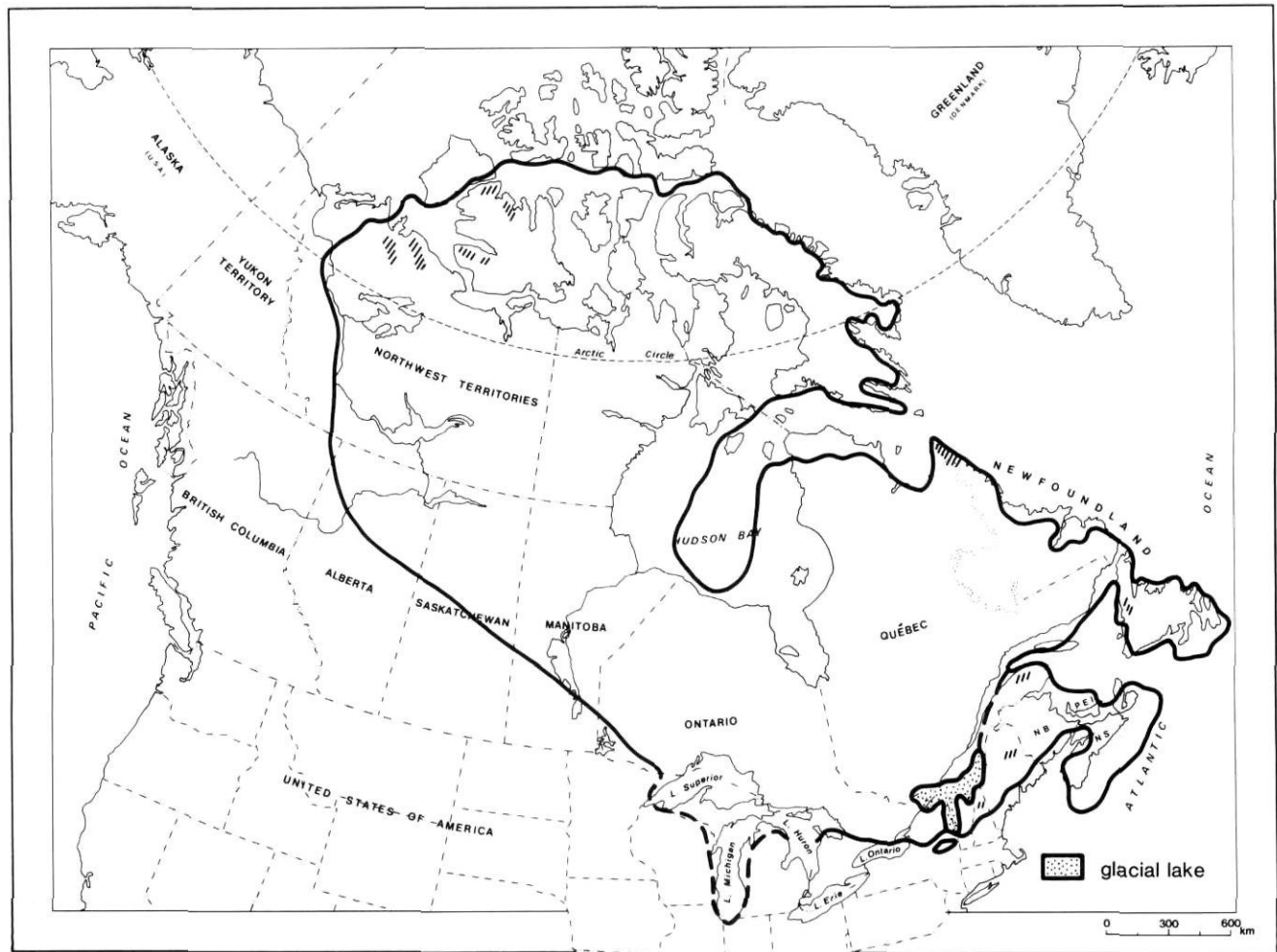

FIGURE 4. Middle Wisconsinan ice limits, with a dynamically induced calving bay into the heart of the ice sheet (Hypothesis III).

Limites glaciaires au Wisconsinien moyen, avec une baie de vêlage qui résulte de l'instabilité dynamique de la masse glaciaire et qui s'avance au centre de la calotte glaciaire (hypothèse III).

maintenance of extensive ice cover, is shown as Hypothesis III (Fig. 4). This shows the same ice sheet configuration as Hypothesis I but with a large embayment in Hudson Bay. The assumption here is that in addition to ice retreat in the south and west due to climatic factors, rising sea level may have induced dynamic instability of the marine-based portion of the ice mass over Hudson Bay, which led to at least partial break-up of ice in that area, and incursion of the sea. The lower amino acid ratios for shell fragments in the uppermost till in the central part of the Hudson Bay Lowlands may be explained as resulting from incorporation of shells after this marine event. If this opening were of limited extent, then the observed lithostratigraphic records, ice flow patterns recorded in the lithostratigraphic record in the Hudson Bay lowlands and global ice volume changes could be accommodated.

Due to the present inadequacies of our dating methods, all three configurations should be considered as working hypotheses.

ACKNOWLEDGMENTS

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