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The Early Wisconsinan History of the Laurentide Ice Sheet
L'évolution de la calotte glaciaire laurentidienne au Wisconsinien inférieur
Geschichte der laurentischen Eisdecke im frühen glazialen Wisconsin

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Résumé de l'article

L'identification, surtout en périphérie de l'inlandsis, de dépôts glaciaires que l'on croit postérieurs à la mise en place de sédiments non glaciaires ou de paléosols datant de l'interglaciaire sangamonien (phase 5) et antérieurs aux sédiments non glaciaires ou des sols mis en place au Wisconsinien moyen (phase 3) a amené de nombreux chercheurs à supposer que la calotte laurentidienne s'est d'abord développée au Sangamonien ou au Wisconsinien inférieur (phase 4). On passe en revue les différentes preuves associées au début de la formation de la calotte glaciaire wisconsinienne recueillies au Canada et au nord des États-Unis. En l'absence quasi généralisée de données géochronométriques sûres pour déterminer l'âge des dépôts glaciaires datant probablement du Sangamonien ou du Wisconsinien inférieur, on peut aussi bien supposer, pour une période donnée, que les glaces ont entièrement envahi une région ou en étaient tout à fait absentes. En tenant pour acquis (?) que la calotte laurentidienne était en fait très étendue au Wisconsinien inférieur, on présente une carte montrant son étendue maximale et un tableau de corrélation entre les unités glaciaires. Les glaciers postérieurs au Sangamonien sensu stricto (sous-phase 5e) et antérieurs au Wisconsinien moyen sont généralement plus étendues qu'au Wisconsinien supérieur (phase 2). La géométrie de la marge glaciaire et les quelques données sur la direction de l'écoulement montrent que les inlandsis du Wisconsinien inférieur et du Wisconsinien supérieur se sont développés de façon similaire. On présente enfin un modèle hypothétique de croissance de la calotte laurentidienne après le dernier interglaciaire.

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THE EARLY WISCONSINAN HISTORY OF THE LAURENTIDE ICE SHEET*

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ABSTRACT The identification, particularly at the periphery of the ice sheet, of glacigenic sediments thought to postdate nonglacial sediments or paleosols regarded as having been laid down sometime during the Sangamonian Interglaciation (stage 5) and thought to predate nonglacial sediments or soils reckoned to be of Middle Wisconsinan age (stage 3), has led numerous authors to propose that the Laurentide Ice Sheet initially grew during the Sangamonian and/or the Early Wisconsinan (stage 4). The evidence for the beginning of the Wisconsinan ice sheet in various areas of Canada and the northern United States is briefly reviewed. The general absence of sound geochronometric frameworks for potential Sangamonian or Early Wisconsinan glacial deposits has led to a situation where in most areas it can be argued, depending on one's interpretation, that ice completely inundated or was completely absent at that time. On the premise (perhaps false) that Laurentide Ice was in fact extensive during the Early Wisconsinan, a map showing maximum possible ice extent, as put forward by some authors is presented and the glacigenic units possibly recording the ice advance are shown in a correlation chart. This post Sangamonian *sensu stricto* (substage 5e) -pre Middle Wisconsinan limit of ice extent is generally more extensive than the Late Wisconsinan (stage 2) limit. The geometry of the ice sheet margin and scanty available information on direction of ice movements indicate that this assumed Early Wisconsinan ice likely developed in a very similar manner to that of the Late Wisconsinan ice complex. A hypothetical growth model of the Laurentide Ice Sheet, following the last interglaciation is also proposed.

RÉSUMÉ *L'évolution de la calotte glaciaire laurentidienne au Wisconsinien inférieur.* L'identification, surtout en périphérie de l'inlandsis, de dépôts glaciaires que l'on croit postérieurs à la mise en place de sédiments non glaciaires ou de paléosols datant de l'Interglaciaire sangamonien (phase 5) et antérieurs aux sédiments non glaciaires ou des sols mis en place au Wisconsinien moyen (phase 3) a amené de nombreux chercheurs à supposer que la calotte laurentidienne s'est d'abord développée au Sangamonien ou au Wisconsinien inférieur (phase 4). On passe en revue les différentes preuves associées au début de la formation de la calotte glaciaire wisconsinienne recueillies au Canada et au nord des États-Unis. En l'absence quasi généralisée de données géochronométriques sûres pour déterminer l'âge des dépôts glaciaires datant probablement du Sangamonien ou du Wisconsinien inférieur, on peut aussi bien supposer, pour une période donnée, que les glaces ont entièrement envahi une région ou en étaient tout à fait absentes. En tenant pour acquis (?) que la calotte laurentidienne était en fait très étendue au Wisconsinien inférieur, on présente une carte montrant son étendue maximale et un tableau de corrélation entre les unités glaciaires. Les glaciers postérieurs au Sangamonien *sensu stricto* (sous-phase 5e) et antérieurs au Wisconsinien moyen sont généralement plus étendues qu'au Wisconsinien supérieur (phase 2). La géométrie de la marge glaciaire et les quelques données sur la direction de l'écoulement montrent que les inlandsis du Wisconsinien inférieur et du Wisconsinien supérieur se sont développés de façon similaire. On présente enfin un modèle hypothétique de croissance de la calotte laurentidienne après le dernier interglaciaire.

ZUSAMMENFASSUNG *Geschichte der laurentischen Eisdecke im frühen glazialen Wisconsin.* Zahlreiche Autoren sind zu der Annahme gekommen, daβ die laurentische Eisdecke während des Sangamoniums und/oder des frühen glazialen Wisconsin (Phase 4) zu wachsen anfing. Diese Annahme stützt sich auf die Identifizierung glacialer Sedimente, die man für älter als nichtglaziale Sedimente oder Paleoböden hält, die ihrerseits irgendwann während der Interglazialzeit des Sangamoniums (Phase 5) abgelagert worden sind und vermutlich nichtglazialen Sedimenten oder Böden, die der mittleren glazialen Wisconsin-Zeit (Phase 3) zugeordnet werden, vorausgehen. Die Belege für den Beginn der Wisconsin-Eisdecke in verschiedenen Gebieten Kanadas und der nördlichen Vereinigten Staaten wird kurz zusammengefaβt. Das volkommene Fehlen eines gesicherten geo-chronometrischen Gerüsts für mögliche glaziale Ablagerungen im Sangamonium oder frühen glazialen Wisconsin führte dazu, daβ in den meisten Gebieten je nach Interpretationsweise das Eis in jener Zeit entweder vollständig überflutete oder gar nicht vorhanden war. Ausgehend von der (vielleicht falschen) Prämisse, daβ sich das laurentische Eis tatsächlich während des frühen glazialen Wisconsin ausdehnte, wird eine Karte mit der möglichen maximalen Eisausdehnung gezeigt, entsprechend der Annahme einiger Autoren; und in einer dazu in Verbindung stehenden Übersicht werden die glazialen Einheiten gezeigt, die den vermutlichen Eisvorstoβ dokumentieren. Diese Grenze der Eisausdehnung im Postsangamonium *sensu stricto* (Unterphase 5e) vor dem mittleren glazialen Wisconsin ist im Allgemeinen ausgedehnter als die Grenze im späten glazialen Wisconsin (Phase 2). Die Geometrie des Eisdeckenrands und ungenügende zugängliche Informationen über die Richtung der Eisbewegungen zeigen, daβ dieses vermutlich aus dem frühen glazialen Wisconsin stammende Eis möglicherweise sich ähnlich entwickelte wie die Eisdecke des späten glazialen Wisconsin. Auβerdem wird ein hypothetisches Wachstumsmodell der laurentischen Eisdecke nach der letzten Interglazialzeit vorgestellt.

* Geological Survey of Canada Contribution 33186

INTRODUCTION

The continental evidence for the beginning of the Laurentide Ice Sheet[1] sometime during the Sangamonian (marine oxygen isotope stage 5) or Early Wisconsinan (stage 4) and before the Middle Wisconsinan (stage 3) is the subject of this paper. This evidence comes mainly from the identification, at the periphery of the ice sheet, of glacigenic deposits postdating nonglacial sediments regarded as having been laid down at some time during the Sangamon Interglaciation and predating nonglacial deposits thought to be of Middle Wisconsinan age. Field evidence from various areas will be presented first, then a brief discussion on the inception, growth, possible extent, and timing of the early ice sheet will be put forward.

The time at which the build up potentially occurred lies well outside the interval which can be accurately dated by the radiocarbon method (about 45 ka for wood and 20 ka for shells). Assignment of specific ages to deposits and events is therefore tenuous at best. Workers have usually established relative age frameworks on the assumption that a specific glacial event took place at an indeterminate time after the deposition of nonglacial beds sometime during the Sangamonian (stage 5; 130-80 ka BP[2]) and before the deposition of nonglacial interstadial beds at sometime during the Middle Wisconsinan (stage 3; 65-23 ka BP). Although the largest marine isotopic excursion during the period between substage 5e and stage 2, occurred during stage 4 (Early Wisconsinan; 80-65 ka BP), some authors speculate that the Laurentide Ice Sheet may have developed during the Sangamonian *sensu láto* (substages 5a-5d; see ST-ONGE, 1987) and may still have been present over large areas during the Middle Wisconsinan (see DREDGE and THORLEIFSON, 1987).

The lack of sound geochronometric frameworks has also led to a situation where it is possible to argue that glacigenic units, at the periphery of the ice sheet, which were assigned a Sangamonian or Early Wisconsinan age, are in fact older or younger. This has led many researchers (for example CLARK, 1986) to argue for the absence or at least for the restricted growth of the Laurentide Ice Sheet in post Sangamonian *sensu stricto* — pre-Late Wisconsinan time. In this paper we purposely avoided siding with the researchers who have opted either for limited or for extensive ice development; rather we have chosen to express the various view points having in mind that no definitive solutions will surface until adequate dating methods are found. The portrayal of a maximum ice extent beyond the Late Wisconsinan limit and presentation of a model which shows ice sheet growth to this limit should not therefore be seen as expressing a preference for one view point at the expense of another. The documents only serve to illustrate a view point. The location of sites mentioned in the text is shown on Figure 1 and numbers in brackets throughout the paper refer to this figure.

1. Following PREST (1957, 1970, 1984), DYKE *et al.* (in press) have defined the Laurentide Ice Sheet as "an ice sheet of complex morphology centred on the Canadian Shield *during the Wisconsin Glaciation* but also covering at times large areas peripheral to the Shield. Precursors during earlier glaciations could be referred to as Laurentide ice".

2. The Quaternary chronologic framework and ages assigned to the various marine oxygen isotopic stages follow FULTON (in press).

REGIONAL STRATIGRAPHIC AND CHRONOLOGIC EVIDENCE FOR THE BEGINNING OF THE LAURENTIDE ICE SHEET

EASTERN ARCTIC ARCHIPELAGO

The occurrence of one or possibly two Laurentide ice advances in the Eastern Arctic Archipelago before the Middle Wisconsinan is apparently well established. Summaries of available information are found in ANDREWS and MILLER (1984), ANDREWS (1985, in press) and ANDREWS *et al.* (1985) for Baffin Island (1), and KLASSEN (1985) for Bylot Island (2). These indicate that Laurentide Ice built up on Baffin Island and in the marine basin west of it and extended to the outer east coast as outlet glaciers through the fiords carved in the coastal mountain belt. Glacigenic deposits of this ice advance are assigned to the Ayr Lake Stade of the Foxe (= Wisconsin) Glaciation (Table I, Column 1). Pollen-bearing A horizons of paleosols underlying Ayr Lake Stade deposits and overlying older glacial and marine sediments on Broughton Island (3) and Clyde Foreland (4) are thought to date from the Sangamon Interglaciation because of their high *Betula* content (MODE, 1985). In numerous sites, particularly on Cumberland Peninsula (5) and Clyde Foreland (4), raised ice-proximal glaciomarine and marine deposits associated with the Ayr Lake Stade advance have provided non-finite radiocarbon ages ranging from > 39 to > 54 ka BP. For example *in situ* shells in a delta at Cape Aston (6) have been dated at > 54 ka BP (Y-1703; ANDREWS, in press) and whale bone on McBeth Fiord (7) at > 52 ka BP (QL-976-2; ANDREWS, in press). In addition, the pre-Late Wisconsinan age of Ayr Lake Stade deposits has been well documented by using amino acid analyses and comparing the weathering and soil development characteristics of moraines of that age with that of younger Baffinland Stade (= Late Foxe = Late Wisconsinan/Holocene) moraines. ANDREWS *et al.* (1985), on the basis of all available information, have recently concluded that a period of "extensive glaciation occurred in the western sector of Baffin Bay during the latter part of marine isotope stage 5 and continued (expanded?) into 4".

On Bylot Island (2), ice of continental origin advanced in channels around the island and impinged on the coastal areas early during Wisconsin Glaciation. Near Pond Inlet (8), organic beds with a fauna and flora indicating warmer conditions than today are capped by Eclipse Glaciation (= Early Wisconsinan) sediments (Table I, Column 2). As on Baffin Island, raised marine deposits postdating the ice advance have provided nonfinite radiocarbon ages (*e.g.* > 43 ka, GSC-3410; ANDREWS, in press).

In the eastern Arctic, as in the western Arctic (see below), ice of the proposed earlier advance during the Wisconsinan (Early Foxe Glaciation) generally extended farther than that of the later ice advance (Late Foxe Glaciation). On the basis

FIGURE 1. Map of northern North America with location of sites mentioned in the text.

Carte de l'Amérique du Nord septentrionale montrant la localisation des sites mentionnés dans le texte.

(1) Baffin Island, (2) Bylot Island, (3) Broughton Island, (4) Clyde Foreland, (5) Cumberland Peninsula, (6) Cape Aston, (7) McBeth Fiord, (8) Pond Inlet, (9) Baffin Bay, (10) Banks Island, (11) Victoria Island, (12) Melville Island, (13) Nelson River (Banks Island), (14) Sachs Harbour, (15) Graveyard Bay, (16) Beaufort Sea, (17) Yukon Coastal Plain, (18) Tuktoyaktuk Peninsula, (19) Mackenzie River and Delta, (20) Bathurst Peninsula, (21) Alaskan Coastal Plain, (22) Amundsen Gulf, (23) Richardson Mountains, (24) Bonnet Plume basin, (25) Rat River basin, (26) Alberta, (27) Manitoba, (28) Medicine Hat, (29) Saskatoon, (30) Qu'Appelle Valley, (31) Montana, (32) Dakotas, (33) Minnesota, (34) Iowa, (35) Illinois, (36) Wisconsin, (37) Michigan, (38) Indiana, (39) Ohio, (40) Pennsylvania, (41) New York, (42) Ontario, (43) Lake Ontario, (44) St. Lawrence River, (45) Québec, (46) Toronto, (47) Eastern Townships, (48) New England, (49) Atlantic Provinces, (50) Long Island, (51) Martha's Vineyard, (52) New Hampshire, (53) Maine, (54) New Sharon, (55) Nantucket Island, (56) Nova Scotia, (57) Gaspésie, (58) New Brunswick, (59) Scotian Shelf, (60) Îles de la Madeleine, (61) Cape Breton Island, (62) Newfoundland, (63) Grand Banks, (64) Hudson Bay Lowland, (65) Hudson Bay, (66) Severn River, (67) Abitibi River, (68) Labrador, (69) British Columbia, (70) Northwest Territories, (71) Queen Elizabeth Islands, (72) Nelson River (Manitoba), (73) Clay Belt, (74) Hudson Strait, (75) Gulf of Boothia, (76) Lancaster Sound.

TABLE I

Correlation of lithostratigraphic or climatostratigraphic units tentatively assigned by various authors to the time spanning the interval between the Sangamonian and the Middle Wisconsinan

Chronostratigraphy		Oxygen isotope Stratigraphy (Ka)	1 Baffin Island	2 Bylot Island	3 Western Arctic Archipelago	4 Northern Interior Plains	5 Montana Plains	6 Southern Interior Plains	7 Minnesota and Iowa	8 Illinois and Wisconsin
Wisconsinan	Middle	3 (65)			Unnamed interstade (organic beds)	Unnamed interstade (organic beds)		Watino nonglacial Interval		Roxana Silt ?Capron Till?
Wisconsinan	Early	4 (80)	Foxe Glaciation: ? ↑ raised marine seds ↓ ?	? ↑ raised marine seds ↓ ?	Amundsen Glaciation: ? ↑ raised marine seds ↓ ? ↑ M'Clure Stade ↓ ?	? ↑ raised marine seds ↑ ? ↓ Buckland Glaciation Toker Point Stade Franklin Bay Stade ↓ ?	Extensive erosion and weathering	? ↑ Burke Lake Glaciation ↓ ?	? ↑ Deposits of Wadena Lobe ↓ ?	
Sangamonian		5a-5d	Ayr Lake Stade (2) Ayr Lake Stade (1)	↑ Eclipse Glaciation ↓ ?						
Sangamonian		5e (130)	paleosols	buried organic beds ↓ ?	Cape Collinson Interglaciation	Liverpool Bay Interglaciation		Osler Nonglacial Interval		Sangamon paleosol

References used in constructing the table.

Column 1: ANDREWS and MILLER (1984); AKSU (1985)
Column 2: KLASSEN (1985)
Column 3: VINCENT (1984, in press)
Column 4: RAMPTON (in press)
Column 5: FULLERTON and COLTON (1986)
Column 6: FENTON (1984)
Column 7: WRIGHT *et al.* (1973); CLAYTON and MORAN, 1982
Column 8: BERG *et al.* (1985); JOHNSON (1986)
Column 9: FULLERTON (1986)
Column 10: FULLERTON (1986)
Column 11: KARROW (1984)
Column 12: OCCHIETTI (1982), in press); LASALLE (1984)
Column 13: BORNS and CALKIN (1977); OLDALE (1982); SIRKIN (1982); KOTEFF and PESSL (1985); NEWMAN *et al.* (1985)
Column 14: GRANT (in press)
Column 15: SHILTS (1984)

of amino acid analyses on Broughton Island (3) and Clyde Foreland (4), ANDREWS and MILLER (1984) and ANDREWS (in press) believe that the Ayr Lake Stade may in fact be composed of two distinct ice advances since amino acid ratios on shells found in deposits of Early Foxe age, cluster into two discrete groups. This may well be supported by offshore studies in Baffin Bay (9). On the basis of mineralogical and paleo-oceanographic evidence, gathered from cores, AKSU (1985) believes that a period of major ice accumulation occurred on nearby land at the transition from stages 5 to 4 (peak at *ca.* 72 ka BP) and a minor one at the transition between substages 5e and 5d (peak at *ca.* 118 ka BP) (Table I, Column 1). The observations of Aksu may well provide a good estimate of the time at which the Laurentide Ice Sheet reached its full development in the Eastern Arctic during the early part of the Wisconsin Glaciation.

TABLEAU I

Corrélation entre les unités lithostratigraphiques et climato-stratigraphiques provisoirement attribuées par divers auteurs à l'intervalle entre le Sangamonien et le Wisconsinien moyen

9	10	11	12	13	14	15
Michigan SE Indiana SW Ohio	**Central Ohio To New York**	**Southern Ontario**	**Southern Quebec**	**New England**	**Atlantic Provinces**	**Hudson Bay Lowland**
paleosol and interstadial seds.	paleosol and interstadial seds	Meadowcliffs and Seminary tills Port Talbot Interstade	Gentilly Till ?	?Nassauan? Stadial	Paleosols	
? till near Grand Rapids Fairhaven Till Whitewater Till ?	? Jelloway, Millbrook, Mogadore, Titusville Warrensville, Broome, and Olean tills ?	? Sunnybrook and Bradtville tills ?	?		? Red Head, East Milford, Richmond etc. tills ?	? till ?
		Pottery Road Formation Scarborough Formation ?	St-Pierre and Massawipi seds Bécancour and Johnville tills ?	? Montauk, Nash Stream, New Sharon, St. Francis tills ?	Bras d'Or Interstade ? tills ?	Fawn River gravels Adam Till ?
Sangamon paleosol	Sangamon paleosol	Don Formation		Sangamon deposits	Magdalen Interglaciation	Missinaibi Interglacial beds

Of all areas at the periphery of the ice sheet, Baffin Island seems to be the one where the suggested chronologic framework is the best established. It should nevertheless be understood that much rests on the correct age assignment of the Kogalu Aminozone to stages 4-5 (ANDREWS *et al.*, 1985) and not to an older period such as the stage 6 to 5 transition. One of the major implications of an Early Wisconsinan age for the Kogalu Aminozone is that the mean annual temperature since that time would have been some 5°C warmer than present (see Table 3 in ANDREWS and MILLER, 1984).

WESTERN ARCTIC ARCHIPELAGO

On the basis of the stratigraphical, paleoecological, and chronological data, VINCENT (1984, in press) has concluded that Laurentide ice advanced in the western Arctic Archipelago at some time between Sangamonian and Middle Wisconsinan nonglacial intervals. On Banks (10), Victoria (11), and Melville (12) islands, widespread till sheets (Jesse, Sachs, Mercy, Bar Harbour, and Bolduc tills), glaciolacustrine, and marine deposits recording substantial glacio-isostatic depression argue for an extensive early Laurentide Ice Sheet advance in the western Arctic Archipelago (VINCENT, 1982, 1983, 1984, in press; HODGSON *et al.*, 1984). The glacigenic and marine deposits assigned by Vincent to the M'Clure Stade of Amundsen Glaciation (Table I, Column 3) are believed to have been laid down after the deposition of nonglacial beds regarded as Sangamonian and before a nonglacial period assigned to the Middle Wisconsinan. In coastal bluffs, near the mouth of Nelson River (13) and near Sachs Harbour (14) on southern Banks Island, *in situ* organic-rich tundra pond sediments of the Cape Collinson Formation underlie till and marine or glaciomarine deposits of M'Clure Stade. These have been radiocarbon dated at > 61 ka (QL-1230; VINCENT, 1983) and > 49 ka (GSC-3560-2; VINCENT *et al.*, 1983) respectively and document, on the basis of faunal and floral remains, a climate distinctly warmer than today (MATTHEWS *et al.*, 1986). Plant remains at three sites on Banks Island, and marine shells at five localities on both Banks and Melville (12) islands, postdate M'Clure Stade and predate Russell Stade glacigenic deposits and have provided non-finite and Middle Wisconsinan radiocarbon ages. On Victoria Island near Graveyard Bay (15), floral remains, including a pocket of willow leaves which were dated at > 37 ka (GSC-3613; VINCENT, in press), have been found in nonglacial sediments between two tills thought to be of Wisconsinan age.

If the age assignment of the M'Clure Stade is correct, then Laurentide glacial buildup in the early part of Wisconsin Glaciation was considerably greater in the western Canadian Arctic Archipelago than it was in the Late Wisconsinan. Ice flow directions and glacial erratic provenance indicate that the ice came from a source on the mainland to the southeast of Banks Island.

It has however been argued that the M'Clure Stade is of Late Wisconsinan age (DENTON and HUGHES, 1983; DYKE, 1987). In this interpretation M'Clure ice advances early in the Late Wisconsinan, retreats, and then readvances to another but less extensive (Russell Stade) Late Wisconsinan position. This would imply that Wisconsinan Laurentide Ice extended onto Banks and Melville (12) islands only in the Late Wisconsinan and hence there would be no record in the area of an earlier Wisconsinan glaciation because no other glacigenic sediments postdate the Cape Collinson Interglaciation beds.

NORTHERN INTERIOR PLAINS

Glacial and marine deposits on the coastal plain south of Beaufort Sea (16) (Table I, Column 4) are thought to record a Laurentide Ice Sheet advance early during the Wisconsin Glaciation (RAMPTON, 1982, in press; VINCENT, in press). Glacial sediments assigned to the Buckland Glaciation (= stade) on the Yukon Coastal Plain (17), to the Toker Point Stade on Tuktoyaktuk Peninsula (18) — Mackenzie Delta (19) area, and to the Franklin Bay Stade on "Bathurst" Peninsula (20) are viewed as having been laid down during an early Laurentide ice advance after the deposition of nonglacial beds interpreted as Sangamonian in age and before a nonglacial period regarded as Middle Wisconsinan. On the Yukon Coastal Plain (17), Buckland Till overlies organic-rich fluvial and marine sediments which have yielded several non-finite radiocarbon ages. The Buckland Till is the surface till but in places it is overlain by nonglacial organic-rich sediments which have yielded a finite radiocarbon age of 22 400 ± 240 (GSC-1262; RAMPTON, 1982). The Flaxman Member of the Gubik Formation, which on the Alaskan Coastal Plain (21) is found up to about 7 m asl and has been dated at *ca.* 75 ka BP by the thermoluminescence method (CARTER *et al.*, 1986), is also present on the Yukon Coastal Plain (17) and may represent a distal glaciomarine facies of the Buckland ice advance (VINCENT, in press). On Tuktoyaktuk Peninsula (18) and Mackenzie Delta (19) area Toker Point Stade till overlies likely eolian sands of the Kittigazuit Formation and underlies marine sands with shells which gave non-finite radiocarbon ages (> 35 ka, GSC-562; > 37 ka, GSC-690; see discussion in VINCENT, in press). Finally, on the eastern side of "Bathurst" Peninsula (20), Malloch Till was laid down by westerly advancing ice in Amundsen Gulf (22) during the Franklin Bay Stade. Liverpool Bay Interglaciation deposits (= Sangamon) on "Bathurst" Peninsula (20) which among other environments record a > 10 m high sea level, predate the Toker Point/Franklin Bay glacigenic deposits. Fragile willow twigs, in terrace sands postdating Franklin Bay Stade have been dated at 33 800 ± 800 BP (GSC-1974; RAMPTON, in press).

From the above record it therefore seems that Laurentide Ice on the mainland built up sometime in the early part of the Wisconsinan (VINCENT, in press) and advanced to a position beyond that of the later Wisconsinan ice advance on the Coastal Plain. Here again this record is not unanimously accepted. On the eastern flanks of the Richardson Mountains (22) and the lower Mackenzie River (19) basin, the most extensive Wisconsinan ice advance is thought to be "late" Middle Wisconsinan and "early" Late Wisconsinan on the basis of radiocarbon dates on materials found above and below till (HUGHES *et al.*, 1981; CATTO, 1986). In the Bonnet Plume basin (23), allochthonous wood from below Hungry Creek Glaciation till (correlated with Buckland Glaciation till by HUGHES *et al.*, 1981) gave a radiocarbon age of 36 900 ± 300 BP (GSC-2422; HUGHES *et al.*, 1981) providing a maximum age for the ice advance to its all time limit. In the upper Rat River basin (24), organic detritus found in glaciolacustrine sediments likely postdating the same extensive till sheet have given radiocarbon ages of 21 300 ± 270 BP (GSC-3371) and 21 200 ± 240 BP (GSC-3813) (CATTO, 1986) thus providing a minimum age for the ice advance. Hence in the northern Interior Plains, as in the western Arctic Archipelago, distinct glacial limits are considered by some as representing two distinct Wisconsinan stades separated by a Middle Wisconsinan interstadial (RAMPTON, 1982, in press) whereas others believe that the younger limit merely represents a halt in the retreat or a readvance of a more extensive glacier advance in the later part of the Wisconsin Glaciation (HUGHES, in press). As indicated by VINCENT (in press) it should be noted that the resolution of the conflicts in the interpretation of the records must take the regional sea level history into account. During the earlier stadial the crust in the Beaufort Sea area was depressed to a much greater extent than during the later stadial — thus indicating greater thicknesses and extent of ice during the first advance.

SOUTHERN INTERIOR PLAINS

In the Southern Interior Plains, researchers are still debating whether or not ice developed early during the Wisconsinan Stage. Some (FULLERTON and COLTON, 1986) believe that ice did not extend into the Plains at any time between the Illinoian and the Late Wisconsinan (Table I, Column 5). In contrast, others (LEMKE *et al.*, 1965; CLAYTON and MORAN, 1982; FENTON, 1984; STALKER *et al.*, in press) think that one of the most powerful and extensive Laurentide glacial advances may have occurred in the early part of the Wisconsinan Stage (Table I, Column 6).

In the Canadian Prairies, FENTON (1984) assigns to the Burke Lake Glaciation (= Early Wisconsinan Substage) deposits laid down after the Osler Nonglacial Interval (= Sangamonian) and before the Watino Nonglacial Interval (= Middle Wisconsinan). Numerous sections (FENTON, 1984) from northwestern Alberta (26) to southeastern Manitoba (27) record this glacial advance which is supposed to have joined with Cordilleran ice (STALKER and HARRISON, 1977; STALKER *et al.*, in press) to the west, and have extended into the United States.

Since numerous older finite and non-finite radiocarbon ages have been obtained on organic matter from nonglacial beds overlying the Burke Lake Glaciation deposits (FENTON, 1984), there is little doubt that the ice advance predates the Late Wisconsinan. However its age assignment to the Early Wisconsinan is entirely dependent on the assignment to the Sangamonian of the Osler Nonglacial deposits. According to FENTON (1984): "the local units are assigned to this event on the basis of: (1) vertebrate fossils, (2) invertebrate fossils, (3) stratigraphic position (that is, the next nonglacial deposits below the Middle Wisconsinan deposits), and (4) record of a climate warmer than the present". Critical nonglacial beds near Medicine Hat (28) (Mitchell Bluff Formation), near Saskatoon (29) (Riddell Member of Floral Formation) and in the Qu'Appelle Valley (30) (Echo Lake Gravels) are referred to the Sangamonian using those criteria. Once again the existence of ice in the early part of the Wisconsin Glaciation has been questioned. It is possible that the Osler Nonglacial beds are in fact older than the last interglaciation. This is the stand taken by FULLERTON and COLTON (1986; Table I, Column 5) on the basis of widely different interpretations of the stratigraphic, paleontologic and chronologic data. They believe that the Osler Nonglacial beds and the overlying Burke Lake Glaciation deposits are late-Middle Pleistocene (Illinoian) in age, and that following the deposition of the glacigenic deposits, a long nonglacial (= Watino Nonglacial) interval existed over the Plains from the Sangamonian to the end of the Middle Wisconsinan.

In Montana (31) and the Dakotas (32), LEMKE *et al.* (1965) and CLAYTON and MORAN (1982), on the basis of numerous studies, traced a glacial limit which they have tentatively assigned to an early stade of the Wisconsin Glaciation. In Montana, this limit is mainly documented by erratics whereas in the Dakotas sediments, glacial landforms, and meltwater channels record the ice advance named the Napoleon Glaciation by CLAYTON (1962).

According to the paleogeographic maps of CLAYTON and MORAN (1982) the Early Wisconsinan ice was more extensive than the Late Wisconsinan. As is the case for the Canadian record, FULLERTON and COLTON (1986) questioned the age assignment of this ice advance in the Plains. They refer the glacigenic deposits either to the Late Wisconsinan or to the Late Illinoian.

It is therefore obvious that major differences in interpretation of the data exist in the Interior Plains of southern Canada and northern United States. The question of the presence or absence of major ice advance(s?) early during the Wisconsin Glaciation remains open.

GREAT LAKES REGION

East of the Dakotas, in Minnesota (33) and Iowa (34), glacigenic deposits of the Wadena Lobe are found beneath drift of the Late Wisconsinan Des Moines and Superior lobes (WRIGHT *et al.*, 1973; Table I, Column 7). Although chronological control is lacking, ice of the Wadena Lobe "more likely" advanced to northernmost Iowa, as portrayed by CLAYTON and MORAN (1982), in the earlier part of the last Glaciation.

In Illinois (35) and Wisconsin (36) certain subsurface till sheets (Argyle Till Member of the Winnebago Formation in Illinois; Merrill or Arnott tills in Wisconsin) have been thought to date from the Altonian Substage or earlier part of the Wisconsin Glaciation (FRYE *et al.*, 1965; FRYE and WILMAN, 1973; CLAYTON and MORAN, 1982). These till sheets are covered by glacial deposits left by the Late Wisconsinan Superior and Michigan lobes and in some instances by organic rich silts, often of eolian origin, which have provided both older finite and non-finite radiocarbon ages. The ice of this early advance which deposited the tills seemingly covered all of Wisconsin except for the southwestern part and possibly northeastern Illinois. A small area in north central Illinois and south central Wisconsin, where Argyle Till is the surface deposit, may not have been covered by later advances. Recent work by BERG *et al.* (1985) and JOHNSON (1986) indicates that some of the tills (including the Argyle Till) are better considered to be Illinoian in age since the Sangamonian soil is thought to have developed in or on them (Table I, Column 8). Roxana Silt (loess), originally associated with an Early Wisconsinan ice advance, is also now thought to date from the Middle Wisconsinan (28 ~ 40 ka; McKAY, 1979) at a time when the Laurentide Ice Sheet was close by.

Michigan and Huron-Erie lobe tills are found beneath Late Wisconsinan glacial deposits in Michigan (37) (till near Grand Rapids) and in southeastern Indiana (38) and southwestern Ohio (39) (Whitewater and Fairhaven tills) (FULLERTON, 1986; Table I, Column 9). These tills have been assigned mainly an Early Wisconsinan age since they underlie non-glacial deposits which have provided non-finite radiocarbon ages. Father east, in central and eastern Ohio (tills in buried valleys of central Ohio; Jelloway, Millbrook, and Mogadore tills), in Pennsylvania (40) (Titusville and Warrensville tills), and in New York (41) (Broome and part of Olean tills), numerous till sheets laid down by the Huron, Erie or Ontario lobes have been assigned an Early Wisconsinan age (FULLERTON, 1986; Table I, Column 10) since they overlie a soil or beds assigned a Sangamonian age and they appear to lie beneath the Sidney (FORSYTH, 1965) and other paleosols of Middle Wisconsinan age. From eastern Ohio to eastern Pennsylvania, the till sheets actually lie a short distance south of the assumed Late Wisconsinan boundary indicating that Early Wisconsinan ice extended somewhat farther than Late Wisconsinan ice.

In southern Ontario (42), a widely accepted view is that sediments regarded as documenting two ice advances, separated by an interstade, overlie undoubted interglacial beds of the Don Formation (Sangamonian *sensu stricto*?) and underlie nonglacial beds (Thorncliffe Formation), of the Middle Wisconsinan Port Talbot Interstade, which have provided both finite and nonfinite radiocarbon ages (Table I, Column 11). The earliest presence of Laurentide Ice is inferred from the occurrence of deltaic beds of the Scarborough Formation. In order to have a delta formed some 45 m above the present day altitude of Lake Ontario (43), ice must have blocked the St. Lawrence River Valley (44) (KARROW, 1984). Fossil-bearing fluvial deposits of the Pottery Road Formation are cut into the Scarborough deltaic beds and are correlated with the St. Pierre Sediments of Southern Québec (45). Overlying these nonglacial beds is the Sunnybrook Till which documents the ice inundation of southern Ontario at some time during the early part of the Wisconsin Glaciation. Recently, SHARPE and BARNETT (1985) and SHARPE (in press) have partly challenged this interpretation by stating that the Pottery Road "fluvial" deposits may not have been laid down subaerially but may have been carved either by subglacial or sublacustrine streams. Thus the beds of the Scarborough, Pottery Road, and Sunnybrook formations may represent only one glacial stade rather than two, and the correlation of the Pottery Road Formation with the St. Pierre Sediments in Québec may not be valid (Table I, Columns 11 and 12). Furthermore, EYLES and EYLES (1983) have argued that the Sunnybrook "diamict" was laid down under floating ice. If this is the case: (1) no grounded ice reached the Toronto region (46) of Lake Ontario and both the Scarborough and Sunnybrook deposits would be distal records of Laurentide glacial events occurring further north (or east) during the early part of the Wisconsin Glaciation, and (2) the Early Wisconsinan age assignments of tills in Pennsylvania and New York discussed earlier would be erroneous since these states lie down-ice from Lake Ontario.

In the St. Lawrence River Lowlands (44) of Québec (Table I, Column 12), Bécancour and other correlated tills of the Nicolet Stade underlie assumed interstadial lacustrine and fluvial beds assigned to the St. Pierre Sediments, dated at 74.7 ka (QL-198; STUIVER *et al.*, 1978) by isotopic enrichment. In the Eastern Townships (47) of southern Québec, Johnville and other correlated tills underlie nonglacial sediments assigned to the Massawipi Formation (McDONALD and SHILTS, 1971; LASALLE, 1984; OCCHIETTI, 1982, in press). The tills and the correlated St. Pierre and Massawipi beds are generally thought to date from the earlier part of the Wisconsin Glaciation (Nicolet Stade). The age assignment is still the subject of much controversy since no warm climate deposits which can be assigned to the Sangamon Interglaciation are known to occur below the Bécancour or Johnville tills, and since it could be argued that the St. Pierre Sediments could be as old as the Sangamonian *sensu stricto* (marine isotopic substage 5e) or as young as the Middle Wisconsinan (OCCHIETTI, 1982). Figure 2 lucidly portrays uncertainties inherent in our stratigraphic interpretations of southern Québec.

Thus in the Great Lakes area as in other areas, the issue of the presence or absence of Laurentide Ice in the earlier part of the Wisconsin Glaciation can still be debated after decades of intensive investigations (CLARK, 1986). In the areas west of central Ohio, many workers believe that ice did

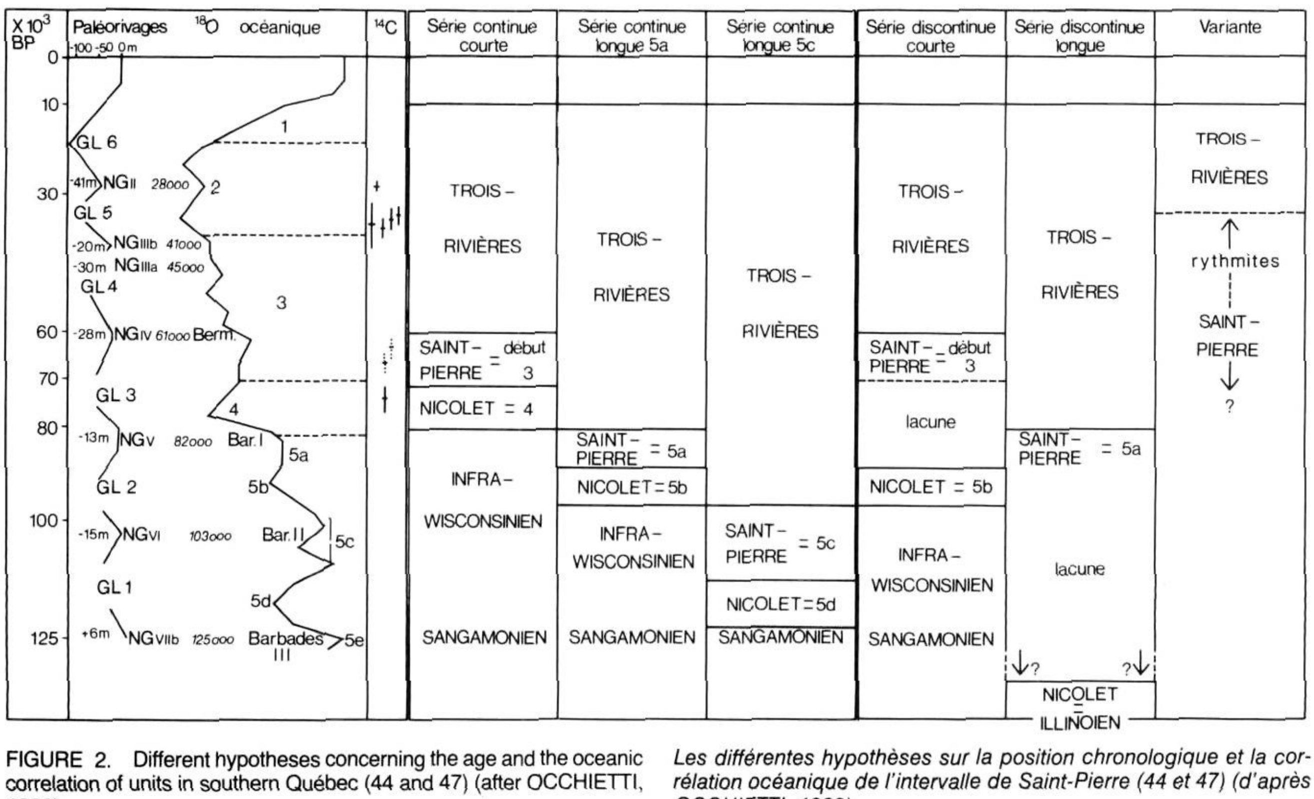

FIGURE 2. Different hypotheses concerning the age and the oceanic correlation of units in southern Québec (44 and 47) (after OCCHIETTI, 1982).

Les différentes hypothèses sur la position chronologique et la corrélation océanique de l'intervalle de Saint-Pierre (44 et 47) (d'après OCCHIETTI, 1982).

exist at that time but that it did not advance as far as during the Late Wisconsinan. East of central Ohio, the presence of ice in the earlier part of the Wisconsinan is generally accepted but it is thought that it extended somewhat farther at that time than during the Late Wisconsinan. The situation nevertheless is not clear-cut. For example, in Illinois, where the basic frameworks extensively used for correlation purposes have evolved, some workers (JOHNSTON, 1986) now believe that certain till sheets have been wrongly assigned to the Early Wisconsinan and that they were in fact deposited during older ice advances. Similarly, the interpretation of critical reference sections in southern Ontario are being questioned. The resolution of the problems will probably only come when new absolute dating techniques become available.

NEW ENGLAND AND ATLANTIC PROVINCES

In New England (48) a commonly weathered "lower" till sheet, underlying Late Wisconsinan deposits, has been tentatively assigned an Early Wisconsinan age by various authors (Table I, Column 13; STONE and BORNS, 1986). On Long Island (50), the Montauk Till, which lies above presumed Sangamonian beds and under Middle Wisconsinan beds which have provided finite and non-finite radiocarbon ages, has been assigned an Altonian Substage (= Early Wisconsinan) age (SIRKIN, 1982). To the northeast, till on Martha's Vineyard (51) has been tentatively correlated with the Montauk Till of Long Island (OLDALE, 1982). Further inland, in New Hampshire (52), weathered Nash Stream Till has been assigned to an Early Wisconsinan ice advance (KOTEFF and PESSL, 1985). Similarly in Maine (53), both the New Sharon Till (BORNS and CALKIN, 1977) and the St. Francis Till (NEWMAN *et al.*, 1985) are thought to date from the Early Wisconsinan. These age assignments of the New England "lower" tills have been questioned because of the lack of radiometric dates except at two locations: New Sharon (54) and Nantucket Island (55). OLDALE and ESKENASY (1983) for example assigned a pre-Wisconsinan (Illinoian?) age to a till found below marine deposits near the Late Wisconsinan limit on Nantucket Island (55) in Massachusetts. They state that this till may well correlate with other tills of the northeastern United States and southeastern Canada up to now considered as Early Wisconsinan.

In the Atlantic Provinces (49) of Canada, particularly in Nova Scotia (56), numerous glacial units overlying organic beds of presumed Sangamonian age and underlying possible soils or deposits assigned a Middle Wisconsinan age (Table I, Column 14) have been associated with Early Wisconsinan or even Sangamonian Laurentide Ice advances (GRANT and KING, 1984; GRANT, in press). According to GRANT (in press), this ice advance was much stronger than the Late Wisconsinan and generally moved southward over Gaspésie (57), New Brusnwick (58), and Nova Scotia, and extended onto the Scotian Shelf (59). It deposited a characteristic red brown till (= east Millford, Richmond, Red Head tills). At the same time Laurentide Ice advanced into the Gulf of St. Lawrence overridding both the Îles de la Madeleine (60) and Cape Breton Island (61). Ice from the Newfoundland (62) ice cap extended as outlet glaciers onto the continental shelf. De VERNAL and MOTT (1986) and De VERNAL *et al.* (1986) do not favour a Sangamonian ice advance but rather imply that the Atlantic Provinces were glaciated in the Early Wisconsinan and the Early Middle Wisconsinan. Similarly KING and FADER (1986) postulate that grounded ice and/or ice shelves covered at least part of the Scotian Shelf (59) and Grand Banks (63) continuously from the Early Wisconsinan to the Late Wisconsinan. PREST *et al.* (1976) on the other hand, argue for somewhat more limited ice since they do not believe the Îles de la Madeleine (60) were overridden by Laurentide Ice during the Wisconsin Glaciation.

HUDSON BAY LOWLAND

In the Hudson Bay Lowland (64) of Ontario and Manitoba, the presence of as many as four distinct till sheets, above beds of the Missinaibi Formation, thought to date from the last interglaciation, have been recognized (SKINNER, 1973; DREDGE and COWAN, in press). Other investigations aimed at establishing the lithostratigraphic and chronostratigraphic framework of the area have been recently completed by ANDREWS *et al.* (1983), SHILTS (1984) and NIELSEN *et al.* (1986).

Waterlain sediments have been observed in many places between the till sheets. Some authors (DREDGE and NIELSEN, 1985; DREDGE and COWAN, in press) interpret these as having been laid subglacially, whereas others (ANDREWS *et al.*, 1983) (Table I, Column 15) believe they represent non-glacial episodes and therefore ice free periods during the Wisconsinan. Recently, clustering of 300 + results of amino acid racemization analyses of shell fragments, collected in the individual till sheets, have led ANDREWS *et al.* (1983) to propose that Hudson Bay (65) was open twice during the Wisconsinan, initially around 75 ka and later around 35 ka ago. Surprisingly few marine beds have been found between Wisconsinan age till sheets. Some marine beds, on the Severn (66) and Abitibi (67) rivers have however been referred to as interstadial (WYATT *et al.*, 1986; FORMAN *et al.*, submitted) but the possibility that these were laid down in the Pre-Wisconsinan Bell Sea cannot be ruled out.

If the scenario advocated by ANDREWS *et al.* (1983) is correct, then the Hudson Bay Lowland, at the centre of the Laurentide Ice Sheet, was subjected to ice advance and retreat twice during the period from the post-Sangamon Interglaciation *sensu stricto* (substage 5e) and the late Middle Wisconsinan. If on the other hand, the scenario proposed by DREDGE and COWAN (in press) is correct, then the Hudson Bay Lowland was continuously covered by ice from the Sangamonian or Early Wisconsinan through to the Late Wisconsinan. The Hudson Bay Lowland is obviously critical to our understanding of the dynamics of the Laurentide Ice Sheet during the Wisconsin Glaciation. Did Wisconsinan ice grow, and cover much of northern North America and retreat to its central core(s) only once during the Wisconsin Glaciation or did it do so several times? The answer likely lies in the Hudson Bay Lowland but interpretations of the record there are at present far from conclusive. It is likely to remain unclear until more details of the lithostratigraphic and chronostratigraphic framework are established.

DISCUSSION AND ICE SHEET GROWTH MODEL

At the periphery of the area covered by the Laurentide Ice Sheet, researchers have found evidence arguing for at least one Wisconsin Glaciation ice advance at some time between the Sangamonian and the Middle Wisconsinan. This evidence is not firm since in all areas some workers have, with strong arguments, cast doubt on the age assignments of the advances. Numerous glacigenic units at one time thought to date from the earlier part of the Wisconsin Glaciation are now associated with Middle Pleistocene (Illinoian) glaciations or with Middle or Late Wisconsinan ice advances. In addition the age assignments of organic bearing units above or below glacigenic sediments have been reinterpreted. Thus glacial deposits thought to date from the earlier part of the Wisconsin Glaciation can no longer be confidently assigned that age. The fact that interpretations can vary so widely is simply a reflection of the lack of reliable absolute dating tools for materials older than the limit of the radiocarbon method.

Having in mind the varying, if not completely contradictory, interpretations of the regional stratigraphic records, it is impossible to arrive at a definitive statement on the extent and for that matter the definitive existence of Early Wisconsinan

FIGURE 3. Possible extent of the Laurentide Ice Sheet in post-Sangamonian *sensu stricto* pre-Middle Wisconsinan time.

Étendue possible de la calotte glaciaire laurentidienne après le Sangamonien et avant le Wisconsinien moyen.

ice. It is clear that on the one hand one could, by systematically questioning the age assignments of both glacial and nonglacial sediments, argue that there was no or little ice development during the Early Wisconsinan. On the other hand, if the Early Wisconsinan age assignments of glacial deposits and limits of many authors are accepted, then it is feasible to draw a map showing the possible extent of ice at that time. Figure 3 is such a map. As with similar documents portraying the Late Wisconsinan ice sheet (PREST, 1969, 1984; DENTON and HUGHES, 1981; DYKE and PREST, 1987), this map shows one interpretation of the position of the outer limit reached by ice and it should be understood that the ice would not have reached this limit everywhere at the same time.

On the Atlantic seaboard, following PREST (1984) the limit has been placed at the shelf edge and at least in the Atlantic Provinces (49) there is relative unanimity that the Early Wisconsinan advance was extensive (GRANT and KING, 1984; KING and FADER, 1986; GRANT, in press). On Baffin Island (1) the limit follows the Eclipse Glaciation limit of KLASSEN (1985) and the Early Foxe limit of DYKE *et al.* (1982), and east of Labrador (68) an offshore limit depicted by JOSENHANS *et al.* (1986). From Long Island (50) to central Ohio (39) the limit coincides with that of FULLERTON (1986) and from Illinois (35) to southwestern Alberta (26) it follows that of CLAYTON and MORAN (1982). In southwestern and west central Alberta and in northeastern British Columbia (69), Laurentide ice coalesced with the Cordilleran Ice Sheet (STALKER *et al.*, in press). In the westernmost Northwest Territories (70) and the southwestern Arctic Archipelago, the limit of ice extent follows that of VINCENT (1984, in press). In the southcentral and southeastern Queen Elizabeth Islands (71) the ice is shown to have coalesced with local ice as it did in the Late Wisconsinan (DYKE and PREST, 1987). It should be noted that in the areas east of Labrador (68), in Montana (31) and in the western Northwest Territories (70) and the southwestern Arctic Archipelago, the drawn limits are considered by some (respectively JOSENHANS *et al.*, 1986; FULLERTON and COLTON, 1986; DYKE and PREST, 1987) to be Late Wisconsinan in age. The portrayed Late Wisconsinan limit, added for comparative basis, is the one proposed by PREST (1984) in his minimum ice portrayal.

As portrayed on Figure 3, the hypothetical post-Sangamonian *sensu stricto* pre-Middle Wisconsinan limit of ice extent is generally more extensive than the minimum extent Late Wisconsinan limit. The general configuration of the limit indicates that it is likely that this ice would have come from similar ice centres to those developed in the Late Wisconsinan (DYKE and PREST, 1987) although the Labrador centre may have been more vigourous than the Keewatin centre as indicated by till lithologies and fabrics across the Hudson Bay Lowland (64) (DREDGE and COWAN, in press) and the extensive advance of the ice on the shelf in the Maritimes.

Although much could be said about ice movements at the periphery of the ice sheet, as recorded by the orientation of till fabrics, landforms, and glacially inscribed bedrock, little is known about these movements in the central part of the ice sheet. Fabrics and pebble lithologies in presumably Early Wisconsinan tills in the Hudson Bay Lowland indicate that ice flowed west and southwest (from Québec) (45) in southern Hudson Bay area and in the lowlands of northern Ontario (64) (PREST, 1963; PREST *et al.*, 1968; SKINNER, 1973; MACDONALD, 1971), while in northern Manitoba (27) it was westerly south of Nelson River (72) and southerly north of that river (DREDGE and COWAN, in press; NIELSEN *et al.*, 1986). In the Clay Belt (73) of Ontario and Québec, the older movements predating the Late Wisconsinan are southwesterly (VEILLETTE, 1986) and are consistent with a Labrador Ice dispersal centre.

In view of all the above and for the sake of discussion, a hypothetical model (Fig. 4) of the growth of the ice sheet is herewith presented. One premise used in constructing this model is that at the end of the Sangamon Interglaciation, isostatic adjustment was nearly complete and hence the floor of Hudson Bay (65) was above sea level except for minor inlets and bays in its north central part. Our hypothetical and conceptual model shows a possible growth pattern for a period of 21 ka in 2 ka intervals. It assumes that this growth accounts for the full or nearly full development of Labrador Sector or Baffin Sector ice in the south, east and north but does not cover the full development of Keewatin Sector ice in the west.

The depicted limits of glacier cover for the early growth (first 10 ka) rely on the idea of instantaneous glaciation (IVES, 1957) and are based on the considerations and modelling data of (BARRY *et al.* (1975), IVES *et al.* (1975), ANDREWS and MAHAFFY (1976), WILLIAMS (1978, 1979), and OCCHIETTI (1982). The boundaries for later growth (more than 10 ka after inception) are based on broad topographic controls and our knowledge of the general pattern of flow of Early Wisconsinan ice.

In the above process of instantaneous glacierization, as the snow line lowers, high ground areas become covered by a snow field which slowly changes through firn into glacier ice. Thus a broad flat ice field is developed, with but a narrow marginal zone having a relatively steep profile and minor outward flow. As the ice field thickens the marginal zone of actively flowing ice will broaden until the central zone has thickened to the point where an ice cap profile is fully developed with flow outward from an ice divide. The instantaneous glacierization process is perhaps best exemplified by the early growth of the Labrador Sector ice in Labrador (68) and Québec (45), but vast areas of Baffin Island (1) and the eastern Northwest Territories (70) were probably also covered by ice growing through this process. Later growth of the Laurentide Ice Sheet was probably by a more normal expansion of glacier ice, but the full story of the growth of the Laurentide Ice Sheet remains enigmatical. Excellent broad-ranging discussions are given by LOEWE (1971), ANDREWS *et al.* (1975) and BEATY (1978).

Under the conditions of experiment 1 of ANDREWS and MAHAFFY (1976), after 10 ka of growth the central part of Labrador (68)/Québec (45) and most of Baffin Island (1) were ice covered, with the southern end of the latter ice occupying or plugging the western end of Hudson Strait (74). Under the conditions of their experiment 2 after 10 ka of growth, most of Labrador/Québec was glacierized and the Baffin Ice had expanded westward into eastern Northwest Territories (70) and northwestward to Victoria Island (11), but the relatively narrow Hudson Strait (74) remained open. We favour the experiment 2 model because of its greater development of both Labrador Sector and Baffin Sector ice, but are convinced that Hudson Strait would have been plugged by ice early in the expansion process. Limiting early ice flow along the Strait would make it possible for ice in Hudson Bay (65) to thicken and flow southward into Ontario (42) and the northern United States to reach the presumed Early Wisconsinan limits (Figs. 3 and 4).

We believe that Hudson Strait (74) was probably ice-filled by combined Labrador Sector and Baffin Sector ice after 9 ka of growth and drainage from Hudson Bay (65) was northward into the Gulf of Boothia (75). By 11 ka Baffin and Keewatin Sector ice had merged so that a lake was dammed between these and Labrador Sector ice masses (glacial Lake Zissaga of ADAMS, 1976). After 13 ka of growth Labrador Ice and Keewatin Ice had merged and thereafter the line of confluence migrated southwestward, thereby forcing the lake to drain southwestward and south over the height of land and eventually into the Mississippi River system.

FIGURE 4. Hypothetical growth of the Laurentide Ice Sheet following the last interglaciation (in thousand of years after inception).

Modèle hypothétique montrant la croissance de la calotte glaciaire laurentidienne après le dernier interglaciaire (en milliers d'années après le début de sa formation).

Similarly, at the northern margin of Laurentide Ice Sheet, confluence between Laurentide and Innuitian Ice in Lancaster Sound (76) is shown after 11.0 ka of growth. The zone of confluence is shown as slowly migrating westward between 11 and 21 ka. Of course we have no pertinent age control and we merely assume that there would have been further slow growth in this region, towards its maximum extent.

In northern Ontario (42), where the Late Wisconsinan ice receeded northeastward toward Hudson Bay (65) but also eastward into Québec (45), there is field evidence that an earlier ice flow was toward the west and northwest (PREST, 1963; PREST and NIELSEN, 1987). Thus the growing of Laurentide ice is shown as a "nose" advancing across northern Ontario, somewhat earlier than the infilling of Hudson Bay. Similar elongate prongs of glacier ice are shown as advancing over the higher ground in the eastern Northwest Territories (70).

The timing of the main growth period of the Laurentide Ice Sheet is still conjectural and the maximum could well have been reached during marine isotopic stage 4 which records a relative lowering of world sea level of nearly the same magnitude as that during the Late Wisconsinan stage 2. One thing that should be kept in mind is that ice sheet growth may have occurred during the Sangamonian and that substantial volumes of ice may have been present at the start of the Wisconsinan.

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