QUATERNARY STRATIGRAPHY OF CANADA — A CANADIAN CONTRIBUTION TO IGCP PROJECT 24

Canada

Geological Survey of Canada
Paper 84-10

QUATERNARY STRATIGRAPHY OF CANADA — A CANADIAN CONTRIBUTION TO IGCP PROJECT 24

Edited by

R.J. Fulton

IUGS
UNESCO
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1984

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

100 West Pender Street
Vancouver, British Columbia V6B 1R8
(mainly B.C. and Yukon)

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-84/10E Canada: $10.00
ISBN 0-660-11725-8 Other countries: $12.00

Price subject to change without notice

Cover

Twin Cliffs Bluff, on the northeast bank of the South Saskatchewan River about 5 km north of Medicine Hat, Alberta. The river has cut through fill in its pre-glacial valley to expose four till sheets overlying silt and sand laid down during the approach of the first glacier in the region. Photo by A. MacS. Stalker, 1971.

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Cowichan Head, southern Vancouver Island: A complex of glacial and fluvial sediments lies at the base of the right end of this section; the lowest dark band consists of marine and glaciomarine diamicton; the light coloured sand with left-dipping stratification at the left edge of the section is Cowichan Head Formation (Middle Wisconsinan); the roughly horizontal unit in the middle of the section is Quadra Sand (Late Wisconsinan advance outwash); and the thin massive unit at the top is Late Wisconsinan till and glaciomarine sediment. Photo and stratigraphy by R.J. Fulton, GSC 203193-P.

FOREWORD

This collection of papers is the final report of the Canadian Working Group of IGCP Project 73/1/24, Quaternary Glaciations in the Northern Hemisphere. In his introduction to this volume, A. Dreimanis, the Work Group leader, describes the project and the nature and extent of Canadian participation. Most regional papers included here were presented at a symposium *Quaternary Stratigraphy of Canada* organized at the annual meeting of the Geological Association of Canada in Winnipeg, 1982, by A. Dreimanis and J.T. Teller. The three summary papers (Western, Arctic, and Eastern Canada) have been submitted as Canada's contribution to the final international report of Project 24.

Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24 represents our current understanding of the Quaternary stratigraphy and history of Canada. This volume outlines several solidly based chronologies which provide a firm foundation for future Quaternary work in Canada. In addition it presents a number of speculative correlations. These and the many gaps that are apparent in our regional knowledge indicate how far we must yet go before we truly understand the Quaternary of Canada.

Students of stratigraphy will note a lack of consistency in the nature of units discussed. Ideally, a regional synthesis should present descriptions and correlations of formally defined lithological units, interpretations of the environmental significance of these along with possible designation of event units, and should provide a time-stratigraphic framework based on the physical units. A summary paper should provide a correlation of regional time-stratigraphic frameworks and a synthesis of changes in geological environments which might be placed in a framework of event units. These practices have not always been followed. In several places workers have merely designated a series of event units (glaciations, advances, flow phases) without defining the material units which are necessary to establish event units. In other places workers have described material units, given these informal designations, but have not set up formal units which could be correlated from section to section, have not described local sequences of events, and have not developed time-stratigraphic frameworks. As a result, the summary tables correlate time-stratigraphic units in one area, with event units in another, with lithological units in a third. Although this is not good stratigraphic procedure, it is hoped that readers will note these problems and in the future pay strict attention to basic stratigraphic principles and procedures in carrying out their own work.

I am indebted to an editorial committee consisting of J.T. Andrews, A. Dreimanis, D.R. Grant, P.F. Karrow, and V.K. Prest, who aided in the critical review of manuscripts, and also to the other authors who undertook the review of manuscripts covering areas adjacent to the regions for which they were responsible. H. Dumych, in her role as Technical Editor, improved the clarity and succinctness of many papers and played a major role in assuring consistency in terminology.

R.J. Fulton

AVANT-PROPOS

Le présent recueil d'études constitue le rapport final du Groupe de travail canadien du projet 73/1/24 du PICG, Quaternary Glaciations in the Northern Hemisphere. Dans son introduction, M. A. Dreimanis, chef du Groupe de travail, décrit le projet ainsi que la nature et l'ampleur de la participation canadienne. La plupart des rapports régionaux ci-inlus ont été présentés lors d'un colloque intitulé *Quaternary Stratigraphy of Canada*, organisé par MM. A. Dreimanis et J.T. Teller à l'occasion de la réunion annuelle de l'Association géologique du Canada, tenue à Winnipeg en 1982. Le Canada a contribué trois rapports sommaires sur l'Ouest du Canada, l'Arctique et l'Est du Canada au rapport international définitif sur le projet 24.

Le texte intitulé *Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24* présente la situation actuelle de la stratigraphie et de l'histoire du Quaternaire au Canada. Ce volume expose brièvement plusieurs chronologies bien justifiées sur lesquelles pourra se fonder toute étude ultérieure du Quaternaire au Canada. Il présente également un certain nombre de corrélations provisoires. Ces corrélations, conjuguées aux nombreuses lacunes dont font preuve les connaissances régionales au pays, révèlent jusqu'à quel point beaucoup d'autres travaux restent à être entrepris avant de vraiment connaître le Quaternaire au Canada.

Les individus qui s'intéressent à la stratigraphie remarqueront sans doute le manque d'uniformité en ce qui a trait à la nature des unités étudiées. Une synthèse régionale devrait présenter des descriptions et des corrélations d'unités lithologiques officiellement définies, une interprétation de l'importance environnementale de ces unités et une désignation provisoire des unités événementielles ainsi qu'un plan chronostratigraphique fondé sur les unités physiques. Un rapport sommaire doit présenter une corrélation des plans chronostratigraphiques régionaux et une synthèse des changements se produisant dans les milieux géologiques et susceptibles de faire partie d'un plan d'ensemble des unités événementielles. Ces pratiques n'ont pas toujours été adoptées. Souvent, les chercheurs ont tout simplement identifié une série d'événements (glaciations, avancées, phases d'écoulement), sans définir les unités matérielles nécessaires pour établir les unités événementielles. D'autres chercheurs ont établi les désignations officieuses d'unités matérielles qu'ils ont décrites, mais sans définir les unités officielles pour lesquelles il serait possible d'établir une corrélation entre différentes sections, sans décrire la succession locale d'événements et sans élaborer de plans chronostratigraphiques. Il en résulte que les tableaux sommaires mettent en corrélation les unités chronostratigraphiques d'une région avec les unités événementielles d'une autre région et avec les unités lithologiques d'une troisième région. Bien qu'il ne s'agisse pas d'une bonne pratique stratigraphique, les auteurs espèrent que les lecteurs prendront note des problèmes et qu'à l'avenir ils suivront rigoureusement les principes et les pratiques stratigraphiques fondamentales dans leurs propres travaux.

J'aimerais remercier les membres du comité de rédaction, soit MM. J.T. Andrews, A. Dreimanis, D.R. Grant, P.F. Karrow et V.K. Prest, qui ont participé à la lecture critique des manuscrits, ainsi que les autres auteurs qui ont relu les manuscrits portant sur les régions contigues aux leurs. À titre de rédactrice technique, Mlle H. Dumych a amélioré la précision et la concision d'un grand nombre de rapports et a assuré l'uniformité de la terminologie utilisée.

R.J. Fulton

SUMMARY: QUATERNARY STRATIGRAPHY OF CANADA
SOMMAIRE: STRATIGRAPHIE QUATERNAIRE AU CANADA

Tom Creek, southeastern Yukon Territory: Grey till overlain by gravel, sand, silt, and clay containing wood dated at 23.9 ka; two units of till lie on top. Photo and stratigraphy by R.W. Klassen, GSC 202881-Q.

Ruisseau Tom, sud-est du Yukon. Le till gris, recouvert par du gravier, du sable, du silt et de l'argile, contient du bois datant de 23,9 ka; deux unités de till se trouvent sur le toit de la formation. Photo et stratigraphie par R.W. Klassen, GSC 202881-Q.

SUMMARY: QUATERNARY STRATIGRAPHY OF CANADA

SOMMAIRE: STRATIGRAPHIE QUATERNAIRE AU CANADA

R.J. Fulton[1]

Fulton, R.J., Summary: Quaternary Stratigraphy of Canada/Sommaire: stratigraphie quaternaire au Canada; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 1-5, 1984.

All Canada was glaciated repeatedly during the Quaternary, with the exception of an area in northern and western Yukon and small nunatak areas in the southwestern Prairies and eastern and northeastern Canada. The Quaternary deposits present are overwhelmingly glacial in origin and no long uninterrupted sequences of nonglacial deposits occur. As later glaciations either removed or buried older deposits, exposures of materials deposited before the last glaciation are rare and consequently our knowledge of earlier parts of the Quaternary record is meagre. Locally extensive sequences of Quaternary sediments are exposed and our concept of the Quaternary of Canada as presented in this volume hinges on the deposits of these few isolated sections.

A summary of the major chronostratigraphic names used in Canada is presented in Table 1. The scheme has grown out of the subdivision of Quaternary deposits into glacial and nonglacial units. The time units associated with these deposits have been referred to as glaciations, interglaciations, nonglacials, stades, and interstades which are all highly time-transgressive. The Canadian Work Group for IGCP Project 24 decided that in comparing and correlating the Quaternary record of one part of the country with that of another region, it was best to use a stage and substage subdivision of the Quaternary. The boundaries of these chronostratigraphic units are time-parallel and were set at positions that were felt to approximate the age of significant geological boundaries on a Canada-wide basis.

The following is a brief description of the Canadian Quaternary record as it is summarized in Table 1.

Sediments that can be documented to predate the last interglaciation have been studied in few parts of Canada. Southern Alberta and Saskatchewan (Prairies) and Banks Island (Western Arctic) are the only areas where sediments older than Sangamonian have been studied in any detail. In the Prairies vertebrate paleontology has been used to demonstrate a succession of glacial and nonglacial deposits which appears to extend back as far as the Olduvai Event (1.67 to 1.87 Ma). In addition, the Wascana Creek Ash (which correlates with the Pearlette 0 tephra of the Midwest United States, dated 610 ka) has been found in lake sediments, suggesting nonglacial conditions at the time of deposition. On Banks Island, deposits of at least two pre-Wisconsinan glaciations are separated by interglacial deposits and underlain by nonglacial materials; the older tills and associated glacial deposits are paleomagnetically reversed and hence are probably older than 790 ka (the Bruhnes-Matuyama boundary). Three pre-Sangamonian periods of deposition of speleothems have been documented in caves in the Rocky Mountains: the youngest is 235-185 ka, the next oldest 320-275 ka, and the oldest approximately or older than 350 ka (^{230}Th-^{234}U dates). These periods are considered to have been interglacials. Quaternary sediments on eastern Baffin Island appear to date back more than 600 ka but most old deposits have not been subdivided into glacial and interglacial units and dating is very tentative. In Hudson Bay Lowland, deposits correlated with the Sangamonian Stage are underlain by at least four tills which represent at least two

Tout le Canada a été recouvert par les glaces à maintes reprises au cours du Quaternaire, à l'exception d'une partie du nord et de l'ouest du Yukon et de petites régions à nunataks dans le sud-ouest des Prairies et dans l'est et le nord-est du Canada. Presque tous les dépôts quaternaires ont une origine glaciaire et aucune séquence longue et ininterrompue de sédiments non glaciaires n'a été reconnue. Puisque les glaciations ultérieures ont soit enlevé, soit enfoui les dépôts plus anciens, il est rare de trouver des affleurements de matériaux mis en place avant la dernière glaciation. On connaît donc mal les périodes les plus éloignées de l'histoire du Quaternaire. De vastes séquences de sédiments quaternaires affleurent par endroits et la notion du Quaternaire présentée dans le présent volume se fonde sur les sédiments de ces rares sections isolées.

Le tableau 1 présente un résumé des principaux noms chronostratigraphiques utilisés au Canada. Ce plan est fondé sur la subdivision des dépôts quaternaires en unités glaciaires et non glaciaires. Les unités chronologiques associées à ces dépôts sont appelées glaciations, interglaciaires, intervalles non glaciaires, stades et interstades et sont toutes fortement diachrones. Le Groupe de travail canadien du projet 24 du PICG a décidé qu'il serait préférable de subdiviser le Quaternaire en étages et en sous-étages afin de comparer et de mettre en corrélation l'histoire quaternaire de différentes régions du Canada. Ces unités chronostratigraphiques ont des limites chronologiquement parallèles dont les positions correspondent à peu près à l'âge des grandes limites géologiques du Canada.

Les paragraphes suivants présentent une brève description de l'histoire du Quaternaire au Canada telle qu'elle est résumée au tableau 1.

On a étudié, à très peu d'endroits, les sédiments mis en place au Canada avant le dernier interglaciaire. Les sédiments accumulés avant le Sangamonien ont été étudiés en détail seulement dans le sud de l'Alberta et de la Saskatchewan (Prairies) et dans l'île Banks (ouest de l'Arctique). Dans les Prairies, la paléontologie des vertébrés a permis d'identifier une succession de dépôts glaciaires et non glaciaires qui semble s'étendre jusqu'à l'épisode d'Olduvai (il y a 1,67 à 1,87 Ma). De plus, la présence de la cendre de Wascana Creek dans les sédiments lacustres semble indiquer que des conditions non glaciaires dominaient au moment de leur mise en place. La cendre de Wascana Creek semble correspondre au tephra de Pearlette 0 du Midwest américain, vieille de 610 ka. Dans l'île Banks, des dépôts interglaciaires séparent les sédiments d'au moins deux glaciations antérieures au Wisconsinien qui reposent sur des matériaux non glaciaires; les tills plus anciens et les sédiments glaciaires connexes ont un paléomagnétisme inversé et ont donc vraisemblablement plus de 790 ka (limite entre les époques de Bruhnes et de Matuyama). On a identifié trois périodes pré-sangamoniennes de mise en place de spéléothèmes dans les cavernes des Rocheuses: la plus récente date de 235 à 185 ka, la suivante de 320 à 275 ka et la plus ancienne d'au moins 350 ka (datation au Th^{230}/U^{234}). Ces périodes représentent vraisemblablement des interglaciaires. Les sédiments quaternaires dans la partie est de l'île de Baffin semblent avoir plus de 600 ka, mais la plupart des dépôts anciens n'ont pas encore été subdivisés en

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Table 1. Framework for Canadian Quaternary stratigraphy.

			STAGE (ka)	SUBSTAGE (ka)	OXYGEN ISOTOPE STAGES (ka)	ka	DATED ISOLATED EVENTS (Other than ^{14}C)
QUATERNARY	HOLOCENE				1		
			10				
					13		
	PLEISTOCENE	LATE	WISCONSINAN	LATE	2		
				23			
					32	28	
				MIDDLE	3		Speleothem deposition (Vancouver Island)[1]
				64	64	64	
				EARLY	4		
			75		75		
			SANGAMONIAN		5		
					128		
		MIDDLE	ILLINOIAN		6	185	
					7	235	Speleothem deposition (Cordillera)[2]
					8	275	
					9	320	Speleothem deposition (Cordillera)[2]
						? 350 ?	Speleothem deposition (Cordillera)[2]
					15	610	Wascana Creek Ash (Saskatchewan)[3]
		EARLY				790	Bruhnes-Matuyama boundary (Banks Island)[4]
						1670	Olduvai (?) nonglacial deposition (Saskatchewan)[5]
						1870	

1 Gascoyne et al., 1980 3 Westgate et al., 1977 5 Foster and Stalker, 1976
2 Harmon et al., 1977 4 Vincent et al., 1983

glaciations. In the Toronto area, boreholes have encountered several tills which are older than the Sangamonian Don Formation; the youngest of these has been assigned to the Illinoian but the others are essentially unstudied.

Considerable controversy exists about how the last interglacial stage should be defined in Canada. The name Sangamon, which is used in the United States, is generally used in Canada. It has been argued that Sangamon is the name of an interglacial and hence the term should not be used for a period during which glacial deposits or deposits associated with a cooler climate than at present were formed. If this narrow definition was followed, it would mean limiting the Sangamonian Stage in Canada to the period represented by oxygen isotope substage 5e. On the other hand, it has been argued that the terms glaciation and interglaciation can only have significance in a world-wide sense. According to this argument, a warm period can only be considered as an interglacial if world ice volumes are nearly equal to, or less than, those at present, and a cold period can only be a glaciation if world ice volumes are significantly greater than those of today. If this last definition is used, a glaciation or an interglaciation cannot be defined in terms of parameters observed in a local area but can only be based on parameters such as oxygen isotope ratios which reflect world ice volumes. In addition the timing of local advances and retreats cannot be used to define glaciations and interglaciations on a global scale. The summary reports take this broad global approach and define the Sangamonian Stage as beginning about 128 ka and lasting until 75 ka – the limits of oxygen isotope stage 5. Environmental fluctuations during the Sangamonian have not been well documented in Canada. In lower St. Lawrence valley and Atlantic areas, glacial deposits apparently were laid down during the middle Sangamonian, separating warm climate deposits in the early Sangamonian from cool climate deposits in the late Sangamonian. In the Great Lakes area, warm climate deposits in the early Sangamonian are

Tableau 1. Structure de la stratigraphie du Quaternaire canadien.

			ÉTAGE (ka)	SOUS-ÉTAGE (ka)	ÉTAGES DÉTERMINÉS PAR ISOTOPE D'OXYGÈNE (ka)	ka	ÉVÉNEMENTS ISOLÉS D'ÂGE DÉTERMINÉ (autrement que par ^{14}C)
QUATERNAIRE	HOLOCÈNE				1		
			10				
					13		
	PLÉISTOCÈNE	SUPÉRIEUR	WISCONSINIEN	SUPÉRIEUR	2		
				23			
					32	28	
				MOYEN	3		Mise en place de spéléothèmes (île de Vancouver)
				64	64	64	
				INFÉRIEUR	4		
			75	75	75		
			SANGAMONIEN		5		
			128		128		
		MOYEN	ILLINOIEN		6	185	
					7	235	Mise en place de spéléothèmes (Cordillère)[2]
					8	275	
					9	320	Mise en place de spéléothèmes (Cordillère)[2]
						? 350 ?	Mise en place de spéléothèmes (Cordillère)[2]
		INFÉRIEUR			15	610	Cendres de Wascana Creek (Saskatchewan)[3]
						790	Limite entre les époques de Bruhnes et de Matuyama (île Banks)[4]
						1670	Mise en place au cours de l'Olduvai (?) de matériel nonglaciaire[5]
						1870	

1 Gascoyne et coll., 1980 3 Westgate et coll., 1977 5 Foster et Stalker ., 1976
2 Harmon et coll., 1977 4 Vincent et coll., 1983

unités glaciaires et interglaciaires et leur datation est donc provisoire. Dans les basses-terres de la baie d'Hudson, les dépôts correspondant au Sangamonien reposent sur au moins quatre tills qui représentent au moins deux glaciations. Dans la région de Toronto, les trous de forage ont traversé plusieurs tills plus anciens que la formation sangamonienne de Don; le plus récent de ces tills date de l'Illinoien, mais les autres ont été très peu étudiés.

La définition du dernier étage interglaciaire suscite une grande controverse au Canada. Le nom Sangamonien, utilisé aux Etats-Unis, est également utilisé au Canada. Certains affirment que le Sangamonien désigne un interglaciaire et qu'il ne faudrait donc pas utiliser ce nom pour désigner une période durant laquelle il y a eu accumulation de dépôts glaciaires ou de dépôts associés à un climat plus froid que celui d'aujourd'hui. Toutefois, si l'on adopte cette définition étroite, il faudrait limiter l'étage sangamonien au Canada à la période représentée par le sous-étage 5e des isotopes d'oxygène. Par contre, d'autres affirment que les termes glaciation et interglaciaire n'ont qu'un sens mondial. Une période chaude serait un interglaciaire seulement si les volumes mondiaux de glace étaient presque égaux ou inférieurs aux volumes actuels et une période froide serait une glaciation seulement si les volumes mondiaux dépassaient de beaucoup ceux d'aujourd'hui. Si l'on utilise cette dernière définition, il serait impossible de définir une glaciation ou un interglaciaire en fonction des paramètres observés dans un endroit restreint; il faudrait se fonder sur des paramètres comme les rapports des concentrations en isotopes d'oxygène, qui reflètent les volumes mondiaux de glace. En outre, on ne pourrait pas se servir du rythme des avancées et des retraites locales pour définir les glaciations et les interglaciaires à l'échelle mondiale. Les rapports sommaires adoptent le point de vue global et définissent l'étage Sangamonien comme ayant commencé il y a environ 128 ka et s'étant terminé il y a 75 ka; il s'agit des limites de l'étage 5 des isotopes d'oxygène. Les fluctuations environnementales au cours du Sangamonien ne sont pas bien documentées au Canada. Dans la vallée du bas Saint-Laurent et dans la région atlantique, des dépôts glaciaires, vraisemblablement mis en place durant le Sangamonien moyen, séparent les dépôts de climat chaud separated from moderately warm climate, young deposits by cooler climate sediments. Subdivisions at this level of detail have not been made in the west, but several workers have suggested that the warmest part of the Sangamonian was followed by a long period of cooler but not glacial conditions.

The Wisconsinan Stage corresponds to the last major period of glaciation. There is controversy over whether it extends back to the preceding period of maximum warmth (oxygen isotope stage 5e) or whether the most useful position for its lower limit would be at the end of the last general warm phase (oxygen isotope stage 5). For Canadian purposes the end of oxygen isotope stage 5, approximately 75 ka, seems to be the most useful position because in many places it is possible to document a continuous sequence of events or deposits reaching back this far but it is not possible to document what occurred during oxygen isotope stage 5. The Wisconsinan is subdivided into Early, Middle, and Late substages.

Early Wisconsinan has been referred to as a time of major ice sheet glaciation in most parts of Canada. Many workers feel that Wisconsinan ice sheets reached their maximum extent during this time. The beginning of the Early Wisconsinan is placed at 75 ka, an age approximating the time of the end of deposition of the St. Pierre Sediments in the St. Lawrence Lowlands and the approximate time placed on the contact between oxygen isotope stages 4 and 5 from deep-sea cores.

The Middle Wisconsinan Substage is a time when ice retreated from much of western and southern Canada. The nonglacial period appears to have been relatively continuous in the west, broken by a period of ice advance in the Great Lakes region and possibly marked only by thinning of ice but not by deglaciation in the Atlantic region. The lower limit of the Middle Wisconsinan is placed at 64 ka. Deposits spanning this boundary have not been found in Canada but one date of $58\,800 \pm ^{2900}_{2100}$ BP (QI-195, Clague, 1977) and a number of dates in the >50 ka range have been obtained on deposits thought to belong in the Middle Wisconsinan Substage. A limit of 64 ka was chosen because, according to studies of deep-sea cores, a major decrease in world-wide ice volume occurred at that time (boundary between oxygen isotope stages 3 and 4).

The Late Wisconsinan extends from the Holocene to about 23 ka. It corresponds to the last time Canada was covered by major ice sheets. Certainly the last major build-up of ice began earlier in many areas and maximum coverage was achieved some time later, but 23 ka is approximately the time when much of Canada was coming under the influence of ice.

There is little emphasis on the Holocene record in this volume. This is largely because the authors have concentrated on knowledge obtained from stratigraphic studies whereas our knowledge of the Holocene in most parts of Canada comes from paleobotanical rather than stratigraphic studies. We do know that the climate was cool enough to cause local advances of alpine glaciers in the Cordillera between 2.2 and 3.0 ka and that the maximum Holocene advance occurred in the last century. On Baffin Island several glacial advances occurred after retreat of the last ice sheet; the earliest of these was about 3.5 ka and the most extensive ended within the last 100 years.

du Sangamonien inférieur des dépôts de climat froid du Sangamonien supérieur. Dans la région des Grands Lacs, les sédiments de climat froid séparent les dépôts de climat chaud du Sangamonien inférieur des dépôts récents de climat tempéré. Les subdivisions à ce niveau n'ont pas encore été établies dans l'ouest, mais plusieurs chercheurs croient que la partie la plus chaude du Sangamonien a été suivie par une longue période marquée par des conditions plus froides mais non glaciaires.

L'étage du Wisconsinien correspond à la dernière grande période de glaciation. Les chercheurs ne sont pas tous d'accord sur la position de sa limite inférieure, à savoir si l'étage s'étend jusqu'à la période précédente de chaleur maximale (étage 5e des isotopes d'oxygène) ou s'il serait plus utile d'établir sa limite à la fin de la dernière phase chaude générale (étage 5 des isotopes d'oxygène). Il serait plus utile, pour les travaux canadiens, d'utiliser la fin de l'étage 5 des isotopes d'oxygène (il y a environ 75 ka), puisqu'il est possible, à de nombreux endroits, de documenter une séquence continue d'événements ou de dépôts qui s'étend jusqu'à ce point, mais qu'il est impossible de déterminer ce qui s'est passé durant l'étage 5 des isotopes d'oxygène. Le Wisconsinien est divisé en trois sous-étages, l'inférieur, le moyen et le supérieur.

Au cours du Wisconsinien inférieur, de grands inlandsis ont recouvert presque tout le Canada. De nombreux chercheurs croient que les inlandsis du Wisconsinien ont atteint leur étendue maximale durant ce sous-étage. Le début du Wisconsinien inférieur date d'environ 75 ka, soit à peu près le même âge que la fin de la mise en place des sédiments de St-Pierre dans les basses-terres du Saint-Laurent et que le contact des étages 4 et 5 des isotopes d'oxygène déterminé à partir de carottes océaniques.

Le Wisconsinien moyen a été marqué par la retraite de la glace dans une grande partie de l'ouest et du sud du Canada. La période non glaciaire semble avoir été relativement continue dans l'ouest, interrompue par une période d'avancée dans la région des Grands Lacs et possiblement caractérisée par un amincissement de la glace, mais non une déglaciation, dans la région atlantique. La limite inférieure du Wisconsinien moyen est placée à 64 ka. On n'a pas trouvé de dépôts de cet âge au Canada, mais on a daté à $58\,800 \pm ^{2900}_{2100}$ BP (QI-195, Clague, 1977) et à plus de 50 ka des dépôts appartenant vraisemblablement au Wisconsinien moyen. La limite a été établie à 64 ka puisque l'étude des carottes océaniques indique qu'il y a eu réduction marquée du volume mondial de glace à ce moment (limite entre les étages 3 et 4 des isotopes d'oxygène).

Le Wisconsinien supérieur s'étend de l'Holocène jusqu'à il y a 23 ka et correspond à la dernière grande glaciation du Canada. La dernière grande accumulation de glace a certainement commencé plus tôt en de nombreux endroits et la couverture maximale a été réalisée un peu plus tard, mais une grande partie du Canada était recouverte de glace il y a à peu près 23 ka.

Le présent volume traite très peu de l'histoire de l'Holocène, notamment parce que les auteurs se sont concentrés sur les renseignements provenant d'études stratigraphiques et que les connaissances actuelles portant sur l'Holocène dans la plupart des régions du Canada proviennent d'études paléobotaniques. Le climat a été assez froid pour permettre l'avancée locale des glaciers alpins dans la Cordillère, il y a entre 2,2 et 3 ka, et la plus grande avancée de l'Holocène s'est produite au cours du dernier siècle. Dans l'île de Baffin, plusieurs avancées glaciaires se sont produites après la retraite du dernier inlandsis, la première il y a environ 3,5 ka, et la plus étendue prenant fin au cours des 100 dernières années.

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INTRODUCTION

THE CANADIAN WORK GROUP OF IGCP PROJECT 24, QUATERNARY GLACIATIONS IN THE NORTHERN HEMISPHERE

GROUPE DE TRAVAIL CANADIEN DU PROJET 24 PICG GLACIATIONS QUATERNAIRES DE L'HÉMISPHÈRE NORD

Rancherio River near confluence with Liard River, southeastern Yukon Territory: Fractured, blocky basalt (~2 m thick) of Early Pleistocene age overlies glacial gravel and underlies gravel and till. Photo and stratigraphy by R.W. Klassen, GSC 202881-R.

Rivière Ranchero près de la confluence de cette rivière avec la Liard, sud-est du Yukon. Couche de basalte fracturé à configuration en blocs (~2 m d'épaisseur) du début du Pléistocène reposant sur du gravier glaciaire et recouverte de gravier et de till. Photo et stratigraphie par R.W. Klassen, GSC 202881-R.

THE CANADIAN WORK GROUP OF IGCP PROJECT 24 QUATERNARY GLACIATIONS IN THE NORTHERN HEMISPHERE

GROUPE DE TRAVAIL CANADIEN DU PROJET 24 PICG GLACIATIONS QUATERNAIRES DE L'HEMISPHERE NORD

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Dreimanis, A., The Canadian Work Group of IGCP Project 24, Quaternary Glaciations in the Northern Hemisphere/Groupe de travail Canadien du Projet 24 PICG (Programme international de corrélation géologique), glaciations quaternaires de l'hemisphère Nord; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 9-20, 1984.

THIS VOLUME AND IGCP PROJECT 24

This volume of *Quaternary Stratigraphy of Canada* is the result of collective effort by the Canadian Work Group of IGCP Project 24, "Quaternary glaciations in the Northern Hemisphere".

The project "Quaternary glaciations in the Northern Hemisphere" was proposed about 1970 by Dr. V. Šibrava at the Geological Survey, Prague, Czechoslovakia and was first discussed and approved by INQUA (International Union for Quaternary Research) in 1971. The first work was initially done within IUGS project PA 7145 "Correlation of European and American glaciations", focusing on correlations inside Europe (Šibrava, 1974, p. 5-6). At the April 1974 session of the international IGCP Board in Vienna, the project was approved as a joint venture of IGCP (International Geological Correlation Programme), UNESCO (United Nations Educational, Scientific, and Cultural Organization), and IUGS (International Union of Geological Sciences), under the number 73/1/24 with V. Šibrava as a project leader (Šibrava, 1975, p. 5). Later known simply as IGCP Project 24, it was classified in the group A ("Key Projects") meaning that the project was well developed internationally and of major importance. In addition to representatives from eight European countries, two from North America, including myself from Canada, were appointed by V. Šibrava. This was done to meet one of the objectives for 1974-75: "to concentrate in the first stage on the correlation between the Late Pleistocene glaciation of the North American continent and that of northern Europe" (V. Šibrava, personal communication, 1973). The Canadian National Committee of IGCP decided to participate in this project and approved me as the leader of the Canadian Work Group of IGCP Project 24 in 1975. A work group was set up by selecting from among the Canadian Quaternary stratigraphers, keeping the group small (Appendix 1) but representative of various Canadian regions and various stratigraphic approaches. Each member was requested to consult with others working in his area or specialty.

THE FIRST YEARS (1975-76) OF THE CANADIAN WORK GROUP

In order to stimulate correlations between Europe and North America, the third international session of the project was held at Bellingham, Washington, U.S.A. This meeting in North America was used as a stimulus to organize the Canadian Work Group. By March 1975, 12 Canadian Quaternary stratigraphers were participating in this project. Two of them – J.E. Armstrong and R.J. Fulton – organized a four-day field trip in south-central and southwestern British Columbia as part of the 1975 meeting; the Geological Survey of Canada supported this field trip financially and by permitting participation of its staff.

LE PRÉSENT VOLUME ET LE PROJET 24 DU PICG

Le présent volume de la Stratigraphie quaternaire du Canada est le produit des efforts collectifs du Groupe de travail canadien du Projet 24 du PICG, <<Quaternary Glaciations in the Northern Hemisphere>>.

Le projet portant sur les glaciations quaternaires dans l'hémisphère Nord a été proposé vers 1970 par M. V. Šibrava, de la Commission géologique de Prague, Tchécoslovaquie, et a fait l'objet d'une discussion préliminaire et d'une approbation de l'AIEQ (Association internationale pour l'étude du Quaternaire) en 1971. Au début, les premiers travaux avaient été réalisés dans le cadre du Projet PA 7145 de l'UISG portant sur la corrélation des glaciations européennes et américaines, et étaient axés sur les corrélations à l'intérieur de l'Europe (Šibrava, 1974 p. 5-6). À la session d'avril 1974 de la Commission du PICG à Vienne, le projet a été approuvé au titre de coentreprise entre le PICG (Programme international de corrélation géologique), l'UNESCO (Organisation des Nations Unies pour l'éducation, les sciences et la culture), et l'UISG (Union internationale des sciences géologiques), sous le numéro 73/1/24 avec V. Sibrava comme chef de projet (Šibrava, 1975, p. 5). Plus tard, connu simplement sous le nom de Projet 24 du PICG, il a été classé dans le groupe A (<<Projets clés>>), ce qui signifie que le projet avait été bien mis au point à l'échelon international et était d'une importance majeure. En plus des représentants de huit pays européens, V. Šibrava a nommé deux représentants d'Amérique du Nord y compris moi-même qui représente le Canada. Cela avait été fait pour satisfaire à l'un des objectifs de 1974-1975: <<se concentrer au premier stade sur la corrélation entre la glaciation de la fin du Pléistocène du continent nord-américain et celle du Nord de l'Europe>> (V. Šibrava, communication personnelle, 1973). Le Comité national canadien du PICG a décidé de participer à ce projet et a approuvé ma nomination en qualité de chef du Groupe de travail canadien du Projet 24 du PICG en 1975. Un Groupe de travail a été organisé en faisant une sélection parmi les spécialistes canadiens de la stratigraphie du Quaternaire, en veillant à garder un groupe de taille réduite (annexe 1) mais représentatif des diverses régions canadiennes et des diverses méthodes stratigraphiques. On a demandé à chaque membre de consulter ses autres collègues travaillant dans son domaine ou sa spécialité.

LES PREMIÈRES ANNÉES (1975-1976) DU GROUPE DE TRAVAIL CANADIEN

Afin de stimuler les corrélations entre l'Europe et l'Amérique du Nord, la troisième session internationale du projet a été tenue à Bellingham, Washington, aux États-Unis. Cette réunion en Amérique du Nord a servi de stimulant pour l'organisation du Groupe de travail canadien. Vers mars 1975, douze (12) spécialistes canadiens du Quaternaire participaient à ce projet. Deux d'entre eux, soit MM. J.E. Armstrong et R.J. Fulton, ont organisé une excursion de quatre jours dans le centre-sud et le sud-ouest de la Colombie-Britannique dans

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On July 14, 1975, the first circular was sent to 15 members of the Canadian Work Group. It contained announcements of the Bellingham meeting, the Canadian field trip on September 14-17, and of the first Canadian Work Group meeting at Port Moody, British Columbia, on September 16. In addition, it requested that Canadian members prepare regional status reports on Late Pleistocene stratigraphy of Canada and reviews of dating methods. Since then, 37 circulars have been mailed to the Canadian Work Group members, informing them about the Canadian Work Group activities, international IGCP Project 24 meetings, and publications and meetings of interest to the Canadian Quaternary stratigraphers. Various background papers and correlation charts were also distributed, particularly at Work Group meetings.

At the Bellingham meeting, September 8-9, 1975, six Canadian reports were presented orally and a seventh, by authors who could not participate, was distributed as a preprint (Appendix 2). These papers were eventually published in Reports 3 and 4 of Project 73/1/24 (Appendix 3). Future Canadian plans were discussed at the Port Moody meeting, including a decision to hold a two-day workshop in Ottawa in March 1976 and to begin compiling a list of all known pre-Wisconsinan Quaternary deposits in Canada.

The first workshop was held at the Geological Survey of Canada on March 19-20, 1976, with 25 participants (15 members, 10 nonmembers). Its first session dealt with methods applicable for absolute dating and correlations, particularly the amino acid method, paleomagnetism, tephrachronology, and the problems in radiocarbon dating. The second, longer session discussed the present status of the stratigraphy of last glaciation along three traverses: (1) the west side of the continent from British Columbia to Yukon Territory, (2) Alberta to the Atlantic coast along the southern part of Canada, and (3) Arctic Canada and northeastern Labrador. This was probably the first meeting of Canadian Quaternary stratigraphers where the last ice age stratigraphy of Canada was discussed from the Pacific to the Atlantic, and from its southern border to the Arctic. Areas lacking stratigraphic information and intervals lacking absolute chronology were noted. Also, it was concluded that the glaciations and climatic events of the northeastern Arctic were not in phase with those along the southern Canadian border, and that 'glacial styles' in the Laurentide and Appalachian glaciated areas during the Late Wisconsinan were different (Grant and Prest, 1975). Though the relationships between the Cordilleran and Laurentide ice sheets had not been well established, it appeared that their advances and retreats were slightly out of phase in several areas (Fulton, 1976).

REGIONAL AND TOPICAL SUBGROUPS

Because of the large size of Canada and to facilitate future discussions on specific regional and/or topical matters, five regional subgroups (Cordilleran, Interior Plains, Great Lakes – St. Lawrence, Atlantic Canada, Arctic Canada) and one topical subgroup – on inventory of the pre-Wisconsinan sites – were established in 1976. During subsequent years, the number and the boundaries of the regional subgroups changed, increasing to eleven in 1978 and later decreasing to nine. By 1981, while preparations for the completion of the Canadian part of the IGCP project were under way, the following regional subgroups were in existence:

- Cordilleran Region – leader R.J. Fulton
- corridor between the Cordilleran and Laurentide ice sheets – leader N.W. Rutter

le cadre de la réunion de 1975; la Commission géologique du Canada a appuyé cette excursion en la finançant et en autorisant son personnel à y participer.

Le 14 juillet 1975, la première circulaire a été envoyée à 15 membres du Groupe de travail canadien. Elle contenait des annonces au sujet de la réunion de Bellingham, de l'excursion canadienne du 14 au 17 septembre, et au sujet de la première réunion du Groupe de travail canadien à Port Moody (Colombie-Britannique), le 16 septembre. En outre, cette circulaire demandait que les membres canadiens préparent des rapports de situation régionale sur la stratigraphie de la fin du Pléistocène au Canada et passent en revue les méthodes de datation. Depuis lors, 37 circulaires ont été envoyées par la poste aux membres du Groupe de travail canadien afin de les informer des activités du groupe, des réunions internationales du Projet 24 du PICG, ainsi que des publications et des réunions pouvant intéresser les spécialistes canadiens de la stratigraphie du Quaternaire. Divers documents de travail et des graphiques de corrélation ont aussi été diffusés, particulièrement aux réunions du Groupe de travail canadien.

À la réunion de Bellingham, tenue les 8 et 9 septembre 1975, six rapports canadiens ont été présentés oralement et un septième, dont les auteurs ne pouvaient participer à la réunion, a été diffusé sous forme d'ébauche (annexe 2). Ces exposés ont été finalement publiés dans les rapports 3 et 4 du Projet 73/1/24 (annexe 3). À la réunion de Port Moody, on a discuté des futurs plans canadiens, y compris la décision de tenir un atelier de deux jours à Ottawa en mars 1976 et d'entamer la compilation d'une liste de tous les dépôts connus du Quaternaire pré-wisconsinien au Canada.

Le premier atelier a été organisé à la Commission géologique du Canada les 19 et 20 mars 1976, avec 25 participants (15 membres et 10 non membres). Sa première séance a été consacrée aux méthodes applicables à la datation absolue et aux corrélations, en particulier la méthode aux acides aminés, le paléomagnétisme, la téphrachronologie, et les problèmes de datation au carbone radioactif. La deuxième séance, plus longue, a permis de discuter de l'état actuel de la stratigraphie de la dernière glaciation selon trois axes: (1) le côté ouest du continent, de la Colombie-Britannique au Yukon, (2) de l'Alberta à la côte atlantique le long de la partie sud du Canada, et (3) l'Arctique canadien et le nord-est du Labrador. Il s'est agi là sans doute de la première réunion de spécialistes canadiens du Quaternaire au cours de laquelle a été étudiée la stratigraphie de la dernière ère glaciaire du Canada, du Pacifique à l'Atlantique et de sa frontière sud à l'Arctique. On y a relevé les régions pour lesquelles les renseignements manquaient en ce qui concerne la stratigraphie et les intervalles pour lesquels une chronologie absolue faisait défaut. On a aussi conclu au cours de cette réunion, que les glaciations et les événements climatiques du nord-est de l'Arctique n'étaient pas en phase avec ceux qui se sont produits le long de la frontière sud du Canada et que les <<styles glaciaires>> dans les régions glaciaires des Laurentides et des Appalaches au cours de la fin du Wisconsinien étaient différents (Grant et Prest, 1975). Bien que les relations entre les inlandsis de la Cordillère et des Laurentides n'aient pas été bien établies, les recherches semblaient indiquer que leurs avances et leurs retraits étaient légèrement déphasés dans plusieurs régions (Fulton, 1976).

SOUS-GROUPES RÉGIONAUX ET PONCTUELS

Étant donné la vaste étendue du Canada et afin de faciliter les futures discussions sur des questions régionales particulières ou ponctuelles, cinq sous-groupes régionaux (de la Cordillère, des plaines Intérieures, des Grands Lacs et du

- Canadian Prairies – leader M.M. Fenton
- Hudson Bay Lowland and District of Keewatin region – leader W.W. Shilts (up to 1980 Hudson Bay Lowland was handled separately by W.R. Cowan; see Dreimanis et al., 1981)
- Great Lakes – St. Lawrence region – co-leaders A. Dreimanis and P.F. Karrow
- Québec – leader P. LaSalle
- Atlantic Canada – leader D.R. Grant
- Western Canadian Arctic Archipelago – leader J-S. Vincent
- Eastern Canadian Arctic – leader J.T. Andrews

Two subgroups dealt with broad nonregional topics:

- The pre-Wisconsinan (pre-Late Wisconsinan) stratigraphy – leader P.F. Karrow
- Quaternary dating methods – leader N.W. Rutter

Each subgroup leader was free to invite as many co-workers as he desired. Most communications were done by correspondence, though some subgroups held their own workshop meetings, e.g., the Great Lakes – St. Lawrence region subgroup had two workshop meetings and in 1978 the Eastern Canadian Arctic subgroup started annual meetings.

ANNUAL CANADIAN WORK GROUP MEETINGS, 1978-82

After the Ottawa workshop of 1976, the next general meeting of the Canadian Work Group was held April 14-15, 1978 at the University of Western Ontario, London, with 23 participants from 14 institutions in Canada and the United States. It dealt with cross-Canada stratigraphic correlations of the major units of the last glaciation, the maximum extent of Late Wisconsinan glaciation and its equivalents, the pre-Wisconsinan, and dating methods and their problems (thermoluminescence, radiocarbon – new developments, U-disequilibrium, amino acid, fission tracks, tephrachronology, paleomagnetism).

Beginning with 1978, Canadian Work Group meetings were held every year, usually in association with a national or international conference.

The 1979 meeting took place at York University, Toronto, on May 16-17, with 18 participants from 13 institutions. Reports on subtill organics and dating methods were given by the leaders of these topical subgroups followed by regional reports of subgroup leaders; an attempt was made to correlate the events of the last glaciation across Canada. As a result of this correlation and subsequent correspondence, a tentative correlation chart was prepared and presented at the sixth international IGCP Project 24 conference at Ostrava, Czechoslovakia on August 18, 1979. This summary report, prepared by seven subgroup leaders, was revised by correspondence in the winter of 1979-80 and subsequently published (Dreimanis et al., 1981).

The 1980 general Canadian meeting was held at Halifax on May 21, with 20 participants. It dealt mainly with the maximum extent of Late Wisconsinan Laurentide and Appalachian ice sheet complexes (Prest, this volume) and retreat from this glacial limit.

The 1981 general meeting, at York University, Toronto, on May 25 was attended by 20 participants from 13 institutions. Besides 12 regional stratigraphic progress reports and their discussions, a large part of the meeting dealt with technical matters related to completion of the Canadian part of IGCP Project 24.

Saint-Laurent, de la Région atlantique du Canada, de l'Arctique canadien) et un sous-groupe ponctuel chargé de l'inventaire de l'emplacement des dépôts pré-wisconsiniens, ont été établis en 1976. Au cours des années suivantes, le nombre et les limites des sous-groupes régionaux se sont modifiés et sont passés à onze en 1978 pour retomber par la suite à neuf. Vers 1981, au cours de la préparation de l'achèvement de la partie canadienne du projet du PICG, les sous-groupes régionaux suivants avaient été constitués:

- région de la Cordillère – chef: R.J. Fulton;
- corridor entre les inlandsis de la Cordillère et des Laurentides – chef: N.W. Rutter;
- Prairies canadiennes – chef: M.M. Fenton;
- basses-terres de la baie d'Hudson et région du district de Keewatin – chef: W.W. Shilts; jusqu'en 1980, les basses-terres de la baie d'Hudson étaient traitées de façon distincte par W.R. Cowan (voir Dreimanis et coll., 1981);
- région des Grands Lacs et du Saint-Laurent – chef: A. Dreimanis et P.F. Karrow;
- Québec – chef: P. LaSalle;
- Région atlantique du Canada – chef: D.R. Grant;
- Ouest de l'Archipel arctique canadien – chef: J.-S. Vincent; et
- Est de l'Arctique canadien – chef: J.T. Andrews;

Deux sous-groupes traitaient de vastes sujets non régionaux:

- la stratigraphie du pré-Wisconsinien (antérieure au Wisconsinien supérieur) – chef: P.F. Karrow; et
- méthodes de datation du Quaternaire – chef: N.W. Rutter.

Chaque chef de sous-groupe était libre d'inviter autant de collègues qu'il le désirait. La plupart des communications avaient été faites par correspondance, bien que certains sous-groupes aient organisé leurs propres réunions-ateliers, p. ex., le sous-groupe de la région des Grands Lacs et du Saint-Laurent a organisé deux réunions-ateliers et en 1978, le sous-groupe de l'Est de l'Arctique canadien a lancé des réunions annuelles.

RÉUNIONS ANNUELLES DU GROUPE DE TRAVAIL CANADIEN; 1978-1982

Après l'atelier de 1976 tenu à Ottawa, la réunion générale suivante du Groupe de travail canadien a été tenue les 14 et 15 avril 1978 à l'université Western Ontario, à London (Ontario) avec 23 participants provenant de 14 établissements du Canada et des États-Unis. Cette réunion a traité des corrélations stratigraphiques de tout le Canada en ce qui concerne les principales unités de la dernière ère glaciaire, l'étendue maximale de la glaciation de la fin du Wisconsinien et de ses équivalents, le pré-wisconsinien, et les méthodes de datation et leurs problèmes (thermoluminescense, faits nouveaux dans le domaine du carbone radioactif, déséquilibre de l'U, acides aminés, traces de fission, théphrachronologie, paléomagnétisme).

À compter de 1978, les réunions du Groupe de travail canadien ont été tenues chaques année, habituellement en association avec une conférence nationale ou internationale.

La réunion de 1979 a eu lieu à l'université York, à Toronto, les 16 et 17 mai, avec 18 participants provenant de 13 établissements. Des rapports sur les dépôts organiques submorainiques et sur les méthodes de datation ont été présentés par les chefs de ces sous-groupes ponctuels et ils ont été suivis de rapports régionaux des chefs de sous-groupes

The final Canadian meeting a symposium on "Quaternary Stratigraphy of Canada" - was held at University of Manitoba, Winnipeg, on May 16, 1982, with 55 participants from Canada and the United States. Ten regional papers were presented and followed by panel discussions on two topics – the pre-Wisconsinan glaciations and the Wisconsin Glaciation, with improvised correlations across Canada. The business meeting dealt mainly with the publication of our project's results (see further).

CO-OPERATION WITH U.S.A. QUATERNARY STRATIGRAPHERS

Though the Canadian and U.S.A. Work Groups of IGCP Project 24 worked independently, close co-operation existed from the time of the international meeting at Bellingham in 1975. The closest correlations were achieved in the eastern part of Interior Plains and the Great Lakes regions, with correlation disagreements remaining in some other areas.

CANADIAN PARTICIPATION AT THE INTERNATIONAL IGCP PROJECT 24 CONFERENCES

The international meetings of IGCP Project 24 (or 73/1/24) were held every year in order to exchange information among the participants from the various countries and to present the latest results of research pertinent to Project 24. A field trip was organized at each conference, giving an opportunity to examine and discuss local Quaternary stratigraphy. A list of conferences and Canadian participation is given in Appendix 2.

Most of the papers presented at the international conferences were subsequently published in the "Report" volumes of IGCP Project 73/1/24 *Quaternary glaciations in the Northern Hemisphere* (nine published by 1983). Most reports were printed by Geological Survey, Prague, and distributed without charge to all active participants. The reports and the Canadian papers published in them are listed in Appendix 3.

PRE-WISCONSINAN STRATIGRAPHY AND PRE-LATE WISCONSINAN ORGANIC DEPOSITS

The emphasis in the Canadian Work Group activities in the framework of IGCP Project 24 was on the last glaciation, as the deposits of the last ice age have been extensively studied by many investigators. At the first meeting of the Work Group, however, it was suggested that an inventory be taken of subtill organics older than the last glaciation. A topical subgroup on the pre-last ice age organics, led by P.F. Karrow, was created. The regional subgroup leaders, while working mainly on the last ice age stratigraphy, were requested to submit information on all the buried organic sites to P.F. Karrow. Descriptions of the sites will be published by the University of Waterloo with P.F. Karrow as editor.

As a display for the 6th international session of IGCP Project 24 at Ostrava, Czechoslovakia, in 1979, D.R. Grant plotted locations of "Pre-Late Wisconsinan 'Buried Organic' Deposits" on a 1:7.5 M scale map of Canada and attached a list of the localities and brief descriptions. Since great interest in this map was expressed at the Ostrava meeting, it was proposed that the Geological Survey of Canada publish the map, a list of locations, and a brief text, with D.R. Grant and P.F. Karrow as co-editors.

Though initially the above publications were intended to deal essentially with the deposits older than the Wisconsin Glaciation or its equivalents, the lack of absolute dates for

régionaux; on avait essayé de faire la corrélation entre les événements de la dernière ère glaciaire du Canada. Par suite de cette corrélation et de la correspondance qui a suivi, une ébauche de carte de corrélation a été établie et présentée à la sixième conférence internationale du Projet 24 du PICG à Ostrava, Tchécoslovaquie, le 18 août 1979. Ce rapport sommaire, établi par sept chefs de sous-groupes, a été revisé par correspondance au cours de l'hiver 1979-1980 et publié par la suite (Dreimanis et coll., 1981).

L'assemblée générale canadienne de 1980 a été tenue à Halifax le 21 mai, avec 20 participants. Elle a principalement traité de l'étendue maximale des complexes glaciaires de la fin de l'ère wisconsinienne, soit l'inlandsis des Laurentides et celui des Appalaches (Prest, présent volume), ainsi que du retrait par rapport à cette limite glaciaire.

L'assemblée générale de 1981 a eu lieu à l'université York, à Toronto, le 25 mai et 20 participants provenant de 13 établissements y participaient. Mis à part les 12 rapports d'avancement des travaux de stratigraphie régionale et de leur discussion, une grande partie de la réunion a traité de questions techniques liées à l'achèvement de la partie canadienne du Projet 24 du PICG.

La dernière réunion canadienne, un symposium sur la stratigraphie quaternaire du Canada, a été tenue à l'université du Manitoba, à Winnipeg, le 16 mai 1982 avec 55 participants venus du Canada et des États-Unis. Dix exposés régionaux ont été présentés et ont été suivis de discussions en table ronde sur deux sujets, les glaciations pré-wisconsiniennes et la glaciation du Wisconsin, avec des corrélations improvisées pour tout le Canada. La réunion d'affaires traitait principalement de la publication des résultats de notre projet (voir plus loin).

COLLABORATION AVEC LES SPÉCIALISTES AMÉRICAINS DE LA STRATIGRAPHIE DU QUATERNAIRE

Bien que les groupes canadiens et américains du Projet 24 du PICG aient travaillé de façon indépendante, une étroite collaboration s'est établie au moment de la réunion internationale de Bellingham en 1975. Les corrélations les plus proches ont été réalisées dans la partie est des plaines Intérieures et dans la région des Grands Lacs, malgré la persistance de quelques désaccords de corrélation dans certaines autres zones.

PARTICIPATION CANADIENNE AUX CONFÉRENCES INTERNATIONALES DU PROJET 24 DU PICG

Les réunions internationales du Projet 24 du PICG (ou 73/1/24) ont été tenues chaque année afin de permettre aux participants d'échanger et de présenter les derniers résultats des recherches se rapportant au Projet 24. Une excursion a été organisée au cours de chaque conférence leur donnant ainsi l'occasion d'examiner la stratigraphie locale du Quaternaire et d'en discuter. Une liste des conférences et des participants canadiens est donnée à l'annexe 2.

La plupart des articles présentés aux conférences internationales ont été publiés par la suite dans les volumes de rapports du Projet 73/1/24 du PICG sur les glaciations quaternaires de l'hémisphère Nord (sept ont été publiés jusqu'en 1982 et deux sont en voie de publication). Les rapports ont été imprimés par la Commission géologique de Prague, et diffusés gratuitement à tous les participants actifs. Les rapports et les exposés canadiens qui y sont publiés sont énumérés à l'annexe 3.

most of them made it impossible to exclude Wisconsin interstadial deposits. The publications, therefore, will contain all known sites older than Late Wisconsinan. Also, it will not be restricted to buried organics, but will include soils and other pre-Late Wisconsinan nonglacial deposits.

DATING AND CORRELATION METHODS

Regional and Canada-wide stratigraphic correlations require reliable absolute dates and correlation methods that permit tele-correlations. In order to evaluate the existing dating methods and to stimulate development of new methods, particularly beyond the range of radiocarbon dating, considerable attention was paid to the methods of dating and correlations from the beginning of the Canadian Work Group. Starting in 1977, a topical subgroup on dating and correlation methods was established, with N.W. Rutter as leader.

In 1978, this subgroup began to publish a series of papers on "Dating methods of Pleistocene and their problems" in Geoscience Canada (Appendix 4). During the period 1978-82, eight papers were published. These papers are being updated for publication as a book, with N.W. Rutter as its editor.

QUATERNARY STRATIGRAPHY OF CANADA

The main objective of the Canadian Work Group of IGCP Project 24 was to prepare a summary report representing our present knowledge of the Quaternary stratigraphy of Canada, and to use it for correlations with similar reports on the United States and other areas. The regional reports for various parts of Canada, the data on pre-Late Wisconsinan organics, and the discussions on dating methods were originally meant to be auxiliary materials used in preparing the Canadian summary report. As mentioned in the preceding discussions, however, the two topical subgroups – on the pre-Late Wisconsinan organics and on dating methods – accumulated sufficient information to warrant separate reports. At the 1981 meeting of the Canadian Work Group it was decided to go beyond the original plans of publishing a Canadian summary.

It was decided, therefore, to publish a Canadian report "Quaternary Stratigraphy of Canada" consisting of regional reports, plus correlations. J.T. Andrews, R.J. Fulton, D.R. Grant, P.F. Karrow, and V.K. Prest were appointed to its editorial board, and R.J. Fulton agreed to be chief editor.

ACKNOWLEDGMENTS

On this occasion I would like to thank all those who have participated with their knowledge and their skills in the Canadian Work Group of IGCP Project 24 and its many subgroups, or who have assisted in organizing its meetings and field trips. Their number is too large to be listed here. Among the organizations, particular thanks are due to the Canadian National Committee of the International Geological Correlation Programme (IGCP) and the Geological Survey of Canada for their understanding of our objectives and for their financial assistance. Further thanks are expressed to the employing institutions of our members and their co-workers and the agencies granting research funds for their direct and indirect assistance to field and laboratory work of the participants of this large project.

STRATIGRAPHIE DU PRÉ-WISCONSINIEN ET DÉPÔTS ORGANIQUES ANTÉRIEURS AU WISCONSINIEN SUPÉRIEUR

Dans le cadre du Projet 24 du PICG, les activités du Groupe de travail canadien se sont axées sur la dernière glaciation étant donné que les dépôts de la dernière ère glaciaire ont été étudiés de façon étendue par de nombreux chercheurs. Toutefois, au cours de la première réunion du Groupe de travail, on a suggéré l'établissement d'un inventaire des dépôts organiques submorainiques précédant la dernière glaciation. Un sous-groupe ponctuel des dépôts organiques précédant la dernière glaciation a été créé sous la direction de M. P.F. Karrow. Les chefs de sous-groupes régionaux, tout en travaillant principalement sur la stratigraphie de la dernière glaciation, avaient été priés de remettre des informations sur tous les emplacements de dépôts organiques enfouis en les adressant à M. P.F. Karrow. Les descriptions de ces emplacements seront publiées par l'université de Waterloo dans une publication dont M. P.F. Karrow sera le rédacteur.

À titre de présentation à la sixième session internationale du Projet 24 du PICG à Ostrava, Tchécoslovaquie, en 1979, M. D.R. Grant a reporté les emplacements des dépôts organiques enfouis antérieurs au Wisconsinien inférieur sur une carte du Canada à l'échelle de 1/7,5 M et a annexé une liste des localités des emplacements et des descriptions sommaires. Étant donné le vif intérêt que cette carte a suscité à la réunion d'Ostrava, on a proposé que la Commission géologique du Canada publie la carte, la liste des emplacements et un texte sommaire dont MM. D.R. Grant et P.F. Karrow seraient les corédacteurs.

Bien qu'il ait été prévu, à l'origine, que les publications ci-dessus traiteraient essentiellement des dépôts plus anciens que la glaciation du Wisconsin ou ses équivalents, le manque de dates absolues pour la plupart d'entre eux a empêché d'exclure les dépôts mis en place au cours des interstades du Wisconsin. Par conséquent, les publications contiendront tous les emplacements connus antérieurs au Wisconsinien supérieur. En outre, ces publications ne se limiteront pas aux dépôts organiques enfouis, mais incluront les sols et d'autres dépôts non glaciaires mis en place avant le pré-Wisconsinien supérieur.

MÉTHODES DE DATATION ET DE CORRÉLATION

Les corrélations stratigraphiques régionales et celles s'appliquant à tout le Canada exigent des dates absolues fiables et des méthodes de corrélation qui permettent des télécorrélations. Afin d'évaluer les méthodes de datation existantes et de stimuler la mise au point de nouvelles méthodes, en particulier au-delà de la fourchette de la datation au carbone radioactif, on a accordé une attention considérable aux méthodes de datation et de corrélation dès le début des travaux du Groupe de travail canadien. À compter de 1977, un sous-groupe ponctuel des méthodes de datation et de corrélation a été établi sous la direction de M. N.W. Rutter.

En 1978, ce sous-groupe a commencé la publication d'une série d'articles sur les méthodes de datation du Pléistocène et leurs problèmes dans Geoscience Canada (annexe 4). Au cours de la période allant de 1978 à 1982, huit articles ont été publiés. Ces articles font l'objet d'une mise à jour en vue de leur publication sous forme de livre; N. N.W. Rutter en sera le rédacteur.

STRATIGRAPHIE QUATERNAIRE DU CANADA

Le but principal du Groupe de travail canadien du Projet 24 du PICG était de préparer un rapport sommaire présentant nos connaissances actuelles de la stratigraphie

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quaternaire du Canada et d'utiliser ce rapport pour établir des corrélations avec des rapports similaires sur les États-Unis et d'autres régions. Les rapports régionaux de diverses parties du Canada, les données sur les dépôts organiques antérieurs au Wisconsinien supérieur, et les discussions sur les méthodes de datation avaient été conçus à l'origine pour servir de moyens auxiliaires dans l'établissement du rapport sommaire sur le Canada. Toutefois, tel que déjà mentionné dans les discussions précédentes, les deux sous-groupes ponctuels des dépôts organiques précédant le pré-Wisconsinien supérieur et des méthodes de datation, avaient accumulé suffisamment d'information pour justifier des rapports distincts. À la réunion de 1981 du Groupe de travail canadien, il avait été décidé d'aller au-delà des plans originaux de publication d'un sommaire canadien.

Par conséquent, on a décidé de publier un rapport canadien sur la stratigraphie quaternaire du Canada comprenant les rapports régionaux plus les corrélations. MM. J.T. Andrews, R.J. Fulton, D.R. Grant, P.F. Karrow et V.K. Prest ont été nommés rédacteurs et M. R.J. Fulton a accepté d'agir en tant que rédacteur en chef.

REMERCIEMENTS

Je voudrais profiter de l'occasion pour remercier tous ceux qui ont fait profiter le Groupe de travail canadien du Projet 24 du PICG et ses nombreux sous-groupes de leurs connaissances et de leurs compétences ou qui ont aidé à en organiser les réunions et excursions. Ils sont trop nombreux pour figurer ici. Parmi les organismes, je remercie particulièrement le Comité national canadien du Programme International de Corrélation Géologique (PICG) et la Commission géologique du Canada pour avoir si bien compris nos objectifs et nous avoir aidés financièrement. Je remercie aussi les organismes qui ont accordé des fonds de recherche pour leur aide directe et indirecte aux travaux menés en laboratoire et sur le terrain par les participants de ce projet de grande envergure.

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APPENDIX 1

IGCP Project 24 Canadian Work Group Members

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ANNEXE 1

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* a travaillé de 1975 à 1982.

APPENDIX 2

IGCP Project 24 International Sessions with Canadian Participation

Second session at Salzburg, Austria, September 10-14, 1974.

Paper presented by A. Dreimanis – Last glaciation in eastern and central Canada.

Third session at Bellingham, Washington, U.S.A., September 8-9, 1975.

Papers presented:

J.T. Andrews – Chronology and events of the last glaciation in the eastern Canadian Arctic: results based on C-14, U-series, amino acid and biostratigraphic analyses (co-authors, G.H. Miller, B.J. Szabo, M. Stuiver, R.W. Feyling-Hanssen).

J.E. Armstrong – Post-Vashon glaciation, Fraser Lowland, British Columbia.

J.J. Clague – Quadra sediments and the timing of Late Wisconsin (Weichselian) glacial advance in southwest British Columbia.

A. Dreimanis – Progress report on the Late Pleistocene stratigraphy of southeastern Canada.

E.B. Evenson – Late glacial (13,500-10,000 years B.P.) history of Great Lakes region and possible correlations (co-author, A. Dreimanis).

R.J. Fulton – Quaternary history, south-central British Columbia and correlations with adjacent areas.

Written report distributed:

M.M. Fenton and J.T. Teller – The Quaternary stratigraphy of southern Manitoba.

Field trip in south-central British Columbia was organized by J.E. Armstrong and R.J. Fulton, September 14-17, 1975.

Fourth session at Stuttgart, Germany, September 5-13, 1976.

Papers presented:

A. Dreimanis – Late Pleistocene stratigraphy of southeastern Canada (co-author, D.R. Grant).

R.J. Fulton – Late Pleistocene stratigraphic correlations, western Canada.

Written report distributed:

J.T. Andrews – Status of Late Quaternary correlations (<125,000 BP) along the eastern Canadian seaboard – latitude 45°N to 82°N.

Fifth session at Novosibirsk, USSR, July 18-29, 1978.

Paper presented by R.J. Fulton – Quaternary deposits of Canada.

Sixth session at Ostrava, Czechoslovakia, August 16-25, 1979.

Papers presented:

A. Dreimanis – Last glaciation in Canada, progress report (co-authors, J.T. Andrews, W.R. Cowan, M.M. Fenton, R.J. Fulton, N.W. Rutter).

N.W. Rutter – Relationship between Late Pleistocene Laurentide and Cordilleran glaciations, Canada.

D.R. Grant – A display on pre-Late Wisconsinan "buried organic" deposits (a map and selected drawings and photos of sections) from data prepared by members of the Canadian Work Group.

Papers published on dating methods were distributed.

ANNEXE 2

Sessions internationales du Projet 24 du PICG comptant une participation canadienne

Deuxième session à Salzbourg, Autriche, du 10 au 14 septembre 1974.

Communication présentée par M. A. Dreimanis – Last glaciation in eastern and central Canada.

Troisième session à Bellingham, Washington, États-Unis, les 8 et 9 septembre 1975.

Communications présentées:

J.T. Andrews – Chronology and events of the last glaciation in the eastern Canadian Arctic: results based on C-14, U-series, amino acid and biostratigraphic analyses (co-authors, G.H. Miller, B.J. Szabo, M. Stuiver, R.W. Feyling-Hanssen).

J.E. Armstrong – Post-Vashon glaciation, Fraser Lowland, British Columbia.

J.J. Clague – Quadra sediments and the timing of Late Wisconsin (Weichselian) glacial advance in southwest British Columbia.

A. Dreimanis – Progress report on the Late Pleistocene stratigraphy of southeastern Canada.

E.B. Evenson – Late glacial (13,500-10,000 years B.P.) history of Great Lakes region and possible correlations (co-author, A. Dreimanis).

R.J. Fulton – Quaternary history, south-central British Columbia and correlations with adjacent areas.

Rapport rédigé distribué:

M.M. Fenton and J.T. Teller – The Quaternary stratigraphy of southern Manitoba.

Une excursion dans le centre-sud de la Colombie-Britannique a été organisée par MM. J.E. Armstrong et R.J. Fulton du 14 au 17 septembre 1975.

Quatrième session à Stuttgart, RFA, du 5 au 13 septembre 1976.

Communications présentées:

A. Dreimanis – Late Pleistocene stratigraphy of southeastern Canada (co-author, D.R. Grant).

R.J. Fulton – Late Pleistocene stratigraphic correlations, western Canada.

Rapport rédigé distribué:

J.T. Andrews – Status of Late Quaternary correlations (<125,000 BP) along the eastern Canadian seaboard – latitude 45°N to 82°N.

Cinquième session à Novosibirsk, URSS, du 18 au 19 juillet 1978.

Communication présentée par R.J. Fulton – Quaternary deposits of Canada.

Sixième session à Ostrava, Tchécoslovaquie, du 16 au 25 août 1979.

Communications présentées:

A. Dreimanis – Last glaciation in Canada, progress report (co-authors, J.T. Andrews, W.R. Cowan, M.M. Fenton, R.J. Fulton, N.W. Rutter).

N.W. Rutter – Relationship between Late Pleistocene Laurentide and Cordilleran glaciations, Canada.

Seventh session at Kiel, Germany, September 18-20, 1980.

Papers presented:

A. Dreimanis – Synchronism and diachronism of ice-marginal fluctuations during Late Wisconsin.

N.W. Rutter – Amino acid dating techniques.

Eighth session at Kyoto, Japan, July 28-August 6, 1981.

Papers presented:

A. Dreimanis – Stratigraphy of last Glaciation in eastern Canada.

R.J. Fulton – Quaternary geology of the Canadian Cordillera.

F.C. Mayr – Magnetic control of climate.

Ninth session at Paris, France, September 1-17, 1982.

Papers presented:

R.J. Fulton – Correlation of Quaternary events in Canada.

D.R. Grant – Laurentide Ice Sheet.

S. Occhietti – Stratigraphie et paléoenvironnements du Quaternaire au Québec (co-authors, C. Hillaire-Marcel, M. Lamothe, P. Pagé, G. Prichonnet).

V.K. Prest – Late Wisconsinan glacier complex in North America.

D.R. Grant – A display on pre-Late Wisconsinan "buried organic" deposits (a map and selected drawings and photos of sections) from data prepared by members of the Canadian Work Group.

Des communications publiées sur les méthodes de datation ont été distribuées.

Septième session à Kiel, RFA, du 18 au 20 septembre 1980.

Communications présentées:

A. Dreimanis – Synchronism and diachronism of ice-marginal fluctuations during Late Wisconsin.

N.W. Rutter – Amino acid dating techniques.

Huitième session à Kyoto, Japon, du 28 juillet au 6 août 1981.

Communications présentées:

A. Dreimanis – Stratigraphy of last Glaciation in eastern Canada.

R.J. Fulton – Quaternary geology of the Canadian Cordillera.

F.C. Mayr – Magnetic control of climate.

Neuvième session à Paris, France, du 1er au 17 septembre 1982.

Communications présentées:

R.J. Fulton – Correlation of Quaternary events in Canada.

D.R. Grant – Laurentide Ice Sheet.

S. Occhietti – Stratigraphie et paléoenvironments du Quaternaire au Québec (co-auteurs, C. Hillaire-Marcel, M. Lamothe, P. Pagé, G. Prichonnet).

V.K. Prest – Late Wisconsinan glacier complex in North America.

APPENDIX 3

Reports and Canadian contributions

IUGS-UNESCO International Correlation Programme Project 73/1/24 Quaternary Glaciations in the Northern Hemisphere

Note: All reports published by Geological Survey, Prague, Czechoslovakia; except Report No. 8, available from

Institution of Paleolimnology and Paleoenvironment on Lake Biwa, Kyoto University, Takashima, Shiga-Ken 520-11, Japan.

Report No. 1, 1974, ed. V. Šibrava: no Canadian reports.

Report No. 2, 1975, ed. V. Šibrava:

A. Dreimanis – Last glaciation in eastern and central Canada; p. 130-142.

Report No. 3, 1976, ed. D.J. Easterbrook and V. Šibrava:

J.E. Armstrong – Post-Vashon Wisconsin glaciation, Fraser Lowland, British Columbia, Canada; p. 13-23.

J.T. Andrews, R.W. Feyling-Hanssen, G.H. Miller, C. Schlüchter, M. Stuiver, and B.J. Szabo – Alternative models for Early and Middle Wisconsin events, Broughton Island, Northwest Territories, Canada: Toward a Quaternary chronology; p. 28-61.

R.J. Fulton – Quaternary history, south-central British Columbia and correlation with adjacent areas; p. 62-89.

ANNEXE 3

Rapports et contributions canadiennes

Projet 73/1/24 du Programme international de corrélation de l'UISG-UNESCO Glaciations quaternaires dans l'hémisphère Nord

Nota: Tous les rapports ont été publiés par la Commission géologique de Prague, Tchécoslovaquie; sauf le Rapport n^{o} 8 disponible auprès de la

Fondation de paléolimnologie et des paléomilieux au lac Biwa, université de Kyoto, Takashima, Shiga-Ken 520-11, Japon.

Rapport n^{o} 1, 1974, rédacteur: V. Sibrava: aucun rapport canadien.

Rapport n^{o} 2, 1975, rédacteur: V. Sibrava:

A. Dreimanis – Last glaciation in eastern and central Canada; p. 130-142.

Rapport n^{o} 3, 1976, rédacteurs: D.J. Easterbrook et V. Sibrava:

J.E. Armstrong – Post-Vashon Wisconsin glaciation, Fraser Lowland, British Columbia, Canada; p. 13-23.

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R.J. Fulton – Quaternary history, south-central British Columbia and correlation with adjacent areas; p. 62-89.

E. Evenson and A. Dreimanis – Late glacial (14,000-10,000 years B.P.) history of the Great Lakes region and possible correlations; p. 217-239.

A. Dreimanis – Progress report on Late Pleistocene stratigraphy of southeastern Canada; p. 240-249.

J.J. Clague – Quadra sand and the timing of the Late Wisconsin glacial advance in southwest British Columbia; p. 315-326.

Report No. 4, 1977, ed. V. Šibrava:

A. Dreimanis and D.R. Grant – The Canadian Work Group of the IGCP Project 73/1/24, and Late Pleistocene stratigraphy of southeastern Canada; p. 126-134.

J.T. Andrews – Status of Late Quaternary correlations (<125,000 BP) along the eastern Canadian seaboard – latitude 45°N to 82°N; p. 180-195.

M.M. Fenton and J.T. Teller – The Quaternary stratigraphy of southern Manitoba; p. 196-203.

R.J. Fulton – Late Pleistocene stratigraphic correlations, western Canada; p. 204-217.

Report No. 5, 1979, ed. V. Šibrava and F.W. Shotton:

R.J. Fulton – Quaternary deposits of Canada; p. 117-128.

Report No. 6, 1981, ed. V. Šibrava and F.W. Shotton:

A. Dreimanis, J.T. Andrews, W.R. Cowan, M.M. Fenton, R.J. Fulton, D.R. Grant, and N.W. Rutter – Last glaciation in Canada: Progress report; p. 61-71.

N.W. Rutter – Relationship between Late Pleistocene Laurentide and Cordilleran glaciations, Canada; p. 205-218.

Report No. 7, 1982, ed. D.J. Easterbrook, P. Havlíček, K.-D. Jager, and F.W. Shotton:

A. Dreimanis – Synchronism versus diachronism in ice-marginal fluctuations during Late Wisconsin in North America; p. 73-81.

Report No. 8, 1982, ed. Shoji Horie:

A. Dreimanis – Comments on Hettner-Stein at Inekoki, Azusa valley, Japan; p. 38-39.

R.J. Fulton – Quaternary geology of the Canadian Cordillera; p. 89-100.

F.C. Mayr – Magnetic control of climate; p. 152-171.

Report No. 9, 1983, ed. A. Billard, O. Conchon, and F.W. Shotton:

R.J. Fulton – Correlation of Quaternary events in Canada; p. 70-89.

V.K. Prest – The Late Wisconsinan Glacier Complex; p. 90-102.

D.R. Grant – Pre-Late Wisconsinan organic deposits in Canada; p. 103-108.

E. Evenson and A. Dreimanis – Late glacial (14,000-10,000 years B.P.) history of the Great Lakes region and possible correlations; p. 217-239.

A. Dreimanis – Progress report on Late Pleistocene stratigraphy of southeastern Canada; p. 240-249.

J.J. Clague – Quadra sand and the timing of the Late Wisconsin glacial advance in southwest British Columbia; p. 315-326.

Rapport n° 4, 1977, rédacteur: V. Sibrava:

A. Dreimanis and D.R. Grant – The Canadian Work Group of the IGCP Project 73/1/24, and Late Pleistocene stratigraphy of southeastern Canada; p. 126-134.

J.T. Andrews – Status of Late Quaternary correlations (<125,000 BP) along the eastern Canadian seaboard – latitude 45°N to 82°N; p. 180-195.

M.M. Fenton and J.T. Teller – The Quaternary stratigraphy of southern Manitoba; p. 196-203.

R.J. Fulton – Late Pleistocene stratigraphic correlations, western Canada; p. 204-217.

Rapport n° 5, 1979, rédacteur: V. Sibrava et F.W. Shotton:

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Rapport n° 6, 1981, rédacteur: V. Sibrava et F.W. Shotton:

A. Dreimanis, J.T. Andrews, W.R. Cowan, M.M. Fenton, R.J. Fulton, D.R. Grant, and N.W. Rutter – Last glaciation in Canada: Progress report; p. 61-71.

N.W. Rutter – Relationship between Late Pleistocene Laurentide and Cordilleran glaciations, Canada; p. 205-218.

Rapport n° 7, 1982, rédacteurs: D.J. Easterbrook, P. Havlicek, K.-D. Jager, et F.W. Shotton:

A. Dreimanis – Synchronism versus diachronism in ice-marginal fluctuations during Late Wisconsin in North America; p. 73-81.

Rapport n° 8, 1982, rédacteur: Shoji Horie:

A. Dreimanis – Comments on Hettner-Stein at Inekoki, Azusa valley, Japan; p. 38-39.

R.J. Fulton – Quaternary geology of the Canadian Cordillera; p. 89-100.

F.C. Mayr – Magnetic control of climate; p. 152-171.

Rapport n° 9, 1983, rédacteurs: A. Billard, O. Conchon, et F.W. Shotton:

R.J. Fulton – Correlation of Quaternary events in Canada; p. 70-89.

V.K. Prest – The Late Wisconsinan Glacier Complex; p. 90-102.

D.R. Grant – Pre-Late Wisconsinan organic deposits in Canada; p. 103-108.

APPENDIX 4

Publications on dating and correlation in the series

Dating methods of Pleistocene and their problems in *Geoscience Canada*

Dreimanis, A., Hutt, G., Raukas, A., and Whippey, P.W.
1978: Dating methods of Pleistocene and their problems: 1. Thermoluminescence dating; Geoscience Canada, v. 5, p. 55-60.

Schwarcz, H.P.
1978: Dating methods of Pleistocene and their problems: 2. Uranium-series disequilibrium dating; Geoscience Canada, v. 5, p. 184-188.

Litherland, A.E.
1979: Dating methods of Pleistocene and their problems: 3. The promise of atom counting; Geoscience Canada, v. 6, p. 80-82.

Rutter, N.W., Crawford, R.J., and Hamilton, R.D.
1979: Dating methods of Pleistocene and their problems: 4. Amino acid racemization dating; Geoscience Canada, v. 6, p. 122-128.

ANNEXE 4

Publications sur la datation et la corrélation dans la série

Méthodes de datation du Pléistocène et leurs problèmes dans Geoscience Canada

Westgate, J.A. and Briggs, N.D.
1980: Dating methods of Pleistocene and their problems: 5. Tephrochronology and fisssion-track dating; Geoscience Canada, v. 7, p. 3-10.

Barendregt, R.W.
1981: Dating methods of Pleistocene and their problems: 6. Paleomagnetism; Geoscience Canada, v. 8, p. 56-64.

Evans, L.J.
1982: Dating methods of Pleistocene and their problems: 7. Paleosols; Geoscience Canada, v. 9, p. 155-160.

Brookes, I.A.
1982: Dating methods of Pleistocene and their problems: 8. Weathering; Geoscience Canada, v. 9, p. 188-199.

Ellesmere Island, southwest of Lake Hazen: Outlet glaciers at the northwestern margin of the Viking Ice Cap. NAPL A16694-139.

THE LATE WISCONSINAN GLACIER COMPLEX

V.K. Prest[1]

Prest, V.K., The Late Wisconsinan Glacier Complex; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 21-36, 1984.

Abstract

The limits, component parts, and generalized ice flow directions of the last glacier complex in North America are portrayed on Map 1584A. Because a single line boundary cannot reasonably be fitted to the available information, two portrayals of ice extent are presented. The maximum portrayal limit is the outermost one that can reasonably be attributed to the Late Wisconsinan (<25 ka). The minimum portrayal limit is an attempt to correlate a wide variety of field studies that indicate, suggest, or infer less extensive Late Wisconsinan ice than has generally been claimed. Neither the minimum nor the maximum portrayals can presently be accepted entirely; the actual maximum limit may lie somewhere in between the two.

The approximate times when the ice limits were reached are indicated though little general agreement exists as to the implication of these dates; they do serve to indicate the nonsynchronous development of the ice cover. Because age concepts are in most places embodied in the minimum and maximum portrayals, a number of anomalies occur; for example in some places the minimum (younger?) portrayal overlaps the maximum (older?) (as in Minnesota and the Dakotas). In other areas, such as along the Pacific coast, the outer or maximum portrayal of the Late Wisconsinan limit cannot be separated from the all-time glacial limit. In the western Queen Elizabeth Islands it is presently impossible to show a maximum portrayal of the Late Wisconsinan ice limit, in view of existing controversies.

This report provides information on the component parts of the North American Late Wisconsinan ice sheet complex, discusses their inter-relationships and the problems of establishing their outer limits. The report points out the controversial aspects of our knowledge of the last ice sheet and thereby focuses attention on the problems and areas of greatest concern.

Résumé

La carte 1584A présente l'extension maximale, les composantes et les directions d'écoulement généralisées du dernier complexe de glaciers en Amérique du Nord. Puisqu'il n'est pas raisonnable d'établir une seule limite en fonction de l'information disponible, la carte présente deux limites de l'extension glaciaire. La représentation maximale est l'extension la plus externe qu'il soit raisonnable d'attribuer à la glaciation du Wisconsinien supérieur (<25 ka). La représentation minimale tente de mettre en corrélation une vaste gamme d'études sur le terrain qui indiquent, laissent croire ou concluent que la limite glaciaire du Wisconsinien supérieur serait moins étendue qu'on ne le croyait jusqu'à présent. À l'heure actuelle, il est impossible d'accepter pleinement les représentations maximale et minimale; l'extension maximale véritable se situe peut-être entre les deux représentations.

La carte indique les dates approximatives auxquelles la glace a atteint son extension limite. Bien qu'on ne parvienne pas à s'accorder sur l'importance de ces dates, elles témoignent toutefois de la nature non synchrone de la croissance de la couverture glaciaire. Puisque la notion d'âge est presque partout sous-entendue dans les représentations maximale et minimale, il existe un certain nombre d'anomalies. Ainsi, en certains endroits (p. ex. au Minnesota et dans les Dakotas), la représentation minimale (plus récente?) chevauche la maximale (plus ancienne?). Dans d'autres régions, comme le long de la côte du Pacifique, il est impossible de distinguer la représentation externe ou maximale de l'extension limite au Wisconsinien supérieur de la limite glaciaire ultime. Vu la controverse soulevée, il est présentement impossible d'établir l'extension maximale de la glace au Wisconsinien supérieur dans la partie ouest des îles de la Reine-Élisabeth.

Le présent rapport fournit des renseignements sur les composantes du complexe glaciaire du Wisconsinien supérieur en Amérique du Nord et présente une discussion des liens existant entre les composantes et des problèmes liés à l'établissement de leurs limites externes. Il souligne les éléments discutables des connaissances acquises sur le dernier inlandsis et fixe l'attention sur les problèmes et les domaines offrant le plus d'intérêt.

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Manuscript received: 1983-01-04
Final version approved for publication: 1983-07-20

INTRODUCTION

The Late Wisconsinan glacier complex over North America was composed of several discrete units. The Greenland part (Greenland Ice Sheet) will not be dealt with here. The Laurentide Ice Sheet covered the vast interior part of Canada and extended southward into the northern United States during the Wisconsinan. The Cordilleran Ice Sheet covered the mountainous and intervening lower areas of far western Canada and extended into Alaska and into Washington. The extent of glacier ice cover over the Queen Elizabeth Islands in the Arctic Archipelago during the Wisconsinan is somewhat uncertain; therefore, the name Queen Elizabeth Islands Glacier Complex (Prest, 1970, p. 750), is retained here pending further regional studies. The terms Innuitian Ice Sheet (Blake, 1970) and Franklin Glacier Complex (England, 1976) for specific ice masses over these islands will be discussed below. Appalachian Glacier Complex (Prest, 1970, p. 706) refers to all the Late Wisconsinan ice masses in the Atlantic Provinces. The complex was made up of several component parts, some of which were contiguous. The Island of Newfoundland and the Avalon Peninsula maintained their own radially spreading ice masses in Late Wisconsinan time. It is likely that parts of Gaspésie Peninsula and the Maritime Provinces also supported Late Wisconsinan ice that was independent of the Laurentide Ice Sheet; such ice masses probably extended westward into New England (Kite and Lowell, 1982).

This report has been prepared to amplify the map of Late Wisconsinan ice limits in North America (Map 1584A) which is included in this volume. The first section describes each of the constituent ice masses in general terms, and the second discusses the information used in preparing the map and some of the controversy surrounding the position and age of the ice limits.

DESCRIPTION OF THE GLACIER COMPLEX

Laurentide Ice Sheet

The Laurentide Ice Sheet of the Late Wisconsinan was composed of three major parts – the Labradorean, Keewatin, and Foxe-Baffin sectors. Though these formed a confluent ice mass during much of this time, they maintained separate flow patterns.

Foxe-Baffin Sector

The Foxe-Baffin Sector constitutes the northeastern part of the Laurentide Ice Sheet. Wisconsinan glaciers are presumed to have developed on the Baffin upland (west of the coastal mountains) and advanced westward as a plateau or piedmont glacier into Foxe Basin. Ultimately the basin became the centre of a radially flowing major ice sheet that was confluent in places with Keewatin ice on the southwest and Labradorean ice on the south. Various facets of the development and flow of this sheet have been described (Bird, 1953; Mercer, 1956; Sim, 1960; Ives and Andrews, 1963; Ives, 1964; Falconer et al., 1965; Blake, 1966) and summary accounts given (Prest, 1970; Andrews and Ives, 1978).

Keewatin Sector

The Keewatin Sector of the Laurentide Ice Sheet formed in District of Keewatin, presumably induced by a deteriorating climate and resulting lowering of snowline. The moisture source is not understood – perhaps an open Arctic Ocean contributed moisture during the build-up period (Donn and Ewing, 1966), though this concept has long been disputed. As the Keewatin ice thickened and expanded, it flowed northward over the southern arctic islands and impinged on the south shores of some of the Queen Elizabeth Islands. Direct westward expansion was blocked by the Cordilleran mountain chain west of Great Slave and Great Bear lakes, and the ice was therefore directed down Mackenzie valley towards Beaufort Sea. To the southwest, Keewatin ice, faced by an upslope climb towards the Foothills and Rocky Mountains, flowed south and southeast along the regional trend of Cretaceous strata though there were many exceptions.

Recently, an ice dome, or more properly a dispersal ridge, has been envisaged to have extended from central District of Keewatin into M'Clintock Channel east of Victoria Island (Dyke et al., 1982b). The former presence of this dome is used to account for eastward and westward movement of ice from this northern arm of the Keewatin ice mass. To maintain consistency of nomenclature, this dispersal area is referred to as M'Clintock ice on Map 1584A.

Keewatin ice also flowed eastward into Hudson Bay throughout the Late Wisconsinan (Shilts, 1980). On encountering ice expanding westward from Quebec (Labradorean Sector ice), the Keewatin ice was deflected northeastward and southwestward (Prest et al., 1968; Map 1584A).

Labradorean Sector

Glacier development of the Labradorean Sector began on the Labrador-Quebec interior upland and this led to a radially flowing ice mass that finally merged with Foxe-Baffin ice on the north and Keewatin ice on the west and also flowed southward into and beyond the Great Lakes-St. Lawrence basin. At its maximum the Labradorean Sector ice extended westward onto the Prairies but, because later flow of Keewatin ice also covered this region, its maximum westward extent is not known.

In a general way the Labradorean Sector ice may be considered as a single entity but, as discussed below, it too consisted of a number of semi-autonomous dispersal centres which developed, shifted, and disappeared during the Late Wisconsinan.

Ungava Bay Ice

The writer believes that during the growth of the Late Wisconsinan ice sheet, a dispersal centre or ice dome developed in Ungava Bay, where ice from the north, west, and south converged and grounded. It was confined on the east by two islands and an intervening bedrock sill on the inner side of which is some 600 m of drift (Fillon, 1978; Muller, 1980). This dispersal centre was probably a northern bulbous protuberance of an early Labradorean dumbell-shaped 'ice divide' extending south-southwest into north-central Quebec. That it was a semi-independent dispersal centre is indicated by the early retreat of the ice from northern Labrador and northeastern Quebec towards the west and northwest, rather than to the southwest and the central part of 'Labrador Ice Divide'. The Ungava ice plugged the northern end of the George River basin and thereby allowed the formation of Naskaupi and McLean glacial lakes (Ives, 1960a, b; Matthew, 1961; Barnett and Peterson, 1964; Barnett, 1967; Prest et al., 1968). As recession progressed and the sea entered Ungava Bay, the northern bulbous protuberance of the 'ice divide' dissipated and the glacial lakes drained. The ice flow from central Quebec was then northward into Ungava Bay from the southern part of the former dumbell-shaped 'ice divide' or dispersal centre. Dissipation of the Ungava ice no doubt initiated incursion of the sea into Hudson Strait and Hudson Bay shortly before 8 ka. The opening of Hudson Bay may have promoted renewed activity of the New Quebec ice and a shifting of the dispersal areas; ice flow features in the glacial Lake McLean area suggest late ice flow towards the northwest; perhaps the basin was reoccupied by glacier ice. The final remnants of active ice were along the horseshoe-shaped 'Labrador Ice Divide'.

The writer also believes that the occurrence of glacial lakes in the George River basin demands more limited ice east of the central part of the basin, at the Late Wisconsinan climax, than has heretofore been claimed; therefore the minimum portrayal limit is shown near the New Quebec/Labrador height-of-land rather than off the present coast. This allows for early ice retreat into the river basin while the Ungava ice remains dominant in and immediately south of the bay. Had the interior ice been thick enough to overtop the Labrador highlands and reach the present coastal area, it is unlikely that Ungava Bay could have retained its active ice cover during the long period of ice retreat westward from the Labrador coast and across the George River basin.

Hudson Bay Ice Controversy

It has been suggested that central Canada was occupied by a single ice dome flowing radially out of Hudson Bay (Flint, 1943; Mayewski et al., 1981). Recent work west of Hudson Bay, however, has shown that Keewatin ice flowed easterly into the bay throughout the Late Wisconsinan (Shilts, 1980, 1982). Earlier it had been suggested that this occurred only during a late retreat, glaciomarine phase (Lee, 1959; Prest et al., 1968; Prest, 1969), retreat being towards a Keewatin ice centre, perhaps west of the Keewatin Ice Divide (Lee, 1959). In any case, the field evidence refutes the concept of a single, radially flowing ice dome centred over Hudson Bay. In addition there is no evidence of ice flowing eastward from Hudson Bay or from James Bay (Hardy, 1977).

The ice was thick over Hudson Bay, however, due to the merging of the Labradorean and Keewatin ice in Hudson Bay and because drawdown along Hudson Strait was restricted by Foxe-Baffin ice and probably blocked by Ungava ice. Thus Late Wisconsinan glacier recession fostered flow towards the south and southwest. The latter is evident from late glacial ice flow features in northeastern Manitoba and the northern part of northwestern Ontario. Prior to the development of the overly thick ice in Hudson Bay, however, Labradorean ice had flowed westward across these regions as is indicated by the dispersion of distinctive erratics from southern Hudson Bay (Prest, 1963; E. Nielsen and L.A. Dredge, personal communication, 1980). Also, a general southwestward dispersal of fine grained materials is indicated by the investigations of Adshead (1983). The same distinctive erratics also occur in a number of older tills (E. Nielson and L.A. Dredge, personal communication, 1981), hence westward expansion of Labradorean ice has also occurred on previous occasions.

The late, active ice in Hudson Bay was in contact with Keewatin ice on the west and contributed to the formation of several interlobate moraines in northwestern Manitoba (Prest et al., 1968; Nielsen, E., et al., 1981). The late Hudson Bay ice was also in contact with late, active Labradorean ice on the east. Along the eastern side of James Bay the contact between ice moving generally southward from Hudson Bay and that moving west and southwest from central Quebec is marked by morainal deposits that form a number of islands. The moraine was originally regarded as an end moraine of the Labradorean ice (Low, 1888). Wilson (1938) suggested that the James Bay moraine system might continue southward to 50°N, 78°W and join with a drift-covered drainage divide area, between Harricana and Bell-Nottaway rivers. The elevated drift area was regarded as possibly interlobate in origin between a Labradorean and a western ice sheet because of a divergence of glacial striations on either side of it and because of the dispersion of erratics. Other workers have since confirmed the former activity of two lobes of ice in this region (Tremblay, 1950; Allard, 1974; Tremblay, 1974; Hardy, 1977; Veillette, 1983a, b). Hardy (1977) named the interlobate feature the Harricana Moraine and designated the relevant ice masses as Hudson and New Quebec ice. The relations of the ice lobes and their bearing on the development of glacial lakes in this region are discussed in detail by Vincent and Hardy (1979) and Veillette (1983a). The contact between these ice masses may continue northward from James Bay to near the Ottawa Islands, but this connection remains unproven. South of about 48°N, 78°W the break between Hudson and New Quebec ice flow patterns has been traced westward toward Lac Témiscamingue (Veillette, 1983a, b). The southern end of this discontinuity between Hudson and New Quebec ice is also revealed by the break in the trend of ice flow features shown on the Glacial Map of Canada (Prest et al., 1968). Over a large area south of James Bay the break is partially masked by till of the Cochrane ice advances which were solely from a Hudson source. Thus the two dispersal centres were operative over an extended period of late glacial time, but Hudson ice must not be regarded as the centre of the main, radially flowing Late Wisconsinan ice mass.

Appalachian Glacier Complex

In Canada's Atlantic Provinces a number of autonomous to semi-autonomous ice masses are now recognized. Formerly most Pleistocene scientists believed that Labradorean-derived, Late Wisconsinan ice swept over the whole region to near the edge of the continental shelf – though before the turn of the century both surficial and bedrock geologists had recognized the importance of local ice masses (Chalmers, 1895; Bailey, 1898). The concept of complete dominance by Laurentide ice became popular in the 1920s and only recently has a swing back to the former ideas been considered (Prest and Grant, 1969; Prest, 1973; Grant, 1977). Dominant Laurentide and/or Appalachian ice in Nova Scotia is now considered to be Early Wisconsinan in age (Grant and King, this volume).

Newfoundland

Recent investigations along the west coast of Newfoundland (Grant, 1969a, b; Brookes, 1970, 1974) have shown clearly that local ice flowed westward into Gulf of St. Lawrence during the Late Wisconsinan. Only on the northern part of Northern Peninsula is there evidence that Labradorean ice invaded the island (Grant, 1977, p. 249), and this perhaps during the Early Wisconsinan; elsewhere it either did not reach the island or was held offshore by the active Newfoundland Ice Cap. But at some time during the Wisconsinan, Labradorean and Newfoundland ice were in contact for ice along the west coast was directed southward as far as Port au Port Peninsula.

Avalon Peninsula of southeast Newfoundland also maintained its own ice cap (Henderson, 1972). The Newfoundland Ice Cap was unable to expand across the length of the Avalon Isthmus, and mixing of debris from the two sources was limited to a relatively small area on the isthmus.

Some evidence now exists of Middle Wisconsinan deposits in Newfoundland, which bear directly on the outer limit of the last ice sheet. Tucker and McCann (1980) have documented a sequence of events on Burin Peninsula and on the French islands of St. Pierre, Langlade, and Miquelon as follows: (1) a probable pre-Wisconsinan ice advance from a Newfoundland Ice Cap, represented by sparse occurrences of a weathered till; (2) a major Early Wisconsinan glaciation, also from Newfoundland-centred ice, represented by a widespread till blanket; (3) marine overlap of southwest Burin

Peninsula and the nearby French islands in Middle Wisconsinan time; (4) a late Middle Wisconsinan advance of ice over part of Burin Peninsula from an ice mass lying off the southeast coast of the peninsula; and (5) a Late Wisconsinan advance of the Newfoundland-centred ice to the northern end of, but not over, the peninsula and concurrent development of small separate ice masses along the central spine of the northern part of the peninsula. Grant (1975) had earlier noted the evidence for multiple glaciation of the peninsula and of ice scour from a shelf-based ice mass centred southeast of the peninsula. In any case, it is clear that the Late Wisconsinan ice was much less extensive than formerly conceived.

Shelf-based Ice Domes

As noted above there is evidence of a shelf-based ice dome east of Burin Peninsula. According to Grant (1975; personal communication, 1983) this Middle Wisconsinan ice occupied the whole of Placentia Bay and overlapped onto Avalon Peninsula. It is noteworthy that Henderson (1972) also stressed the importance of active offshore ice in and south of St. Mary's Bay, though he considered it Late Wisconsinan.

Features noted by Grant (1977) and in Prest et al. (1972) on Cape Breton Island also require an offshore dispersal centre on the continental shelf east of that island. This Early or Middle Wisconsinan ice mass was at least 1200 m thick close to the present southeast coast of the island and flowed landward over 300 m-high hills and thence into southern Gulf of St. Lawrence.

There is also evidence of offshore-centred ice north of Prince Edward Island (Prest, 1973; Rampton and Paradis, 1981b; Rampton et al., 1984). But here again this ice dispersal centre is considered to be Late Wisconsinan.

Nova Scotia

Most of mainland Nova Scotia was overridden by an ice flood from the northwest (Grant, 1980), presumably in the Early Wisconsinan. This glacier may have shrunk in size during the Middle Wisconsinan without any significant land areas being exposed as currently there is scant evidence of deposits of that age. A small coastal strip along St. Mary's Bay (44°20'N, 66°10'W) and parts of the highlands bordering the Bay of Fundy, however, may not have been inundated by Late Wisconsinan ice (Grant, 1977). This concept is supported by the marine studies of L.H. King (personal communication, 1983) which indicate that Early Wisconsinan ice may have reached the shelf edge but that the till remnants, lying between the Fundian Moraine of Drapeau and King (1972) and the shelf edge, date from the Middle Wisconsinan; thereafter orderly retreat continued to coastal Nova Scotia.

New Brunswick

Results of recent Pleistocene investigations in New Brunswick (Rampton and Paradis, 1981a, b, c; Rampton et al., 1984) are in accord with those from Newfoundland and Nova Scotia as regards reduced Late Wisconsinan ice cover: An early flood of ice from the northwest was followed by a complex pattern of ice retreat from local areas of accumulation with active ice lobes deployed in lowland areas rather than stemming from the northern highlands. By Late Wisconsinan time New Brunswick ice was largely independent from Laurentide and/or Appalachian ice to the west, although the two ice masses remained in contact for some time. In the middle reaches of Saint John River valley, a phase of the New Brunswick ice flowed northwestward into a glacial lake; this lake (once thought to have drained southward) was forced to drain to the north, towards the retreating Laurentide ice, into St. Lawrence River valley (R.C. Gauthier, personal communication, 1979). The implications of this are relevant to the whole picture of active, locally deployed ice in the New Brunswick lowlands.

Gaspésie Peninsula

As is the case with the rest of Atlantic Canada, the penetration of Late Wisconsinan Labradorean ice into the eastern Gaspésie Peninsula was more restricted than formerly believed (Hétu and Gray, 1981). Late Wisconsinan radial flow from the eastern part of Gaspésie Peninsula was proven also by other investigators including McGerrigle (1952) and Lebuis and David (1977). It has not been proven that Late Wisconsinan Labradorean ice overrode eastern Gaspésie; but Early Wisconsinan ice may well have done so. The 1260 m-high Mont Jacques-Cartier (48°58'N, 65°55'W) was a nunatak during the last glaciation, whereas the 1140 m-high Mont Albert (48°54'N, 66°12°W), only 20 km to the west, was glaciated, but the source of this ice has not been determined.

Late Wisconsinan Laurentide and Gaspésie ice are shown in contact along the north side of Gaspésie (Map 1584A), but the eastward extent of the contiguous ice masses is not known. Gaspésie ice was in contact with the sea (at 8 or 9 m a.s.l.) at the northeastern end of the peninsula by at least 12 700 ± 180 BP (GSC-2376), and the Bay of Chaleur was a calving bay by 12 400 ± 150 BP (GSC-2494). Also from my own observations, the Late Wisconsinan eastern limit of the Gaspésie ice was inland of the present shore (Map 1548A) much as indicated by Chalmers (1895).

Restricted Laurentide ice in Laurentian Channel is also indicated by the trend of ice-flow features on Anticosti Island; these are more or less perpendicular to the length of the island and indicate free flow across the island and into the channel. According to Gwyn et al. (1983) it was Late Wisconsinan ice that overrode the island. If this is the case, the minimum portrayal limit in southeastern Quebec is too far north. The southward trend of ice-flow features across Anticosti Island is indicative of an ice-free Laurentian Channel. From the eastern end of the island the glacier limit might swing northward to the northern end of Northern Peninsula, Newfoundland, to adjoin Newfoundland ice as depicted by Grant (1977).

The maximum portrayal of The Late Wisconsinan ice limit in the Gulf of St. Lawrence (Map 1584A) is deduced on the basis of unrestricted southward ice flow across Anticosti Island but with more extensive ice in the northern gulf, sufficient to deflect Newfoundland ice southward along that coast as far as Port au Port Peninsula (Brookes, 1970, 1974). In either case the Gulf of St. Lawrence was more ice-free than previously shown by Prest (1969).

Prince Edward Island

The history of glaciation of Prince Edward Island fits well into the concept of contiguous but restricted ice cover throughout the Late Wisconsinan with a reorientation of flow during ice retreat (Prest, 1973). Ice first flowed east-southeast across the length of the island from a major ice cap in New Brunswick. Later the ice centred on the Magdalen shelf north of Prince Edward Island, flowed onto and across the western end of the island, and thence westward towards New Brunswick; but the eastern end of the island was not affected by this later ice flow.

Magdalen Islands

In the more central part of the Gulf of St. Lawrence, the Magdalen Islands remained unglaciated during the Late Wisconsinan (Prest, 1957, 1970; Prest et al., 1976), though shelf and berg ice were nearby and may locally have grounded on the islands. Such ice may have been responsible for much of the nearly massive to well bedded sandy diamicton and certain bouldery deposits which mantle the lower slopes of the Magdalen Islands. Some of the drift may represent the washing of a somewhat clayey, lodgment-type till such as that seen in two places only on the eastern end of the southernmost island; at both sites the clayey, lodgment till lay beneath the Demoiselle drift which has been regarded as Late Wisconsinan. D.R. Grant and L.A. Dredge (personal communication, 1982) noted the numerous striated 'beach' stones in the uppermost gravelly parts of the Demoiselle drift and related this to evidence of widespread ice-thrusting of the Demoiselle deposits and some underlying siltstones; they considered the thrusting, and hence the Demoiselle deposits, to be Early Wisconsinan.

Striated bedrock or ice-flow features in drift have not been observed on the Magdalen Islands; an "end moraine" (Coffin Island Moraine) reported on the northeastern island (Alcock, 1941) is but a thin mantle of bouldery to gravelly substratified materials, probably derived from floating ice, draped over an irregular, eroded surface of silty to sandy horizontally stratified deposits lying on sandstone. Grant and King (this volume), however, interpreted these features as end moraine but attributed them to the Middle Wisonsinan.

Nowhere on the island is there evidence of any kind of glacial drift above the presumed marine limit, the elevation of which varies from island to island and is higher in the southeast than in the northwest. This suggests that 'glacial' materials were deposited by floating rather than by grounded ice, a conclusion also reached by Coleman (1919). Some of the lower northern islands have an ice-rafted mantle of bouldery materials, containing a great variety of igneous rocks, that is unlike the red, sandy diamicton of the southern islands. This indicates that the late Quaternary history of the northern and southern islands was different. In any case, there is no evidence that the Magdalen Islands were scoured by ice during the Late Wisconsinan; hence they remain beyond the ice limit portrayals on Map 1584A. The presence of large, flat-bottomed drainage channels radiating from the high, central part of the largest island, and developed in the sandy stratified deposits, suggests semi-permanent snow or possibly local hilltop ice fields during the Late Wisconsinan.

Queen Elizabeth Islands Glacier Complex

Because of the controversy over the extent of ice cover on the Queen Elizabeth Islands and the limited field data available, the term 'glacier complex' has been used for this northern part of the continental ice (Prest, 1970). The first Glacial Map of Canada (Wilson et al., 1958) showed several unglaciated western islands whereas the next one (Prest et al., 1968), based on the Innuitian Ice Sheet concept (Blake, 1970), showed the entire region as glaciated. The presence of scattered erratic boulders on some of the western islands led Fyles (1965) to suggest that they were once covered by Laurentide-derived ice; this presumed extensive glaciation is likely a much older event. Certainly the northern limit of the Late Wisconsinan Laurentide Ice Sheet did not extend beyond the southernmost part of Melville Island (Hodgson et al., in press) where it is considered to be shelf ice (Hodgson and Vincent, in press).

Blake (1970), on the other hand, advocated the concept of an Innuitian Ice Sheet, which covered both the islands and the intervening channels and was contiguous with both Laurentide and Greenland ice. The concept was based largely on the westward-rising shorelines in Jones Sound and on the magnitude of Late Wisconsinan marine overlap in the west-central parts of the Archipelago. Recent investigations on Ellesmere Island (England, 1976, 1978a, b, 1983; Hodgson et al., in press) have indicated a more restricted ice cover in the eastern Arctic Islands during the Late Wisconsinan. The term Franklin Ice Complex was applied to this much reduced ice cover of the islands (England, 1976). But the problem of the magnitude of postglacial marine overlap of the west-central islands remains. Blake (1964) reported that Laurentide ice did not override Bathurst Island, though the island was glaciated during the 'Wisconsin', and that marine overlap was greater in the northwest than in the east and southeast parts of the island. Several radiocarbon dates on shells from high level beaches indicate that there was little or no ice on the island by about 9 ka.

Cordilleran Ice Sheet

The Cordilleran Ice Sheet refers to the system of intermontane, piedmont, and valley glaciers of the Cordilleran region of Western Canada which, at one or more Wisconsinan maxima, was an integrated mass; it was formerly termed the Cordilleran Glacier Complex (Flint, 1957, 1971; Prest, 1970). At its maximum development, the Cordilleran Ice Sheet was more than 2000 m thick in the central and southern interior of British Columbia and its surface probably stood higher than the confining mountain ranges. Though generally the ice flowed along the intermontane valleys, it did flow across some ranges as in east-central and north-eastern British Columbia (Gabrielse, 1963; Tipper, 1971).

Map 1584A differs somewhat from the earlier portrayal (Prest, 1969) in that the new map pertains specifically to the Late Wisconsinan. In addition, Cordilleran ice during the Late Wisconsinan was probably more restricted along its eastern boundary than previously shown, so that a more extensive corridor existed between this and Laurentide ice in western Alberta. Rutter (1980, this volume) has shown the Late Wisconsinan ice limit along the Yukon-Northwest Territories boundary; this position is similar to the inner edge of the area of uncertain ice cover on the Glacial Map of Canada (Prest et al., 1968). Evidence exists, however, of more extensive ice flow into this area (Gabrielse et al., 1973); presumably this was partly due to somewhat older ice movements.

Vancouver and Queen Charlotte islands appear to have developed their own ice caps early during the last glaciation. The ice on Vancouver Island was later mainly overrun by flow from the mainland Cordilleran Ice Sheet (Fyles, 1963a; Clague et al., 1980; Clague, 1981). The Queen Charlotte Islands, on the other hand, remained essentially independent from the mainland ice sheet with some ice flowing eastward into Hecate Strait (Sutherland Brown and Nasmith, 1962; Sutherland Brown, 1968). The eastward-flowing ice was deflected to both the north and south by the mainland ice. Recent field studies, supported by radiocarbon dates, further suggest that the Late Wisconsinan ice cover on the Queen Charlotte Islands was rather restricted (Clague et al., 1982).

MINIMUM/MAXIMUM PORTRAYALS OF LATE WISCONSINAN LIMITS

The Late Wisconsinan glacier complex in North America has left a record of glacial features and events that have been studied by scientists for well over a hundred years. But in spite of great advances being made and vast areas mapped, both on land and offshore, a great diversity of opinion exists as to the outer limit of the glacier complex. Nevertheless, Map 1584A, which accompanies this report, is an attempt to encompass most of the contrasting viewpoints as to the limit of the Late Wisconsinan glacier complex by presenting minimum and maximum portrayal limits. These portrayals do not fully reflect the diversity of information that is available but, hopefully, cover most of it; they will provide food for thought and serve to point out areas and problems meriting further attention.

In some regions the Late Wisconsinan glaciers were at least as extensive as at any time during the Pleistocene whereas in other areas they were almost as restricted as today. Determining the limits of the ice masses is complicated by the nonsynchronism of the ice borders and the lack of precise knowledge of the time periods involved. In some regions radiocarbon age determinations suggest a maximum Late Wisconsinan development approaching 25 ka; in others the ice limit was not attained until early Holocene time; locally, present-day mountain glaciers are more extensive than at any earlier time. In some regions the same outer limit may have been attained twice during the Late Wisconsinan. This may have been the case in Alaska (T.D. Hamilton, personal communication, 1981) and perhaps on, and to the east of, Long Island, New York (Sirkin, 1981). In the south and in Alaska, ages ranging from 18 ka to about 25 ka are generally accepted for the Late Wisconsinan ice maximum. In the southern Cordillera, however, the maximum development was not attained until about 14.5 ka. In the south-central Prairies a late ice advance (possibly a surge) at about 14.5 ka went well beyond the 18 ka ice frontal position (H.E. Wright, personal communication, 1981). In areas where the limit was reached later, little or no information exists on the position of the ice margin during the early Late Wisconsinan.

Map 1584A is an attempt to bracket the Late Wisconsinan ice limit using inferred 'maximum' and 'minimum' portrayals. The maximum portrayal limit in most places is the position shown as the 'Wisconsin' limit by Prest (1969); although this 'Wisconsin' limit is still in use today, the author feels that this limit, in many regions, more accurately portrays the extent of Early rather than Late Wisconsinan glaciers. The following sections discuss the limits in specific areas and cite references for data used.

Laurentide Ice Sheet

Gulf of Maine - Montana - Southern Alberta

Even using minimum and maximum portrayals to present the extent of Late Wisconsinan ice in North America, the Gulf of Maine presents a major problem. The Canadian view of shrinkage of the main Early Wisconsinan ice from its maximum extent on the continental shelf, to a greatly reduced mass and an 'open' Bay of Fundy during the Late Wisconsinan (Grant, 1977), is in marked contrast with generally accepted views in the United States that the southeastern part of the Late Wisconsinan ice sheet was at the all-time maximum corresponding to the outer moraine system on Long Island, New York (Schafer and Hartshorn, 1965; Muller, 1965; Sirkin and Mills, 1975; Map 1584A). This moraine system extends eastward to Nantucket Island, and a major glacier lobe flowed down the channel east of Nantucket Island, reaching a point some 90 km southeast of that island (Schlee and Pratt, 1970; Tucholke and Hollister, 1973; Bothner and Spiker, 1980; Oldale, 1981); this ice limit has, therefore, been shown on Map 1584A as the maximum portrayal limit of Late Wisconsinan ice. The eastern side of this ice lobe is believed to loop around the northern side of Georges Bank and extend across a channel to Browns Bank at the edge of the continental shelf. This position lies somewhat beyond the limit of Middle Wisconsinan till according to L.H. King (personal communication, 1983); Early Wisconsinan ice, however, is believed to have reached the shelf edge. The maximum extent of Late Wisconsinan ice off Nova Scotia (landward of the known till limit) might be marked by the Fundian moraine system which has been mapped as far west as 42°40'N, 68°W. This is a very prominent feature (King et al., 1972; Fader et al., 1977).

The minimum portrayal limit of Late Wisconsinan ice in New Brunswick and Nova Scotia presents an open Bay of Fundy and presumably restricted ice cover in Gulf of Maine. It is indeed difficult to rationalize such limited ice in the northern part of Gulf of Maine and at the same time maintain an extensive Late Wisconsinan ice lobe east and southeast of Nantucket Island, though the respective ice lobes may well have had different sources and regimens. In an attempt to present an integrated picture of the minimum portrayal limit of Late Wisconsinan ice in the Gulf of Maine, the Harbour Hill (Long Island) to Sandwich (Cape Cod) morainal positions have been chosen to represent such an ice limit; spruce wood in the Harbour Hill Moraine was dated at 23 ka (Sirkin, 1977). A second major ice lobe has been assumed east of Cape Cod and its eastern margin extended northward in the Gulf to join with the assumed lobe off the Maine – New Brunswick border. The minimum portrayal limit in the Bay of Fundy area was attained about 14.5 ka – not an unlikely age for both ends of the system. The maximum portrayal limits in the Gulf of Maine region may yet prove to be early Late Wisconsinan, that is of the order of 22-23 ka (Sirkin, 1981) rather than only 15-16 ka as formerly held. The problem of dating the Atlantic Coast morainal systems will not soon be resolved for although datable materials are present in many areas, ice-thrusting has mixed the materials and also the order of some stratigraphic units; the problem of distinguishing between deposits of grounded ice and of ice shelves presents further complications. In addition many of the radiocarbon dates may be unreliable because they are mainly on the total carbon fraction of marine sediments derived from older sedimentary rocks or sediments.

Westward through Pennsylvania, the concept of the position of the Wisconsinan ice limits has changed little since 1894 (Crowl and Sevon, 1980). The extent of the last ice sheet has, however, been shown to be somewhat less than that of the presumed Early Wisconsinan, and the last maximum is now thought to date around 16 ka rather than 18 ka (Crowl and Sevon, 1980). In Ohio, Indiana, Illinois, and Wisconsin the limit of the last major ice lobes is similar to that given in earlier reports (Goldthwait et al., 1965; Frye et al., 1965). Several ice lobes in this region appear to have reached their termini at different times between 19 and 21.5 ka (Dreimanis, 1977). An additional problem is that there was a significant retreat followed by a major readvance to within 10 to 50 km of the Late Wisconsinan terminus over a broad region at about 17.2 ka (Dreimanis, 1977). It is conceivable that such a late ice advance might, in other areas, have gone beyond the earlier stands of the ice; this may be the case in Pennsylvania. Thus the outer limit of the southern extent of the Late Wisconsinan ice sheet on Map 1584A shows a diversity of age determinations and estimates.

In Minnesota there is a former glaciated area that was not covered by Late Wisconsinan ice (Wright, 1972). The complex interrelations of major ice lobes from the west, north, northeast, and east make any reconstruction of the ice limits rather tenuous; Map 1584A is but an attempt to present reasonable, distinct minimum and maximum portrayals based mainly on the work of Wright and Ruhe (1965) and Wright (1972), though it is realized that ice from the west occupied areas earlier vacated by Late Wisconsinan ice from the north and northeast.

Farther west, in South Dakota, North Dakota, and Montana, little recent regional data related to the Late Wisconsinan glacier limit are available. The Wisconsinan ice limit mapped by Lemke et al. (1965) is now regarded by some scientists as the Late Wisconsinan limit;

others believe that one of the moraines mapped as a retreatal position is the Late Wisconsinan limit (Clayton and Moran, 1982). This latter, more recent interpretive position is shown on Map 1584A as part of the maximum portrayal. Certain data from southern Alberta suggest an even more reduced ice sheet at this time. Three radiocarbon dates on wood (in the 24.5-28.5 ka range) overlain by two tills, the mapped outer limits of these tills, and other data indicate that the Late Wisconsinan limit was in southern Alberta rather than south of the 49th parallel (Stalker, 1977, 1980; Jackson, 1979). This limit is shown as the minimum portrayal limit of Late Wisconsinan ice. This reduced limit necessitates an enlarged "ice-free corridor" between Keewatin and Cordilleran or Rocky Mountain ice, and it is accordingly extended northward (Map 1584A).

Northern British Columbia - Mackenzie River Delta

The western boundary of the Late Wisconsinan Laurentide ice (Keewatin Sector) in northern British Columbia and the Northwest Territories is but little changed from former portrayals (Prest, 1969) because along the mountain front significant changes in thickness of the ice had relatively little areal expression. Furthermore, field studies are limited in this region and airphotos remain the main source of information except along the Alaska Highway where ground observations have confirmed the juxtaposition of the ice masses (Mathews, 1980).

In the Fort St. John part of Peace River valley, at the Late Wisconsinan climax, the Keewatin and Cordilleran/Rocky Mountain ice masses were either in contact or the one overlapped areas recently vacated by the other (Mathews, 1963). An extensive glacial lake in the Fort St. John region drained southeast into Alberta; an early phase of this lake system may have comprised a part of the ice-free corridor. Between Peace River valley and Liard River valley the two masses were in contact at the Late Wisconsinan climax; but immediately upon retreat of the Keewatin ice, glacial lakes were ponded along its western margin with drainage northward towards a corridor between Keewatin ice and the Mountains on the west (Mathews, 1980).

In Mackenzie valley and northern Mackenzie Mountains problems also occur in distinguishing Late Wisconsinan and earlier limits. Hughes et al. (1981) have suggested that the last ice sheet was the one that achieved the all-time maximum extent in the Bonnet Plume River basin (Hughes, 1972). It reached this limit possibly as early as 30 ka and plugged a minor valley farther north thereby giving rise to a glacial lake in northern Yukon Territory which drained westward via Porcupine River. The northward extension of such an extensive ice mass would have occupied the Mackenzie Delta region and extended northwestward to the vicinity of Herschel Island. Rampton (1982), however, considered this ice mass and the resulting deposits to be Early Wisconsinan. The northern margin of this ice sheet, east of the delta, would have extended along Tuktoyaktuk Peninsula and then swung southward leaving a major re-entrant between this ice and a major lobe in Amundsen Gulf. This ice mass is shown as the maximum portrayal limit of the Late Wisconsinan on Map 1584A. The all-time limit, shown farther offshore, marks the position of a shoreline deposit at a present depth of about 45 m. The materials of this submerged shoreline are coarser than those of modern analogues along Mackenzie Delta or Tuktoyaktuk Peninsula, and the inference is drawn that these developed on Laurentide glacial deposits and that Laurentide ice at the time of deposition must have been more extensive than during the Late Wisconsinan (B.R. Pelletier, personal communication, 1981).

The minimum portrayal is based on a formerly expressed view that the above mentioned Yukon glacial lakes were Middle Wisconsinan in age. It was also believed that drainage from the western margin of Laurentide ice during the Late Wisconsinan was eastward into Mackenzie River, and that the ice terminus lay within the delta proper (Rampton and Bouchard, 1975; Rampton, 1982). The eastern side of this Mackenzie ice lobe, as determined by airphoto interpretation and limited field observations, extended southward up Mackenzie valley as far as 67°N, where it swung eastward and then lobed northward in a small river valley where a possible Late Wisconsinan ice margin was mapped (Hughes et al., 1974; Hanley et al., 1975). Farther east this ice merged with an ice mass in the Anderson-Hornaday valleys which pushed northward to about 69°N but, based on my airphoto interpretations, did not reach Amundsen Gulf. A roughly east-west terminal position is marked by an extensive system of hummocky moraine south of Darnley Bay. East of Hornaday River the ice swung southward around a highland (Melville Hills, 69°N, 122°W) adjoining the Dolphin and Union Strait ice lobe (Klassen, 1971; R.J. Fulton, personal communication, 1979).

Amundsen Gulf - Baffin Island

Continuing eastward around the northern edge of the Laurentide Ice Sheet, the maximum portrayal limit of the Late Wisconsinan ice is shown as a major lobe in Amundsen Gulf (Map 1584A); the northward extension of this ice mass overlaps the east coast of Banks Island and extends westward along M'Clure Strait. This limit was shown as the 'Wisconsin' terminus by Prest (1969). A slight variant of this ice margin is considered Early Wisconsinan by Vincent (1978, 1982), but is retained on Map 1584A as the Late Wisconsinan maximum portrayal limit. According to Vincent, this ice lobe in M'Clure Strait was shelf ice, the northern edge of which abutted Prince Patrick and Melville islands; hence the northern extension of this Laurentide ice is not shown to extend around the western Queen Elizabeth Islands as portrayed by Prest (1969). The northern edge of this M'Clure shelf ice has instead been traced eastward to Dundas Peninsula, Melville Island (Hodgson et al., in press); thus, a Late Wisconsinan maximum portrayal limit cannot be shown elsewhere in the western Queen Elizabeth Islands. The suggested all-time glacial limit indicated at the northwestern edge of these islands is based on limited soundings and hydrographic records, from the channels between the outer islands, interpreted by and obtained from B.R. Pelletier (personal communication, 1981).

The envisaged minimum portrayal limit of the Late Wisconsinan Laurentide ice in the Amundsen Gulf – M'Clure Strait region would correspond with an ice lobe entering Amundsen Gulf from the southeast and east (Map 1584A). The northern extension of this ice limit crosses northwestern Victoria Island and loops around the eastern side of the Shaler Mountains (72°N, 112°N); the ice then flowed into Viscount Melville Sound (J-S. Vincent and D.A. Hodgson, personal communication, 1982). This ice mass, here part of the M'Clintock Dome (Dyke et al., 1982b), thrust westward and deposited segments of end moraine along the north side of Victoria Island (Fyles, 1963b). The ice reached the northeast tip of Banks Island and the south coast of Melville Island as shelf ice about 10 ka (Hodgson and Vincent, in press). It deposited the Winter Harbour Moraine at this time (Fyles, 1967).

Farther east Laurentide ice did not reach Bathurst Island which retained an independent ice cover (Blake, 1964). Eastward-flowing Laurentide ice reached the western side of Somerset Island but did not overtop an elongate elevated area which remained as a nunatak between this ice and locally developed ice on the main northern part of the island

(Dyke, 1983). The ice limit on Somerset Island was attained about 9.5 ka. Dyke (1979) has reported that farther south Laurentide ice flowed east and northeast across northern Boothia Peninsula and was retreating from the east coast by 9.2 ka. Still farther south the ice also flowed freely eastward into the Gulf of Boothia; only in Committee Bay was the Keewatin Sector ice deflected northward by Foxe-Baffin Sector ice. Thus the Late Wisconsinan margin of the Foxe-Baffin ice is shown trending northward in Gulf of Boothia and thence eastward across southern Brodeur and Borden peninsulas; these regions probably harboured independant ice caps (A.S. Dyke, personal communication, 1981). Furthermore, limited ice at the northern end of Baffin Island is shown by the presence of an independent ice cap on Bylot Island during the Late Wisconsinan (Klassen, 1981). Klassen has shown that only Early Wisconsinan or perhaps even older ice flowed eastward in Lancaster Sound into Baffin Bay. Some scientists, however, believe that it was Late Wisconsinan ice that flowed freely into Baffin Bay both from the Arctic Islands and from Baffin Island; thus a maximum portrayal limit is indicated on Map 1584A.

Baffin Island - Labrador

The minimum portrayal limit on northern Baffin Island is shown as correlative with the Holocene-age Cockburn Moraine system at about 8-8.4 ka (Andrews et al., 1970; Miller and Dyke, 1974) and the Cockburn Substage moraines between 8 and 9 ka as redefined by Andrews and Ives (1978). This ice margin is well marked and can easily be traced along the length of northeastern Baffin Island. Nearby to the south on Cumberland Peninsula, independent ice masses were present which began to retreat by about 8.8 ka (Dyke et al., 1982a). It is clear that Laurentide ice was more extensive on Baffin Island at some earlier time; some of the more extensive ice was definitely pre-Late Wisconsinan but there is little to indicate where the ice margin was between 25 and 9 ka and some scientists regard the Cockburn system of moraines as retreatal positions. A few Late Wisconsinan ^{14}C dates from sites beyond the Cockburn moraines, and deductions based on marine overlap data, do suggest more extensive ice in the fiords of northeastern Baffin Island. Because of this, the maximum portrayal limit is shown mainly offshore.

Farther south, on Hall Peninsula, there is definitive evidence of a Late Wisconsinan ice advance beyond the Cockburn moraine system, and older than that of the Cockburn Glacial Phase (Andrews and Ives, 1978). Shells from deltaic sediments deposited at the start of glacier retreat of a major ice lobe in outer or lower Frobisher Bay have been dated at 10 790 ± 70 BP (QL-1173). The outermost Cockburn-age moraine, on the other hand, correlates with the Frobisher Moraine near the head end of the bay (Miller, 1980); this moraine has been dated at 8230 ± 240 BP (GSC-462). Hence, though the Cockburn moraine system on northeastern Baffin Island is commonly regarded as the outer limit of the last ice sheet (minimum portrayal), farther south it is necessary to extend the limit beyond the Cockburn to the mouth of Frobisher Bay (Map 1584A). This may be evidence of nonsynchronous ice margins, relative to different ice regimens, but it also lends credence to reports of more extensive Late Wisconsinan ice in the fiords of northeastern Baffin Island immediately prior to the Cockburn Glacial Phase.

There is, furthermore, evidence of complex, nonsynchronous interrelationships between three distinct ice masses in the lower end of Frobisher Bay; a local ice cap on Meta Incognita Peninsula and a major ice lobe from Ungava Bay remained active in the southeastern end of the bay after the Foxe-Baffin Sector ice had receded up the bay (Muller, 1980).

The maximum portrayal limit of the Late Wisconsinan ice immediately east of Baffin Island is more or less that of Prest (1969), this mainly offshore position is retained to account for the known occurrence of Baffin Island sediments dated in the 9-10 ka range – the Remote Lake Substage of Andrews and Ives (1978). Also nothing is known as to the extent of ice from 25 to 11 ka, though it is generally assumed that it was less extensive than outermost Cockburn moraines.

Minimum and maximum portrayal limits of Late Wisconsinan ice are shown at the mouth of Hudson Strait. The seaward extension of the minimum portrayal limit would lie between the islands off southeast Baffin and the northeast tip of the Quebec/Labrador peninsula where its position has been suggested by Fillon (1978). The seaward extension of the maximum portrayal limit is taken in part from the offshore work of Fillon and Harmes (1982), though southward their Late Wisconsinan limit would appear to correlate with the Early Wisconsinan limit of Josenhans (1983).

The eastern limit of Laurentide ice as shown by Ives (1957, 1958) on the northern end of the Quebec/Labrador peninsula has been extended southward on the basis of elevations and presence or absence of eskers and ice flow features as seen on airphotos. This limit is well inland from the coast and from the offshore 'Wisconsin' limit shown by Prest (1969). Such an inland ice-frontal position would indicate much thinner ice in the interior than was formerly believed and allows for retreat of the ice front westward into the George River basin at an early stage of recession to impound the glacial lakes which formed in that area (Ives, 1960b). A major shift in position of the zones of accumulation and active ice flow obviously occurred during Late Wisconsinan time. Matthew (1961) noted nearly opposed ice-flow indicators within the George River basin. At one time ice flow in Hudson Strait, fed from the north, west, and south, must have contributed to the grounding of ice in Ungava Bay and development of an ice dome while accumulation was minimal in north-central Quebec. Only upon the opening of Ungava Bay did the lakes drain and the New Quebec ice again flow northward into Ungava Bay.

Southward, the minimum portrayal limit, which lies along the Quebec/Labrador boundary, swings eastward to the sea coast at about 55°N (Map 1584A), suggesting movement from a major ice lobe centred west of the Hamilton Inlet-Lake Melville area. South of Hamilton Inlet this ice front swings inland along the Paradise Moraine (Fulton and Hodgson, 1979); the writer, through airphoto interpretation, has extended the course of this moraine southwestward for some 200 km. The moraine trends toward the Mingan Islands on the north shore of St. Lawrence valley opposite the west end of Anticosti Island. It is interesting in this connection to note that Dredge (1983, p. 21) has stated that the limit of the "grounded Labradorean ice from the Laurentian Highlands extended beyond the North Shore only to about the 300 m bathymetric contour". T.E. Bolton and M.J. Copeland (personal communication, 1982) reported extensive outwash immediately north of the bare southern sides of the Mingan Islands; the outwash may be related to the limit of this ice mass. The ice might then have looped around the western end of Anticosti Island and extended a short distance along Laurentian Channel. But Late Wisconsinan ice has been said to have crossed central Anticosti Island and calved into the sea about 12.5-13 ka according to J.M. Dubois (personal communication, 1982). This is difficult to reconcile with a minimum portrayal Late Wisconsinan ice limit at the Paradise Moraine in southeastern Quebec. The maximum portrayal limit is retained offshore along the Labrador coast; the area of older tills as determined by Josenhans (1983) lies beyond this limit.

Atlantic Provinces

The maximum portrayal limit of Late Wisconsinan Laurentide ice in Gulf of St. Lawrence is shown close to the west coast of Newfoundland; this is necessary to account for the deflection of Newfoundland ice southward as far as Port au Port Peninsula (Brookes, 1974). No evidence has been found of a deflection of the Late Wisconsinan ice flowing south across Anticosti Island; this suggests that there was little ice in Laurentian Channel and a much more expansive calving bay in Gulf of St. Lawrence than shown by Prest (1969). A relatively ice-free Gulf of St. Lawrence was suggested by Grant (1977) based on his field observations in western Newfoundland and on the opposing Quebec shore. Thus neither the minimum nor maximum portrayals of Late Wisconsinan ice limits shown on Map 1584A are in accord with all the reported data but they merely indicate extremes in some of the viewpoints recorded in the literature.

If the Paradise Moraine of southeastern Quebec and eastern Labrador did indeed represent the Late Wisconsinan ice terminus at about 10 ka, then clearly the Island of Newfoundland had an independent ice cap; the Laurentide ice that flowed eastward across the northern tip of Northern Peninsula, Newfoundland, as shown by Grant (1977), therefore had to be older. The limit in this position does not fit well with other data. Grant (1977) has identified segments of piedmont moraines in the lower ends of the west coast fiords and reported that they are at or close to the Late Wisconsinan terminus on the basis of the slope of a fresh surface trimline indicating the former presence of valley ice (evidence of more extensive and hence thicker ice in the valleys is associated with weathered surfaces that denote Early Wisconsinan and/or older glaciations). Several ^{14}C dates on shells associated with the early retreat of the piedmont ice lobes are in the range 12-13 ka. It has to be assumed that the northern tip of the peninsula had its own mantle of ice at this time for there was west-flowing ice along the west coast of the lowland prior to the Ten Mile Lake advance of upland ice into the lowland area at about 11 ka (Grant, 1969). Thus, although the configuration of the minimum portrayal limit of ice along the west coast in the south is relatively well defined by the field observations of Brookes (1974) and Grant (1977), that portrayed on the northern end of the peninsula (Map 1584A) is conjectural.

The maximum portrayal limit of Late Wisconsinan ice over Newfoundland allows for a greater expansion of the Labrador Sector ice such that it overran the northern lowland part of the peninsula but elsewhere was restricted by the presence of the Northern Peninsula and interior ice. There is evidence of southward-flowing ice along the west coast of Newfoundland, which suggests that Labradorean and Newfoundland ice were in contact as far south as Port au Port Peninsula (Brookes, 1970, 1974). This situation is not in accord with the view of Late Wisconsinan terminal piedmont moraines along the coast. Brookes (1974) has shown that the ice in St. Georges Bay was in contact with the sea at about 14 ka. It is probable that central Gulf of St. Lawrence was more open than formerly indicated by Prest (1969).

In the Maritime Provinces the minimum portrayal limit of the Late Wisconsinan ice is modified but slightly (Prest, 1973; V.N. Rampton, personal communication, 1982) from the limit shown by Grant (1977). The ice calved into the sea near Saint John, New Brunswick, around 14.5 ka; shells of **Hiatella arctica** from a site about 35 m a.s.l. gave a date of 14 400 ± 530 BP (GSC-2573). This date lends support to the 14 100 ± 200 BP (GSC-1259) date obtained on algae from marine beds in the northern part of St. Mary's Bay, Nova Scotia (44°20'N, 66°10'W). According to D.R. Grant (personal communication, 1982) the terminus of the Late Wisconsinan ice in southern Nova Scotia corresponded with an end moraine along the coast near Yarmouth. D.J.W. Piper (personal communication, 1981) has identified a major morainal ridge off the mouth of Malone Bay, south of Halifax, that may well mark the limit of the ice; L.H. King (personal communication, 1981) also feels that the terminus lay but a short distance off the southeast coast of Nova Scotia. That the Bay of Fundy was open about 14-14.5 ka is supported by field observations in New Brunswick (Rampton and Paradis, 1981c; Rampton et al., 1984). Grant, furthermore, considers the ice-frontal stand in the northern end of Bay of Fundy to coincide with the terminus of the Late Wisconsinan ice.

In Gulf of St. Lawrence, evidence exists of ice flow onto the east coast of New Brunswick from an ice mass in the northern end of Northumberland Strait or somewhat farther north (Escuminac Ice Centre of Rampton and Paradis (1981b; Rampton et al., 1984). This may well correspond to a younger ice mass situated over and north of Prince Edward Island as envisioned by Prest (1973). In any case Rampton et al. (1984) believed that the last ice sheet covered the entire eastern shore of New Brunswick whereas Chalmers (1895) and Grant (1977) suggested that the Shippegan Island area (northeastern tip of New Brunswick) may not have been covered. On Gaspésie Peninsula my field observations support those of Chalmers (1895) – a narrow coastal strip along Chaleur Bay and the easternmost Gaspésie lay beyond the Late Wisconsinan ice terminus.

For the maximum portrayal limit it is assumed that the entire maritime region, except for south-central Gulf of St. Lawrence, was ice covered. This picture is in somewhat better accord with the envisioned greater ice coverage in Gulf of Maine as mentioned above, but again differences remain as to both extent and timing.

Cordilleran Ice Sheet

In western Washington State the Late Wisconsinan ice terminus is well established at about 14.5-15 ka (Crandell, 1965) and there has been little controversy or confusion as regards any older Wisconsinan termini. Nevertheless, minimum and maximum portrayal limits are depicted on Map 1584A. In British Columbia a major Late Wisconsinan ice advance followed a long nonglacial interval (Clague, 1981). The buildup of Late Wisconsinan ice was such that glaciers from the Coast Mountains reached Strait of Georgia opposite Vancouver Island about 18.5 ka (Clague et al., 1980). As the glaciers advanced from the Coast Mountains, and probably also from Vancouver Island (Fyles, 1963a), the Strait was filled with ice and a major ice lobe advanced southward to its terminus near Seattle about 14.5 ka (Mullineaux et al., 1965; Crandell, 1965). In addition, an ice lobe pushed westward into Juan de Fuca Strait, and mainland ice overflowed Strait of Georgia and moved southwestward across Vancouver Island to reach its maximum westward extent on the island after 16 ka (Clague et al., 1980).

It is probable that the process and timing of Late Wisconsinan glacier development farther north, in Hecate Strait, were somewhat similar to those in Strait of Georgia. Glaciation of the Queen Charlotte Islands bordering Hecate Strait was described by Sutherland-Brown (1968); his picture of ice movements in the northeastern Queen Charlotte Islands has been substantiated by detailed investigations at the northeastern end of the island by Clague et al. (1982). The north and north-northwest trends of ice-flow features there, associated with till of local provenance, clearly suggest that mainland ice occupied Hecate Strait during the last glaciation of the Queen Charlotte Islands. The possibility must, however, be entertained that these features predate the Late Wisconsinan because the local till overlies organic-bearing sediments that have 'greater than' radiocarbon ages and is overlain by organic-bearing sediments that suggest that deglaciation of the islands took place before 16 ka.

Northward along the coast of the Alaskan panhandle the Late Wisconsinan ice margin lies well offshore (Péwé et al., 1965) and is shown on Map 1584A as the maximum portrayal limit. Farther west in Alaska the Late Wisconsinan ice may have reached a limit near the continental shelf edge; hydrographic data suggest that ice reached this limit twice during the Late Wisconsinan at about 24 and 14 ka (T.D. Hamilton, personal communication, 1981). The earlier concepts of a Late Wisconsinan ice limit close to the present shoreline and bordered by an unglaciated shelf area (Hopkins, 1972), and of a possible ice-free enclave in Cooke Inlet and in an intermontane valley in the vicinity of 63°N, 144°W (Péwé et al., 1965; T.D. Hamilton, personal communication, 1981), have been combined to present the minimum portrayal limit of Late Wisconsinan ice. This portrayal limit corresponds well with the limit of Wisconsinan glacial ice given by Péwé (1982). Elsewhere in Alaska the Late Wisconsinan ice limits are as supplied by T.D Hamilton (personal communication, 1981).

The terminal position of the last ice sheet in western Yukon Territory is taken from Bostock (1966), Vernon and Hughes (1966), Hughes et al. (1969), and Rampton (1971). The ice retreated from this limit about 13.5 ka. Extending this limit to the north and east into the Northwest Territories, based on elevational control, leaves a re-entrant between Cordilleran and Laurentide ice of only some 50 to 100 km (Prest, 1969). This is shown as the maximum portrayal limit. Less extensive Cordilleran ice and a much broader re-entrant have been shown by Rutter (1981; this volume). This eastern limit of Cordilleran ice appears to be the equivalent of the "Wisconsin (last or classical) glaciation" limit shown on the Glacial Map of Canada (Prest et al., 1968). Gabrielse et al. (1973), however, have shown that the Cordilleran Ice Sheet was more extensive than previously conceived, and a new ice border is therefore shown on Map 1584A.

Queen Elizabeth Islands Glacier Complex

Blake (1970) used the term Innuitian Ice Sheet for an ice mass that covered the Arctic Islands and was contiguous with both Laurentide and Greenland ice. He regarded the Innuitian Ice Sheet as Wisconsinan in age and this was shown on the Glacial Map of Canada (Prest et al., 1968). Recent studies on some of the islands indicate that Late Wisconsinan ice on the Queen Elizabeth Islands was greatly restricted (England, 1976; England et al., 1981; D.A. Hodgson, personal communication, 1982). On northeastern Ellesmere Island the Late Wisconsinan ice was at its maximum extent from about 11 to 8 ka (J. England and J. Bednarski, personal communication, 1982). Shells from higher and more extensive marine terraces, above and beyond the 11 ka terminus, have yielded some older but finite ^{14}C ages, and subsequent amino acid ratios further suggest the terraces are pre-Late Wisconsinan. As a consequence of this work it is felt that the Innuitian Ice Sheet was not Late Wisconsinan and because an alternative maximum portrayal limit is not available for this area, only a minimum portrayal limit is shown.

The Late Wisconsinan ice limit on western Ellesmere and northernmost Devon islands at 9 ka is from D.A. Hodgson (personal communication, 1981). Elsewhere to the west, the ice masses as shown are mainly interpretations made on the basis of scattered data in published and unpublished reports and from discussions with numerous arctic investigators.

The all-time ice limit is deduced from Pelletier (1966).

ACKNOWLEDGMENTS

The author would like to thank all those who through discussion and correspondence have contributed to this report and the accompanying map. Many direct contributions are acknowledged in the text as personal communications. The following list gives the affiliations of personal communication contributors who are not with the Geological Survey of Canada.

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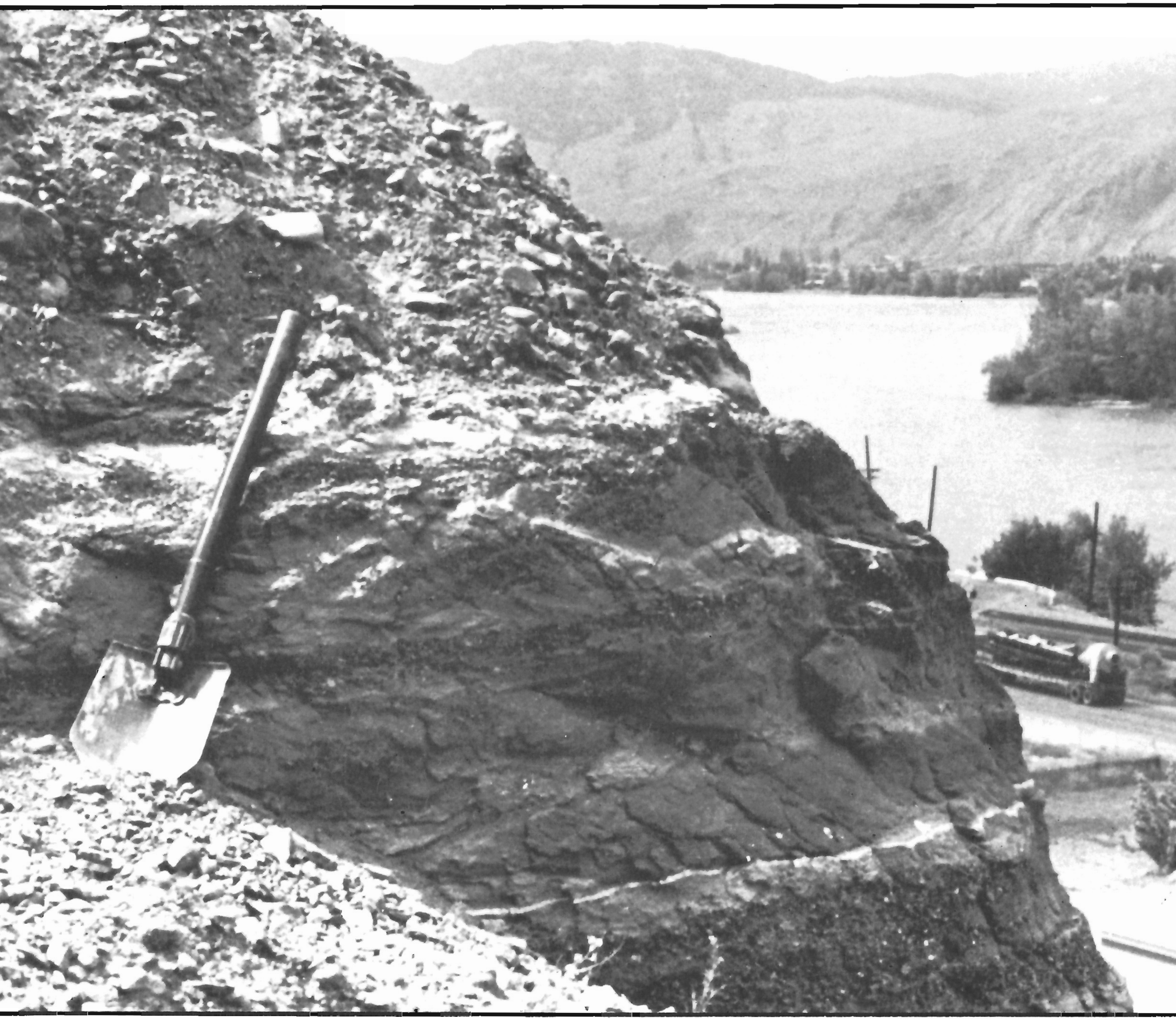
WESTERN CANADA



Kamloops, south-central British Columbia: Gravel containing approximately 1 m of sand which has thin, white tephra units near its base and top. The upper volcanic ash, named Duncan Lake tephra, is about 34 ka old. Photo and stratigraphy by R.J. Fulton, GSC 203193-R.

QUATERNARY GLACIATION, CANADIAN CORDILLERA

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Fulton, R.J., Quaternary glaciation, Canadian Cordillera; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 39-48, 1984.

Abstract

Evidence exists for at least four Quaternary glaciations in the Canadian Cordillera. Other glaciations undoubtedly occurred but these have not yet been stratigraphically documented. During the last major ice advance all of the Cordillera, with the exception of the extreme north and scattered small nunataks, was ice covered. Little information exists, however, on the extent of ice cover during earlier glaciations.

Evidence is present for two main nonglacial periods. The oldest appears to have been warmer than present and is correlated with the last main interglaciation (Sangamon-Eemian). The younger period, which occurred between the last two major ice advances, is well documented and was a time when the climate was almost as warm as that at present. Radiocarbon dating indicates that this event began earlier than the limit of radiocarbon dating and ended by 20-25 ka.

The cooling in advance of the last major ice buildup began at least 25 ka ago, but the Cordilleran Ice Sheet did not reach maximum coverage in Canada until after 17 ka. Ice retreat had begun by 13 ka and was nearly complete 3 ka later. It is not possible at present to subdivide the last glaciation into stades and interstades that can be correlated throughout the region.

Early Holocene climate was warm and appears to have not cooled to present levels until after the Hypsithermal. Well documented ice advances occurred between 3 and 2.2 ka ago but in most places the alpine glaciers did not expand to their Holocene maximum positions until the past few centuries.

Résumé

On possède des indices d'au moins quatre glaciations quaternaires dans la Cordillère canadienne. Il y en a eu certainement d'autres, mais les études stratigraphiques entreprises n'ont pas encore réussi à démontrer leur existence. Pendant la dernière avancée glaciaire d'importance, la totalité de la Cordillère, à l'exception de l'extrême nord et de petits nunataks dispersés, était couverte de glace. On possède peu de renseignements, toutefois, sur l'étendue du manteau glaciaire au cours des glaciations antérieures.

La région porte les traces de deux principales périodes non glaciaires. La plus ancienne, qui était apparemment plus chaude que le climat actuel, est mise en corrélation avec le dernier grand interglaciaire (du Sangamon à l'Eemien). La plus récente, qui sépare les deux dernières avancées d'importance, a laissé des traces abondantes; le climat y était presque aussi chaud qu'aujourd'hui. La datation au carbone radioactif indique que cet événement a débuté à une époque hors de la portée de la méthode actuelle, et a pris fin il y a entre 20 et 25 ka.

Le refroidissement ayant précédé la dernière progression glaciaire d'importance a commencé il y a au moins 25 ka, mais le glacier de la Cordillère n'a connu son maximum d'extension au Canada qu'il y a moins de 17 ka. Le recul du front glaciaire date d'environ 13 ka et était presque achevé 3 ka plus tard. Il n'est pas possible, pour l'instant, de subdiviser la dernière glaciation en stades et en interstades pouvant être corrélés à travers toute la région.

Le climat était chaud au début de l'Holocène et ne s'est apparemment refroidi jusqu'aux degrés actuels qu'après l'Hypsithermal. Des avancées glaciaires abondamment documentées ont eu lieu entre 2,2 et 3 ka mais, presque partout, les glaciers de type alpin n'ont atteint leur maximum d'extension holocène que depuis quelques siècles.

INTRODUCTION

This is the final report on the Canadian Cordillera prepared as a contribution to the Canadian Work Group of IGCP Project 24, Quaternary Glaciations in the Northern Hemisphere. It covers the Cordillera from the United States Border north to the limit of continental-style glaciation and from the Pacific coast to the Rocky Mountains. The Quaternary of the Rocky Mountains and of the unglaciated area of the northern Cordillera is the subject of a separate report (Rutter, this volume).

The Canadian Cordillera consists predominantly of mountain ranges but includes extensive plateaus, plains, and basins. Quaternary studies have been conducted at widely separated points, access to much of the area is difficult, developments which might provide exposures are few and far between, and consequently our knowledge is fragmentary. We know that the area included in this report, with the possible exception of local nunataks, has been glaciated during the Quaternary and that locally evidence exists for as many as four glaciations. In general, however, most of our information relates only to the last major ice advance and the time falling within the limit of radiocarbon dating.

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Manuscript received: 1981-11-26
Final version approved for publication: 1982-07-15

Table 1. Radiocarbon dates used in this report

Lab. No.	Date	Material	Reference	Lab. No.	Date	Material	Reference
GSC-948	2250 ± 130	peat	Fulton, 1971	GSC-2344	18 700 ± 170	wood	Hicock and Armstrong, 1981
GSC-938	2940 ± 130	peat	Fulton, 1971	GSC-913	19 100 ± 240	plant fibres	Fulton and Smith, 1978
Y-140 bis	5260 ± 200	wood	Clague, 1980	GSC-194	21 500 ± 300	wood	Dyck et al., 1965
GSC-1069	7470 ± 140	wood	Rutter, 1976	GSC-2416	21 700 ± 130	wood	Hicock and Armstrong, 1981
GSC-1993	7640 ± 80	wood	Clague, 1980	GSC-84	22 600 ± 300	plant fibres	Clague, 1976
GSC-1390	9120 ± 540	charcoal	van Ryswyk, 1971	GSC-2273	25 800 ± 310	wood	Armstrong and Clague, 1977
GSC-1497	9280 ± 200	bone	Rutter, 1976	GSC-2859	25 800 ± 320	tusk	Lowdon and Blake, 1979
GSC-939	9510 ± 160	peat	Fulton, 1971	GSC-573	25 940 ± 380	plant material	Rutter, 1976
GSC-1753	10 000 ± 160	wood	Lowdon and Blake, 1979	GSC-95	28 800 ± 740	wood	Clague, 1976
GSC-1012	10 100 ± 150	wood	Lowdon and Blake, 1976	I-933	29 010 ± 920	wood	Alley, 1979
GSC-909	11 000 ± 180	marl	Lowdon and Blake, 1970	Y-1385	30 100 ± 600	organic matter	Denton and Stuiver, 1967
GSC-2523	11 300 ± 100	wood	Lowdon and Blake, 1978	GSC-1754	34 000 ± 690	bone	Harington et al., 1974
I-2244A	11 600 ± 1000	tusk	Rutter, 1976	Y-1356	37 700 $\pm^{1500}_{1300}$	organic matter	Denton and Stuiver, 1967
Y-1386	12 500 ± 200	organic matter	Denton and Stuiver, 1967	GSC-2167	40 500 ± 1700	wood	Armstrong and Clague, 1977
GSC-2290	12 700 ± 120	shells	Lowdon and Blake, 1979	GSC-740	43 800 ± 800	wood	Fulton, 1968
GSC-2193	12 900 ± 170	shells	Lowdon et al., 1977	GSC-1687	43 800 ± 1830	wood	Harington et al., 1974
GSC-495	13 660 ± 180	organic silt	Rampton, 1971	QL-195	58 800 $\pm^{2900}_{2100}$	wood	Armstrong and Clague, 1977
GSC-3222	13 700 ± 100	moss	Clague, 1981	GSC-960	>38 000	peat	Rampton, 1971
GSC-2768	16 700 ± 150	wood	Clague et al., 1980	GSC-552	>42 000	organic silt	Rampton, 1971
I-10022	17 240 ± 300	wood	Clague et al., 1980	Y-1486	>49 000	peat	Denton and Stuiver, 1967
GSC-2297	17 800 ± 150	wood	Clague et al., 1980	QL-194	>62 000	wood	Lowdon and Blake, 1978

Terminology for Quaternary deposits in the Canadian Cordillera has not been used uniformly, few stratigraphic units have been formally defined, and the "informal" terminology is, in several cases, ambiguous. The last major ice advance has generally been referred to as a "glaciation" (e.g. Fraser Glaciation), but in reality it is a stade of the last global glacial stage. The nonglacial period that preceded the last major ice advance originally was referred to as an "interglacial" (Olympia Interglaciation), but in world climate terms it is an interstade. In most cases the stratigraphic successions have been subdivided into "drift" -- sediments deposited during glaciation – and "sediments" -- materials laid down under nonglacial conditions. In other cases, however, material and stratigraphic units have not been mentioned and authors have only referred to glacial "advances". Rather than try to redefine the Quaternary units in this report, the original terminology has been used.

Radiocarbon dates used in this report are listed in Table 1. The reader is referred to Clague (1980) for a complete list of geologically relevant radiocarbon dates for British Columbia. All ages are given in radiocarbon years.

This report discusses the local Quaternary stratigraphy of five regions of the Canadian Cordillera. Correlations within the regions are relatively straight-forward but correlations between the regions are speculative, especially for deposits beyond the radiocarbon dating limit. This work draws heavily on earlier regional correlations of this type (Fulton, 1971, 1976; Clague 1981).

Acknowledgments

The author is indebted to N.F. Alley, Mines and Energy, South Australia; J.E. Armstrong and J.J. Clague, Geological Survey of Canada, Vancouver; S.R. Hicock, University of Western Ontario, London; V.N. Rampton, Terrain Analysis and Mapping Services Ltd., Carp, Ontario; and N.W. Rutter, University of Alberta, Edmonton, all of whom, as part of a loosely organized working group, discussed correlations and made available unpublished information.

SOUTH COASTAL BRITISH COLUMBIA

The south coastal region of British Columbia (Fraser Lowland – Strait of Georgia area, Fig. 1) contains both the most extensive and most intensively studied Quaternary deposits of the Canadian Cordillera. Summaries of the Quaternary record of this area are available in Fyles (1963), Clague (1976), Armstrong and Hicock (1976), Hicock (1980), Armstrong (1981), Clague (1981), and Hicock and Armstrong (1983).

Unstudied glacial and nonglacial sediments have been encountered in drillholes in the Fraser Lowland. Armstrong (1975) reported the occurrence of as much as 95 m of this material underlying his oldest named unit (Westlynn Drift). These materials have not been fitted into the Quaternary stratigraphic framework.

The oldest named Quaternary unit is Westlynn Drift. This consists of till, glaciomarine deposits and associated gravel and sand, and rhythmically bedded silt and clay. It outcrops in only a few places and has not been extensively studied. It predates the last interglaciation (Sangamon-Eemian) but has no recognized distinctive diagnostic features. Consequently, it can only be recognized where the stratigraphy of the overlying materials is clear.

Muir Point Formation (Hicock, 1980; Hicock and Armstrong, 1983) and Highbury Sediments (Armstrong, 1975) are nonglacial sediments in south coastal British Columbia which are thought to have been deposited during the last interglaciation (Fig. 2). They consist of gravel, sand, and silt

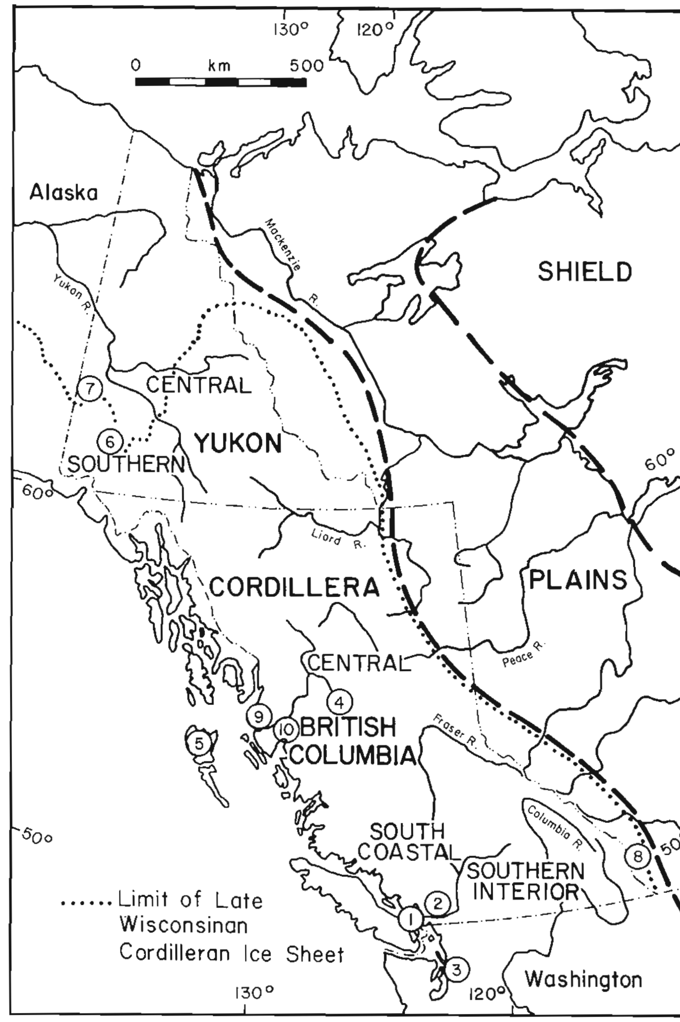

Figure 1. Location map of the Canadian Cordillera: (1) Strait of Georgia, (2) Fraser Lowland, (3) Puget Lowland, (4) Babine Lake, (5) Queen Charlotte Islands, (6) Kluane Lake, (7) Snag-Klutlan area, (8) southern Rocky Mountain Foothills, (9) Prince Rupert, and (10) Kitimat-Terrace area.

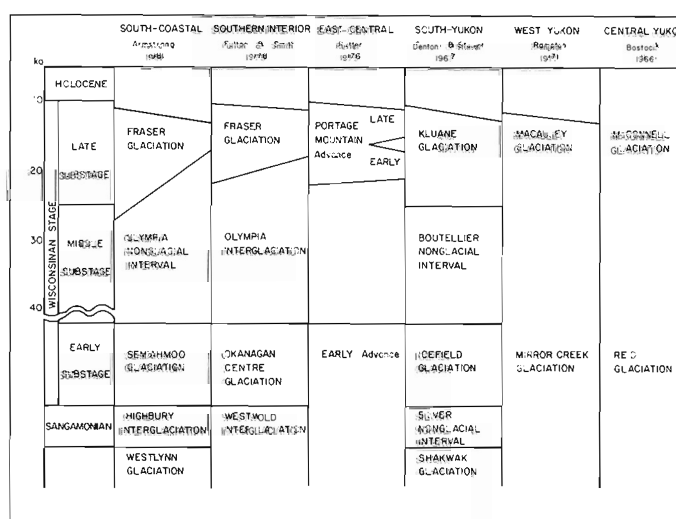

Figure 2. Correlation chart for Cordilleran regions discussed in this report.

containing organic remains and peat, which were deposited under fluvial and locally marine conditions. Muir Point Formation contains a relatively high abundance of thermophyllous pollen compared to overlying Wisconsinan age sediments (Hicock, 1980; Hicock and Armstrong, 1983), suggesting interglacial rather than interstadial deposition.

The glacial deposits overlying Muir Point Formation and Highbury Sediments are referred to as Dashwood Drift (Fyles, 1963; Hicock, 1980; Hicock and Armstrong, 1983) and Semiahmoo Drift (Armstrong, 1975). These consist of a complex mixture of lodgment till, glaciofluvial sand and gravel, rhythmically bedded silt and clay, and marine and glaciomarine silt, stony clay, and diamicton. All samples radiocarbon dated from this unit have had ages beyond the limit of this dating method with the oldest number obtained being >62 000 BP (QL-194)[1]. This unit is considered to have formed during a period when ice completely covered the area and a period of marine submergence which occurred immediately following deglaciation.

Cowichan Head Formation is the name given to the nonglacial sediments deposited on Dashwood-Semiahmoo Drift. It consists of silt, sand, and gravel containing organic remains and peat which was deposited in fluvial, estuarine, and marine environments (Armstrong and Clague, 1977). Radiocarbon dates on wood from this unit range from 25 800 ± 310 BP (GSC-2273) to 40 500 ± 1700 BP (GSC-2167) and are possibly as old as 58 800 ± $^{2900}_{2100}$ BP (QL-195). Cowichan Head Formation is interpreted as having been deposited during an interstade (Olympia Interglaciation of Armstrong et al., 1965) characterized by a climate that was generally slightly cooler and more moist than present, but which at times was as warm as at present (Alley, 1979).

Cowichan Head Formation is commonly overlain by Quadra Formation which generally consists of extensively crossbedded white sands with scarce organic material. This unit is distal outwash which was deposited during climatic deterioration which preceded the advance of the last ice sheet (Clague, 1976). Consequently, the base of the unit is diachronous, with material as old as 28 800 ± 740 BP (GSC-95) in the northern part of the south coastal area and as young as 22 600 ± 300 BP (GSC-84) from the southern end. A local till unit, interpreted as resulting from an alpine advance, lies within sand correlated with Quadra Formation in one valley north of Vancouver. This is referred to as Coquitlam Drift (Hicock and Armstrong, 1981) and was deposited between 21 700 ± 130 BP (GSC-2416) and 18 700 ± 170 BP (GSC-2344). Vashon Drift (Fyles, 1963) is the direct glacial deposit laid down by the last major ice sheet to occupy the south coastal area. This major ice sheet appears to have been advancing into the Vancouver area by 17 800 ± 150 BP (GSC-2297) and had not covered the south coast of Vancouver Island by 16 700 ± 150 BP (GSC-2768; Clague et al., 1980). It reached its maximum position in Puget Lowland, 250 km south of the area, by about 15 ka (Mullineaux et al., 1965) and had retreated so that the sea could invade the Strait of Georgia by 12 900 ± 170 BP (GSC-2193). During retreat of the last ice sheet from south-central British Columbia, stony marine and glaciomarine clay, till, and glaciofluvial deposits were laid down. The stony clays and other marine deposits that formed beyond the retreating ice margin are referred to as Capilano Sediments; the interbedded glaciomarine and glacial sediments that formed in the zone characterized by fluctuating ice margins are referred to as Fort Langley Formation; and the till and glaciofluvial materials overlying Fort Langley Formation and representing the final readvance are referred to as Sumas Drift (Armstrong, 1981). Sumas Drift was deposited about 11 300 ± 100 BP (GSC-2523) with rapid retreat occurring soon after this time so that the Fraser Lowland was probably free of ice by 11 ka (Clague, 1981).

SOUTHERN INTERIOR BRITISH COLUMBIA

The oldest Quaternary deposits fitted into the stratigraphic succession in the southern interior of British Columbia are nonglacial materials referred to as Westwold Sediments (Fulton and Smith, 1978) which predate two sets of glacial deposits (Fig. 2). These materials are exposed in only a few places and consist of fluvial sands and gravels but include minor lacustrine material. Because of their stratigraphic position and content of fossils suggesting a climate as warm as present, these deposits were likely formed during the last interglaciation (Sangamon-Eemian), but possible cold climate indicators near the top of the unit suggest that deposition continued into the period of cooler climate which followed the main interglacial warm period.

The glacial deposits that overlie Westwold Sediments have been named Okanagan Centre Drift (Fulton and Smith, 1978). They consist of till, glaciofluvial sands and gravels, and lacustrine sediments.

Bessette Sediments (Smith, 1969) were deposited throughout the southern interior during a major nonglacial period which preceded the last major ice advance. They are predominantly sand and gravel but locally consist of fine grained sediments and peat and contain disseminated organic material. The oldest radiocarbon date obtained on Bessette material is 43 800 ± 800 BP (GSC-740). Deposition ended when the last ice sheet overrode the area, an event that occurred after 21 500 ± 300 BP (GSC-194) at 52°N, after 19 100 ± 240 BP (GSC-913) at 50°N, and after 17 240 ± 300 BP (I-10022) at 49°N. The climate of the southern interior was warmer and drier than present about 40 ka, was similar to present about 30 ka, began cooling to near glacial conditions 25 ka, ameliorated briefly about 20 ka ago, and then cooled to glacial conditions (N.F. Alley, personal communication, 1979).

The last ice sheet to occupy the southern interior of British Columbia deposited till and glaciofluvial and glaciolacustrine sediments referred to as Kamloops Lake Drift (Fulton, 1975). This glacial period undoubtedly began with a buildup of ice in the mountains, followed by development of piedmont glaciers which then coalesced to form an ice sheet. Hard data on the chronology of early alpine advances have not been found. As mentioned above, climatic deterioration leading to development of the ice sheet was apparent by 25 ka but the area was not completely overridden until after 17 240 ± 300 BP (I-10022). The Cordilleran Ice Sheet had, however, reached its maximum position in northern Washington and was in the process of retreating by 13 ka – the time of the last Lake Missoula flood (Mullineaux et al., 1978). The ice sheet appears for the most part to have retreated in an orderly manner without widespread stillstands or readvances. In the Rocky Mountain Trench, however, Clague (1975) found evidence for three stades and two interstades, and in the Trail-Castlegar area, extensive kame terrace deposits suggest a significant stillstand during the final stages of retreat. The oldest postglacial dates in the area are 11 000 ± 180 BP (GSC-909) on marl from 49°30'N, 10 100 ± 150 BP (GSC-1012) on wood from 50°N, and 10 000 ± 160 BP (GSC-1753) on wood from 51°N. A date of 9510 ± 160 BP (GSC-939) on material from the bottom of a bog adjacent to a modern glacier in the Coast Mountains suggests that most of the southern interior was free of ice by this time.

Early Holocene climate appears to have been as warm as, if not warmer than, that at present. This is indicated by a radiocarbon date of 9120 ± 540 BP (GSC-1390) on charcoal collected above present treeline near 49°N. Alley (1976) has shown that the climate between 8.4 and 6.6 ka in Okanagan valley was warmer and drier than that at present. In addition, wood from beneath snow, ice, or glacial deposits at widely scattered localities, ranging in age from

[1] Radiocarbon dates are listed in Table 1.

7640 ± 80 BP (GSC-1993) to 5260 ± 200 BP (Y-140 bis), also indicates warmer than present middle Holocene conditions. Cooler, more moist climate followed this general early and middle Holocene warm period and resulted in an advance of Tiedemann Glacier between 2940 ± 130 BP (GSC-938) and 2250 ± 130 BP (GSC-948) (Fulton, 1971). In general, however, it appears that the coolest, wettest Holocene climate occurred during the last few centuries because this is the time when most alpine glaciers in the southern Cordillera reached their Holocene maxima (Clague, 1981).

CENTRAL BRITISH COLUMBIA

Little Quaternary stratigraphic information is available for central British Columbia; this is because the area is heavily forested, access to large parts of the area is difficult, and conducting field work is expensive and arduous. The best information available comes from the eastern part of the area where Quaternary studies were carried out during development of a hydroelectric project. Rutter (1976) recorded evidence of four glacial advances and two nonglacial intervals. The oldest deposits are nonglacial and because of their "interglacial" character might correlate with the Sangamonian. This unnamed unit consists of fluvial sands and gravel that have been strongly oxidized and contain wood fragments and blocks of peat and marl.

The oldest glacial unit – "early advance till" (Rutter, 1976; Fig. 2) – overlies the "interglacial" deposits and is thought to be overlain by sand containing organic material which has been dated 25 940 ± 380 BP (GSC-573). This advance is considered to have completely covered the area, but outside of knowing that ice retreat was sufficient to permit plants to invade the area, the significance of the following nonglacial period is not known.

The glaciation that followed is referred to as the Portage Mountain advance (Rutter, 1976). It resulted in the deposition of two tills separated by glaciofluvial sand and lacustrine silt. The early and more extensive advance occurred after 25 940 ± 380 BP (GSC-573) and the late advance ended by 11 600 ± 1000 BP (I-2244A); however, the validity of this last date has been questioned and a rerun has given an age of 25 800 ± 320 BP (GSC-2859). According to Rutter (1976), a later minor advance (Deserter's Canyon) occurred after 9280 ± 200 BP (GSC-1497) but the ice had retreated by 7470 ± 140 BP (GSC-1069). Luckman and Osborn (1979, p. 72) pointed out that the above mentioned limiting dates are not directly associated with glacial deposits and, because a relatively major advance at this time conflicts with events in adjacent areas, questioned whether this might in fact be a pre-Holocene event.

Little Quaternary stratigraphic information is available for central British Columbia west of the Rocky Mountain Trench. Organic-rich silts from below a single till in the Babine Lake area (4 of Fig. 1) have yielded dates of 43 800 ± 1830 BP (GSC-1687, on wood) and 34 000 ± 690 BP (GSC-1754, on bone). The reason for the difference between the two dates is not known but if it represents real time then the first age could date the sediment and the second the time at which the mammoth became mired. This would indicate that this part of the Cordillera was not covered by ice between about 44 and 34 ka. A shrub tundra pollen assemblage is indicated by one sample from this locality (Harington et al., 1974) but further work is necessary before any conclusions can be drawn.

Until recently deposits older than Late Wisconsinan were unknown in coastal British Columbia north of Vancouver Island. Warner et al. (in press) reported on a peat bed between tills on Queen Charlotte Islands that is dated 45 700 ± 900 BP (GSC-3534-1) at the bottom and 27 500 ± 400 BP (GSC-3530) at the top. Climate at the time of deposition was wetter and 1-2°C cooler than at present. This occurrence indicates that Late Wisconsinan ice advanced from the mountains of Queen Charlotte Islands after 27.5 ka. Warner et al. (1982) indicated that the area east of the mountains on Graham Island (largest of the Queen Charlotte Islands) was deglaciated before 16 000 ± 570 BP (GSC-3370).

Other dates related to deglaciation indicate that ice had retreated from lowland areas of Queen Charlotte Islands by 13 700 ± 100 BP (GSC-3222), from the mainland coast at Prince Rupert by 12 700 ± 120 BP (GSC-2290), and from the fiord between Terrace and Kitimat by 11-10.5 ka (Clague, 1981; Fig. 1).

SOUTHERN AND CENTRAL YUKON

Three glacial and two nonglacial periods are recognized in the pre-Holocene Quaternary record of southwestern Yukon (Denton and Stuiver, 1967; Fig. 2). The oldest unit, Shakwak Drift, consists of thick till and outwash which were oxidized during the following nonglacial period. No deposits have yet been related to this nonglacial episode but the period during which alteration of Shakwak Drift occurred has been referred to as the Silver Nonglacial Interval. The unconformity at the top of Shakwak Drift is overlain by till, outwash, and lacustrine sediments referred to as Icefield Drift. Organic material from the lower part of Icefield Drift is beyond the limit of radiocarbon dating (>49 000 BP, Y-1486). Organic material from silt said to be contained within the upper unit of Icefield Drift has been dated as 37 700 $^{+1500}_{-1300}$ BP (Y-1356) and 30 100 ± 600 BP (Y-1385). These dates are used to define the start of the Boutellier Nonglacial Interval which was responsible for the retreat of Icefield glaciers. Denton and Stuiver (1967) suggested that nonglacial conditions persisted for several thousand years based on the degree of dissection and weathering of Icefield deposits. Kluane Drift overlies Icefield Drift and is the material laid down during the last major ice advance which in this area occurred after 30 100 ± 600 BP (Y-1385); by 12 500 ± 200 BP (Y-1386) the ice had begun to retreat. Kluane Drift consists of at least three separate till units and interbedded outwash and lacustrine sediments, but the stratigraphic succession is likely due to dominance of ice from different source valleys at different times rather than to glacial stades and interstades (Denton and Stuiver, 1967).

Rampton (1971), working in the Snag-Klutlan area, 150 km northwest of the region reported on by Denton and Stuiver, found glacial deposits of two ages but no evidence of an intervening period of weathering (Fig. 2). Deposits of his oldest glaciation – Mirror Creek – are overlain by sediments containing organic material beyond the limit of radiocarbon dating (>38 000 BP, GSC-960). Lack of deep weathering profiles on deposits of Mirror Creek Glaciation, however, led Rampton to suggest that they are Early Wisconsinan in age. Ice of the last glaciation in the Snag-Klutlan area – the Macauley – was receding from its maximum position about 13 660 ± 180 BP (GSC-495). Consequently, it in part correlates with the Kluane Glaciation of Denton and Stuiver (1967). Rampton could find no evidence of a major retreat of Macauley ice which would have corresponded to Denton and Stuiver's Boutellier Nonglacial Interval. It is possible that major deglaciation occurred but the evidence has not been found. In addition, organic material from sediments underlying and in basal parts of Macauley Drift are beyond the limit of radiocarbon dating (e.g., >42 000 BP, GSC-552) suggesting that the lower part of Macauley Drift is older than Kluane Drift. Thus it appears that Macauley ice did not retreat significantly in this area during the Boutellier warm period. A possible explanation is that the source of glaciers in Rampton's area was farther removed from the maritime influence of the Pacific than that of Denton and Stuiver's and consequently would have been less sensitive to climatic changes.

Retreat from the glacial maximum in both south Kluane Lake and Snag-Klutlan areas was rapid (Rampton, 1971, p. 295; Denton and Stuiver, 1967, p. 503). Conditions were not again conducive to general ice advance until neoglacial advances between 2.9 and 2.1 ka and a second general period of Holocene glacial advance which occurred during the last several centuries (Denton and Karlén, 1977).

Other studies of glacial limits in the central Yukon show similar chronologies. Hughes et al. (1972) referred to the Macauley and Kluane advances of southern and western Yukon as main Wisconsinan and correlated these with the McConnell (Bostock, 1966; Fig. 2) and the "last" glaciation (Vernon and Hughes, 1966) of central Yukon. They correlated the Mirror Creek and Shakwak glaciations of southern and western Yukon with the Reid (Bostock, 1966) and "intermediate" (Vernon and Hughes, 1966) glaciations of central Yukon; they did not, however, conclude whether these advances are Early Wisconsinan or pre-Sangamonian in age.

CORRELATIONS

The interregional correlations discussed in this report are illustrated in Figure 2. Figure 3 shows possible correlations with Quaternary chronologies from adjacent areas. The correlations are relatively straightforward for that part of the Quaternary controlled by radiocarbon dating but correlation of the older units has largely been accomplished by "finger matching".

Puget Lowland

Easterbrook's (1976) most recent chronology for the late Pleistocene of Puget Lowland and Olympic Peninsula is shown in column 2 of Figure 3. In general this stratigraphy matches well with that of the south coastal region, and Quaternary deposits of Puget Lowland can essentially be traced directly into those of the Fraser Lowland – Strait of Georgia area. There is, however, one exception – the Possession Drift (Hansen and Easterbrook, 1974) which is used to define the Oak Harbor Stade of Easterbrook (1976). This unit has not been recognized in the Canadian Cordillera. It has been argued (Fulton et al., 1976) that if this deposit is the product of a regional scale glaciation, the depositing ice had to move from the north and if this had occurred, glacial deposits of this age would be preserved in Canada. None, however, are present, so consequently it has been suggested that Possession "Drift" must be of an origin other than glacial. Easterbrook has used a climatic model based on palynological information from the west (unglaciated) side of the Olympic Peninsula (Easterbrook, 1976) to back up his stratigraphic interpretation. The validity of this climatic argument has been questioned on the grounds that even though Middle Wisconsinan climate in the area was cooler than that at present, the intense cool periods were not of sufficient duration to lead to a Cordilleran Ice Sheet (Clague, 1978).

Southern Rocky Mountain Foothills

Direct stratigraphic correlation between south-central British Columbia and the southern Foothills of Alberta is not possible. Alley (1973) and Stalker and Harrison (1977) have devised chronologies which they correlate with the standard Quaternary time scale and consequently which can be matched with the chronology of the southern Cordillera (column 3, Fig. 3).

Alaska

Hughes et al. (1972) have made tentative correlations of Yukon Quaternary chronologies with those of Alaska (Péwé et al., 1965). These are based on the similarity of glacial morphology as modified by postdepositional processes and the relative positions of moraines with respect to centres of glacial accumulation. They correlated the deposits of the last glaciation in the Yukon – the Macauley, Kluane, and McConnell – with the last glaciation in the Alaska ranges – the Donnelly (column 4, Fig. 3). Reid, Mirror Creek, and Shakwak glaciations are tentatively correlated with Delta Glaciation. Recent work (Weber et al., 1981) in the Fairbanks area of Alaska, has turned up evidence that Delta Glaciation is not of pre-Sangamonian age as was suggested by Péwé et al. (1965; column 4, Fig. 3). This gives added weight to Rampton's suggestion that Mirror Creek Glaciation was not pre-Sangamonian.

Southern Ontario

Far more detail is available for the Quaternary stratigraphy of the Great Lakes – St. Lawrence Lowland region (Dreimanis and Karrow, 1972) than for most parts of the Canadian Cordillera. However, even in the Strait of Georgia – Fraser Lowland region, where considerable detail is available, it is not possible to make detailed stade and interstade correlations with the Great Lakes record. At the level of substages, however, there is fairly good correspondence between the Quaternary chronology of the Great Lakes area and that of all regions of the Cordillera (column 5, Fig. 3).

SUMMARY

Most parts of the Canadian Cordillera show elements of a common series of Quaternary events. Evidence for the oldest of these is too fragmentary to fit into the Quaternary time scale but it is known that several glaciations and interglaciations occurred before the last main interglaciation (Sangamon-Eemian). Deposits and other evidence of the last major interglaciation are not common; these have been assigned to named units in the south coastal region (Highbury), southern interior (Westwold), and Yukon Territory (Silver). The penultimate glaciation has been named in three areas: south coastal region (Semiahmoo), southern interior (Okanagan Centre), and Yukon Territory (Icefield). During

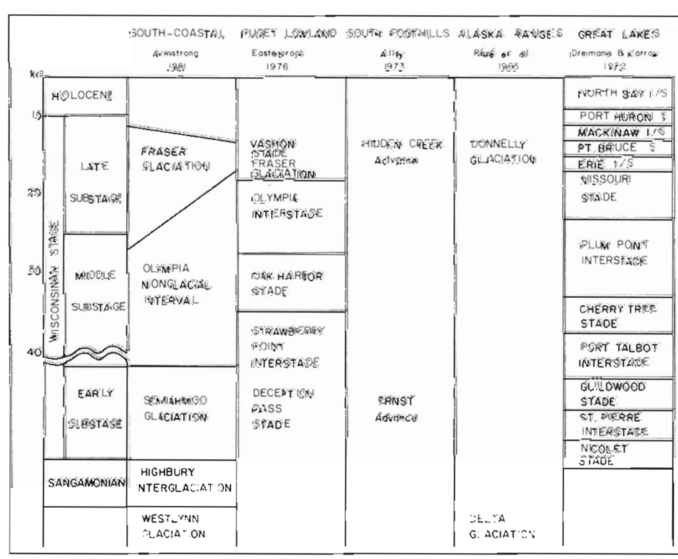

Figure 3. Correlation between late Quaternary units of the Cordillera and those of adjacent areas.

the nonglacial period separating the last two main ice advances, the Canadian Cordillera was largely free of ice from before the limit of radiocarbon dating until 20-25 ka ago. Deposits or evidence of this significant period are widely scattered and the time period has been named Olympia Nonglacial Interval (southern British Columbia) and Boutellier Nonglacial Interval (Yukon). Ice buildup during the last main advance began about 25 ka throughout most of the Canadian Cordillera but maximum coverage was not attained until after 17 ka. Ice had begun to retreat by 13 ka and probably had receded to near present limits by 10 ka. During the Holocene there were major advances of alpine glaciers between about 3 and 2.2 ka and within the last several centuries.

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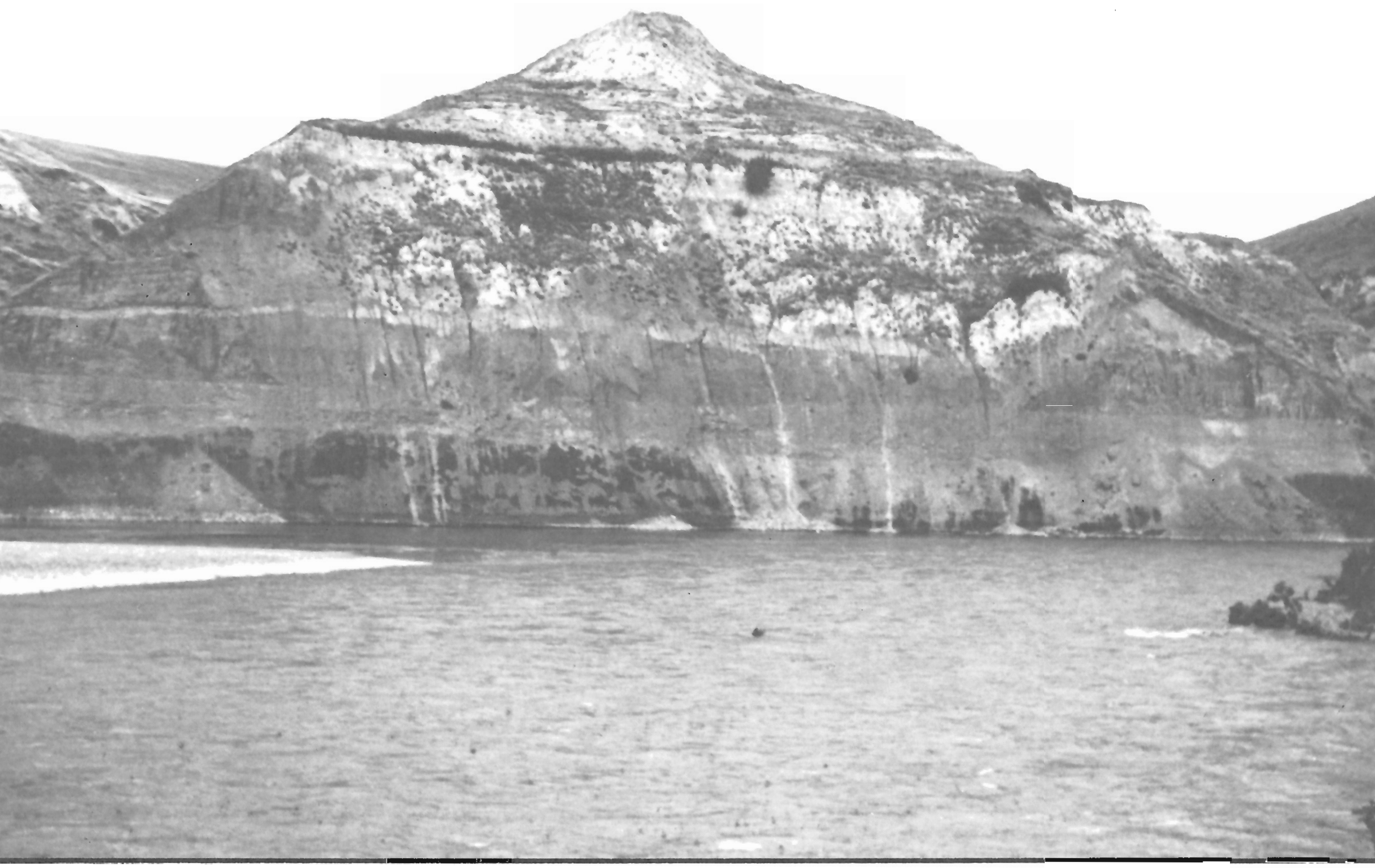

Kipp section on Oldman River, southwestern Alberta: Cretaceous shale at the base is overlain by Early Pleistocene sand and gravel; Late Wisconsinan glacial lake clay and silt lies at the surface; at least four tills of both eastern and western provenance, glacially transported bedrock, and interbedded gravel and sand occupy the central part of the succession. Photo and stratigraphy by A. MacS. Stalker, GSC 203193-Y.

PLEISTOCENE HISTORY OF THE WESTERN CANADIAN ICE-FREE CORRIDOR

N.W. Rutter [1]

Rutter, N.W., Pleistocene history of the western Canadian ice-free corridor; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 49-56, 1984.

Abstract

The ice-free corridor is a belt of land that was largely ice free during maximum Pleistocene glaciations and that extended northward from about the Canada-United States border, east of the Rocky, Mackenzie, and Richardson mountains between Cordilleran and Laurentide glaciers. The most complete record is for Wisconsinan-age events. Although other interpretations have merit, it appears that Early Wisconsinan glaciers flowed out of the mountains, coalescing with westward flowing Laurentide glaciers, at least in southwestern Alberta. In Yukon Territory and Northwest Territories, Cordilleran ice was restricted and confined within mountain valleys whereas Laurentide glaciers reached the mountain front. No Middle Wisconsinan glacier activity is recorded. During Late Wisconsinan time Laurentide glaciers advanced as far west as Lethbridge, Calgary, and Edson in southern Alberta, whereas Cordilleran glaciers terminated near the mountain front or within the major valleys. Therefore, an ice-free corridor was present from about the International Boundary to the Jasper-Hinton area. In northeastern British Columbia, Cordilleran glaciers flowed beyond the mountain front and coalesced with Laurentide ice advancing from the east. In Yukon Territory and Northwest Territories, Laurentide glaciers penetrated the Mackenzie and Richardson mountains but Cordilleran ice did not advance far down the mountain valleys, resulting in an ice-free corridor in this region.

Résumé

Au cours des maximums glaciaires du Pléistocène, il y avait, à l'est des Rocheuses, des monts Mackenzie et des chaînons Richardson, entre le glacier des Laurentides et celui de la Cordillère, une zone en grande mesure libre de glace que l'on appelle un <<couloir non glacié>> et qui s'étendait vers le nord, à partir de la frontière internationale. Les événements d'âge wisconsinien y sont les mieux représentés. Parmi les interprétations possibles, d'ailleurs toutes méritoires, les auteurs du présent rapport ont retenu celle-ci: il semble que des glaciers du Wisconsinien inférieur, à leur sortie des montagnes, se sont soudés au complexe des Laurentides, qui se dirigeait vers l'ouest, du moins dans la région sud-ouest de l'Alberta. Au Yukon et dans les Territoires du Nord-Ouest, le glacier de la Cordillère était confiné dans des vallées montagneuses, tandis que le complexe des Laurentides atteignait la montagne. On n'a pas relevé de traces d'activité glaciaire datant du Wisconsinien moyen. Durant le Wisconsinien supérieur, toutefois, le front glaciaire des Laurentides a progressé vers l'ouest, atteignant même Lethbridge, Calgary et Edson dans le sud de l'Alberta, tandis que l'inlandsis de la Cordillère était limité à la montagne ou confiné dans les grandes vallées. C'est ainsi qu'un couloir a été épargné entre les environs de la frontière internationale et la région de Jasper et Hinton. Dans le nord-est de la Colombie-Britannique, le complexe de la Cordillère a franchi le front montagneux et s'est soudé au glacier des Laurentides qui arrivait de l'est. Au Yukon et dans les Territoires du Nord-Ouest, le glacier des Laurentides a pénétré dans les monts Mackenzie et les chaînons Richardson, tandis que le glacier de la Cordillère ne progressait que très peu dans les vallées montagneuses, laissant ainsi dans la région un couloir non glacié.

INTRODUCTION

The increased number of earth scientists engaged in Quaternary investigations in Western Canada in the past few years has meant a better understanding of the relationship between Laurentide and Cordilleran glaciers during the Pleistocene. From this, it has been possible to elucidate the timing, configuration, dimensions, and duration of ice-free corridors between the two ice masses. Many problems remain however. The ice-free corridor, as defined here, is a belt of land that was largely ice free during the maximum extent of Pleistocene glaciation, and that stretched northward from about the Canada-United States border, east of the Rocky, Mackenzie, and Richardson mountains between Cordilleran and Laurentide glaciers. The purpose of the present discussion is to examine the geological and geochronological evidence for the movement of ice into this corridor during the Pleistocene. The most complete picture is for Wisconsinan-age events and, therefore, will be emphasized here. Earlier reviews of this problem were presented by Reeves (1973) and Rutter (1980). For discussion purposes, the area is divided into three parts: southwestern Alberta, from the International Boundary to the Edmonton-Jasper region; northwestern Alberta – northeastern British Columbia, from the Edmonton-Jasper region to about the Yukon Territory – Northwest Territories border; and Yukon Territory and Northwest Territories.

SOUTHWESTERN ALBERTA

Detailed Quaternary investigations in southernmost southwestern Alberta have been carried out for about fifty years (Nichols, 1931; Johnston and Wickenden, 1931; Wickenden, 1937; Bretz, 1943; Horberg, 1952, 1954). Most knowledge, however, has been accumulated during the last 25 years mainly through the work of Stalker and a few others

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Manuscript received: 1981-12-04
Final version approved for publication: 1982-07-15

(Stalker, 1963, 1969; Wagner, 1966; Alley, 1973; Alley and Harris, 1974). Recently, probably the most significant works that elucidate the probable timing and extent of ice-free conditions in late Pleistocene time are Stalker and Harrison (1977; Fig. 1) and Stalker (1977).

In southwestern Alberta, the Cordilleran record is based primarily on geomorphology and distribution of deposits, a few multiple till sections, and radiocarbon dates. In the area affected by Laurentide glaciers, multiple till sections, till characteristics, and relatively more radiocarbon dates than found in the Cordillera are the major criteria utilized in establishing the stratigraphy.

The relationship between Cordilleran and Laurentide glacial advances is fragmentary in pre-Middle Wisconsinan time. In Late Wisconsinan time, it is becoming more and more apparent that glaciation was not as extensive as previously thought (Rutter, 1980). In the discussion that follows, arguments are made that Late Wisconsinan Laurentide ice reached only to the Lethbridge area whereas Cordilleran glaciers were restricted to the mountains. This resulted in an ice-free north-south corridor from about the International Boundary to the Edmonton-Jasper area during the maximum extent of Late Wisconsinan ice (Fig. 2).

In the Waterton Lakes National Park area, Stalker and Harrison (1977) recognized evidence for extensive Cordilleran and Laurentide advances that were out of phase but overlapped in the corridor region (Fig. 1). Based on stratigraphic evidence, they have assigned an Illinoian age to this event. Evidence for later, well documented events includes three Cordilleran (Waterton II, III, and IV) and three corresponding Laurentide advances (advance that deposited the Buffalo Lake Till, Erratics Train advance, and Lethbridge advance), each less extensive than the last, and with the Cordilleran glaciers advancing previous to the corresponding Laurentide advances. Evidence for the Cordilleran advances is based principally upon breaks-in-slope and lateral moraines at various elevations on valley sides, and to a lesser extent on end moraines, surface and subsurface tills; evidence for the Laurentide advances is based mainly on characteristics of surface tills, stratigraphic sequences, and on end moraines. Brocket and Maunsell tills are shown in Figure 1 in the same way as they were by Stalker and Harrison (1977). The western extent of the Laurentide ice that deposited these tills is unknown and the possibility of the existence of equivalent Cordilleran units is indicated in Figure 1 even though such units have not been recognized.

Waterton II extended out onto the plain east of the mountain front whereas, according to Stalker and Harrison (1977), the equivalent Laurentide advance deposited till (Buffalo Lake) as far west as the mountains. Waterton III glaciers reached the mountain front and the corresponding Erratics Train advance also came near the mountain front. It should be mentioned that the distinctive boulders which make up the Erratics Train emanated from the mountains near Jasper about 500 km to the northwest (Stalker, 1956). The ice carrying this debris was incorporated into and deflected southward by Laurentide ice (Stalker and Harrison, 1977). With present information, it is not clear if Waterton II and III advances, and the advance that deposited the Buffalo Lake till and the Erratics Train advance, were separated by an interstadial. After a major withdrawal of ice, however, Waterton IV and Lethbridge advances took place. Waterton IV ice terminated well up the mountain valleys with the Lethbridge advance developing a prominent end moraine at Lethbridge short of the mountain front.

Their interpretation requires ice-free conditions east of the mountain front during the maximum extent of Waterton III and Erratics Train advances and again during the maximum extent of Waterton IV and the Lethbridge advances (Fig. 1). In the latter case, where more information is

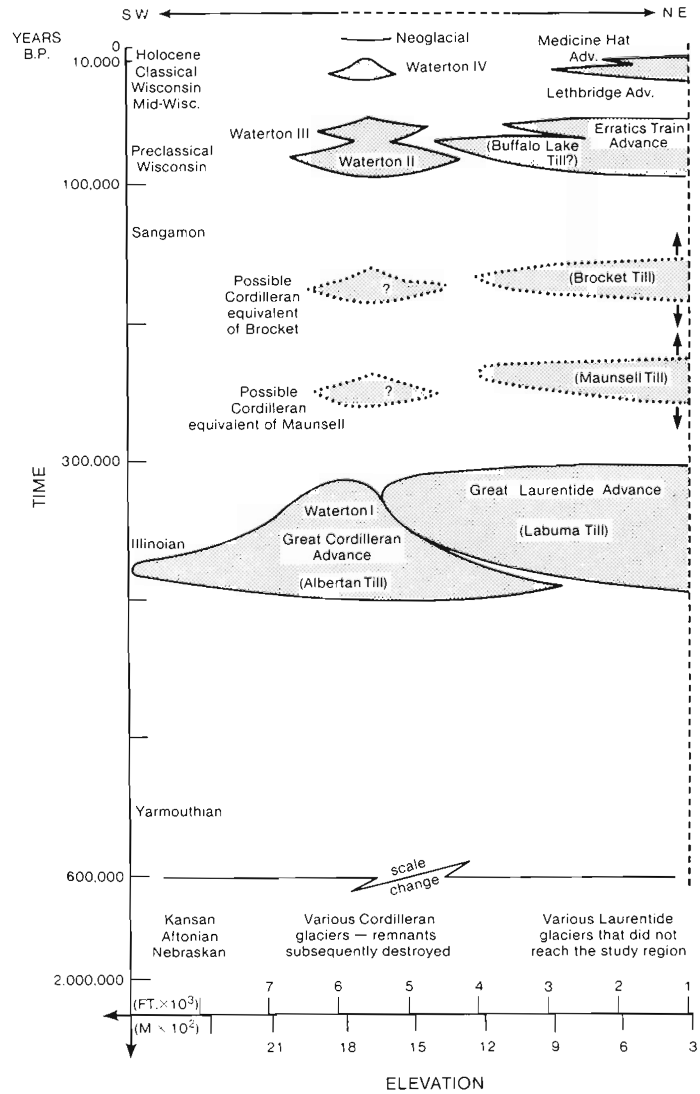

Figure 1. Glacial record of Waterton-Castle River region, showing duration, elevations, and interrelationships of its various Cordilleran and Laurentide glaciers, along with their assumed positions in the mid-continent glacial chronology (from Stalker and Harrison, 1977).

available, the questions are when and how far north did an ice-free corridor exist. The answer depends on the age and significance of the Lethbridge advance and the age of the surface till that was deposited west of the limit of the Lethbridge advance. The limit of the Lethbridge advance is marked by an east-west trending end moraine system extending from the Saskatchewan border to Lethbridge; it then continues roughly north-northwestward towards Calgary and to Hinton west of Edmonton (as correlated by Stalker, 1977), a distance of more than 400 km, but it has been traced no farther (Fig. 2). North of Lethbridge the moraine becomes less prominent, with the limit marked by differences in weathering and erosion on either side, by blocking and diversions of streams, and by truncation of ice-flow markings (Stalker, 1977). There are problems in determining this limit in some places, such as near Medicine Hat where several parallel or subparallel morainal ridges occur. In any event, the approximate limits have been determined (Stalker, 1977). Fresher-looking topography east of the moraine than to the west, truncation of ice-flow

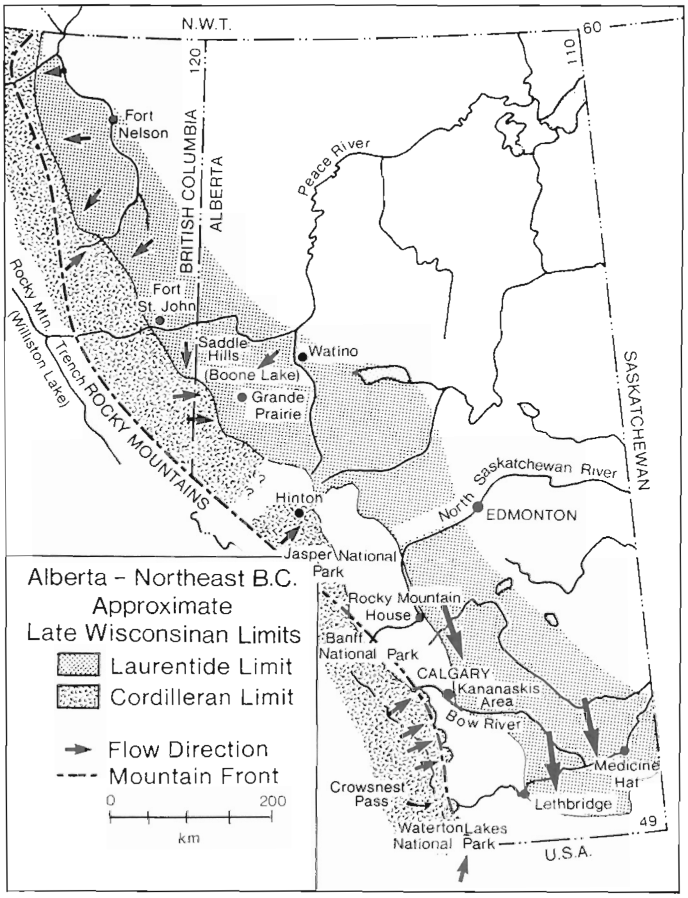

Figure 2. *Possible Late Wisconsinan limits, Alberta and northeastern British Columbia (modified after Rutter, 1980).*

markings, and deep incision of major valleys beyond this limit are the major reasons for making the Lethbridge advance a separate advance rather than a halt during a general retreat. The Lethbridge advance is considered Late Wisconsinan (ca. 10-25 ka) by Stalker (1977). At Medicine Hat, east of the Lethbridge moraine, ^{14}C dates varying in age from about 24 to 38 ka have been obtained from material underlying two tills (Stalker and Harrison, 1977). Although there are correlation problems, Stalker and Harrison (1977) equated the lower of these two tills to the Lethbridge moraine advance and the upper till to an advance that terminated between Lethbridge and Medicine Hat (the Medicine Hat advance). The dating of this moraine is the key to Stalker and Harrison's (1977) absolute chronology in the Waterton area. If the correlation of the Lethbridge advance with the Waterton IV advance that terminated well up the mountain valleys is accepted, then the surface west of the Lethbridge moraine well into the mountains is older than Late Wisconsinan. In this part of Western Canada, no worker has presented any evidence for Middle Wisconsinan glacier activity - a period from more than 50 ka to about 25 ka ago. The surface, therefore, is older than 50 ka, and older still beyond the limits of pre-Middle Wisconsinan Laurentide glaciers. However, Stalker's (1977) limit of Late Wisconsinan Laurentide ice represented by the Lethbridge moraine has not gone unchallenged. G. Richmond (personal communication, 1980) contended that Late Wisconsinan ice flowed farther south and west than the limits favoured by Stalker. Richmond's evidence is based mainly on the similarity of morainal topography in parts of southern Alberta and Montana with that north and east of the Lethbridge moraine. This is contrary to Stalker's (1977) suggestion that there is fresher-looking topography east of the moraine than to the west. In addition, Richmond (personal communication, 1980) suggested that what are believed to be Late Wisconsinan mountain tills of northern Montana can be traced laterally into lacustrine deposits which in turn can be traced into Laurentide tills. If these correlations are correct, then the Late Wisconsinan Laurentide ice limit lies considerably to the west and south of the Lethbridge moraine.

In order to determine the extent of ice-free conditions at the time of advance to the Lethbridge limit, we have to examine evidence for the eastward expanse of Late Wisconsinan Cordilleran ice. Between Waterton and Jasper, several workers have investigated areas within the mountain front and beyond (Rutter, 1972; Alley, 1973; Roed, 1975; Jackson, 1977; Boydell, 1978; Fig. 3). In most cases, a well defined three-fold sequence of Cordilleran advances in various mountain valley systems has been recognized. (Although it is too early to report, work currently being undertaken by graduate students at University of Alberta may alter this interpretation in the Banff and Jasper areas.) These advances are represented mainly by surface tills and glacial geomorphological features such as lateral moraines. As in Waterton, the oldest advance spread well beyond the mountain front, the next advance terminated near the mountain front, and the youngest well up the mountain valleys. Although there is little absolute dating control in any of these studies, many workers have assumed that ice that flowed out of the valley onto the plains in one area corresponded to ice that did the same in another valley, and so on. Further, these events were considered most likely as Late Wisconsinan. This assumption was influenced, among other things, by the three-fold Late Wisconsinan sequence determined in the United States Rocky Mountains by Richmond (1965) and later by absolute dating control of glacial events in northeastern British Columbia (Rutter, 1977). In the Jasper-Hinton area (Roed, 1975), Rocky Mountain House area (Boydell, 1978), and Kananaskis region (Jackson, 1977) it appears that the advance spreading beyond the mountain front was incorporated with and deflected southward by Laurentide ice. In the Jasper-Hinton area there is little doubt that the earlier flow (Roed's Malboro-Raven Creek advance) from Athabasca valley equates with the tongue of ice that deposited the Foothills Erratics Train (Stalker, 1956). Therefore, accepting Stalker's evidence for the Late Wisconsinan limit and for the stratigraphic position of the Erratics Train advance (Foothills Erratics Train), this main flow from the mountains could not have been Late Wisconsinan.

Alley (1973) first suggested that the three-fold mountain sequence was not necessarily correlative between areas. In the Crowsnest Pass area, he suggested that the only Late Wisconsinan event recorded is his Hidden Creek advance, that terminated well within the mountain valleys. This interpretation was based mainly on lateral tracings of equivalent lacustrine sediments sandwiched between Laurentide and Cordilleran tills farther east. Alley's Hidden Creek advance corresponds with Stalker and Harrison's Waterton IV advance; Stalker and Harrison would correlate Alley's Ernst (Cordilleran) with their Erratics Train (Laurentide) advance, which is not recorded in Alley's area. Alley correlated his Maycroft advance with the Maunsell advance which is pre-Sangamonian (Stalker and Harrison, 1977); in the Stalker and Harrison scheme, however, the Maycroft would be correlated with the Early Wisconsinan advance that deposited Buffalo Lake Till.

Evidence then is still mounting that the earlier advances from several mountain valleys, onto the plains, are older than Late Wisconsinan. This is further reinforced by a recent ^{14}C date on wood found in Erratics Train Till near Calgary and dated at 49 400 ± 1000 BP (GSC-2409; Jackson, 1979, 1980) and dates on moss of 18 300 ± 380 and 18 400 ± 1090 BP (GSC-2668 and -2670; Jackson, 1979, 1980) obtained well above the base, in a bog core from near Turner valley (southwest of Calgary). The bog dates indicate that this area was ice free well before this time (Mott and Jackson, 1982). It has not been established that all these earlier advances are the same age. For example, the Bow Valley advance (Rutter, 1972) may be younger than Jackson's (1977) Big Rock Stage, as evidenced by the different topographic settings and by flow direction indicators in Bow Valley Till in Bow valley, compared with those of adjacent areas (Fig. 3). As discussed in the next section, evidence from northeastern British Columbia indicates that the most extensive well documented advance in that region is Late Wisconsinan.

It is difficult to determine which of the less extensive mountain advances marks the limit of Late Wisconsinan ice. In the Banff and Kananaskis areas, the limits would be marked by the Canmore advance (Rutter, 1972; Jackson, 1977) and in the Jasper-Hinton area by the Obed advance (Roed, 1975; Fig. 3). This seems reasonable considering ice sources and the evidence from northeastern British Columbia. There are problems, however, such as with the Canmore advance – a tongue of ice that appears to have flowed from the Banff townsite area to the edge of the mountains following withdrawal of Bow Valley ice (Fig. 3). No evidence exists for a major time interval between Bow Valley and Canmore advances as there should be if the Canmore is considered as the maximum Late Wisconsinan advance and the Bow Valley advance as pre-Late Wisconsinan. G. Osborn (personal communication, 1981), however, recently obtained a ^{14}C date of 26 600 ± 320 BP (Beta-2617) on a fractured tibia bone of **Equus** sp. found in gravels believed to have been deposited during the retreat of the Bow Valley advance and before the Canmore advance. Although only one date is available and at that, from bone, it does suggest that the Canmore advance represents the maximum limit of Late Wisconsinan ice in Bow valley. Alternatively, if the Bow Valley and Canmore advances are pre-Late Wisconsinan, then the Eisenhower Junction advance – the youngest and least extensive of Rutter's (1972) three-fold sequence - which terminated well up Bow valley, would be Late Wisconsinan, a suggestion that fits well into Stalker and Harrison's (1977) and Alley's (1973) idea that there was little glacier activity in the Rocky Mountains during the Late Wisconsinan.

In summary, then, the picture that emerges is that an ice-free corridor existed at least from the Edmonton-Jasper area southward to the International Boundary during Late Wisconsinan time. It extended westward from the limits of the Lethbridge advance to at least the mouths of major valleys of the eastern Cordilleran mountain front in the northern part of the area under discussion, and into the major valleys in the southern part (Fig. 2).

NORTHWESTERN ALBERTA – NORTHEASTERN BRITISH COLUMBIA

The glacial history of the Jasper-Hinton area northwestward to the Alberta-British Columbia border is poorly known. Considerable information is available, however, for the Rocky Mountains and plains of northeasten British Columbia. The Cordilleran record is based mainly on multiple till sections, an end moraine, and a few radiocarbon dates whereas in the area affected by Laurentide ice, evidence is based mainly on multiple till sections and radiocarbon dates.

Although evidence of pre-Late Wisconsinan Cordilleran and Laurentide advances is present, Late Wisconsinan activity is best documented. The picture that emerges is that Late Wisconsinan Cordilleran ice flowed out of the mountain front and coalesced with Laurentide ice. This was followed by two less extensive Cordilleran advances with no evidence for equivalent Laurentide activity in this region.

In the Fort St. John area, Mathews (1963) recognized two Laurentide till sheets separated and overlain by glaciolacustrine deposits. West of Fort St. John, sand and till

	SOUTH	CORDILLERAN ORIGIN				NORTH
AUTHOR	*ALLEY (1973)	JACKSON (1977)	*RUTTER (1972)	*BOYDELL (1978)	*ROED (1975)	RUTTER (1977)
AREA	Crowsnest Pass	Kananaskis	Banff	Rocky Mtn. House	Jasper-Hinton	Williston Lake (B.C.)
EARLY HOLOCENE or LATE WISCONSINAN	Hidden Creek	Eisenhower Junction Canmore	Eisenhower Junction Canmore	Jackfish Creek	Drystone Creek Obed	Deserter's Canyon Late Portage Mtn. Early Portage Mtn.
EARLY WISCONSINAN or PRE-WISCONSINAN	Ernst	Erratics Train Glaciation Big Rock	Bow Valley	Lamoral-Athabasca	Marlboro	

(* Stratigraphic position of advances or units modified from cited work)

Figure 3. Possible correlations of late Pleistocene glacial advances or equivalent till units in the eastern Cordillera of Alberta and British Columbia.

overlying the upper glaciolacustrine deposits are attributed to a late Cordilleran advance. Laurentide till is widely exposed on the surface at elevations above the level of the last glacial lake. Grooves and drumlins, meltwater channels, frequency and types of erratics, and traces of ice-dammed lakes are criteria which enabled Mathews (1980) to reconstruct ice-flow directions, glacier limits, and history of deglaciation. Four Cordilleran advances are recorded by Rutter (1977) in the Rocky Mountains west of Fort St. John. The latest three advances display essentially the same pattern as those to the south, that is, an extensive Cordilleran advance that flowed out of the mountains onto the plains (Early Portage Mountain), a later one that terminated near the mountain front (Late Portage Mountain), and one that was restricted far up the mountain valleys (Deserter's Canyon) (Fig. 3). The Early Portage Mountain advance likely coalesced with the Laurentide ice that deposited the upper Laurentide till (Fig. 2). From sections along Peace River, Mathews (1980) recognized a single and continuous near-surface till containing Cordilleran lithologies in the west and Laurentide lithologies in the east at roughly the same elevations and, using this evidence, suggested that the two ice masses coalesced. This relationship is seen only locally.

A ^{14}C date of 27 400 ± 580 BP (GSC-2034; Mathews, 1980) was obtained for tooth apatite of a sample from sediments below Laurentide till-like materials and another of 27 400 ± 850 BP (I-4878; Mathews, 1980) for wood and peat from sediments below Laurentide till to the southeast of Watino, Alberta (Fig. 2). In the Rocky Mountain Trench to the west, a date of 25 940 ± 200 BP (GSC-573; Rutter, 1977) has been obtained from organic material below what is believed to be Early Portage Mountain till. These dates suggest that the surface tills that are shown by Rutter (1977) and Mathews (1980) to have been deposited by coalescing Cordilleran and Laurentide ice are Late Wisconsinan. This is in contrast to what is being suggested for areas farther south where the extent of Late Wisconsinan Cordilleran ice was much less. Probably the best explanation for the more extensive Cordilleran ice in this region is the proximity and influence of the massive Cordilleran Ice Sheet which was situated west of the Rocky Mountain Trench. It can be demonstrated by erractics and ice-flow indicators that ice passed through the Rocky Mountains from west of the Rocky Mountain Trench during this time (Rutter, 1977). This event was followed by two less extensive advances -- the Late Portage Mountain and Deserter's Canyon -- the latter of which may be Holocene in age.

Evidence exists, however, that might cast some doubt on the reconstruction presented above. White et al. (1979) have dated organic matter from four horizons of a core taken from Boone Lake (elevation 872 m) located in the summit area of Saddle Hills about 110 km southeast of Fort St. John (Fig. 2). The two stratigraphically lower dates are 17 570 ± 650 BP (WAT-406) and 30 000 BP (WAT-361), respectively. There is no overlying till, suggesting that the higher parts of the Saddle Hills escaped Late Wisconsinan glaciation; this is doubtful, however, because the local relief is only about 100 m. It seems more likely that these dates result from contamination by fine grained, old carbon (see Nambudiri et al., 1980).

A Late Wisconsinan Laurentide deglaciation pattern has been reconstructed by determining elevations of glacial lakes from shorelines, bottom deposits, and tributary and outlet channels in northeastern British Columbia and northwestern Alberta (Mathews, 1963, 1980; St-Onge, 1972). Radiocarbon dates indicate retreat occurred between about 13.5 and 11.4 ka or that about 2 ka was required for the ice to retreat from near the mountain front to about 240 km to the northeast. Radiocarbon dates and geological interpretation concur well in this region, although one date of 11 600 ± 1000 BP (I-2244A; Rutter, 1977), originally used to date the end moraine at the mountain front (Late Portage Mountain advance), is at least 1 ka too young to be compatible with ages interpreted for glacial lake elevations in the end moraine area and those in northwestern Alberta. The 11.6 ka date was derived from too small an amount of tusk collagen for dating to be precise. A second collagen sample was later carefully extracted from the same tusk in such a way as to avoid contamination of a preservative which had been applied; the new date was 25 800 ± 320 BP (GSC-2859; Mathews, 1980). Because contamination still cannot be ruled out, it would be best to not attempt to use either of these dates to date the Late Portage Mountain moraine.

YUKON TERRITORY – NORTHWEST TERRITORIES

The third area covers eastern and northern Yukon Territory, the eastern slopes of the Mackenzie and Richardson mountains, and the western part of the northern plains and plateau, including Mackenzie River valley (Fig. 4).

The Laurentide record is based mainly on multiple till sections, distribution of erratics, ice marginal channels, and radiocarbon dates. Cordilleran glacial activity is based mainly on distribution and geomorphology of morainal deposits.

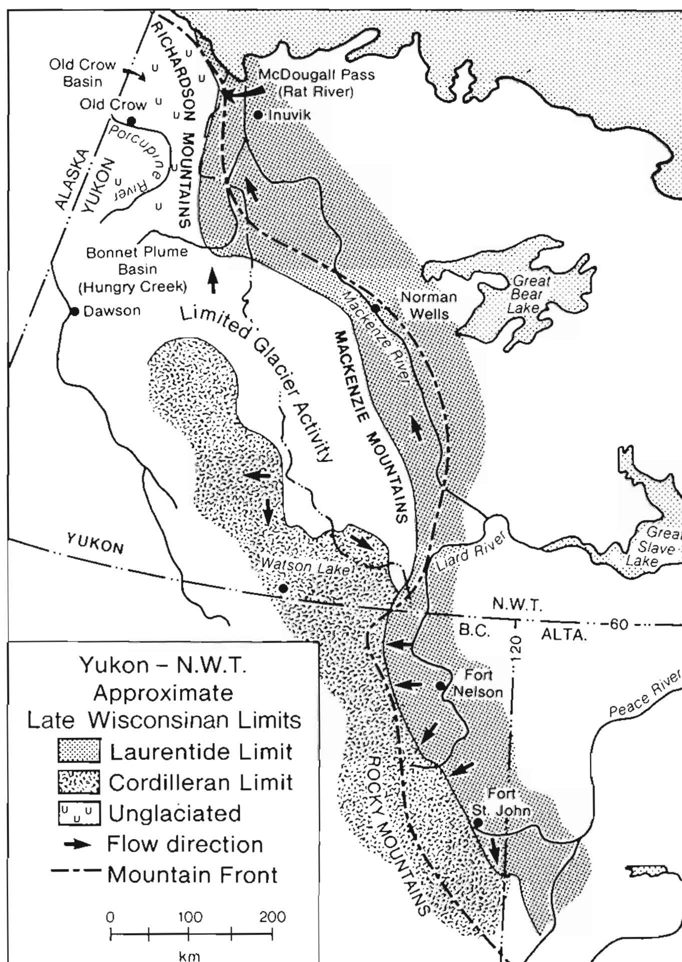

Figure 4. *Possible Late Wisconsinan limits, Yukon Territory and Northwest Territories (modified after Rutter, 1980).*

Laurentide glaciers from the east advanced to the Mackenzie and Richardson mountain fronts whereas the Cordilleran ice was restricted to the cores of mountain ranges. This left extensive areas in northern and western Yukon and areas between the mountain fronts and central parts of the ranges unglaciated. This is in contrast to what occurred in the area to the south where Cordilleran glaciers flowed out of the mountains and Laurentide ice reached the mountain front only in a few areas.

In the Mackenzie valley – eastern Yukon region, two Laurentide advances are recorded (Hughes, 1972); evidence is provided by two tills separated by stratified sediments observed in many sections east of the Richardson and Mackenzie mountains (Hughes, 1972; Rutter et al., 1973). In addition, at least two well defined ice marginal positions, marked by glacial erratics, end moraines, and ice marginal channels are present in the eastern flanks of the Mackenzie and Richardson mountains (Hughes, 1972). Radiocarbon dates of >38 000 BP (GSC-120, -204) were obtained from wood and organic detritus from silt overlying till located in the lower reaches of Rat River (Fig. 4) on the east side of the Richardson Mountains (Hughes, 1972). This led Hughes to correlate the oldest of his tills with the maximum Laurentide advance – thought to be Early Wisconsinan. Since that time, work in the Bonnet Plume Basin has altered this interpretation. A section on Hungry Creek, near the western limit of Laurentide ice, just south of the Richardson Mountains (Fig. 4), has yielded a ^{14}C date on wood of 36 900 ± 300 BP (GSC-2422) from stratified sediments below till (Hughes et al., 1981). It therefore appears that the maximum glaciation here is represented by the youngest till and is Late Wisconsinan in age. It is not, however, clear whether the farthest west ice margin is Late Wisconsinan in all places. For example, the glacial limit near the north end of the Richardson Mountains, believed to be Late Wisconsinan, appears to merge with the limit for Buckland Glaciation – the maximum glaciation in the Yukon Coastal Plain (Rampton, 1982). Buckland Glaciation is believed to be older than Late Wisconsinan, based on two dates on surface marine shells of >35 000 BP (GSC-562, -690) from the periphery of the Mackenzie Delta. Therefore, the age of the maximum ice advance is not clear in all areas.

Farther west, in the nonglaciated part of northern Yukon Territory, in particular Old Crow Basin, thick sequences of Quaternary fluvial and lacustrine sediments outcrop along major rivers (work currently in progress by O.L. Hughes, J.V. Matthews, Jr., Geological Survey of Canada; R.E. Morlan, National Museums of Canada; N.W. Rutter, C.E. Schweger, University of Alberta; Hughes et al., 1981). Although the age and interpretation of some of the oldest sediments are in doubt, a series of Middle Wisconsinan finite ^{14}C dates indicates that the overlying glaciolacustrine sediments started to accumulate shortly after 30 ka. This supports the premise that Late Wisconsinan ice reached the Laurentide maximum position because only if it reached this position could meltwater from the ice front have been diverted into this basin via the Porcupine River drainage system.

Although other evidence could be cited both pro and con, the best interpretation is that the most extensive Laurentide advance in the western Mackenzie region was Late Wisconsinan in age.

Up to three Cordilleran glacial advances are recorded in various parts of the mountainous regions of the Mackenzie River valley – eastern Yukon. The multiple glacial activity is evidenced by relative freshness, configuration, and areal distribution of moraines (Hughes, 1972). Liard River has exposed relatively complete Quaternary sequences near Watson Lake, Yukon Territory. Klassen (1978) cited evidence for four major intervals of glaciation. Until more work is done, it is not possible to relate these to the morainal sequence cited by Hughes (1972).

There is no clear evidence to show how the three Cordilleran events correlate with the two Laurentide events. This correlation is difficult because Cordilleran and Laurentide ice did not coalesce in this area. It is assumed that the fresh-appearing end moraines present in mountain valleys well beyond the limits of Laurentide ice are approximately equivalent to the Late Wisconsinan Laurentide event. The middle or second Cordilleran advance may correlate with the earlier of the two Laurentide events.

Several surface dates are available from east of the mountain fronts which give an indication of the minimum age for final deglaciation. Two of the oldest dates are 11 530 ± 170 BP (I-3734; Mackay and Mathews, 1973) from near Fort Good Hope and 11 800 ± 170 BP (GSC-2745) from the Snake River area. The occurrence of prominent morainal belts exposed on the plains and on sides of plateaus east of the Richardson and Mackenzie mountains suggests that a stillstand or readvance of Laurentide ice occurred during overall deglaciation.

CONCLUSIONS

From the above discussion, it is apparent that there are many unanswered questions associated with the interpretation and dating of Quaternary deposits in the region. Wisconsinan history is the best understood, but even concerning this time period major problems remain. The best evidence at present places the Late Wisconsinan limits at those shown in Figures 2 and 4. Only in northeastern British Columbia did Cordilleran and Laurentide ice coalesce. Putting it another way, during the entire Wisconsinan, although we know very little about the Early Wisconsinan, ice-free conditions in the area of the corridor were the rule rather than the exception.

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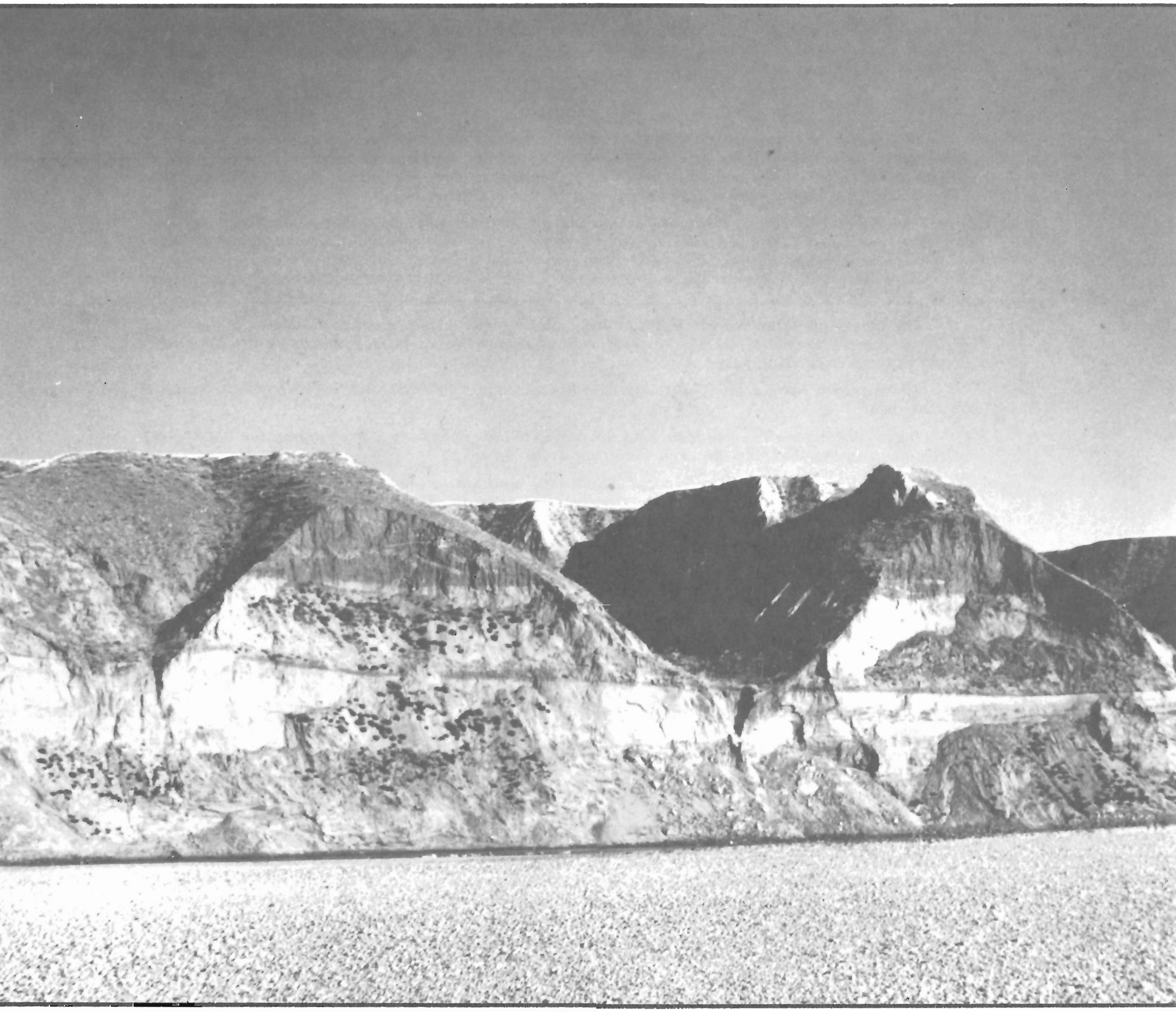

Twin Cliffs section on South Saskatchewan River at Medicine Hat, southeastern Alberta: Nonglacial, fossiliferous sand and gravel (containing a Yarmouthian vertebrate fauna), 20 m thick, lie at the base of the exposure below 20 m of glacial sand and gravel and 16 m of till referred to the Illinoian Glaciation. Two Late Wisconsinan tills lie at the top. Photo and stratigraphy by A. MacS. Stalker, GSC 203193-W.

QUATERNARY STRATIGRAPHY OF THE CANADIAN PRAIRIES

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Fenton, M.M., Quaternary stratigraphy of the Canadian Prairies; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 57-68, 1984.

Abstract

Five major Quaternary events on the Canadian Prairies are of early or middle Pleistocene age – PW Event, Wellsch Nonglacial Interval, Wascana Nonglacial Interval, Redcliff Nonglacial Interval, and Dunmore Glaciation – and four are of late Pleistocene age – Osler Nonglacial Interval, Burke Lake Glaciation, Watino Nonglacial Interval, and Lostwood Glaciation.

The PW Event during which one or more early Pleistocene Laurentide glaciation(s) occurred that were responsible for transporting south the Precambrian stones found in the nonglacial sediment at Wellsch Valley, was followed by the Wellsch Nonglacial Interval. Both events occurred during the Matuyama Reversed Magnetic Epoch and the nonglacial interval probably occurred at least in part during the Olduvai Event.

The glaciation following the Wellsch Nonglacial Interval possibly was responsible for deposition of one or more tills of the Floral Formation and Sutherland Group. A lack of lithostratigraphic data at the Wellsch Valley site makes correlation between these units tentative.

The Wascana Nonglacial of Aftonian age is about 600 ± 40 ka, based on fission track dating of volcanic ash.

During the Redcliff Nonglacial Interval, which is late Kansan to Yarmouthian, the lower group of sediments in the Medicine Hat area were deposited.

During the Dunmore Glaciation of Illinoian(?) age, two or more tills were deposited in the Medicine Hat area. This was the most extensive glaciation to affect the Prairies with one advance extending to the eastern slopes of the Rocky Mountains in southwestern Alberta.

The Osler Nonglacial Interval of Sangamonian age, Burke Lake Glaciation of Early Wisconsinan age, and Watino Nonglacial Interval of Middle Wisconsinan age have all been recognized at a number of places on the Prairies. Lostwood Glaciation of Late Wisconsinan age followed, resulting in ice covering most of the Prairies.

The chronology for pre-Watino events is derived from correlation with events outside the prairies, fission track age dates, or speculation. The chronology for younger events is based on radiocarbon dates. Watino Nonglacial Interval started before 43.5 ka, and perhaps before 52 ka, and ended after 23.7 ka. The succeeding Lostwood Glaciation reached its maximum between about 20 and 18 ka ago and ice had completely retreated from the Prairies by about 10 ka.

Résumé

Le Quaternaire des Prairies canadiennes est marqué par cinq événements importants du Pléistocène inférieur ou moyen (épisode PW, intervalle non glaciaire de Wellsch, intervalle non glaciaire de Wascana, intervalle non glaciaire de Redcliff et glaciation de Dunmore) et par quatre du Pléistocène supérieur (intervalle non glaciaire d'Osler, glaciation de Burke Lake, intervalle non glaciaire de Watino et glaciation de Lostwood).

À l'épisode pré-wellschien, du Pléistocène inférieur, au cours duquel une ou plusieurs avancées du glacier des Laurentides ont transporté vers le sud les pierres précambriennes trouvées dans les sédiments non glaciaires de la vallée de la Wellsch, a succédé l'intervalle non glaciaire de Wellsch. Les deux événements se situent à l'époque de champ magnétique inverse de Matuyama, et il se peut que l'intervalle non glaciaire ait eu lieu pendant l'épisode d'Olduvai.

La glaciation postérieure à l'intervalle non glaciaire de Wellsch est peut-être responsable du dépôt d'un ou de plusieurs tills de la formation de Floral et du groupe de Sutherland. Les lacunes lithostratigraphiques de la vallée de la Wellsch font que toute corrélation entre ces unités n'est que provisoire.

L'intervalle non glaciaire de Wascana date de l'Aftonien; d'après la datation de cendres volcaniques par la méthode des traces de fission, il daterait d'environ 600 ± 40 ka.

La mise en place du groupe inférieur de sédiments dans la région de Medicine Hat a eu lieu au cours de l'intervalle non glaciaire de Redcliff, survenu entre la fin de la glaciation du Kansan et l'intervalle glaciaire de Yarmouth.

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Manuscript received: 1982-06-14
Final version approved for publication: 1983-01-05

Pendant la glaciation de Dunmore (Illinoien?), la région de Medicine Hat a été recouverte d'au moins deux dépôts de till. Il s'agit de la plus vaste des glaciations ayant envahi les Prairies, un des fronts atteignant même les versants est des Rocheuses dans le sud-ouest de l'Alberta.

L'intervalle non glaciaire d'Osler (Sangamonien), la glaciation de Burke Lake (Wisconsinien inférieur) et l'intervalle non glaciaire de Watino (Wisconsinien moyen) ont tous été reconnus à plusieurs endroits dans les Prairies; la glaciation de Lostwood (Wisconsinien supérieur), dont les glaces ont recouvert la majeure partie des Prairies, leur a succédé.

La chronologie des événements ayant précédé le Watino est déduite de corrélations établies avec des épisodes survenus à l'extérieur des Prairies, de la datation par la méthode des traces de fission ou, simplement, d'hypothèses. Pour la chronologie des événements plus récents, on se base sur la datation au carbone radioactif. L'intervalle de Watino a commencé avant 43,5 ka, peut-être avant 52 ka, et a pris fin après 23,7 ka. La glaciation de Lostwood, qui lui a succédé, a atteint son maximum d'extension entre environ 20 et 18 ka; il y a 10 ka que le glacier s'est complètement retiré des Prairies.

INTRODUCTION

Previous IGCP reports dealing with Western Canada have described the local lithostratigraphy at a number of sites (Fulton, 1976, 1977, 1979; Fenton and Teller, 1977). As mentioned by Dreimanis et al. (1981) the discussion of local stratigraphic sequences, dealing mainly with lithostratigraphic units, makes Canada-wide correlation difficult. This report looks at the Prairies as a region and discusses the major geological events that can be deduced from the lithostratigraphic units. New geological event units are defined and references to the origin of existing units are given.

Two types of conceptual geological event are used – glaciation and nonglacial interval. A glaciation is defined here as an event characterized by a major glacial expansion, from a margin lying outside the Prairies, to cover most of the region. A nonglacial interval is an event during which the Prairies were likely free of active glacier ice. These units, although based on lithological units, are conceptual ones and regionally have time-transgressive boundaries (Krumbein and Sloss, 1963, p. 51; Clayton, 1972).

The event units are placed in a chronological framework. The development of a Quaternary chronology for the Prairies has been advanced by development and integration of tephrachronology, magnetostratigraphy, and vertebrate paleontology (Johnson et al., 1975; Opdyke et al., 1977; Barendregt, 1981). This has resulted in a better, although still incomplete, understanding of the Pleistocene of the Prairies than anywhere else in Canada.

Acknowledgments

I wish to thank C.S. Churcher, R.J. Fulton, R.W. Klassen, S.R. Moran, and A. MacS. Stalker for reviewing the manuscript. Their comments are appreciated.

THE PRAIRIES

The area reviewed in this report is bounded by the Canadian Shield on the northeast, the Cordillera on the west, the 49th parallel on the south, and the 60th parallel to the north. It is underlain by generally flat lying sedimentary rocks which consist largely of Paleozoic carbonates along the edge of the Shield, poorly consolidated sandstones of Late Cretaceous and Early Tertiary age along its western margin, and Cretaceous shales in the central area. Most of the region is a flat to gently rolling plain traversed by broad shallow depressions, narrow incised valleys and punctuated by scattered groups of low hills or uplands. Regional slope is towards the northeast, away from the Cordilleran region.

Prior to glaciation the Prairies consisted of broad, northeast trending valleys separated by low uplands. Stream deposits in the valleys were predominantly of quartz sand and gravels dominated by pebbles of resistant quartzite, argilite, and chert derived from the Cordillera or reworked from older Tertiary and Cretaceous deposits. During each ice advance the northeast drainage was dammed so that lakes developed in the valleys and depressions and drainage was diverted to the south. During ice retreat, ice marginal lakes developed as the ice retreated downslope and steep-walled valleys were cut where meltwater flowed from one lake basin to the next, where flow was channelled southward along the ice margin, and where drainage was re-established in drift-filled segments of preglacial valleys. The drainage during nonglacial time roughly followed preglacial valleys but in places was diverted from one valley system to another through trenches cut by meltwater and in many places flowed on a thick fill of drift left behind by the retreating ice. Stream deposits laid down during nonglacial periods consisted in part of sands and gravels containing resistant pebbles similar to those deposited during preglacial times but included important and distinctive admixtures of material from the Precambrian Shield and the adjacent fringe of Paleozoic carbonates that had been transported westward and southward by the glaciers. Repeated glacial and nonglacial intervals produced a complex of valley fills of different ages. Major Holocene rivers have cut new valleys in this complex of Quaternary sediments. The most extensive and complete sections of these deposits are exposed in the old valley systems occupied by South Saskatchewan River in southern Alberta and western Saskatchewan.

EARLY AND MIDDLE PLEISTOCENE EVENTS

Even though the early and middle Pleistocene stratigraphic record of the Prairies is incomplete with many erosional gaps (Fig. 1), it provides evidence of glacial and nonglacial events that have not been documented elsewhere in Canada. The chronological control for early and middle Pleistocene events is based on a combination of vertebrate fossil, paleomagnetic, and tephra data. The deposits on which early and middle Pleistocene events are based have been described in a number of papers, the most significant being Stalker and Churcher (1972), Russell and Churcher (1972), Stalker (1976), and Westgate et al. (1977). Briefly, the present record consists of an early Pleistocene glaciation(s), followed by a long nonglacial interval, which includes the Wellsch, Wascana, and Redcliff event units, followed by a glacial interval in which a number of ice advances occurred (Dunmore Glaciation; Fig. 1).

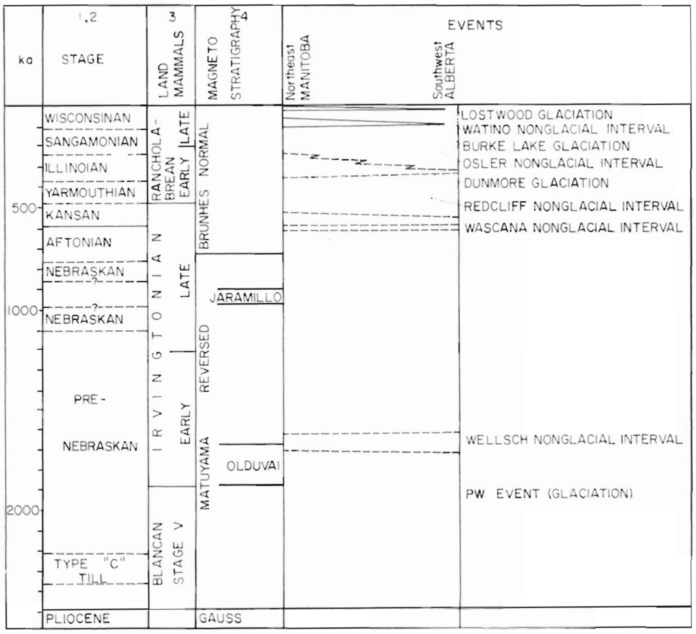
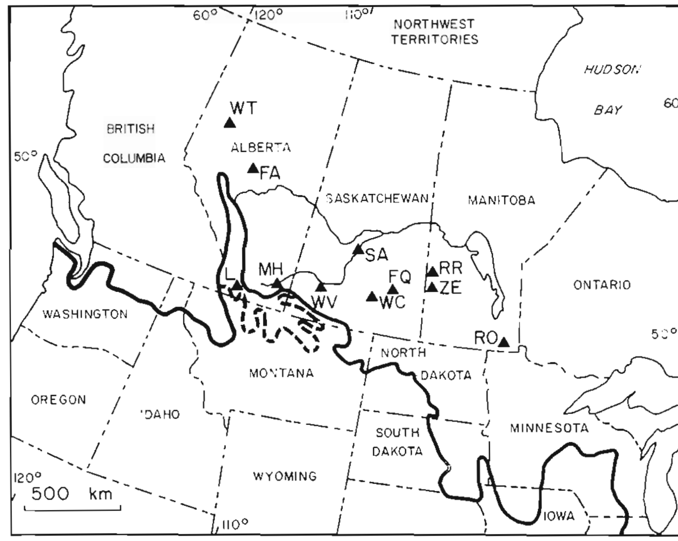


Figure 1. Quaternary event-stratigraphy Prairies western Canada. (1) Dreimanis et al., 1981; (2) Easterbrook and Boellstorff, 1981; (3) Repenning, 1980; (4) Mankinen and Dalrymple, 1979. Detail of Lostwood and Burke Lake glaciations omitted. Approximate boundaries are indicated by dashed lines.



WT	*Watino*	*WC*	*Wascana Creek*
FA	*Fort Assiniboine*	*FQ*	*Fort Qu'Appelle*
L	*Lethbridge*	*RR*	*Roaring River*
MH	*Medicine Hat*	*ZE*	*Zelena*
WV	*Wellsch Valley*	*RO*	*Roseau River*
SA	*Saskatoon*		

Figure 2. Major stratigraphic sites (symbol may indicate multiple sites) and Late Wisconsinan ice limits (modified from Clayton and Moran, 1982; Prest, this volume) for the Prairies.

Evidence for these early events has so far been found only at a few sites. The "gaps" between these intervals probably include both glacial and nonglacial events. There are many testholes and some sections with deposits that appear to be early or middle Pleistocene because they lie near the base of thick Pleistocene sequences but these sites have neither chronological nor paleontological control and available lithostratigraphic data are insufficient to permit correlation with sites having this control.

PW Event

The stones transported from the Canadian Shield in Unit C at the Wellsch Valley site (Stalker and Churcher, 1972; see Wellsch Nonglacial Interval described below), together with the V-shape of the valley containing the sediment (which contrasts with the broad preglacial valleys), provide evidence of at least one glaciation prior to the Wellsch Nonglacial Interval (A. MacS. Stalker, personal communication, 1982). This will informally be referred to as the "PW Event". This glaciation(s) probably occurred about 2 Ma ago and hence is the oldest Quaternary glacial event recognized in Canada (A. MacS. Stalker, personal communication, 1982).

Wellsch Nonglacial Interval

The Wellsch Nonglacial Interval is represented by Unit C of Stalker and Churcher (1972). The reference exposure is the type section for Unit C located at the Wellsch Valley site, southern Saskatchewan (Fig. 2; SE 1/4, sec. 4, tp. 20, rge. 14, W 3rd mer.; Stalker, 1971; Stalker and Churcher, 1972). The event is named after the farm of Mr. G.H. Wellsch on whose property the site is located (Stalker, 1971).

The site has been described in detail in Stalker and Churcher (1972) and Stalker (1976). The succession consists of four or more tills overlying the stratified sediment of Unit C. Unit C consists of (1) a thin (3 m) lag gravel, free of stones from the Canadian Shield; (2) an overlying thick (13 m) silt, sand, and gravel subunit containing vertebrate fossils, stones transported from the Canadian Shield, and a layer of volcanic ash; and (3) an upper subunit consisting of sand and gravel containing Shield stones.

Bones, mainly of large vertebrates and in various states of preservation, are found throughout the middle subunit. These have been described by Stalker and Churcher (1972), Russell and Churcher (1972), and Churcher (1974).

The vertebrate fossils are typical of Early Irvingtonian Land Mammal Age (Churcher, 1983). Some of these sediments are also magnetically reversed (Foster and Stalker, 1976) and likely record the latter part of the Olduvai Event, Matuyama Reversed Epoch (Barendregt and Stalker, 1983). These data show that this unit was most likely deposited about 1.8 Ma and is most likely early Pleistocene (Fig. 1; Churcher, 1983; A. MacS. Stalker, personal communication, 1982). The tephra overlying the fossil-bearing sediment has been dated at 630 and 690 ka (Stalker, 1971; Westgate et al., 1978).

Quaternary deposits of this age have so far been recognized only at the Wellsch Valley site in Western Canada. Magnetically reversed sediments on Banks Island, in the Canadian Arctic (Vincent, 1983; Vincent et al., 1983) may be of equal antiquity.

Wascana Nonglacial Interval

The Wascana Nonglacial Interval is defined by the Wascana Creek Ash and associated clay at Wascana Creek site near Regina, Saskatchewan (Fig. 2). The event is named after Wascana Creek along which the section containing the ash is situated (NE lsd. 9, sec. 29, tp. 18, rge. 21, W 2nd mer.).

The stratigraphy as described by Westgate et al. (1977) beginning at the top of the section: (1) till of the Battleford Formation, (2) well jointed clay within which are lentils of tephra, (3) till of the Floral Formation, (4) a thin layer of sand, (5) tills of the Sutherland Group, and (6) preglacial sediments of the Empress Group. This is the only known exposure of this ash in Canada. Nothing is known about the climate or extent of glaciers during deposition of Wascana Creek Ash. Hence the only statement that can be made is that glacier ice was not present at this site at the time of ash deposition.

Wascana Creek Ash is identical to Pearlette Type O ash (classification of Izett et al., 1972) or Pearlette-restricted (classification of Boellstorff, 1973a, b) and has been fission track dated at 600 ± 40 ka. The clay 15 cm below the ash has a normal magnetic polarity. This, together with the age, suggests that the sediment was deposited during the early Brunhes Normal Epoch (Fig. 1; Westgate et al., 1977).

In other reports (Christiansen, 1968b, 1972; Khan, 1970; SkwaraWoolf, 1981) the Floral Formation is referred to as immediately pre-Sangamonian to Early Wisconsinan in age. The till underlying the Wascana Creek Ash is therefore older than the apparent age of the Floral Formation. Possibly Westgate et al. (1977, p. 362) are correct in expressing some reservations about the stratigraphic correlation at this site and the ash is indeed part of an erratic block.

The Wascana Creek Ash is likely much younger than the sediments at the Wellsch Valley site and slightly older than the oldest sediments at Medicine Hat (Stalker, 1976, p. 393). The Wascana Interval would be of Aftonian age as described by Easterbrook and Boellstorff (1981) and Boellstorff (1978).

This event has so far been documented in Canada only at the Wascana Creek site. The Pearlette Type O ash has been found at sites in Iowa, Nebraska, and Utah (Westgate et al., 1977).

The relationship of the tills and stratified sediment that underlie the Wascana Creek Ash to the sediments representing the Wellsch Nonglacial Interval is unknown. Some or all of the tills at the Wellsch Valley site that overlie the stratified sediments deposited during the Wellsch Nonglacial Interval probably correlate with the Floral Formation. The weathering zone at the top of the Sutherland Group (Christiansen, 1968b) may record the Wellsch interval or possibly some tills of the upper part of the Sutherland Group overlie the sediment deposited during the Wellsch Nonglacial Interval. The Empress Group correlates with the preglacial sediment at the base of the Wellsch Valley site.

Redcliff Nonglacial Interval

The Redcliff Nonglacial Interval is the period represented by the sediments of units VI and VII (Stalker, 1976) exposed in the Twin Cliffs section (N 1/2, sec. 9, tp. 13, rge. 5, W 4th mer.) near Medicine Hat, Alberta (Fig. 2). The interval is named after the town of Redcliff, west of Medicine Hat.

Unit VI consists of gravel and minor sand, Unit VII is carbonaceous, interbedded clay and silt (Stalker, 1976). The wood and pollen in these sediments indicate open grasslands on upland sites with trees and shrubs occupying river banks and other suitable areas; the climate was similar to that at present or slightly cooler and more moist (Mott and Stalker, 1972; Stalker, 1982). The absence of stones from the Shield in these sediments suggests that the earlier PW glaciation(s) did not reach the Medicine Hat area (Stalker, 1976).

Vertebrate fossils are present throughout both units. Bones are of large vertebrates, rarely waterworn but never articulate. Fauna from Unit VI appears to be late Kansan to Yarmouthian and from Unit VII is Yarmouthian (Stalker and Churcher, 1972; Stalker, 1976). The magnetic polarity is normal (Barendregt and Stalker, 1978). This group of sediments therefore is much younger than those at the Wellsch Valley site and slightly younger than those at the Wascana Creek site (Stalker, 1976).

The sediments recording this event have been recognized in sections exposed along about 24 km south of Saskatchewan River near Medicine Hat. A lack of relevant data in other areas of the Prairies prevents correlation with sediments beyond the Medicine Hat region.

Dunmore Glaciation

Dunmore Glaciation is represented by the sediments of units VIII to XIV (Stalker, 1976) in the Medicine Hat area of southeastern Alberta (Fig. 2) and is the first glaciation during which ice of Laurentide provenance covered much of southern Alberta. The majority of these units are exposed in the Twin Cliffs section (N 1/2, sec. 9, tp. 13, rge. 5, W 4th mer.) near Medicine Hat (Stalker, 1976). The event is named for the town of Dunmore located southeast of Medicine Hat.

Stalker (1976) gives a complete description of the sediments representing this event; briefly, they are from the base: Unit VIII, proglacial silt and sand; Unit IX, alluvial sand and clay; Unit XI, black till of Laurentide provenance; Unit XII sand and gravel; Unit XIV, black till of Laurentide provenance.

Stalker (1976, p. 394) stated that the exact relationship of units VIII and IX is uncertain but that they are roughly contemporaneous, both being associated with a proglacial lake ponded in front of the first Laurentide ice to approach the Medicine Hat area. This ice either retreated slightly and readvanced or continued to advance and deposited Unit XI.

Units X and XIII, which are not mentioned above, are tills of Cordilleran provenance found in southwestern Alberta west of Lethbridge (Stalker, 1976; Stalker and Harrison, 1977).

Vertebrate fossils have been found only in Unit IX and are apparently Yarmouthian (Stalker and Churcher, 1972, p. 115, Unit G). Sangamonian vertebrate fossils have been found in the lag gravel overlying Unit XIV (Stalker, 1976); therefore, Dunmore Glaciation is of Illinoian age.

Evidence for the Dunmore event has been recognized in a number of places on the Prairies. The uppermost till(s) underlying Sangamonian deposits in Manitoba and Saskatchewan were likely deposited during this glaciation. Stratigraphically equivalent glacial deposits of Cordilleran origin are recognized in southwestern Alberta (Stalker and Harrison, 1977). Dunmore Glaciation appears to have been the most extensive to have affected the Prairies because Stalker and Harrison (1977) recognized an Illinoian glacial advance that reached the eastern slopes of the Rocky Mountains.

LATE PLEISTOCENE EVENTS

Osler Nonglacial Interval (Sangamonian)

The Osler Nonglacial Interval occurred between the Dunmore and Burke Lake glaciations. This event is represented by sediments of the Riddell Member of the Floral Formation exposed in a section along North Saskatchewan River (SW 1/4, lsd. 5, sec. 13, tp. 37, rge. 5, W 3rd mer.) near Saskatoon, Saskatchewan (Fig. 2). The event is named after the settlement of Osler situated northeast of Saskatoon.

The Riddell Member at the reference section has been described by SkwaraWoolf (1980, 1981). Briefly, it consists of up to 8 m of stratified and crossbedded sand.

Summarizing SkaraWoolf (1981), the sediment contains molluscs and large and small vertebrate fossils which indicate a habitat dominated by open grasslands with trees and shrubs in low areas and along river valleys. Her interpretation was that the climate of this site was more equable than at present with cooler summers and milder winters. The majority of the extant mammals presently cohabit at least 500 km south of the Riddell site. The fauna most likely represents either a late interglacial or a mid-interglacial environment (SkwaraWoolf, 1981).

The Riddell fauna indicates Late Rancholabrean time (SkwaraWoolf. 1981); the deposit is not likely older than Sangamonian and stratigraphically underlies till that underlies Middle Wisconsinan sediments. The Osler Nonglacial Interval is therefore likely Sangamonian.

This is the oldest nonglacial interval generally recognized at sites throughout the Prairie region (Fig. 3, 4). These deposits are beyond the age of radiocarbon dating. 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.

The following discussion describes the main deposits on the Prairies correlated with this event (Fig. 3). Some successions known to be of pre-Middle Wisconsinan age, but indicating a cool climate (could be either interstadial or early or late interglacial), are assigned to the Osler Nonglacial Interval. This is because there is no site in Western Canada where nonglacial deposits of pre-Middle Wisconsinan age are known to overlie Sangamonian deposits.

Little information has been published for the important Watino section in the Peace River area of west-central Alberta (Fig. 2). Churcher and Wilson (1979), however, reported that the gravel at the base of the Watino section contains vertebrate fossils indicating a Sangamonian or perhaps late Illinoian age.

Sangamonian beds are the most studied units in the Medicine Hat area because of their abundant fossil content (Stalker, 1976, p. 396-400). The vertebrate fossils, together with the nature of the sediment, indicate a moderate climate followed by a period of climatic deterioration and periglacial activity.

In Saskatchewan, at the Fort Qu'Appelle site, vertebrate fossils from the Echo Lake Gravels are of Late Rancholabrean age. They indicate a woodland or parkland habitat and have been assigned to the Sangamonian, late Sangamonian, or earliest Early Wisconsinan (Khan, 1970; Christiansen, 1972; SkwaraWoolf, 1981).

In western Manitoba the Roaring River Clay (Klassen et al., 1967) has been assigned to the Sangamon Interglaciation or possibly to an interstade equivalent to the St. Pierre of the St. Lawrence Lowlands. Pollen and invertebrate fossils indicate a cool-warm-cool cycle with change from boreal forest to dry grassland, to oak-savannah, back to boreal forest, and finally to a tundra environment. During the middle of this cycle the climate was warmer than that at present (Ritchie, 1980).

In southeastern Manitoba, the St. Malo Formation has been correlated with the Osler event (Fenton, 1974) because it represents the first nonglacial interval below

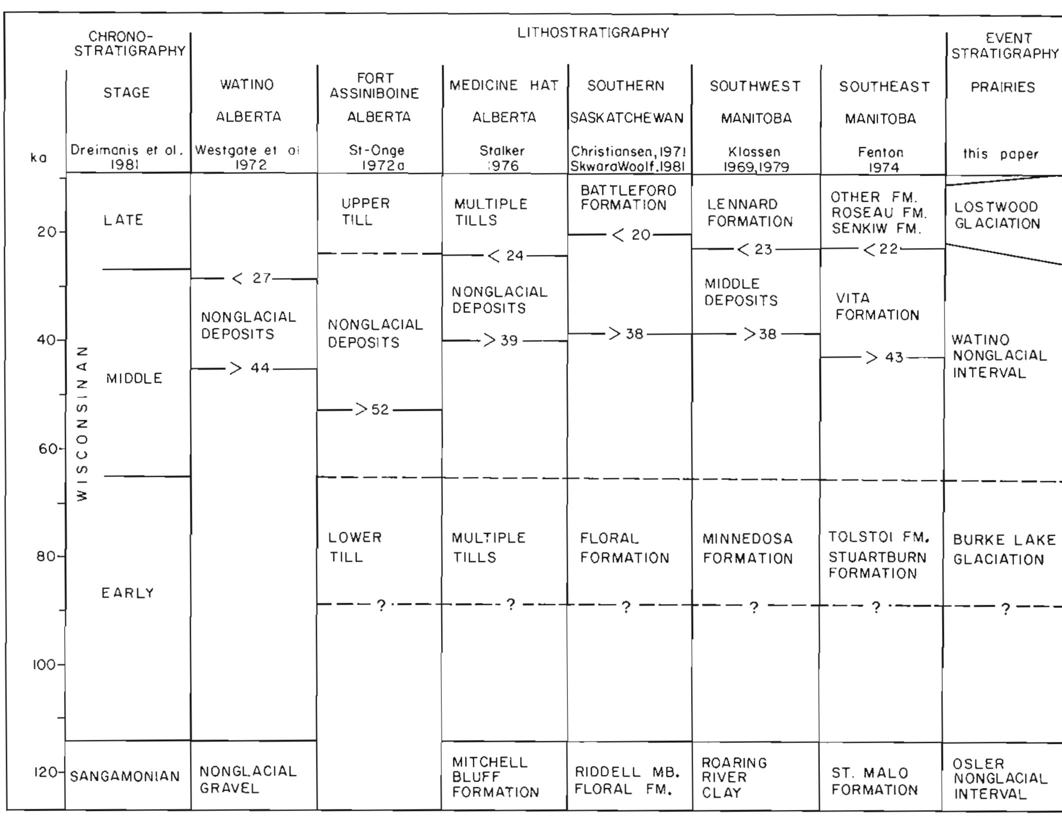


Figure 3. *Correlation chart of lithostratigraphic units in the Canadian Prairies. Boundary with good chronological control is shown as a solid line; approximate boundary with limited chronological control is dashed.*

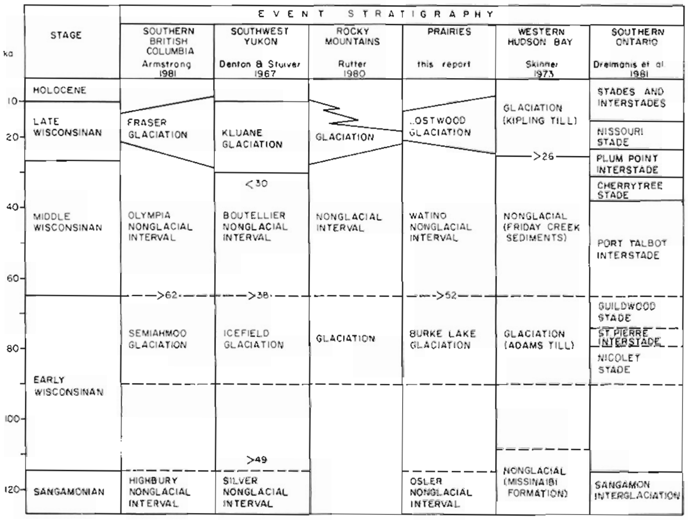


Figure 4. *Correlation of Wisconsinan events in Western Canada with those of adjacent areas. Boundary with good chronological control is shown as a solid line; approximate boundary with limited chronological control is dashed.*

Middle Wisconsinan deposits. Palynological data indicate a closed coniferous forest with spruce declining as pine moves in (Mott, in Fenton, 1974). This environment is similar to the Late Wisconsinan – early Holocene community (that is, early interglacial community) in the area.

Burke Lake Glaciation (Early Wisconsinan)

Burke Lake Glaciation occurred between the Osler and Watino nonglacial intervals.

The event is represented by the upper till unit of the Floral Formation at the Saskatoon site (SE lsd. 14, sec. 14, tp. 37, rge. 5, W 3rd mer.), northeast of Saskatoon (Fig. 2; Christiansen, 1973, p. 6; SkwaraWoolf, 1981). The event is name after Burke Lake located northeast of Saskatoon, Saskatchewan.

Summarizing SkwaraWoolf (1981) and Christiansen (1973), the unit representing the Burke Lake event is a fossil-free, well jointed, iron-stained till of the upper part of the Floral Formation. This till is underlain by the fossiliferous sands of the Riddell Member of Sangamonian age and is overlain by the till of the Battleford Formation.

The weathered upper till of the Floral Formation at other sites is overlain by stratified sediments of the Middle Wisconsinan nonglacial interval (Christiansen, 1968a, b, 1971, 1973, p. 6, 40). Burke Lake Glaciation therefore is Early Wisconsinan.

Sediment deposited during Burke Lake Glaciation has been recognized in many places throughout the Prairies (Fig. 3). The glacial advance extended southward into the United States (Clayton and Moran, 1982) and westward as far as southwestern Alberta (Stalker and Harrison, 1977).

This glaciation was probably characterized, in many areas, by local retreats and readvances; for example, near Medicine Hat, Alberta, Stalker (1976, p. 400) described a sequence of two tills separated by alluvial and pond deposits which appear to correlate with this event.

Watino Nonglacial Interval (Middle Wisconsinan)

The Watino Nonglacial Interval separates Burke Lake and the Lostwood glaciations.

The event is represented by the "massive fine grained, fossiliferous sediments" (Westgate et al., 1972) in the section near Watino, Alberta (SE sec. 3, tp. 78, rge. 24, W 5th mer.; Fig. 2). It is named after the settlement of Watino, Alberta.

The section at Watino has been described by Westgate et al. (1971), Westgate et al. (1972), and Lichti-Federovich (1975). The material representing the Watino interval consists of about 6 m of massive, fine grained, fossiliferous sediment, which is overlain and underlain by laminated, proglacial lacustrine silts and clays.

The sediment contains molluscs, ostracodes, insects, pollen, and plant macrofossils. The local environment alternated between fluvial and oxbow lake (Westgate et al., 1972), and the climate was temperate boreal, similar in many respects to that of present-day central Alberta (Lichti-Federovich, 1975). No arctic, subarctic, or grassland elements were recognized.

Five radiocarbon dates on wood and peat show that sediment was deposited during an interval beginning before 43 500 ± 620 BP (GSC-1020) and ending after 27 400 ± 850 BP (I-4878; Westgate et al., 1972). The Watino Nonglacial Interval is therefore Middle Wisconsinan.

This event has been recognized at a number of locations throughout the Prairies (Fig. 3). Stratified units are assigned to this event because they can be dated as Middle Wisconsinan and/or they are the first nonglacial units underlying the Late Wisconsinan tills.

The Watino event may have been recognized in the Fort Assiniboine area (Fig. 2, 3) where a date of greater than 52 000 BP (GSC-1019-2) was obtained from wood in glaciofluvial gravel lying between two tills, the lower of which is likely Early Wisconsinan (St-Onge, 1972a, p. 162).

In the Medicine Hat area of southern Alberta a number of radiocarbon dates show that this interval extended from before 38 700 ± 1100 BP (GSC-1442-2) to after 24 490 ± 200 BP (GSC-205). The vertebrate fossils and sedimentology suggest a climate that was "not overly cold" followed by a gradual cooling which culminated with periglacial conditions (Stalker, 1976).

A number of sites in Saskatchewan have yielded finite dates ranging from about 38 ka to about 20 ka (Christiansen, 1968a, b, 1971). The dates of 27 750 ± 1200 (S-96) and 38 000 ± 560 BP (GSC-1041) are on wood or gyttja, and the others are on carbonaceous silt or the organic fraction of a weathering zone under Battleford Formation (Fig. 3; Christiansen, 1971, 1973, p. 30; SkwaraWoolf, 1981). No paleoclimatic information nor vertical sequence of dates is available for any site. Christiansen (1971) described a widely recognized weathering zone at the top of the Floral Formation and attributed this to Middle Wisconsinan weathering.

In southwestern Manitoba the Watino Nonglacial Interval is recorded by the sediment in the Zelena section (Fig. 2, 3; Klassen, 1969, 1972, 1979). The dates obtained from his 'middle deposits' are 23 700 ± 290 (GSC-1279) and 37 700 ± 1500 (GSC-653) on charcoal, and 28 220 ± 380 (GSC -711) on marl (Klassen, 1979). These were the first finite subtill dates obtained in Manitoba. Ostracodes from this section indicate that the sediments were deposited in a mesotrophic or eutrophic lake similar to the present local water bodies.

In southeastern Manitoba sediments of the Vita Formation (Fig. 3) likely date from this interval because (1) they are the first nonglacial unit underlying the Late Wisconsinan tills and (2) the radiocarbon dates on wood are >41 000 (GSC-1663) and >43 000 BP (GSC-1801), indicating that these sediments cannot be younger than Middle Wisconsinan (Fenton, 1974). The lowest part of the unit consists of periglacially deformed gravel and sand overlain by floodplain deposits containing wood and vertebrate and invertebrate fossils. These fossils suggest a slightly moist, grassland or tundra environment adjacent to coniferous forest containing some broad leaf trees and indicate a climate cooler and drier than the present (Delorme, in Fenton, 1974).

Radiocarbon dates show that the Watino Nonglacial Interval on the Prairies before 52 ka and ended after 23.7 ka. In all likelihood this nonglacial interval was of greater duration in the west than the east (nearer the ice centre). No evidence has been found for a glacial advance on the Prairies during the Watino Nonglacial Interval, that is, there is no site with two nonglacial units dated as Middle Wisconsinan separated by till. The Watino event falls within the 25 to 65 ka interval of the Middle Wisconsinan Substage as defined by Dreimanis (1982) and discussed by Dreimanis and Raukus (1975).

Lostwood Glaciation (Late Wisconsinan)

Lostwood Glaciation was defined by Clayton (1972) and the name taken from the town of Lostwood in northwestern North Dakota. This is the glaciation that advanced across the Prairies during the Late Wisconsinan and brought the Watino Nonglacial Interval to a close (Moran et al.. 1976, Fig. 2, p. 149).

A more detailed description of this event than for preceding ones is possible because of the greater amount of data that is available. Comment will be made on glacial flow direction, maximum extent, style of deglaciation, and chronology.

The exact location and history of the centres of flow for Lostwood Glaciation are not completely understood (Shilts, 1980; Denton and Hughes, 1981; Dyke et al., 1982) but flow onto the Prairies came from the northeast – Labradorean centre – and from the north – the Keewatin centre. The first advance to reach the Prairies was from the Labradorean centre (Clayton and Moran, 1982; Dredge and Nixon, 1982; Dredge and Grant, 1982; Fenton et al.. 1983) and deposited a sandy till in eastern Manitoba and North Dakota and possibly reached the Manitoba Escarpment (Fenton et al., 1983). This was succeeded by southward and southwestward flow from the Keewatin centre that covered most of the Prairies. Later flow from either a western extension of the Keewatin centre (Clayton and Moran, 1982) or possibly a newly developed western centre (Dyke et al., 1982) resulted in a final southeastward flow over a major part of the Prairies.

Lostwood Glaciation ice covered all of Manitoba, most of Saskatchewan, and much of Alberta (Fig. 2). In northwestern Alberta and northeastern British Columbia this ice from the Canadian Shield coalesced with ice from the Cordillera. In southwestern Alberta, however, an ice-free re-entrant likely remained between these two ice masses (Rutter, 1980, 1981, 1982; this volume; Prest, this volume). Whether the Late Wisconsinan glacier extended southwest into Montana, from Alberta, is still uncertain. Stalker (1977, 1980) and Barendregt and Stalker (1983) favoured a Late Wisconsinan ice margin within Alberta whereas Christiansen (1979), Clayton and Moran (1982), D.S. Fullerton (personal communication, 1982) and Shetsen (1981) favoured an advance terminating in Montana.

The maximum Late Wisconsinan Laurentide ice margin extended south and southeastward from northeastern British Columbia. In Alberta and western Saskatchewan it was relatively close to the Canadian border but farther east it extended southward many hundreds of kilometres to terminate in South Dakota and Iowa (Fig. 2; Prest, this volume).

Lostwood Glaciation is time-transgressive, beginning earliest on the eastern and northern margins of the Prairies. The glaciation reached southern Alberta after 24 490 ± 220 BP (GSC-205, Stalker, 1976, p. 401), likely about 22 ka (Stalker, 1977, 1980), and reached its maximum limit in Iowa, south of the Prairies, by about 20 ka (Ruhe, 1969; Clayton and Moran, 1982). Cordilleran glaciation was approximately synchronous (Fulton, 1982, 1984).

Deglaciation in the central plains was characterized by a series of retreats (generally resulting from stagnation of large areas of ice at the margin) alternating with minor readvances or stillstands. The strength and extent of these readvances varied from one area to the next so that the retreat of the active ice margin was irregular. At least nine ice-marginal positions have been recognized across the Prairies (Christiansen, 1979; Clayton and Moran, 1982).

Recent syntheses of data from stratigraphy, glacial geomorphology, drainage patterns, and radiocarbon dates have allowed the preparation of a number of regional scale histories of deglaciation: Christiansen (1979) covered southern Saskatchewan and adjacent areas; Clayton and Moran (1982), all of the Prairies from Alberta to North Dakota through to Iowa; Fenton et al. (1983), southern Manitoba and the states of Minnesota and North Dakota; Klassen (1972, 1975), southeast Saskatchewan and southwestern Manitoba; St-Onge (1972b), north-central Alberta; Mathews (1980), northeastern British Columbia and adjacent Alberta; and Teller and Fenton (1980), south-central and southeastern Manitoba.

These reports have shown that there are two general views on chronology and the use of radiocarbon dates: one advocates using all of the available stratigraphically significant dates (Klassen, 1972, 1975; Christiansen, 1979), the other advocates using only dates from wood (Teller and Fenton, 1980; Clayton and Moran, 1982; Fenton et al., 1983). The reasons for the second view is a distrust of dates on nonwood materials. Most nonwood samples that have been dated consist of organic-rich silts, marl, or paleosol horizons; these may be contaminated by old carbon from coal which is present in the underlying sediments or from carbonate derived from bedrock. Further discussion of these views and problems can be found in Nambudiri et al. (1980), Clayton and Moran (1982), and Fenton et al. (1983).

In northeastern Alberta the eastward retreat of the Laurentide glacier started sometime before 13.5 ka (St-Onge, 1972b; Mathews, 1980; Rutter, this volume).

Assuming that the Laurentide Ice Sheet extended into Montana, according to Christiansen (1979) it had retreated north of the Canada-United States border by 16.5 ka, but according to Clayton and Moran (1982) it did not retreat into Alberta until 14 ka. In Saskatchewan and southwestern Manitoba the margin retreated north of the International Boundary by about 14 ka (Klassen, 1972, 1975; Christiansen, 1979) but after 12 ka (Clayton and Moran, 1982). In south-central and southeastern Manitoba the glacier readvanced a number of times into glacial Lake Agassiz, which extended southward into North Dakota and Minnesota. The initial retreat across the 49th parallel in this area was about 15.5 ka (Christiansen, 1979) or 14.5 ka (Klassen, 1972, 1975) or after 12 ka (Clayton and Moran, 1982; Fenton et al., 1983). This comparatively late retreat of the ice (after 12 ka) is required to accommodate a readvance of this glacier into South Dakota at 12.3 ka (Clayton and Moran, 1982; Fenton et al., 1983). Active ice had retreated from the Prairies by about 10 ka (Prest, 1969).

Glacial lakes were ponded by the downslope-retreating glacier at a number of places. The largest of these was Lake Agassiz which covered much of Manitoba and parts of Saskatchewan, Ontario, North Dakota, and Minnesota

(Elson. 1967; Teller and Clayton. 1983). These lakes and their spillways formed an interconnected drainage system which emptied first into the Gulf of Mexico. via the Mississippi, later into the Great Lakes, and finally into Hudson Bay. Drainage into Lake Superior for the first time occurred about 10 ka (Clayton, 1983; Fenton et al., 1983; Teller and Thorleifson. 1983). By 7.5 ka the west-central part of Hudson Bay was free of glacial ice, allowing the marine invasion of the Hudson Bay Lowland and the drainage of Lake Agassiz (Craig, 1969; Elson. 1967; Dredge and Grant, 1982; Shilts, 1982; Andrews et al., 1983; Klassen, 1983).

CORRELATION

Figure 4 shows a proposed inter-regional correlation. This correlation has been accomplished by matching units related to the last glacial and the Middle Wisconsinan nonglacial interval at the tops of the columns (the part controlled by radiocarbon dating) and matching the youngest unit showing 'true' interglacial conditions at the base.

SUMMARY

Five early or middle Pleistocene events have been recognized on the Prairies: PW Event, Wellsch Nonglacial Interval, Wascana Nonglacial Interval, Redcliff Nonglacial Interval, and Dunmore Glaciation. The first, the PW Event, represents one or more early Pleistocene Laurentide glaciation(s) which deposited the Precambrian Shield stones found in the nonglacial sediment at Wellsch Valley; however. this glaciation(s) did not reach as far west as Medicine Hat. The Wellsch Nonglacial Interval followed. Both events occurred during the Matuyama Reversed Epoch and the nonglacial probably during the Olduvai Event.

The next recorded event, the Wascana Nonglacial Interval of Aftonian age, is much younger than the Wellsch Nonglacial Interval. The exact temporal relationship between the Wascana and the next event is uncertain.

During the Redcliff Nonglacial Interval of late Kansan to Yarmouthian vertebrate age the lower group of sediments in the Medicine Hat area was deposited.

Dunmore Glaciation followed the Redcliff Nonglacial Interval and deposited two or more tills in the Medicine Hat area. This was the most extensive glaciation to affect the Prairies with one advance extending to the eastern slopes of the Rocky Mountains in southwestern Alberta. The event is estimated to be of Illinoian age.

Four late Pleistocene events have been recognized at a number of sites throughout the Prairies; these are: the Osler Nonglacial Interval, Burke Lake Glaciation. Watino Nonglacial Interval, and Lostwood Glaciation.

The Osler is believed to be of Sangamonian age and the Burke Lake of Early Wisconsinan age; the Watino is Middle Wisconsinan and the Lostwood is Late Wisconsinan.

These events are recognized from stratigraphic, paleontological, and chronological data.

The chronology for the pre-Watino events is derived from correlation with events outside the Prairies, fission track age dates or by speculation. The local chronology for younger events is based on radiocarbon dates. The Watino Nonglacial Interval started before 43.5 ka, and perhaps before 52 ka, and ended after 23.7 ka. The succeeding Lostwood Glaciation ended on the Prairies by about 10 ka.

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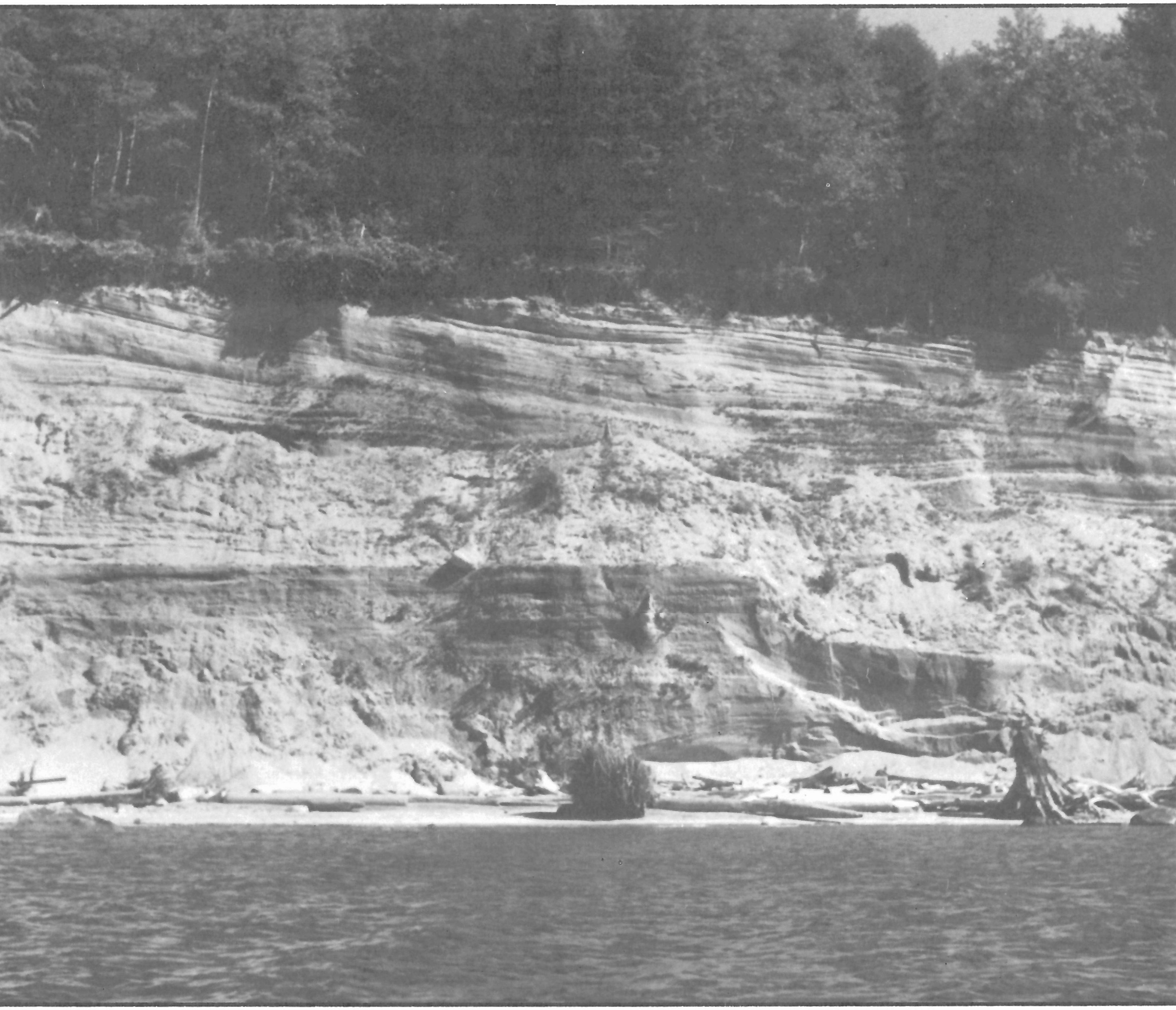

Thormandy Island, western British Columbia: Horizontally stratified, Late Wisconsinan proglacial outwash sand (Quadra Sand) overlain by gently dipping beds of postglacial marine offlap sand. Large boulder at the contact between the two is a remnant of the till which, prior to marine erosion, overlay Quadra Sand. Stratigraphy by J.G. Fyles; photo by R.J. Fulton, GSC 203193-O.

SUMMARY OF QUATERNARY STRATIGRAPHY AND HISTORY, WESTERN CANADA

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Fulton, R.J., Fenton, M.M., and Rutter, N.W., Summary of Quaternary stratigraphy and history, Western Canada; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 69-83, 1984.

Abstract

Deposits of three Wisconsinan substages (Early, Middle, and Late), Sangamonian Stage, Illinoian Stage, and older Quaternary stratigraphic units are recognized in Western Canada. The age assignment of these units is based on radiocarbon dating, vertebrate paleontology, paleomagnetic data, and on dating and correlation of tephra.

Quaternary deposits older than Illinoian are probably present in most parts of Western Canada but only in southern Alberta and Saskatchewan is there definite stratigraphic evidence (vertebrate paleontology and paleomagnetic) which permits assigning ages to these units. Here, faunal assemblages with Aftonian, Kansan, and Yarmouthian affinities have been identified in both glacial and nonglacial deposits.

Glacial deposits referred to the Illinoian Stage are present in many parts of the area. The age of these is generally based on stratigraphic position: they underlie nonglacial deposits or a weathering horizon ascribed to the Sangamonian Stage. The most extensive glaciation of the southern Canadian Plains occurred during this stage and it probably was the first time that Laurentide ice reached the Cordillera.

Nonglacial materials of Sangamonian age have been identified in all parts of the area where intensive Quaternary stratigraphic work has been done. The age assignment of these units is in most places based on their warm climate affinities, stratigraphic position below Middle Wisconsinan nonglacial units, content of vertebrate fossils, and presence of organic material older than the limit of radiocarbon dating.

Early Wisconsinan glacial deposits occur in all areas where Sangamonian interglacial and Middle Wisconsinan nonglacial deposits have been recognized. In most other areas they are difficult to separate from older glacial deposits.

There is abundant evidence that the Middle Wisconsinan Substage was primarily a nonglacial period in Western Canada. Recognition of Middle Wisconsinan deposits is primarily based on the presence of organic material, 20 to 50 ka, dated by the radiocarbon method.

Evidence of cooler climates, heralding Late Wisconsinan glaciation, is locally present as early as 29 ka. The southern Canadian Plains were probably covered by Laurentide ice by 20 ka but the Cordilleran ice was still advancing in southern British Columbia 17.5 ka ago. The Late Wisconsinan Laurentide ice advance in the southern Plains was not as extensive as the Illinoian or Early Wisconsinan advances. The same appears true of the northern sector of the Cordilleran ice sheet, but in the southern sector, the limits of Late Wisconsinan and earlier ice sheets lie outside the area covered by this report. The Late Wisconsinan Cordilleran Ice Sheet was retreating by 13 ka, and by 10 ka glacier cover was little more extensive than at present. The Laurentide Ice Sheet was retreating before 13.5 ka, had probably receded onto the Shield by 11.5 ka, and had disappeared from Western Canada by 7.3 ka.

Résumé

Des dépôts de trois stades du Wisconsinien (inférieur, moyen et supérieur), du stade interglaciaire sangamonien et du stade glaciaire Illinoien, ainsi que des unités stratigraphiques quaternaires plus anciennes ont été identifiés dans l'Ouest canadien. L'âge de ces formations est déterminé au moyen de la datation au carbone radioactif, de la paléontologie des vertébrés, de données paléomagnétiques et de la datation et de la corrélation du tephra.

Il existe probablement des dépôts quaternaires antérieurs à l'Illinoien dans la plupart des régions de l'Ouest canadien, mais c'est uniquement dans le sud de l'Alberta et de la Saskatchewan que l'on rencontre des indications stratigraphiques suffisamment précises (paléontologie des vertébrés et données paléomagnétiques) pour permettre l'attribution d'âges à ces unités. On y a reconnu, dans des dépôts glaciaires et non glaciaires, des assemblages fauniques qui présentent des affinités d'origine aftonienne, kansienne et yarmouthienne.

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Manuscript received: 1983-04-03
Final version approved for publication: 1983-06-13

Beaucoup de parties de cette région contiennent des dépôts glaciaires attribués à l'Illinoien. Leur âge est généralement établi d'après leur position stratigraphique; ils reposent sous des dépôts non glaciaires ou un horizon d'altération attribués au Sangamonien. Non seulement la plus vaste glaciation du sud des Plaines canadiennes a-t-elle eu lieu au cours de cette période, mais il s'agissait aussi, tout probablement, de la première fois que le glacier des Laurentides atteignait la Cordillère.

Des matériaux non glaciaires datant du Sangamonien ont été reconnus dans toutes les parties de la région où ont eu lieu des travaux intensifs de stratigraphie du Quaternaire. Dans la plupart des endroits, l'âge des unités est déterminé d'après leur association avec des climats chauds, leur position stratigraphique sous des unités non glaciaires du Wisconsinien moyen, leur teneur en fossiles vertébrés et la présence de matières organiques dont l'âge ne peut être déterminé par la méthode de datation au carbone radioactif.

On rencontre des dépôts glaciaires du Wisconsinien inférieur dans toutes les zones où des dépôts non glaciaires de l'interglaciaire sangamonien et du Wisconsinien moyen ont été reconnus. Presque partout ailleurs, ils sont difficiles à distinguer des sédiments glaciaires plus anciens.

Beaucoup d'éléments tendent à confirmer que le stade du Wisconsinien moyen était essentiellement une période non glaciaire dans l'Ouest canadien. Les dépôts de cette période se reconnaissent à leur contenu de matières organiques, dont la datation au moyen de la méthode du carbone radioactif établit l'âge à 20 à 50 ka.

Les signes d'un refroidissement des climats, précurseurs de la glaciation du Wisconsinien supérieur, apparaissent par endroits dès 29 ka. La partie sud des Plaines canadiennes a probablement été recouverte par le glacier des Laurentides il y a 20 ka, mais le glacier de la Cordillère était encore en progression dans le sud de la Colombie-Britannique il y a 17,5 ka. L'avancée du glacier des Laurentides dans le sud des Plaines, au Wisconsinien supérieur, n'a pas atteint l'ampleur des phases de croissance de l'Illinoien ou du Wisconsinien inférieur. Ce phénomène se reproduit également, semble-t-il, dans le secteur nord de l'indlandsis de la Cordillère; cependant, dans le secteur sud, l'indlandsis du Wisconsinien supérieur et des glaciers antérieurs ont débordé le territoire qui fait l'objet du présent rapport. Il y a 13 ka, au cours du Wisconsinien supérieur, l'inlandsis de la Cordillère amorçait sa phase de recul et 3 ka plus tard, couvrait à peine plus de territoire qu'aujourd'hui. Quant au glacier des Laurentides, les étapes de sa régression, commencée il y a plus de 13,5 ka, l'ont vu regagner le Bouclier 2 ka plus tard et, depuis 7,3 ka, il a complètement disparu de l'Ouest canadien.

INTRODUCTION

This summary report covers Canada from the Pacific Ocean east to Ontario and includes the areas discussed in the Cordilleran, Prairies and "Ice-free corridor" regional reports (Fulton, this volume; Fenton, this volume; Rutter, this volume).

The Cordilleran region (Fig. 1) consists of generally north-south oriented mountain ranges separated by rolling uplands, major valleys, and local lowlands. During glacial periods the area, with the exception of the northern quarter, was occupied by a mountain ice complex referred to as the Cordilleran ice sheet (Prest, this volume). Areas with good exposures of Quaternary deposits are widely scattered so that our knowledge of the Quaternary in this region is fragmentary; however, forest vegetation predominated during all Quaternary nonglacial periods so that where Quaternary sediments are present they commonly include abundant organic material which can be used for dating and paleoecological studies.

The southern Canadian Plains (Fig. 1) consist largely of a gently rolling plain cut by major river valleys. This area was occupied by southern and western extensions of the Laurentide ice sheet (Prest, 1969, 1970, this volume) during glacial periods. Thick Quaternary sediments are present in many areas but are exposed only where intersected by major Holocene valleys. Some data are available from boreholes but they are generally difficult to interpret. In the south, where most Quaternary stratigraphic studies have been carried out, climate during Quaternary nonglacial periods was generally dry and vegetation limited to grasses; consequently, plant remains in sediments are sparse. This general lack of Quaternary plant materials is however made up for by relatively abundant vertebrate remains which supply relatively good chronological control and paleoecological information.

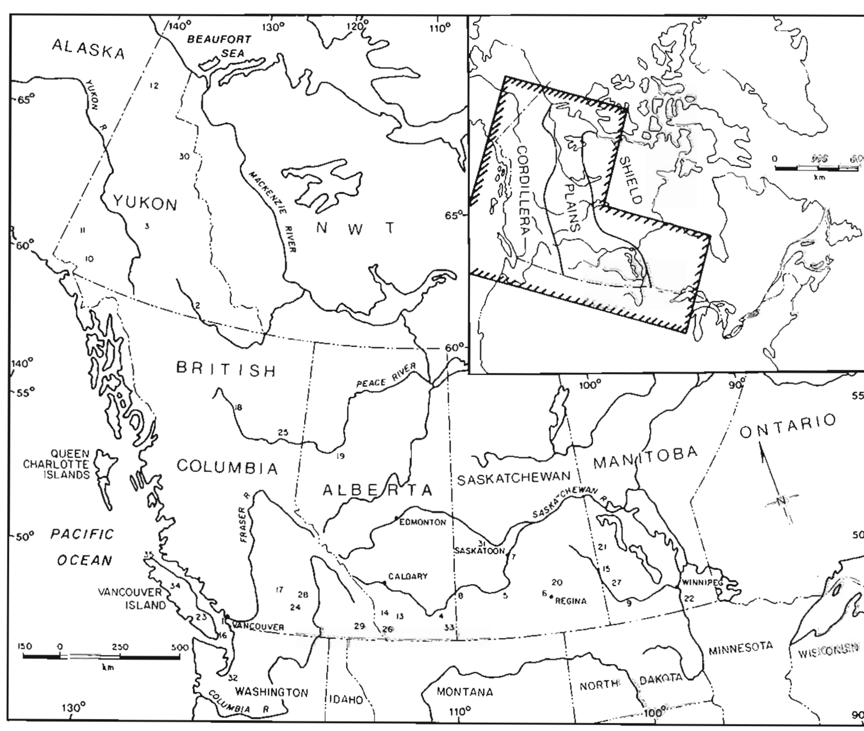

Figure 1. Location map for sites mentioned in the text. The inset map shows the extent of the larger scale map and location of Cordilleran, Plains, and Canadian Shield regions.

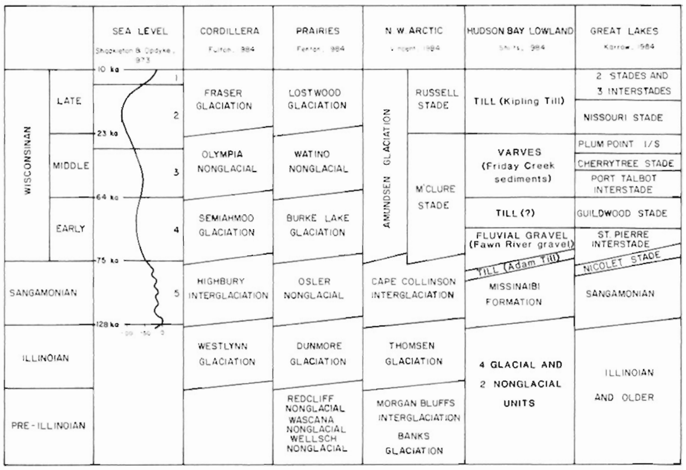

Figure 2. *Correlation chart for Quaternary of Western Canada and adjacent areas. The time scale is nonlinear and consequently the vertical axis of the sea level curve has been adjusted so that the oxygen isotope stage boundaries correspond with the Wisconsinian Substage boundaries as described in the text.*

The "ice-free corridor" is the area between and in the confluence and overlap zone of the Cordilleran and Laurentide ice sheets (Rutter, this volume). The eastern part of this region lies in the Plains and the western part in the Cordillera. The central part consists of the Foothills which mark the transition between the Plains and the Cordillera.

Stage and substage are the chronostratigraphic units used in this summary report. Event units used are: glaciation, interglaciation, and nonglacials. Both interglaciation and nonglacial are periods when the climate may locally have been essentially as warm as present, but the term interglaciation is reserved for periods that appear to correlate with world-wide reduction in ice cover to near present levels; nonglacial is used for periods of significant ice retreat when the global extent of ice is either unknown or is known to have been greater than at present.

This report correlates the events of the Wisconsinan, Sangamonian, and Illinoian stages and combines older events as pre-Illinoian. The Wisconsinan Stage is considered as equivalent to oxygen isotope stages 2 through 4 of Shackleton and Opdyke (1973). The Early, Middle, and Late subdivisions of the Wisconsinan (64-75, 23-64, and 10-23 ka, respectively) are approximately those used by Dreimanis and Karrow (1972) and Dreimanis et al. (1981). The Sangamonian is the last stage during which the climate was as warm as present and global ice cover and sea level stood near present day levels. It is considered to have begun by about 128 ka (oxygen isotope stage 5/6 boundary; Shackleton and Opdyke, 1973, p. 49) and to have ended by about 75 ka (oxygen isotope stage 4/5 boundary; Shackleton and Opdyke, 1973, p. 49). The Illinoian Stage immediately precedes the Sangamonian. In Illinois this stage consists of three substages (Willman and Frye, 1970, p. 84). Because of the difficulty in long distance correlations in earlier parts of the Quaternary record, no attempt is made to identify these substages in Western Canada. Stratigraphy older than Illinoian is simply referred to as pre-Illinoian in this report although locally vertebrate faunas have been assigned to older chronostratigraphic units.

In parts of the Quaternary falling within the radiocarbon dating range (Late and Middle Wisconsinan), correlations are based on this dating method. Correlations of earlier parts of the record are based on relationships with dated units and counting downwards, and in the Canadian Plains on vertebrate paleontology, and paleomagnetic and tephra data.

Acknowledgments

This paper has been improved by the comments of J.T. Andrews, A. Dreimanis, D.R. Grant, P.F. Karrow, and V.K. Prest.

PRE-ILLINOIAN

Individual exposures and areas of deposits known to be pre-Illinoian are present in widely scattered areas but in general too few data are available to permit any valid correlations. Consequently all these "older" Quaternary deposits are discussed as a single unit (Table 1).

Pre-Illinoian deposits are probably present in lower parts of thick valley fills in the Cordilleran region. Armstrong (1975, p. 380; Table 1, 1 of Fig. 1) reported 95 m of sand, silt, till, and gravel underlying his Westlynn Drift in the Fraser Lowlands. No details are available on the age or exact nature of these materials but because Westlynn Drift underlies Highbury Sediments (Sangamonian equivalent?), they are probably of pre-Illinoian age.

Klassen (1978; Table 1, 2 of Fig. 1) reported on thick sections in the southeastern Yukon which contain deposits of "at least 4 major intervals of glaciation". Some of these probably are of pre-Illinoian age but at the moment no evidence of their antiquity has been reported.

Also in the Yukon, the Nansen and Klaza advances (Bostock, 1966; Table 1, 3 of Fig. 1) are probably of pre-Illinoian age. Deposits related to these advances, however, are not known in stratigraphic section and this age assignment is based on the premise of Hughes et al. (1972, p. 5) that Reid Glaciation, which postdates them, is equivalent to Shakwak Glaciation (Illinoian) of Denton and Stuiver (1967).

Deposits known to be of pre-Illinoian age have been studied in the southern part of the Canadian Plains. The oldest Quaternary unit of the southwestern Prairies is the Saskatchewan Gravels and Sands (Stalker, 1968; Table 1, 4 of Fig. 1). This consists of gravels and sands devoid of material derived from the Canadian Shield and lying in "typical broad gentle walled preglacial valleys". The lack of Shield erratics indicates that these deposits predate Quaternary glaciations which later carried clasts of Shield lithology into this area.

Christiansen, in a stratigraphy based largely on borehole data, has indicated that thick Quaternary sediments underlie much of southern Saskatchewan. The Empress Group (Whitaker and Christiansen, 1972; Table 1, 8 of Fig. 1) at the base of this succession consists of late Tertiary to Quaternary stratified sediments and includes the Saskatchewan Gravels and Sands (devoid of Shield erratics) at its base. The uppermost till of the overlying Sutherland Group is of pre-Sangamonian age (Christiansen, 1972, p. 217; Table 1, 7 of Fig. 1), and in Westgate et al. (1977, p. 371) it is speculated that the till unit overlying the Sutherland Group, lower part of Floral Formation, may be as old as 0.6 to 0.7 Ma (fission track date on Wascana Creek Ash). Hence even though specific age assignments have not been made for lower units traced in boreholes over much of Saskatchewan, the Empress Group and at least part of the overlying Sutherland Group are pre-Illinoian.

Stalker and Churcher (1972) and Stalker (1976) reported on a vertebrate fauna of either Aftonian or early Kansan age (based on land-mammal ages which are correlated with glacial ages in Hibbard et al., 1965, p. 514) from gravels at the Wellsch Valley site (5 of Fig. 1) in southwestern Saskatchewan. Paleomagnetic data also show part of the bone-bearing sediment to be magnetically reversed (Foster and Stalker, 1977) and hence probably older than 0.79 Ma

Table 1. Pre-Illinoian Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERA			
SW British Columbia	1	undivided till and stratified sediments	Armstrong, 1975
SE Yukon	2	unnamed tills and stratified sediments	Klassen, 1978
C Yukon	3	Klaza Drift (?)	Bostock, 1966
		Nansen Drift	Bostock, 1966
PRAIRIE		WELLSCH AND REDCLIFF NONGLACIALS	
S Alberta	4	nonglacial sand and silt	Stalker, 1976
	4	Saskatchewan Gravels and Sands	Stalker, 1968
S Saskatchewan	5	nonglacial stony silt, clay sand and gravel (Wellsch Valley)	Stalker and Churcher, 1972
	6	Wascana Creek Ash	Westgate et al., 1977
	7	Sutherland Group	Christiansen, 1968a
	8	Empress Group	Whitaker and Christiansen, 1972
SW Manitoba	9	unnamed lower deposits (glacial and nonglacial)	Klassen, 1969
	9	Souris Gravels and Sands	Klassen, 1969
SE Manitoba	22	stratified drift	Fenton, 1974
		Rosa Formation (till)	Fenton, 1974

(Johnson, 1982). The presence in this gravel of erratic pebbles from the Canadian Shield indicates that at some previous time Laurentide ice had advanced at least this far south. Fenton (this volume) has used this succession to define his Wellsch Nonglacial Interval. Unfortunately there are no data which might provide ages for the four or more till units which overlie this important nonglacial unit.

The Redcliff nonglacial unit (Fenton, this volume), which comprises fossiliferous fluvial and lacustrine sediments lying at the base of sections at Medicine Hat (Stalker, 1976; Table 1, 4 of Fig. 1), is also of pre-Illinoian age (based on vertebrate fauna). The deposits defining this unit are devoid of Shield erratics (predate Laurentide glaciation of this area) and their vertebrate faunal assemblages indicate that they are mid-Kansan through Yarmouthian in age (Stalker, 1976, p. 393). The fact that these deposits do not contain Shield erratics, whereas these are present in older deposits (Aftonian to early Kansan) at Wellsch Valley 220 km to the east, suggests that one or more early glaciations that overrode the Wellsch Valley area did not reach Medicine Hat.

In southwest Manitoba, Klassen (1969) recognized a 'preglacial gravel' (the Souris, Table 1, 9 of Fig. 1) and several unnamed glacial and nonglacial deposits which underlie Shell Till. Shell Till is probably of pre-Sangamonian age and hence these units are probably at least in part pre-Illinoian. By similar reasoning the Rosa Formation and stratified drift which underlie the Woodmore Formation (pre-Sangamonian) of eastern Manitoba are possibly pre-Illinoian (Fenton, 1974, Table 1, 22 of Fig. 1).

ILLINOIAN

The Illinoian Stage is the period of glaciation in Western Canada which immediately preceded the Sangamon (last) Interglaciation.

In the southern Cordillera, only one unit has been defined which probably relates to the Illinoian. This is Westlynn Drift (Armstrong, 1975, p. 280; Table 2, 1 of Fig. 1) which underlies Highbury Sediments (Sangamonian?) in the Fraser Lowlands.

In southwestern Yukon Territory, Denton and Stuiver (1967; Table 2, 10 of Fig. 1) defined the Shakwak as the glaciation that occurred before a marked weathering interval which preceded a Middle Wisconsinan weathering interval. Hence Shakwak Glaciation would appear to be of Illinoian age. Mirror Creek Glaciation (Rampton, 1971; Table 2, 11 of Fig. 1) and Reid Glaciation (Bostock, 1966; Table 2, 3 of Fig. 1) might also be Illinoian but because these have not been shown to underlie deposits of Sangamonian age their precise stratigraphic positions are uncertain (Fulton, this volume, 1984b).

The Old Crow Basin in the northern unglaciated part of the Yukon (12 of Fig. 1) contains deposits referred to as glaciolacustrine which underlie sediments assigned to the Sangamonian (Jopling et al., 1981; Table 2). These might be Illinoian.

The southern end of the "ice-free corridor" contains three glacial units (Labuma, Maunsell, and Brocket tills) which are assigned to the Illinoian (Rutter, this volume; Table 2, 13 of Fig. 1); this assignment is taken from Stalker and Harrison (1977) and is based on stratigraphy in river valleys to the east. In these valleys the oldest glacial deposits containing Laurentide erratics overlie sediments which contain a vertebrate fauna having Yarmouthian affinities (Stalker, 1976). Consequently the oldest Laurentide glacial unit at the southern end of the "ice-free corridor" can be no older than early Illinoian. Erratics left by this advance mark the farthest southwestward advance of Laurentide ice (Stalker and Harrison, 1977, p. 894). These oldest glacial deposits from the Canadian Shield overlie and are thought to be in part contemporaneous with Cordilleran glacial deposits (Albertan Till of Stalker and Harrison, 1977, and Maycroft Till of Alley, 1973) which mark the farthest advance of ice from the west.

In the Prairies, Fenton (this volume) grouped the units that lie between Stalker's youngest fluvial deposits containing Yarmouthian affinity faunal remains and his oldest containing Sangamonian vertebrate assemblages in the Dunmore Glaciation. In the Medicine Hat area this unit includes a lacustrine unit at the base, two tills, and thin interbedded fluvial deposits (Stalker, 1976). Correlative deposits are undoubtedly present farther east in the glacial succession which overlies the basal fluvial unit at Wellsch Valley (Stalker, 1976) and in the Sutherland Group of Christiansen (1968a; Table 2, 7 of Fig. 1) but appropriate stratigraphic data are not available to differentiate units of this age.

Klassen (1969) defined Shell Till (Table 2, 15 of Fig. 1) in southwest Manitoba. This till underlies Roaring River Clay which according to Klassen (1969, p. 13) is possibly of Sangamonian age. In southeast Manitoba Fenton (1974; Table 2, 22 of Fig. 1) recognized the Woodmore Formation which immediately underlies the Sangamonian-age St. Malo Formation.

SANGAMONIAN

The Sangamonian is the oldest time period that workers in most parts of western Canada feel they can recognize with confidence. In general, however, assignment of a unit to the Sangamonian Stage is based on stratigraphic position below Middle Wisconsinan deposits and/or implication of a paleoenvironment similar to or warmer than present.

In southern British Columbia, Muir Point Formation of Hicock and Armstrong (1983; Table 3, 16 of Fig. 1), Highbury Sediments of Armstrong (1975; Table 3, 1 of Fig. 1) and Westwold Sediments of Fulton and Smith (1978; Table 3, 17 of Fig. 1) have all been assigned to the Sangamonian because they appear to have been deposited under climatic

Table 2. Illinoian Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERAN		WESTLYNN GLACIATION	
SW British Columbia	1	Westlynn Drift	Armstrong, 1975
SW Yukon	10	Shakwak Drift	Denton and Stuiver, 1967
W-C Yukon	11	Mirror Creek Glaciation (?)	Rampton, 1971
C Yukon	3	Reid Glaciation (?)	Bostock, 1966
	3	Klaza Drift (?)	Bostock, 1966
N Yukon	12	Unit 1	Jopling et al., 1981
"ICE-FREE CORRIDOR"			
SW Alberta	13	Brocket Till	Stalker and Harrison, 1977
	13	Maunsell Till	Stalker and Harrison, 1977
	13	Labuma Till	Stalker and Harrison, 1977
	13	Albertan Till	Stalker and Harrison, 1977
	14	Maycroft Till	Alley, 1973
PRAIRIE		DUNMORE GLACIATION	
S Alberta	4	Twin Cliffs Formation	Stalker, 1976
S Saskatchewan	7	Sutherland Group	Christiansen, 1968a
SW Manitoba	15	Shell Till	Klassen, 1969
SE Manitoba	22	Woodmore Formation (till)	Fenton, 1974

Table 3. Sangamonian Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERAN		MUIR POINT INTERGLACIATION	
SW British Columbia	16	Muir Point Formation	Hicock, 1980
	1	Highbury Sediments	Armstrong, 1975
S-C British Columbia	17	Westwold Sediments	Fulton and Smith, 1978
SW Yukon	10	Silver nonglacial	Denton and Stuiver, 1967
N Yukon	12	Unit 2	Jopling et al., 1981
"ICE-FREE CORRIDOR"			
E-C British Columbia	18	fluvial gravel and sand	Rutter, 1976
PRAIRIE		OSLER NONGLACIAL	
W-C Alberta	19	basal gravels	Churcher and Wilson, 1979
S Alberta	4	Mitchell Bluff Formation	Stalker, 1976
S-C Saskatchewan	20	Echo Lake Gravels	Christiansen, 1960
	7	Riddell Member	SkwaraWoolf, 1981
SW Manitoba	21	Roaring River Clay	Klassen et al., 1967
SE Manitoba	22	St. Malo Formation	Fenton, 1974

Table 4. Early Wisconsinan Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERAN		SEMIAHMOO GLACIATION	
SW British Columbia	23	Dashwood Drift	Fyles, 1963
	1	Semiahmoo Drift	Armstrong, 1975
	34	Muchalatat River Drift	Howes, 1981
S-C British Columbia	24	Okanagan Centre Drift	Fulton and Smith, 1978
SW Yukon	10	Icefields Drift	Denton and Stuiver, 1967
W-C Yukon	11	Mirror Creek Glaciation (?)	Rampton, 1971
C Yukon	3	Reid advance (?)	Bostock, 1966
N Yukon	12	Unit 2	Jopling et al., 1981
"ICE-FREE CORRIDOR"			
E-C British Columbia	18	"early advance till"	Rutter, 1976
	25	till of penultimate glaciation	Mathews, 1978
SW Alberta	26	Erratics Train Advance	Stalker and Harrison, 1977
	26	Waterton III	Stalker and Harrison, 1977
	26	Buffalo Lake Till	Stalker and Harrison, 1977
	26	Waterton II	Stalker and Harrison, 1977
	14	Ernst Till	Alley, 1973
PRAIRIE		BURKE LAKE GLACIATION	
S Alberta	4	two tills separated by alluvium and pond deposits	Stalker, 1976
S Saskatchewan	7	Floral Formation	Christiansen, 1968a
SW Manitoba	27	Minnedosa Till	Klassen, 1969
SE Manitoba	22	Tolstoi Formation	Fenton, 1974
	22	Stuartburn Formation	Fenton, 1974

conditions similar to or warmer than present and they underlie glacial deposits which are older than Middle Wisconsinan.

The Silver Nonglacial Interval (Denton and Stuiver, 1967; Table 3, 10 of Fig. 1) occupies a similar position in the southern Yukon. Sediments in the Old Crow Basin contain faunal assemblage of probable Sangamonian age (Harington, 1978, p. 62; Jopling et al., 1981, p. 21; Table 3, 12 of Fig. 1); however, the interstratified channel, overbank, and lacustrine sediments which occupy this unglaciated basin have few marker horizons or regionally traceable deposits so that it is difficult to assign units to Quaternary stages.

The only deposits of possible Sangamonian age in the vicinity of the "ice-free corridor" are in Finlay River valley of British Columbia (18 of Fig. 1) where fluvial gravels and sands containing wood fragments and blocks of peat and marl underlie till which underlies sediments containing plant materials dated as Middle Wisconsinan (Rutter, 1976, p. 417; Table 3).

Fenton (this volume) grouped Sangamonian-age deposits of the southern Canadian Plains in his Osler Nonglacial Interval. This included gravel at the base of a section at Watino in west-central Alberta (Churcher and Wilson, 1979; Table 3, 19 of Fig. 1), about 20 m of gravel and sand at Medicine Hat (Mitchell Bluff Formation of Stalker, 1976, p. 397; Table 3, 4 of Fig. 1), Echo Lake Gravels of the Fort Qu'Appelle site in southern Saskatchewan (Kahn, 1970; Table 3, 20 of Fig. 1) and Riddell Member of the Saskatoon area (SkwaraWoolf, 1981; Table 3, 7 of Fig. 1). These deposits all contain vertebrate assemblages of possible Sangamonian age.

In Manitoba the Roaring River Clay (Klassen et al., 1967; Table 3, 21 of Fig. 1), which contains ecological evidence of deposition under conditions as warm or warmer than present, and the St. Malo Formation (Fenton, 1974; Table 3, 22 of Fig. 1) are older than Middle Wisconsinan and hence are referred to as Sangamonian.

EARLY WISCONSINAN

The Early Wisconsinan is the substage between the Middle Wisconsinan Substage and the Sangamonian Stage. In this report the Early Wisconsinan-Sangamonian boundary is placed at the contact between glacial deposits and underlying Sangamonian Stage sediments or a weathering alteration horizon. It is presumed that the contact is about 75 ka – the age of the boundary between oxygen isotope stages 4 and 5 (Shackleton and Opdyke, 1973, p. 49; Fig. 2) – but it could be earlier. The Early Wisconsinan-Middle Wisconsinan boundary is placed at the contact between Middle Wisconsinan nonglacial sediments or alteration horizons and underlying glacial deposits. The age of this contact is assumed to approximate the age of the boundary between oxygen isotope stages 3 and 4 which is about 64 ka (Shackleton and Opdyke, 1973, p. 49; Fig. 2).

Early Wisconsinan units recognized in southern British Columbia include Dashwood Drift (Fyles, 1963; Hicock, 1980; Table 4, 23 of Fig. 1); Semiahmoo Drift (Armstrong, 1975; Table 4, 1 of Fig. 1), Muchalatat River Drift (Howes, 1981; Table 4, 34 of Fig. 1) and Okanagan Centre Drift (Fulton and Smith, 1978; Table 4, 24 of Fig. 1). These all overlie sediments believed to be Sangamonian equivalent and underlie materials dated as Middle Wisconsinan.

Icefields Drift in southwestern Yukon (Denton and Stuiver, 1967; Table 4, 10 of Fig. 1) is probably Early Wisconsinan because it lies on an unconformity which is considered to be approximately of Sangamonian age and includes organic material at its top dated as Middle Wisconsinan. Mirror Creek Glaciation

(Rampton, 1971; Table 4, 11 of Fig. 1) and Reid Glaciation (Bostock, 1966; Table 4, 3 of Fig. 1) at the northern and western limits of ice sheet glaciation in the Yukon, could be of Early Wisconsinan age but no stratigraphic information is available to indicate their positions relative to Middle Wisconsinan and Sangamonian deposits (Fulton, 1984b).

Occurrence of Early Wisconsinan sediments in the Old Crow Basin has been suggested by Jopling et al. (1981; Table 4, 12 of Fig. 1). These are part of a complex unit which contains a vertebrate fauna with general late Pleistocene affinities and includes a tephra unit in its upper part which has been dated at between 56 and 120 ka (Naeser et al., 1982, p. 2171). It overlies a sediment containing a vertebrate fauna of probable late Illinoian age and underlies sediments containing organic materials dated as Middle Wisconsinan. Subdivision of this unit into a lower, Sangamonian subunit and an upper, Early Wisconsinan one is based largely on a general lack of permafrost features in the lower part of the unit and their apparent abundance in the upper part.

In the "ice-free corridor" area the "early advance till" of Rutter (1976; Table 4, 18 of Fig. 1) lies between deposits which might be Sangamonian and sand containing wood that has provided a Middle Wisconsinan age; consequently, it appears to be Early Wisconsinan. Also Mathews (1978, p. 6; Table 4, 25 of Fig. 1) referred a till lying between two nonglacial units (the upper of which contained a bone dated as Middle Wisconsinan) to the "penultimate glaciation". This probably is of Early Wisconsinan age. In southwest Alberta, Stalker and Harrison (1977; Table 4, 26 of Fig. 1), referred to the post-Sangamonian Erratics Train Advance, Buffalo Lake Till, and Waterton II and III as preclassical Wisconsinan and hence these likely are Early Wisconsinan. Alley (1973; Table 4, 14 of Fig. 1) correlated Ernst Till, deposited by a Cordilleran ice advance, with Buffalo Lake Till so that this too is probably Early Wisconsinan.

On the southern Canadian Plains, Fenton (this volume) designated the Burke Lake Glaciation[1] as the period of glacial advance which occurred during the Early Wisconsinan. At Medicine Hat this interval is represented by two tills separated by alluvium and pond deposits containing vertebrate and plant remains (Stalker, 1976, p. 400; Table 4, 4 of Fig. 1). In Saskatchewan, part of the Floral Formation of Christiansen (1968a; Table 4, 7 of Fig. 1) is probably Early Wisconsinan in age in that it underlies material dated as Middle Wisconsinan (Christiansen, 1968b, p. 335) and overlies or includes sediments judged to be Sangamonian in age on the basis of vertebrate fauna (SkwaraWoolf, 1981, p. 321). The Minnedosa Till in Manitoba (Klassen, 1969, p. 13; Table 4, 27 of Fig. 1) is correlated with the Floral Formation and is likely Early Wisconsinan (Klassen, 1979, p. 9). In southeastern Manitoba, Fenton (1974; Table 4, 22 of Fig. 1) referred the Tolstoi and Stuartburn formations to Early Wisconsinan. Little detailed information is available in Canada on the extent of Laurentide ice cover during the Early Wisconsinan but Clayton and Moran (1982, p. 57) indicated that this ice advance was more extensive than the following Late Wisconsinan advance.

MIDDLE WISCONSINAN

Middle Wisconsinan deposits underlie glacial deposits that are younger than 25 ka and either overlie Early Wisconsinan deposits or contain organic material younger than 64 ka. In terms of the deep-sea oxygen isotope curve, this substage extends from the beginning of stage 3 to about the middle of stage 2 (Shackleton and Opdyke, 1973, p. 49; Fig. 2). Occurrence of Middle Wisconsinan organic materials in most parts of Western Canada indicates that this substage included a significant nonglacial period in this region. The length of the nonglacial interval probably varied with distance from ice accumulation centres but there is evidence in the south, especially in southern British Columbia, that nonglacial conditions existed from before 58 ka until as late as about 19 ka (Fulton, 1971, p. 5; 1976, p. 72; Clague, 1981, p. 5). Glacial deposits of this age might be present but would only be recognized where they were both overlain and underlain by sediments dated as Middle Wisconsinan.

The extent of regional ice sheets at this time is largely unknown. The occurrences of nonglacial deposits throughout the Cordillera suggests that the Cordilleran ice sheet completely disintegrated; McDonald (1971, p. 332) suggested that the Laurentide ice sheet retreated to near Hudson Bay and Shilts (1982, p. 327) and Andrews et al. (1983) suggested that Hudson Bay was at least partially free of ice during the Middle Wisconsinan.

Cowichan Head Formation is the nonglacial deposit of Middle Wisconsinan age (Olympia Interglaciation, Armstrong et al., 1965) recognized in southwestern British Columbia (Armstrong and Clague, 1977; Table 5, 16 of Fig. 1). The climate during deposition of the Cowichan Head Formation was generally similar to present until about 29 ka when a gradual cooling began (Alley, 1979, p. 233). In south-central British Columbia, the Bessette Sediments are of Middle Wisconsinan age (Fulton, 1976, p. 68; Table 5, 28 of Fig. 1); these indicate a climate slightly warmer and drier than present until about 32 ka, when conditions similar to present prevailed (N.F. Alley, personal communication, 1979). Cooling of the climate began about 25 ka. Several sites in central British Columbia, have yielded plant materials yielding Middle Wisconsinan dates from sediments underlying Late Wisconsinan glacial deposits (Fulton, this volume).

The Boutellier Nonglacial Interval (Denton and Stuiver, 1967; Table 5, 10 of Fig. 1) of southwestern Yukon is the name given to a Middle Wisconsinan period characterized by ice retreat and soil formation. A radiocarbon date of 32 400 ± 770 BP (GSC-952, McAllister and Harington, 1969, p. 1185) on mollusc and ostracode shells indicates that sediments were being deposited in the Old Crow area of the unglaciated Yukon during the Middle Wisconsinan.

Hughes et al. (1981; Table 5, 30 of Fig. 1) reported a Middle Wisconsinan wood date (36 900 ± 300 BP, GSC-2422) from alternating sand and silt beds in the eastern part of the Yukon which was covered by Laurentide ice. Rutter (1976; Table 5, 18 of Fig. 1) recognized Middle Wisconsinan nonglacial sediments in Finlay River valley of east-central British Columbia. This correlation is based on a single radiocarbon date. Mathews (1978; Table 5, 25 of Fig. 1) recognized that the Middle Wisconsinan was a time of major valley cutting and deposition of a thick valley fill in the Fort St. John area (chronology based on radiocarbon date of 27 400 ± 580 BP, GSC-2034).

On the Canadian Plains, the Middle Wisconsinan sediments were deposited during the Watino Nonglacial Interval (Fenton, this volume). At Watino, 200 km east of Fort St. John (19 of Fig. 1), nonglacial sediment deposition was occurring from before 43.5 ka until after 27.4 ka (Westgate et al., 1972). Farther south at Medicine Hat, Stalker (1976, p. 401; Table 5, 4 of Fig. 1) recognized two units of Middle Wisconsinan age along with evidence of cooling and ponding (possibly due to advancing ice). Deposition of this material began before 38 ka, and after 29 ka sediments are interpreted to have accumulated in a permafrost environment. Organic materials dated as Middle Wisconsinan have been found at the base of glacial deposits in Saskatchewan (Christiansen, 1968b, p. 335). On the basis of finite radiocarbon dates, Klassen and Elson (1972; Table 5, 15 of Fig. 1) referred the Zelena silt to the Middle Wisconsinan. Fenton and Teller (1977; Table 5, 22 of Fig. 1) correlated the Vita Formation of southeastern Manitoba with Middle Wisconsinan.

[1] This unit is in reality a stade of the Wisconsin Glaciation

Table 5. Middle Wisconsinan Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERAN		OLYMPIA NONGLACIAL	
SW British Columbia	16	Cowichan Head Formation	Armstrong and Clague, 1977
S-C British Columbia	28	Bessette Sediments	Fulton and Smith, 1978
SE British Columbia	29	clay, silt, sand, and gravel	Clague, 1975
SW Yukon	10	Boutellier nonglacial	Denton and Stuiver, 1967
N Yukon	12	Unit 2	Jopling et al., 1981
"ICE-FREE CORRIDOR"			
E Yukon	30	alternating sand and silt	Hughes et al., 1981
E-C British Columbia	18	lacustrine and fluvial sediments	Rutter, 1976
	25	river and lake deposits	Mathews, 1978
PRAIRIE		WATINO NONGLACIAL	
W-C Alberta	19	fine grained, fossiliferous sediments	Westgate et al., 1972
S Alberta	4	alluvial silt and clay and organic sediment (Evilsmelling Band)	Stalker, 1976
SW Manitoba	15	Zelena silt	Klassen and Elson, 1972
SE Manitoba	22	Vita Formation	Fenton, 1974

Table 6. Late Wisconsinan Units

REGION	SITE (Fig. 1)	UNIT	REFERENCE
CORDILLERAN		FRASER GLACIATION	
SW British Columbia	1	Sumas Drift	Armstrong, 1981
	1	Fort Langley Formation	Armstrong, 1981
	1	Capilano Sediments	Armstrong, 1981
	1	Vashon Drift	Armstrong, 1981
	1	Quadra Sand	Clague, 1976
	34	Gold River Drift	Howes, 1981
	35	Port McNeill Drift	Howes, 1983
	1	Coquitlam Drift	Hicock and Armstrong, 1981
S-C British Columbia	17	Kamloops Lake Drift	Fulton and Smith, 1978
SE British Columbia	29	deposits of 3 stades and 2 interstades	Clague, 1975
SW Yukon	10	Kluane Drift	Denton and Stuiver, 1967
W-C Yukon	11	Macauley Drift	Rampton, 1971
C Yukon	3	McConnell advance	Bostock, 1966
N Yukon	12	Unit 3	Jopling et al., 1981
"ICE-FREE CORRIDOR"			
E Yukon	30	Hungry Creek Till	Hughes et al., 1981
E-C British Columbia	18	Portage Mountain advances	Rutter, 1976
SE British Columbia	4	Medicine Hat advance	Stalker and Harrison, 1977
	13	Lethbridge advance	Stalker and Harrison, 1977
	26	Waterton IV	Stalker and Harrison, 1977
	14	Hidden Creek Till	Alley, 1973
PRAIRIE		LOSTWOOD GLACIATION	
S Alberta	4	two tills separated by alluvium and lake deposits	Stalker, 1976
S Saskatchewan	31	Battleford Till	Christiansen, 1968b
SW Manitoba	15	Lennard Formation	Klassen, 1969
SE Manitoba	22	Roseau Formation	Fenton, 1974
	22	Senkiw Formation	Fenton, 1974

LATE WISCONSINAN

Table 6 lists the main units which have been used in defining the Late Wisconsinan in Western Canada. In most cases these are referred to the Late Wisconsinan because they either overlie or contain (allochthonous) organic materials dated as Middle Wisconsinan. Other units (Macauley Drift, McConnell advance, Waterton IV, Hidden Creek Till, Roseau Formation, Senkiw Formation) are referred to the Late Wisconsinan because they are the youngest glacial unit in the area or are correlated with Late Wisconsinan units in adjacent regions.

The Late Wisconsinan in Western Canada was a period of glaciation. The probable limits of ice cover at the maximum of this substage are shown by Prest (this volume). The timing of the ice advance is not well known although in most areas there is evidence that it did not occur until after 25 ka. Many readvances took place at the south-central margin of the Laurentide Ice Sheet (Clayton and Moran, 1982) but correlative readvances have not been found in Western Canada. The chronology of ice retreat is known only within broad limits and though there is evidence that it started as early as 14 ka at the western margin of the Cordilleran Ice Sheet, Laurentide ice in North and South Dakota was still near its southern limit as late as 12 ka according to Clayton and Moran (1982).

In the Cordillera, the glacial event that occurred during the Late Wisconsinan has been referred to as Fraser Glaciation[1] (Armstrong et al., 1965); in the southern Canadian Plains of Canada, this glacial event has been referred to as Lostwood Glaciation[1] (Fenton, this volume).

Many dates related to advance of Late Wisconsinan Cordilleran ice are available in southwestern British Columbia. Clague (1976) used these data to trace development of a proglacial outwash wedge in the Strait of Georgia area and Clague (1981, p. 10) speculated on the area of Late Wisconsinan ice cover at 25, 20, and 15 ka. Hicock and Armstrong (1981) described an advance and subsequent minor retreat which occurred about 20 ka; Hicock et al. (1982) discussed paleoecology at this time; and Clague et al. (1980) provided a chronology for advance of the sheet between 22 ka and when it reached its limit south of Puget Inlet in Washington (32 of Fig. 1), about 14.5 ka (Mullineaux et al., 1965, p. 7).

Retreat from the Late Wisconsinan limit in southwestern British Columbia was underway by 14 ka (Mullineaux et al., 1965, p. 7) and the sea had entered the Strait of Georgia by 13 ka (Fulton, 1971, p. 13). A short readvance, referred to as the Sumas, appears to have occurred in the Fraser Lowland (1 of Fig. 1) about 11.4 ka (Mathews et al., 1970, p. 696). Clague (1981, p. 14) postulated ice marginal positions at 15, 12.5, and 10 ka.

In south-central British Columbia the last ice sheet was in the process of engulfing the mountains at 52°N about 20 ka (Fulton, 1982) but did not reach the 49th Parallel until later than 17.5 ka (Clague et al., 1980). Its limit in northern Washington had been reached and the ice was retreating by 13 ka (Mullineaux et al., 1978). There is little evidence of readvance in this area although Clague (1975) reported evidence for three Late Wisconsinan stadials in the southern Rocky Mountain Trench (29 of Fig. 1). Postglacial dates indicate that south-central British Columbia was free of the Cordilleran Ice Sheet by 10 ka (Fulton, 1971, p. 17).

Some data are available relative to deglaciation of the coastal area of central British Columbia. Clague et al. (1982, p. 1792) reported that parts of the Queen Charlotte Islands were ice free as early as 16 ka and that most of the islands were probably ice free by 13.7 ka. Prince Rupert on the mainland east of the Queen Charlotte Islands was ice free by 12.7 ka and a fiord in the Coast Mountains 100 km inland was being deglaciated 10.5 ka (Clague, 1981, p. 16).

Late Wisconsinan chronology is very poorly known in the Yukon. The only date available that is pertinent to ice advance indicates that the Cordilleran Ice Sheet did not reach its maximum in southwest Yukon (10 of Fig. 1) before 30 ka (Denton and Stuiver, 1967). The ice sheet had begun to retreat in this area before 12.5 ka (Denton and Stuiver, 1967) and was retreating in an area 150 km to the northwest (11 of Fig. 1) before 13.6 ka (Rampton, 1971).

Rutter (this volume) showed the ice limits in the zone of interaction between the Cordilleran and Laurentide ice sheets. The Laurentide Ice Sheet, on the eastern side of the Yukon (30 of Fig. 1), is thought to have reached its all-time glacial limit during the Late Wisconsinan (Hughes et al., 1981, p. 358; Prest, this volume). The time at which this limit was reached was later than 36.9 ka and possibly about 30 ka when meltwater is thought to have been diverted into the Old Crow area of the Yukon (Hughes et al., 1981, p. 359). This ice had begun to retreat from its maximum by 16 ka (Hughes et al., 1981, p. 358) and had retreated from the Fort Good Hope area, 250 km east of its limit, before 11.5 ka (Mackay and Mathews, 1973, p. 36).

The ice did not advance into the Watino area of west-central Alberta (19 of Fig. 1) until after 27.4 ka (Westgate et al., 1972) and did not reach the Medicine Hat area of southeastern Alberta until after 24.5 ka (Stalker, 1976, p. 401; 4 of Fig. 1). The only date relating to eastward advance of Cordilleran ice is from Finlay River valley of east-central British Columbia (18 of Fig. 1) where it has been shown that nonglacial deposition was still occurring 25.9 ka (Rutter, 1976, p. 432). Few good limiting dates are available for eastward retreat of Laurentide ice in Alberta. St-Onge (1972, p. 8) reported that Laurentide ice had retreated from upper reaches of little Smokey River valley, 50 km west of Edmonton, by 13.5 ka. It had retreated from Lofty Lake, 100 km north of Edmonton, by 11.5 ka (Lichti-Federovich, 1970, p. 943).

Clayton and Moran (1982) summarized abundant data documenting the timing of the advance of the southern Canadian Plains section of the Late Wisconsinan Laurentide Ice Sheet. The position that they favoured for the limit of Late Wisconsinan ice leaves a long, thin, east-west trending, ice-free re-entrant in south-central and western Saskatchewan and extreme southeastern Alberta. Elsewhere their limit lies south of the 49th Parallel. This limit is similar to the Late Wisconsinan limit drawn in Saskatchewan and eastern Alberta by Christiansen (1979, p. 923). Stalker (1977), on the other hand, favoured a less extensive Late Wisconsinan ice cover with the Laurentide ice remaining north of the Cypress Hills (33 of Fig. 1) and not entering Montana from Alberta. Clayton and Moran (1982) used dates from South Dakota and Iowa to indicate that the maximum Laurentide advance in this area occurred shortly after 20 ka.

At least five moderately well dated Late Wisconsinan advances are documented in North Dakota, South Dakota, and Iowa by Clayton and Moran (1982). One of the latest of these carried the ice margin as far south as southern Minnesota and South Dakota about 12 ka (Clayton and Moran, 1982, p. 71). They correlated some of these advance positions with ice marginal positions in western Canada but in general there is no stratigraphic evidence to corroborate these correlations.

Radiocarbon dates on postglacial materials in Saskatchewan indicate that the Late Wisconsinan ice had retreated north of Qu'Appelle River valley before 12 ka (12 025 ± 205 BP, S-553; Christiansen, 1979, p. 920) and north of Prince Albert before 11.5 ka (11 560 ± 640 BP, GSC-648; Mott, 1973, p. 5). The ice had retreated north of

[1] This in reality is a stade of the Wisconsin Glaciation

Virden in Assiniboine River valley of Manitoba before 11.6 ka (11 600 ± 430 BP, GSC-1081; Klassen, 1975, p. 47) and had completely retreated from Western Canada before 7.3 ka (7270 ± 120 BP, GSC-92; Craig, 1969, p. 69) when Hudson Bay became ice free.

REGIONAL CORRELATION

Correlations of Quaternary stratigraphy of Western Canada with that of adjacent areas have been made by Fulton (1977, 1979, this volume) by Dreimanis et al. (1981), and by Fenton (this volume). What is presented here (Fig. 2) differs little from these earlier works. Correlation of Late Wisconsinan and Middle Wisconsinan units is relatively straightforward and is generally based on radiocarbon dates; correlation of older units is based largely on counting downwards and the matching of glacial and nonglacial units.

In making these correlations, an attempt was made to use the major event units – glaciation, interglaciation, and nonglacial – which approximately fit the chronostratigraphic units used in this report. Unfortunately such units have not been set up for all areas and the detail and degree of precision of these units is not the same in all areas or for all intervals of the time scale. In addition because these geological event units are time-transgressive, they do not necessarily fit exactly into the chronostratigraphic units. Sloping lines have been used at the base of major event units in Figure 2 to indicate this lack of synchroniety. Chronological information is generally not available for events beyond the range of ^{14}C dating; scattered data are, however, available. The Old Crow tephra, which occurs in Late Pleistocene sediments in the Old Crow Basin, has been dated as 56-120 ka (Naeser et al., 1982). Stalker (in Foster and Stalker, 1976, p. 193) suggested that the nonglacial sediments at the base of the Wellsch Valley succession, in part correlate with the Olduvai Event (1.87-1.67 Ma; Mankinen and Dalrymple, 1979). Wascana Creek Ash, which occurs in the Floral Formation of southern Saskatchewan, has been dated as 0.7-0.6 Ma (Westgate et al., 1977). The broadest chronological framework for the area was obtained from cave deposits in the Rocky and Mackenzie mountains by Harmon et al. (1977); using ^{230}Th-^{234}U ages of speleothems, they concluded that major periods of interglacial conditions occurred from present to 15 ka, 90-150 ka, 185-235 ka, 275-320 ka, and $\geq$ 350 ka, with minor speleothem deposition at 57 ka. Gascoyne et al. (1980) confirmed the period of Middle Wisconsinan speleothem growth in reporting on cave deposits which formed on Vancouver Island between 28 and 64 ka. These records correspond in a general way to that from southeast Minnesota where Lively (1983) reported on periods of speleothem growth at 0-13, 35-70, 90-170, 220-240, and 270-290 ka.

There may be a problem with correlation of the Sangamonian-Early Wisconsinan boundary between eastern and western Canada. In this report the Early Wisconsinan is considered to begin at the base of the first major post-Sangamonian glacial advance; on the basis of the oxygen isotope derived sea level curve of Shackleton and Opdyke (1973), this is considered to have occurred about 75 ka. Karrow (this volume) included the St. Pierre Interstade in Early Wisconsinan and suggested an approximate age of 80 ka (finite radiocarbon age of 74 700 $\pm^{2700}_{2000}$ BP; Stuiver et al., 1978). This age assignment would place the St. Pierre in the late Sangamonian (as defined here) and not in the Early Wisconsinan as indicated in his report. In the way in which chronostratigraphic units are used here, the St. Pierre Interstade is a cool period which postdates the warmest part of the Sangamonian but predates the main Wisconsinan ice advances. Similar cool but nonglacial intervals are recognized at the end of the last interglaciation in the Voges Mountains of France (Woillard, 1978, p. 15). The Fawn River gravels of the Hudson Bay Lowland should also be considered as Sangamonian because they have been estimated to be of similar age (76 ka; Shilts, 1982, p. 326).

SUMMARY

The Quaternary stratigraphy of Western Canada has been subdivided according to five defined and one older chronostratigraphic units. These units, the deposits, and events are:

1. Pre-Illinoian – widely scattered occurrences of glacial and nonglacial deposits; locally in southern Alberta and Saskatchewan identified as Aftonian, Kansan, and Yarmouthian according to land mammal age terminology.
2. Illinoian – glacial deposits; recognized where overlying interglacial deposits or weathering horizons are identified; maximum advance of Laurentide ice in southern Canadian Plains.
3. Sangamonian – last interglacial period of weathering and deposition of alluvial, colluvial, and pond deposits; in general identified by indicators of a climate as warm as or warmer than present; locally identified by vertebrate fauna.
4. Early Wisconsinan – glacial deposits; stratigraphic position beneath materials dated as Middle Wisconsinan is the main means of identifying; ice cover considered to be more extensive than during Late Wisconsinan.
5. Middle Wisconsinan – a period of nonglacial deposition and weathering which in some areas lasted from before 58 ka until after 19 ka; climate locally as warm as present but generally cooler; extent of ice cover at this time largely unknown.
6. Late Wisconsinan – glacial substage; evidence of cooling as early as 29 ka and maximum advance between 20 and 15 ka; Canadian Plains and Cordillera essentially ice free by 10 ka.

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ARCTIC CANADA

Duck Hawk Bluffs, southwestern Banks Island, Western Arctic: Sections expose tills and sediments representing three glacial-nonglacial cycles. The oldest glacial deposit predates the Bruhnes/Matuyama boundary and the youngest is considered to be Early Wisconsinan. The bench at the top of the bluffs represents the limit of Early Wisconsinan marine submergence. Photo and stratigraphy by J-S. Vincent, GSC 202775-T.

QUATERNARY STRATIGRAPHY OF THE WESTERN CANADIAN ARCTIC ARCHIPELAGO

Jean-Serge Vincent[1]

Vincent, J-S., Quaternary stratigraphy of the western Canadian Arctic Archipelago; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 87-100, 1984.

Abstract

The western Canadian Arctic Archipelago is a polar desert situated along the margin of North America where continental Quaternary ice sheets, spreading from dispersal centres to the southeast, reached their limit on at least three occasions. On Banks Island, the Worth Point Formation comprises mainly terrestrial preglacial sediments and records the period between the Miocene and the oldest of three recognized full glaciations. Sediments assigned to Duck Hawk Bluffs Formation, Nelson River Formation, and Prince of Wales Formation were laid down during the Banks, Thomsen, and Amundsen glaciations, respectively. Sedimentary sequences show that transgressive marine events, resulting from the buildup of ice, preceded each glacial overlap of the island, and that marine regressive events related to glacio-isostatic recovery of the crust occurred during retreat of each glacier. Paleoecological studies of organic suites of sediments of Morgan Bluffs Formation – found between sediments laid down during the Banks and Thomsen glaciations – and of Cape Collinson Formation – found between sediments laid down during the Thomsen and Amundsen glaciations – indicate that interglacial conditions existed between each of these glacial stages. Deposits on Banks, Victoria, and central Melville Island are attributed to two glacial stades of the last or Wisconsin Glaciation. During the older M'Clure Stade on Banks Island (likely Early Wisconsinan), ice covered most of Victoria Island except for parts of Prince Albert Peninsula and the Shaler Mountains and flowed into Amundsen Gulf impinging on the southwest and east coast of Banks Island and into M'Clure Strait impinging on the north coast of Banks and the southcoast of Melville Island. Following a major retreat, ice advanced again in Late Wisconsinan time (Russell Stade of Banks Island) into eastern Amundsen Gulf and Viscount Melville Sound up to the northeast coast of Banks Island and the south coast of Melville Island leaving large areas of Wollaston, Diamond Jenness, and Prince Albert peninsulas and the Shaler Mountains of Victoria Island unglaciated. In the Viscount Melville Sound area this ice surged in the form of an ice shelf about 10 ka, based on the dating of shell-bearing marine sediments underlying and overlying glacial sediments of this stade on Banks, Victoria, and Melville islands. Although local glaciers may have existed on uplands of eastern and western Melville Island and Prince Patrick Island, there is no direct evidence for complete Wisconsinan Stage ice cover of the western Queen Elizabeth Islands. Glacial sediments are present in these areas but are likely related to an extensive pre-Wisconsinan continental glaciation possibly equivalent to the Banks Glaciation of Banks Island.

Résumé

La partie ouest de l'archipel Arctique canadien est un désert polaire, en bordure de l'Amérique du Nord, où les inlandsis continentaux venant du sud-est ont atteint au moins à trois reprises leur extension maximale. Dans l'île Banks, la formation de Worth Point consiste en des sédiments terrestres d'origine préglaciaire qui témoignent de la période survenue entre le Miocène et la plus vieille de trois glaciations reconnues. Les sédiments des formations de Duck Hawk Bluffs, de Nelson River et de Prince of Wales ont respectivement été mis en place au cours des glaciations de Banks, de Thomsen et d'Amundsen. Les séries sédimentaires indiquent que des événements marins transgressifs, résultant de la progression des glaces, ont précédé chaque empiètement de l'île, et des événements marins régressifs, reliés au relèvement isostatique de l'écorce, ont eu lieu lors du retrait de chaque glacier. L'étude paléoécologique de sédiments organiques de la formation de Morgan Bluffs qui reposent entre les sédiments glaciaires associés aux glaciations de Banks et de Thomsen, et ceux de la formation de Cape Collinson, ces derniers intercalés entre les sédiments glaciaires associés aux glaciations de Thomsen et d'Amundsen, indique que des conditions interglaciaires ont existé entre chaque glaciation. Des sédiments dans les îles Banks, Victoria et Melville sont attribués à deux stades de la glaciation wisconsinienne. Au cours du plus vieux stade de M'Clure dans l'île Banks (datant probablement du Wisconsinien inférieur), les glaces ont recouvert l'île Victoria, sauf pour certains secteurs de la péninsule Prince-Albert et des monts Shaler, et se sont écoulées dans le golfe Amundsen, empiétant sur les côtes sud-ouest et est de l'île Banks, et dans le détroit de M'Clure, empiétant sur la côte nord de l'île Banks et la côte sud de l'île Melville. Un important recul des glaces a précédé une nouvelle avancée, survenue au cours du Wisconsinien supérieur (stade de Russell

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Manuscript received: 1981-11-15
Final version approved for publication: 1982-10-12

dans l'île Banks), dans le secteur est du golfe Amundsen et dans le détroit du Vicomte-Melville. Ces glaces ont progressé jusqu'à la côte nord-est de l'île Banks et la côte sud de l'île Melville en laissant de grandes régions des péninsules Wollaston, Diamond Jenness et Prince-Albert et des monts Shaler dans l'île Victoria libre de glaces. Dans la région du détroit du Vicomte-Melville, la dernière avancée rapide des glaces à l'état de plateforme a eu lieu il y a environ 10 ka, date établie à la suite de l'analyse au carbone radioactif de coquillages contenus dans des sédiments marins trouvés en dessous et au-dessus des sédiments glaciaires associés à ce stade dans les îles Banks, Victoria et Melville. Bien que des glaciers locaux aient pu exister sur les régions plus élevées de l'est et de l'ouest de l'île Melville et de l'île Prince-Patrick, il n'y a pas de preuves directes d'un recouvrement glaciaire complet de la partie ouest des îles de la Reine-Elisabeth au cours du Wisconsinien. Des sédiments glaciaires sont certes présents dans ces îles, mais leur mise en place date sans doute d'une glaciation continentale d'origine pré-wisconsinienne peut-être équivalente à la glaciation de Banks dans l'île Banks.

INTRODUCTION

The western Canadian Arctic Archipelago (Fig. 1) is situated along the margin of North America where the continental[1] Quaternary ice sheets, spreading from dispersal centres to the southeast, reached their limits on at least three occasions.

The area is a polar desert underlain by continuous permafrost. At Sachs Harbour on Banks Island and Mould Bay on Prince Patrick Island, the mean annual temperatures are -14.1°C and -17.8°C, respectively, and the mean annual precipitation, 114.1 and 93.1 mm (Atmospheric Environment Service, 1982). Except for Durham Heights of southern Banks Island, Shaler Mountains of northwestern Victoria Island, and Blue Hills of western Melville Island, the entire region lies below 500 m. The interisland channels, which played an important role in controlling glacial flow, are more than 500 m deep in places (Fig. 1). Geological provinces (Kerr, 1980) include the Minto Uplift (inlier of Proterozoic metasediments), Arctic Platform (horizontally bedded Paleozoic sedimentary rocks), Carbonate Belt (folded Paleozoic sedimentary rocks), Sverdrup and Banks basins (horizontally to inclined poorly lithified to unlithified sediments of Mesozoic and Early Tertiary age), and the Arctic Coastal Plain (Tertiary sand and gravel) (Fig. 1).

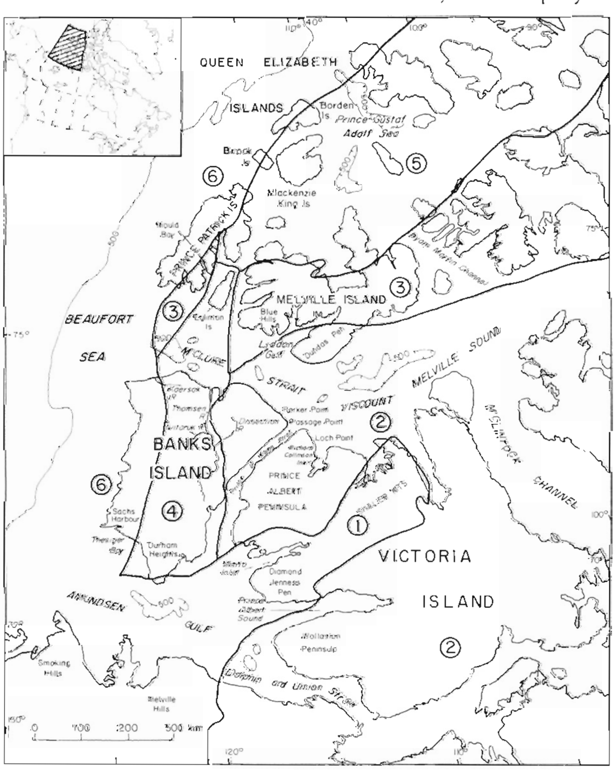


Figure 1. Location map of the western Canadian Arctic Archipelago; geological provinces (Kerr, 1980): 1) Minto Uplift, 2) Arctic Platform, 3) Carbonate Belt, 4) Banks Basin, 5) Sverdrup Basin, and 6) Arctic Coastal Plain.

This report briefly describes the Quaternary stratigraphy of Banks and Victoria islands and of the Queen Elizabeth Islands west of Prince Gustav Adolf Sea and Byam Martin Channel (Melville, Eglinton, Prince Patrick, Brock, Mackenzie King, and Borden islands) (Fig. 1). The overall area has been discussed by Craig and Fyles (1960, 1965) and Prest (1970). The stratigraphic record on Banks Island is the most studied and complete of the area and therefore will be discussed in the most detail.

It should be noted that both geologic-climate and lithostratigraphic units are used in the discussion of Banks Island stratigraphy. "Formation" is restricted to the various members collectively deposited either during a specific glacial stage or an interglaciation. "Member" refers to the glacial and marine lithostratigraphic units deposited during a glacial stade. Some marine units resulted from glacial isostatic depression of the crust and are therefore considered to be related to a glacial event. Deposits of perimarine[2] origin contain organic matter which enables them to be associated with interglacial events. Tentative correlation of units within the area is suggested, but it is my opinion that correlation with adjoining areas should await better chronological basis both within and outside the area.

QUATERNARY UNITS OF BANKS ISLAND

The Quaternary geology of Banks Island was initially investigated by Fyles (1962) and more recently by Vincent (1978, 1980, 1982, 1983) and Vincent et al. (1983, 1984). These provide the basis for the following discussion. Evidence for three continental glaciations – from oldest to youngest, the Banks, Thomsen, and Amundsen glaciations – has been recognized on this island. Ice limits for each glaciation and the distribution of eleven individual till sheets are shown in Figure 2. In the course of the study more than 200 sections were examined along major rivers and marine coasts; Duck Hawk Bluffs, Worth Point Bluffs, the sections east of Nelson River, and Morgan Bluffs (Fig. 2, 3) provide the most complete record. Table 1 is a correlation chart of the units and events (all named by Vincent, 1978, 1980, 1983) described next.

[1] In this report, the term "continental" ice sheets is used for ice sheets centred on the North American mainland. The term Laurentide Ice Sheet is restricted to continental ice sheets centred on the mainland during the last (Wisconsinan) glaciation.

[2] According to Hageman (1972, p. 37), "By the term perimarine area is meant that area where sedimentation and settling took place under the direct influence of the relative sea level movements, but where marine or brackish-water sediments are absent. Perimarine conditions occur mainly in the backswamp areas in the part of the fluviatile areas where levels of the seaward-flowing river waters have been elevated by the rising sea, thus causing the development of thick fluviatile clayey layers, alternating with peat layers cut by fossil gullies filled with sand."

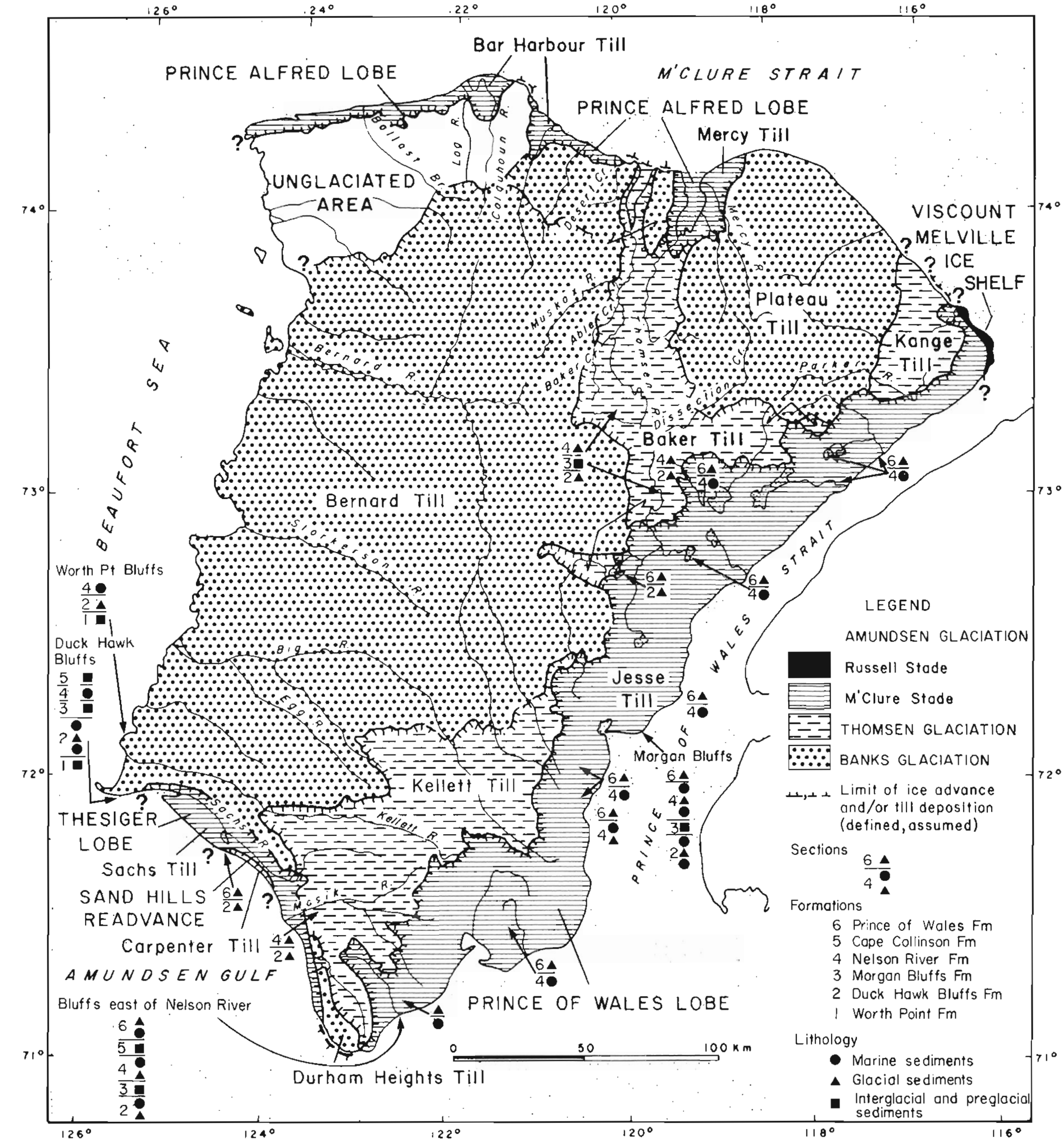


Figure 2. Glacial limits of Banks, Thomsen, and Amundsen glaciations on Banks Island. Also shown is the distribution of the till sheets and the location of the main stratigraphic sections.

Worth Point Formation

The nonglacial sediments, up to 12 m thick, which overlie the Miocene Beaufort Formation and underlie the deposits of Banks Glaciation in the Duck Hawk Bluffs and Worth Point sections (Fig. 3) are grouped into the Worth Point Formation. These sediments, which were studied by Fyles (Craig and Fyles, 1960, 1965), Kuc (1974), Vincent (1980, 1982, 1983) and Vincent et al. (1983, 1984) consist of various units of probable fluvial, lacustrine, eolian, and organic origin. They record mainly terrestrial events which occurred after the deposition of the coastal plain sediments of the Beaufort Formation and before the first recorded glacial overlap of the island. Some of the sediments may be as old as Pliocene and certainly older than 730 ka since preliminary analyses indicate they are magnetically reversed.

Of the sediments mentioned above, the most interesting unit is a >5 m-thick unit of woody peats, containing trunks of **Larix laricina** (Kuc, 1974, Fig. 3). Using floristic composition as evidence, Kuc concluded that the peat accumulated during an "interglaciation", in an open, subarctic forest-tundra environment similar to that of the northern part of the boreal forest today. **Larix** grew discontinuously in the area, while shrubs such as **Alnus crispa**, **Betula glandulosa**, **Salix niphoclada**, **Empetrum nigrum**, **Ledum decumbens**, and **Vaccinium uliginosum** and herbaceous plants such as **Carex**, **Equisetum arvense**, **Pyrola grandiflora**, and **Ranunculus lapponicus** formed a dense cover on the soil. It is impossible at this time to say whether these deposits are entirely preglacial (i.e. late Tertiary to early Quaternary) or whether they accumulated during an early Quaternary interglaciation. Whatever the case, they predate at least three full glacial-interglacial cycles (Table 1).

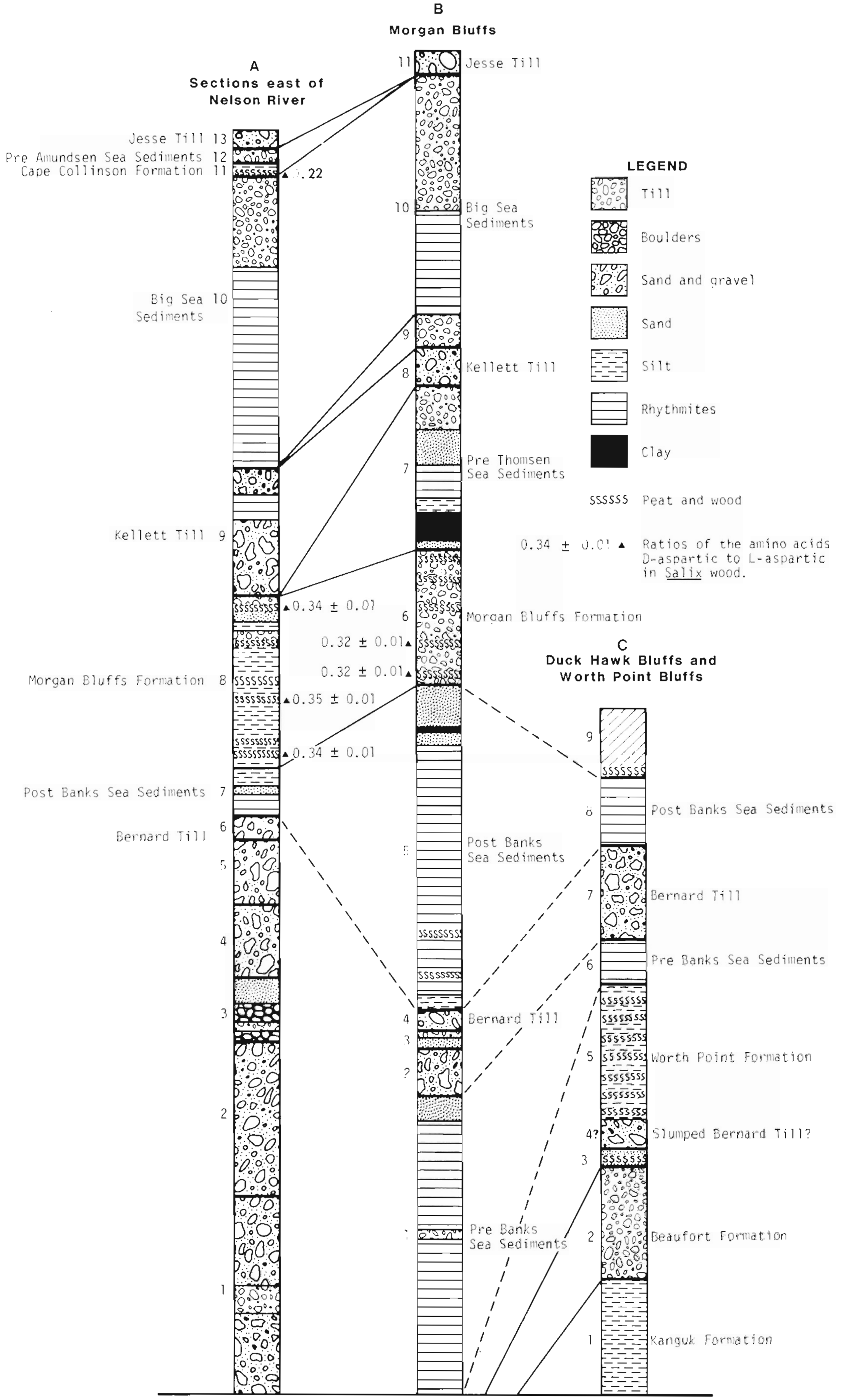
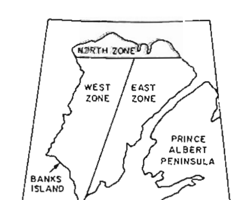


Figure 3. *Stratigraphic correlation of the composite sections east of the mouth of Nelson River, Morgan Bluffs, and Duck Hawk and Worth Point bluffs (cf. Fig. 2). The numbers beside the columns refer to lithological subdivisions described in Vincent (1983).*

Table 1. Correlation of Quaternary events on Banks Island.

Geological Events		Lithostratigraphy[1]				Amino Stratigraphy			^{14}C (ka)	K-Th (ka)	Preliminary Paleomagnetism	
			North Zone	East Zone	West Zone	Shells[2] F	Shells[2] T	Wood[3]				
Postglacial			Organic, eolian, alluvial, marine, and colluvial sediments					0.14	7.8		BRUNHES EPOCH	
AMUNDSEN GLACIATION	RUSSELL STADE	PRINCE OF WALES FM.		Schuyter Point Sea Sediments Passage Point Sediments (Viscount Melville Ice Shelf) Schuyter Point Sea Sediments		-	0.02		10.6 11.2		BRUNHES EPOCH	
AMUNDSEN GLACIATION	M'CLURE STADE	PRINCE OF WALES FM.	Investigator Sea and Meek Point Sea sediments *Lake Ivitaruk and Lake Ballast* Bar Harbour Till and Mercy Till (Prince Alfred Lobe)	East Coast Sea Sediments *Lake Cardwell, Lake De Salis, and Lake Sarfarssuk* Jesse Till (Prince of Wales Lobe) Pre Amundsen Sea Sediments	Carpenter Till (Sand Hills Advance) Meek Point Sea Sediments *Lake Rufus, Lake Masik, and Lake Raddi* Sachs Till (Thesiger Lobe)	0.42-0.51	0.04-0.09		>49.1,>19 >41 >37		BRUNHES EPOCH	N
CAPE COLLINSON INTERGLACIATION				CAPE COLLINSON FORMATION				0.22	>49 >61		BRUNHES EPOCH	N
THOMSEN GLACIATION		NELSON RIVER FM.	Big Sea Sediments Baker Till	Big Sea Sediments *Lake Parker and Lake Dissection* Kellett Till, Baker Till, and Kange Till Pre Thomsen Sea Sediments	Big Sea Sediments Kellett Till	0.54-0.73	0.16-0.20 (0.19)			119	BRUNHES EPOCH	N
MORGAN BLUFFS INTERGLACIATION				MORGAN BLUFFS FORMATION				0.32-0.35			BRUNHES EPOCH MATUYAMA EPOCH	N R
BANKS GLACIATION		DUCK HAWK BLUFFS FM.	Bernard Till and Plateau Till	Post Banks Sea Sediments Bernard Till and Plateau Till Pre Banks Sea Sediments	Post Banks Sea Sediments *Lake Egina and Lake Storkerson* Bernard Till and Durham Heights Till Pre Banks Sea Sediments						MATUYAMA EPOCH	R R
INTERGLACIATION OR PREGLACIAL					WORTH POINT FORMATION						MATUYAMA EPOCH	R N

[1] As well as the formally named lithostratigraphic units, the position of glacial lakes (in italics) is indicated in the stratigraphic sequence.
[2] Ratios of the amino acids D-alloisoleucine to L-isoleucine in the free and total (free and peptide-bound) fractions in **Hiatella arctica**.
[3] Ratios of the amino acids D-aspartic to L-aspartic in **Salix** and **Betula**.



Duck Hawk Bluffs Formation

The Duck Hawk Bluffs Formation includes all the glacial deposits laid down during the oldest recognized glaciation – Banks Glaciation. It overlies Worth Point Formation and underlies Morgan Bluffs Formation. It is composed of 1) the noncontiguous Bernard, Plateau, and Durham Heights tills sheets[1] in the west, the northeast, and the southern tip of the island, respectively, as well as in sections of the southern and eastern half of the island underlying younger glacial and nonglacial (Morgan Bluffs Formation) deposits (Fig. 2); 2) sediments of glacial lakes Egina and Storkerson which formed in the northwest during deglaciation; 3) Pre Banks Sea Sediments which were laid down in coastal areas while the crust was undergoing glacial isostatic depression by the approaching ice; and 4) Post Banks Sea Sediments laid down in the sea that invaded coastal areas following retreat of Banks Glacier.

In Duck Hawk Bluffs, about 14 m of sands and glaciomarine diamictons of the Pre Banks Sea underlies up to 10 m of Bernard Till and up to 9 m of silts and 8 m of gravel of the Post Banks Sea (Fig. 3). A still unstudied volcanic ash bed associated with Pre Banks Sea Sediments was also traced. In the sections east of Nelson River, till identified as Bernard Till, 25 m thick and interstratified with apparently glaciomarine sediments, is overlain by a 3 m-thick suite of sediments containing shell fragments of the Post Banks Sea (Fig. 3). In the Morgan Bluffs, 24 m of fine grained sediments, commonly rhythmically bedded and locally fossiliferous, underlies 6 m of till, associated with Bernard Till, and up to 31 m of fine grained sediments, commonly rhythmically bedded and locally fossiliferous, of the Post Banks Sea (Fig. 3).

All these sediments were deposited in close association with a northwestward-flowing ice sheet of continental origin. Most of the island was covered by the ice, except for the northwest (Fig. 2); coastal areas, glacio-isostatically depressed, were submerged both before and after inundation by the ice. The absolute age of Banks Glaciation is not precisely known; it predates at least two full glaciations and two interglaciations prior to the present interglaciation (Table 1) and it is older than 730 ka since the till and marine deposits in the Duck Hawk Bluffs are magnetically reversed.

Morgan Bluffs Formation

Organic-bearing perimarine sediments, which overlie marine and glacial Duck Hawk Bluffs Formation sediments associated with Banks Glaciation and underlie marine and glacial Nelson River Formation sediments associated with Thomsen Glaciation, are found in the sections east of Nelson River and at Morgan Bluffs (Fig. 2, 3) and possibly in the Duck Hawk Bluffs. Fluvial sediments with organics and paleosols also occur in sections on Thomsen and "Ivitaruk"[2] rivers between Bernard and Baker tills (Table 1). These various sediments are assigned to the Morgan Bluffs Formation which is considered to have been deposited during an interglacial period called the Morgan Bluffs Interglaciation. Correlation of the sediments in the sections east of Nelson River with those of Morgan Bluffs is confirmed by amino acid ratios from fossil wood (Table 1). D-aspartic/L-aspartic ratios in three samples from the sections east of Nelson River range from 0.34 (UA-585,-587) to 0.35 (UA-586), whereas those from two samples from Morgan Bluffs were 0.32 (UA-588,-589) (Fig. 3). In the Duck Hawk Bluffs D/L ratios from wood in what are possibly equivalent beds are lower and range between 0.22 and 0.31 (UA-1000, -1095, -1097, -1102).

In the organic sediments, plant macrofossils such as **Potamogeton filiformis** Pers., **Betula nana** L., or **Menyanthes trifoliata** L. and many species of Coleoptera from the Carabidae, Staphylinidae, and Curculionidae familes[3] were found. These plants and insects do not live on Banks Island today but rather they are restricted to the mainland near treeline. On the basis of this it is possible to affirm that these sediments represent a climate that was slightly warmer than that of today's tundra. It should also be noted that bones of the lemming **Diocrostonyx torquatus** and of a ptarmigan (identified by C.R. Harington of the National Museums of Canada) have also been found in these beds.

The interstratified marine, fluvial, and peat sequences (up to 10 m thick) were probably deposited in a perimarine environment over a relatively long period of time characterized by minor oscillations of sea level. Based on the actual elevations of these sediments in three locations (Duck Hawk Bluffs, bluffs east of Nelson River, and Morgan Bluffs), sea level around Banks Island must have stood 20-30 m higher than today. It is of interest that along the Bering Sea in Alaska, sea levels were about 20 m higher than today during the interglaciation that preceded the Sangamonian (Hopkins, 1967).

The absolute age of Morgan Bluffs Interglaciation is not known. It is believed to predate at least two complete glacial cycles (Table 1).

Nelson River Formation

Nelson River Formation includes all the glacial deposits laid down during Thomsen Glaciation. This formation is composed of 1) Kellett, Baker, and Kange tills which are found in individual areas of the south, the Thomsen River basin, and the northeast of the island, respectively, as well as in sections in the south and east of the island underlying younger glacial and nonglacial (Cape Collinson Formation) deposits (Fig. 2); 2) sediments of glacial lakes Parker and Dissection which covered nonglaciated ground adjoining the ice margin and newly deglaciated terrain in the northeast; 3) Pre Thomsen Sea Sediments which were deposited when the east coast was isostatically depressed by the advancing Thomsen Glacier; and 4) Big Sea Sediments deposited over extensive areas of Banks Island both during and following glaciation.

At Morgan Bluffs, up to 14 m of initially fining upwards then coarsening upwards, fine grained, commonly rhythmically bedded, and in places fossiliferous Pre Thomsen Sea Sediments underlies up to 5 m of Kellett Till and up to 3 m of rhythmically bedded silt and sand capped by fossiliferous deltaic gravels of the Big Sea (Fig. 3). In the sections east of Nelson River, Pre Thomsen Sea Sediments have not been identified; Kellett Till there overlies Morgan Bluffs Formation sediments and underlies up to 11 m of Big Sea rhythmites and more than 15 m of fossiliferous deltaic sands and gravels (Fig. 3). Exposures of Big Sea Sediments, underlying younger Prince of Wales Formation glacial sediments, were observed in numerous sections in eastern Banks Island (Fig. 2).

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[1] Many of the separately named till sheets were likely deposited during a common glacial event. Since they are not contiguous, however, equivalence of age cannot readily be proven and they are presently related simply by comparing their properties and extent.

[2] Geographical names in quotations are unofficial but have been submitted to the Canadian Permanent Committee on Geographical Names.

[3] Unpublished GSC Plant Macrofossil Report No. 76-6 and 78-6 and GSC Fossil Arthropod Report 78-6 by J.V. Matthews, Jr.; unpublished GSC Wood Identification Report No. 78-40, 78-41, and 78-42 by R.J. Mott; unpublished GSC Wood Identification Report No. 77-30, 77-31, 77-32, and 77-33 by L.D. Farley-Gill.

All these sediments were deposited in close association with a northwestward-flowing ice sheet of continental origin which overrode large areas of southern and eastern Banks Island and Thomsen River basin (Fig. 2). The glacio-isostatically depressed coastal areas and the low-lying central portion of the island were submerged up to 215 m by the Big Sea, during and after inundation by the ice.

Based on an uranium-thorium date of 120 $\pm^{10.8}_{9.8}$ ka (UQT-80) on in situ shells from the Big Sea, it is possible that the Thomsen Glaciation is the glaciation that immediately predated the last (Sangamon) interglaciation. Whatever the case, it predates Cape Collinson Interglaciation and postdates Morgan Bluffs Interglaciation (Table 1). Amino acid ratios (total) of D-alloisoleucine to L-isoleucine (alle:Ile) obtained from **Hiatella arctica** shell fragments found in Big Sea offshore and deltaic sediments vary between 0.12 and 0.28 (AAL-894C, -536B). Three of the five samples analyzed, including in situ shells, gave ratios around 0.19 (AAL-527, -534, -535) but the others were either much younger (0.12) or much older (0.28). The free ratios range from 0.44 (AAL-894B) to 0.95 (AAL-536B). The three samples with total ratios around 0.19 had free ratios ranging from 0.54 (AAL-534A) to 0.73 (AAL-527C). The scatter is large and more analyses are needed before results are conclusive. Nevertheless, these ratios, if compared with other ratios obtained in the Canadian Arctic, are indicative of an event which certainly predates the last interglaciation (Szabo et al., 1981; Andrews and Miller, this volume). It may be eventually possible with amino acid analyses to correlate the high level Big Sea of Banks Island with other old high level seas of the Arctic, particularly in the Queen Elizabeth Islands.

Cape Collinson Formation

In one section east of Nelson River a 10 to 20-cm thick sequence of organic-bearing sediments (Fig. 3) overlies Nelson River Formation Big Sea Sediments and underlies Prince of Wales Formation marine (Pre Amundsen Sea) and glacial sediments (Jesse Till) (Table 1). The organic sediments, radiocarbon dated at >61 000 BP (QL-1230), likely accumulated in or close to a small tundra pond during an interglacial period – Cape Collinson Interglaciation – which followed emergence from the Big Sea. The D-aspartic/L-aspartic ratio in one wood sample was 0.22 (UA-998). In the bluffs just east of the Duck Hawk Bluffs, peat beds overlying Big Sea Sediments and underlying glaciomarine and glacial sediments of the Prince of Wales Formation were dated at >49 000 BP (GSC-3560-2) and had a D/L ratio of 0.12 (UA-1094). Other organic beds in the Duck Hawk Bluffs were dated at >39 000 BP (GSC-3585) and had D/L ratios that ranged from 0.12 to 0.13 (UA-1001, -1103). These various beds are also tentatively assigned to the Cape Collinson Formation.

The environment during this interval was distinctly warmer than today as indicated by the dominant presence of tundra species such as **Betula** including **B. nana** L. and **B. glandulosa** Michx[1] and a few species of Coleoptera from the Carabidae and Staphilinidae families[2], which are presently restricted to the mainland near treeline. On the basis of the uranium-thorium 120 ka age of Big Sea shells, the Cape Collinson sediments probably date from the last (Sangamon) interglaciation.

Prince of Wales Formation

Prince of Wales Formation includes glacial deposits laid down during two distinct stades (M'Clure and Russell stades) of the last or Amundsen Glaciation on Banks Island (Table 1).

M'Clure Stade Deposits

During the M'Clure Stade, lobes of Laurentide ice advanced in Thesiger Bay (Thesiger Lobe) and Prince of Wales Strait (Prince of Wales Lobe) from Amundsen Gulf and Victoria Island, and in M'Clure Strait (Prince Alfred Lobe) from Viscount Melville Sound (Fig. 2, 4).

M'Clure Stade sediments, of the Prince of Wales Formation, include (Table 1): 1) Pre Amundsen Sea Sediments, which overlie the Cape Collinson Formation organic bed, and which were deposited in the south while the coast was being depressed by the advancing Prince of Wales Lobe; 2) Jesse Till, deposited along the east coast by the Prince of Wales Lobe; 3) Sachs Till, deposited along the southwest coast by the Thesiger Lobe; 4) Bar Harbour and Mercy tills, deposited along the north coast by the Prince Alfred Lobe (Fig. 2); 5) sediments of glacial lakes Sarfarssuk, Cardwell, and De Salis, of glacial lakes Masik, Rufus, and Raddi, and of glacial lakes Ballast and Ivitaruk, dammed by the Prince of Wales, Thesiger, and Prince Alfred lobes, respectively; 6) sediments of the East Coast Sea, which submerged the east coast up to 120 m following retreat of the Prince of Wales Lobe, of the Investigator Sea, which submerged the north coast up to 30 m following retreat of the Prince Alfred Lobe, and of the Meek Point Sea, which submerged the southwest coast and the nonglaciated west coast up to 20 m following retreat of the Thesiger Lobe; and 7) Carpenter Till, which was deposited by a late readvance of Thesiger Lobe on the southwest coast.

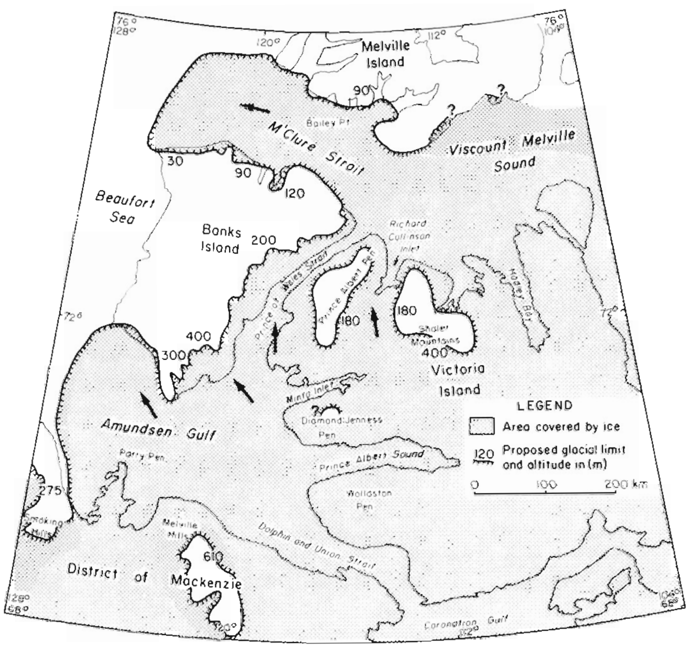

Figure 4. Map of the southwestern Canadian Arctic Archipelago showing the proposed Early Wisconsinan glacial limit.

[1] Most recent botanical surveys on Banks Island have not found **Betula** species. **Betula glandulosa** has been collected in one location (Kuc, 1970) on a warm, south facing slope in the well protected Masik valley. The organic remains in the Cape Collinson Formation were mainly wood, leaves, seed, and pollen of **Betula** (70% of the pollen present, excluding Cyperaceae and **Sphagnum**, was **Betula** and only 4% **Salix**). This indicates a climate much warmer than that at present where **Betula** was dominant.

[2] Unpublished GSC Fossil Arthropod Report No. 76-16 and GSC Macrofossil Report No. 78-6 by J.V. Matthews, Jr.; unpublished GSC Wood Identification Report No. 75-73 by R.J. Mott; unpublished GSC Wood Identification Report No. 77-24 by L.D. Farley-Gill; unpublished GSC Palynological Report No. 77-8, 79-6 by R.J. Mott.

Equivalence in relative age of the three M'Clure Stade lobes is demonstrated in the following manner. First, deltas built into glacial Lake Masik (dammed by Thesiger Lobe) by glacial meltwater streams flowing from the Prince of Wales Lobe prove that ice was present both in Thesiger Bay and over eastern Banks Island at the same time. Second, since glacial Lake Ivitaruk was dammed not only by Prince Alfred Lobe standing in M'Clure Strait but also by Prince of Wales Lobe in upper Thomsen River valley, it is evident that these two lobes were contemporaneous. The three lobes, therefore, impinged on the coastal areas of Banks Island at the same time.

The absolute age of the M'Clure Stade is not precisely known. On the Glacial Map of Canada (Prest et al., 1968) an ice limit approximately corresponding to the limit of the Prince of Wales, Thesiger, and Prince Alfred lobes is shown as "Classical Wisconsinan" (Late Wisconsinan). The following lines of evidence indicate that the M'Clure Stade more than likely predates the Late Wisconsinan:

1. Amino acid ratios (total) of alle:Ile for six fragments of **Hiatella arctica** shells from a delta at 36 m, of the East Coast Sea, vary between 0.04 (AAL-895A) and 0.09 (AAL-895C). These ratios differ from those determined for shells from the pre-last interglacial Big Sea (average of 0.19) and from Late Wisconsinan and Holocene Schuyter Point Sea (average of 0.02) and indicate that the East Coast Sea (and the Prince of Wales Lobe which it immediately postdates) must predate the Late Wisconsinan.
2. Shells of **Astarte** sp., collected on the west coast by D.M. Barnett in a raised spit 3-4 m a.s.l., gave a radiocarbon age of >19 000 BP (GSC-1478, Lowdon and Blake, 1973). The spit is in the large bay immediately south of Worth Point and at a higher elevation than a spit currently forming at the mouth of the bay during the present submergence phase of the west coast. The raised spit was likely constructed during the youngest transgression recognized on the west coast – Meek Point Sea. This sea and Thesiger Lobe, on the basis of the radiocarbon date on the shells from this spit, appear to predate the Late Wisconsinan.
3. In Kaersok River valley, mosses collected by J.G. Fyles from an organic layer, which overlies silts and sands deposited when M'Clure Strait was ice filled, gave a radiocarbon age of >41 000 BP (GSC-1088; Vincent, 1980, 1983). This indicates that the Prince Alfred Lobe is older than the Late Wisconsinan.
4. Peats collected from fluvial sands and gravels near the mouth of Dissection Creek at about 45-50 m by W. Blake, Jr. and the author gave radiocarbon ages of >39 000 BP (GSC-2819) and 49 100 ± 980 BP (GSC-2375-2) (Vincent, 1980, 1983). The peats are likely associated with fluvial sediments deposited when sea level was higher than that of today. Since the Investigator Sea is the last sea to have drowned Thomsen River basin in pre-Late Wisconsinan time, the age determinations may provide a minimum age for the retreat of the Prince Alfred Lobe.
5. Organic matter from the base of a core was collected by J.C. Ritchie in southern Banks Island, in a lake situated in a channel cut by glacial meltwaters flowing from the Prince of Wales Lobe. This sample gave an age of 26 800 ± 1560 BP (GSC-2780, J.C. Ritchie, personal communication, 1979). The sample may be contaminated by coal, which would account for the older age, but pollen spectra from the core may extend, according to Ritchie, into the early part of the Late Wisconsinan though the data are not conclusive. This would again imply an age older than Late Wisconsinan for the Prince of Wales Lobe.
6. As described later, it is possible to define a younger ice limit than that of the Thesiger, Prince of Wales, and Prince Alfred lobes. This limit lies for the most part on Victoria Island to the east and southeast of Banks Island. The limit of the lobes on Banks Island must necessarily be older than the limit on Victoria Island.
7. The eastern coast of Banks Island and northwestern coast of Victoria Island were inundated in the Late Wisconsinan-Holocene by the Schuyter Point Sea. This sea, which produced a strandline that distinctly cuts into surfaces previously covered by the East Coast Sea, is considered to have resulted from the isostatic depression of the crust in an area lying outside the zone covered by ice in Late Wisconsinan time. Two glacial stades of Amundsen Glaciation are therefore represented: the oldest by the Prince of Wales, Thesiger, and Prince Alfred lobes and the East Coast and Meek Point seas; the youngest by ice standing to the east on Victoria Island and by the Schuyter Point Sea. Since the younger stade is Late Wisconsinan in age, the older predates this period.
8. Perhaps the best line of evidence is provided by a radiocarbon date on in situ shells of **Portlandia arctica**, from bluffs near Sachs Harbour, which were collected in fine grained glaciomarine sediments lying immediately below Sachs Till and containing inclusions of the till. The obtained age of >37 000 BP (GSC-3698) on these shells, associated with sediments intimately linked with the advance of the Thesiger Lobe of the M'Clure Stade (Pre Amundsen Sea), clearly indicates that the stade is pre-Late Wisconsinan and likely pre-Middle Wisconsinan in age.

The M'Clure Stade limit (Fig. 4) is correlated with the upper limit of a moraine belt along the flanks of the Melville Hills (Fulton and Klassen, 1969) and high areas to the south on the mainland. The portion north of 69°N was initially traced by Klassen (1971) as the "approximate limit of Late Wisconsin Glaciation".

To the west, the equivalent M'Clure Stade limit in the Smoking Hills area (Fig. 4) is likely the one Fyles et al. (1972) considered as being the limit of the "maximum extent of the Laurentide Glaciation". South of 70°N this limit was mapped as the "approximate limit of Late Wisconsin Glaciation" by Klassen (1971), whereas north of 70°N it was shown as the "Early Wisconsin(?) glacial limit" by Rampton (1981).

Russell Stade Deposits

Russell Stade deposits of the Prince of Wales Formation are made up of two units – Passage Point and Schuyter Point Sea sediments. Passage Point Sediments are glacially deformed fine grained sediments that overlie Jesse Till between Parker and Passage points. They were laid down when the Viscount Melville Sound Ice Shelf (Hodgson and Vincent, in press), which flowed from Viscount Melville Sound, impinged on the extreme northeast tip of the Island (Fig. 2, 3, 5). The locally shell-bearing sediments of the Schuyter Point Sea were deposited up to 25 m a.s.l. on the marginally depressed east coast, to the west of the Late Wisconsinan ice sheet margin.

Passage Point Sediments are Late Wisconsinan in age. Shells, collected by D.M. Barnett at about 85 m in ice-pushed (by the ice shelf) Passage Point Sediments located 16 km north-northwest of Parker Point, were dated at 10 600 ± 270 BP (GSC-1437, Lowdon and Blake, 1973) and give a maximum age for these sediments. The Schuyter Point Sea Sediments, based on shell radiocarbon dates, are Late Wisconsinan/Holocene in age. Five dates indicate the progressive lowering of relative sea level from about

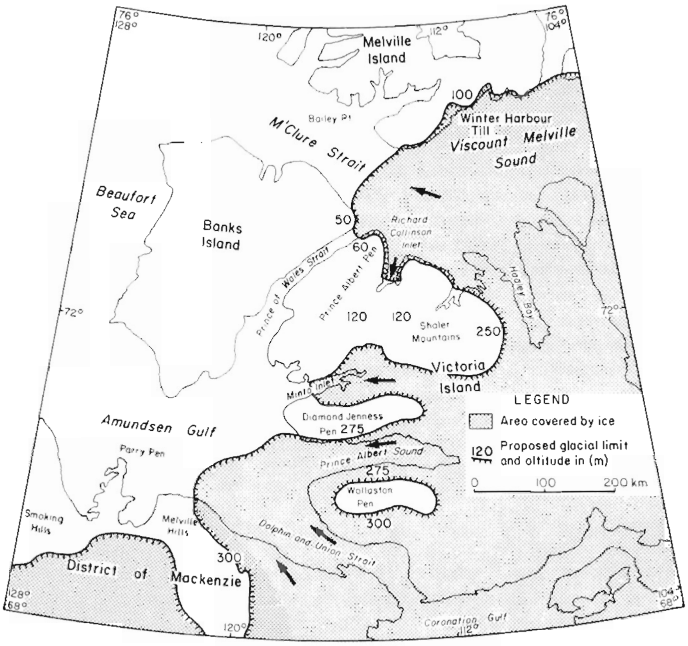

Figure 5. *Map of the southwestern Canadian Arctic Archipelago showing the proposed Late Wisconsinan glacial limit.*

21 m to about 8 m between 11 200 ± 100 (GSC-2545) and 10 200 ± 170 BP (GSC-2099) (Vincent, 1978). It should also be noted that the Russell Stade is correlated with an ice limit in the area south of the Melville Hills (Fig. 5), which follows the contact between a fresh appearing till sheet (<300 m) and a higher (300-600 m) more subdued till sheet probably associated with the M'Clure Stade (information from interpretation of air photographs). To the west of the Melville Hills the limit follows the "minimum Late Wisconsin limit" as shown on Map 1584A (Prest, this volume). This approximately follows the limit of the "Great Bear Lake Ice Lobe" of the "last ice advance" of Mackay (1958).

QUATERNARY UNITS OF VICTORIA ISLAND

The Quaternary geology of Victoria Island was first investigated by Fyles (1963). Vincent (1980, 1982, 1983) linked some of his Banks Island work to Victoria Island and further information was obtained during surficial geology mapping by the Geological Survey of Canada of western Victoria started in 1981 (Hodgson and Vincent, in press). Few sections have been described and no units have been named, but the following general comments can be made.

Figure 4, based on Fyles (1963) and preliminary airphoto interpretation by the author, shows that the central part of Prince Albert Peninsula (as tentatively suggested by Fyles, 1963), parts of Shaler Mountains, and possibly a small area in the centre of Diamond Jenness Peninsula may have escaped the Wisconsinan glaciation – that is, they were not covered by either M'Clure or Russell Stade Laurentide ice. The till that overlies central Prince Albert Peninsula was probably deposited during Thomsen Glaciation and is therefore of equivalent age to the tills of Nelson River Formation on Banks Island (Table 1). Some of the stratified deposits, described by Fyles (1963, p. 4), which underlie the till along Prince of Wales Strait on Prince Albert Peninsula, were likely laid down in the Big Sea (Nelson River Formation) and the overlying till is probably equivalent to Jesse Till (Prince of Wales Formation) of Banks Island. The units in the section first described by Fyles (1963, p. 4) containing intertill organic-bearing deposits, north of Prince Albert Sound on Diamond Jenness Peninsula, cannot at this time be definitely fitted in the stratigraphic framework of the area. The organic deposits, dated >32 400 BP (GSC-388, Blake, 1974), >37 000 BP (GSC-3613), and >33 000 BP (GSC-3592), may have accumulated during a Wisconsinan interstade (equivalent to the one between the M'Clure and Russell stades on Banks Island) or they may be from an earlier interglaciation.

Figure 5 shows the provisional limit of Laurentide ice on Victoria Island during the Late Wisconsinan. Large areas of Prince Albert, Diamond Jenness, and Wollaston peninsulas, and of the Shaler Mountains were not covered during this later advance. Ice flow was controlled by low lying areas centred on Dolphin and Union Strait, Prince Albert Sound, and Minto and Richard Collinson inlets. The ice likely dispersed from a source of outflow to the east of Victoria Island in M'Clintock Channel, described as the M'Clintock Dome by Dyke (1981) and Dyke et al. (1982), and from mainland areas to the south and southeast.

In the extreme northwest, the Viscount Melville Sound Ice Shelf, which is responsible for deposition of Passage Point Sediments on Banks Island and Winter Harbour Till on southern Melville Island (Vincent, 1980, 1982, 1983; Hodgson et al., in press; Hodgson and Vincent, in press), impinged on coastal areas. On the western side of Richard Collinson Inlet, till, deposited by the Viscount Melville Sound Ice Shelf moving south in the inlet, overlies marine sediments of a sea that submerged the coastal areas before they were covered by ice. Shells lying beneath the till, near Loch Point (Fyles, 1963, p. 5) were dated at 11 000 ± 460 BP (GSC-403) (J.G. Fyles, personal communication, 1981) and 11 300 ± 260 BP (GSC-3409). The oldest dated shells found in marine sediments of the same sea but in areas inland from the limit of Viscount Melville Sound Ice Shelf were dated at 12 600 ± 140 BP (GSC-1707; Lowdon and Blake, 1976). Shells clearly postdating the ice shelf advance at Worksop Point were dated at 9880 ± 150 BP (GSC-3527; Hodgson and Vincent, in press). The dates on the shells indicate that the Viscount Melville Sound Ice Shelf impinged on the north coast of Victoria Island between 11 300 ± 260 and 9880 ± 150 BP. The sea, which flooded large areas before the ice advance, is time equivalent to the earlier Schuyter Point Sea on Banks Island and, as discussed later, to the sea that covered southern Melville Island and other marginally depressed areas of the western Queen Elizabeth Islands before Winter Harbour Till was deposited by the Viscount Melville Sound Ice Shelf.

QUATERNARY UNITS OF MELVILLE ISLAND

Aspects of the Quaternary of Melville Island are discussed mainly in Tozer and Thorsteinsson (1964), Fyles (1965, 1967), McLaren and Barnett (1978), Hodgson and Vincent (1982), Hodgson et al. (in press), and Hodgson and Vincent (in press); the last three reports provide the main basis for the following discussion.

Few exposures are available, but the presence of till sheets in central Melville Island and Dundas Peninsula could be attributed to partial overriding of the island by continental ice sheets of three distinct ages dispersing from the south (Fig. 6; Fyles, 1967). The oldest glaciation covered southern Dundas Peninsula and deposited Dundas Till and a major belt of ice contact deposits which is probably a terminal moraine. Dundas Till is probably equivalent to till deposited either during Thomsen Glaciation or more likely Banks Glaciation on neighbouring Banks Island. The numerous Shield and other erratics and patches of till observed on the surface of eastern Melville Island (Tozer and Thorsteinsson, 1964; Barnett, 1972) may have been deposited by the same continental glacier or by an older ice advance.

Shield erratics (Tozer and Thorsteinsson, 1964) and a well developed esker (Fyles, 1965) on northwestern Melville Island may also have been related to this same extensive glaciation.

During a subsequent glaciation, continental ice advanced from the south and impinged on the south coast depositing Bolduc Till (Fig. 6). This ice is likely the same that progressed westward, from Viscount Melville Sound, into M'Clure Strait entering outer Liddon Gulf where it deposited Liddon Till on the northwest coast of Dundas Peninsula and till and other glacial deposits in the Cape Hoare and Bailey Point areas on the north shore of Liddon Gulf (Fig. 6). Bolduc and Liddon tills are possibly equivalent in age to the Bar Harbour and Mercy tills deposited on the north coast of Banks Island during the M'Clure Stade of Amundsen Glaciation. The tills on the north coast of Banks Island and the ones in the Liddon Gulf area were likely deposited by the Prince Alfred Lobe (perhaps an ice shelf?) which moved into M'Clure Strait from Viscount Melville Sound.

Shells, collected by J.G. Fyles, from a marine veneer on the surface of Bolduc Till gave an age of >33 000 BP (GSC-727; Lowdon and Blake, 1968) whereas other shells, also collected by J.G. Fyles, on the surface of the same till gave an age of 42 400 ± 1900 BP (GSC-787; Lowdon and Blake, 1968) – a value that should be regarded as a minimum. As indicated by Hodgson et al. (in press), both samples may date a marine event postdating till deposition for which no other information is available, or they may be glacially transported from marine deposits older than or of similar age to Bolduc Till. Whatever the case, if Bolduc Till is, in fact, correlative with the tills deposited by the Prince Alfred Lobe, the date gives an indication, with others previously mentioned, that the M'Clure Stade predates the Late Wisconsinan.

In the Late Wisconsinan/Holocene, ice from an ice shelf in Viscount Melville Sound advanced and impinged on southern Dundas Peninsula depositing Winter Harbour Till (Fig. 6). Fossiliferous marine sediments clearly underlie Winter Harbour Till in the same way that marine sediments underlie till deposited by the Viscount Melville Sound Ice Shelf in the previously discussed Richard Collinson Inlet area on Victoria Island. Shells from these underlying sediments are as old as 11 700 ± 100 BP (GSC-3249; Hodgson and Vincent, in press; Hodgson et al., in press) and as young as 10 340 ± 150 BP (GSC-278, Lowdon et al., 1967). Viscount Melville Sound was therefore at least partly ice free during this time and may also have been ice free around 27 790 ± 480 BP (GSC-667; Lowdon and Blake, 1968) – the age of ice-transported marine shells collected by J.G. Fyles at the edge of Winter Harbour Till. The oldest shells overlying Winter Harbour Till are 9670 ± 150 years old (GSC-282; Lowdon et al., 1967) – a minimum age for break-up of the Viscount Melville Sound Ice Shelf (Hodgson and Vincent, in press). These bracketing dates of 10 340

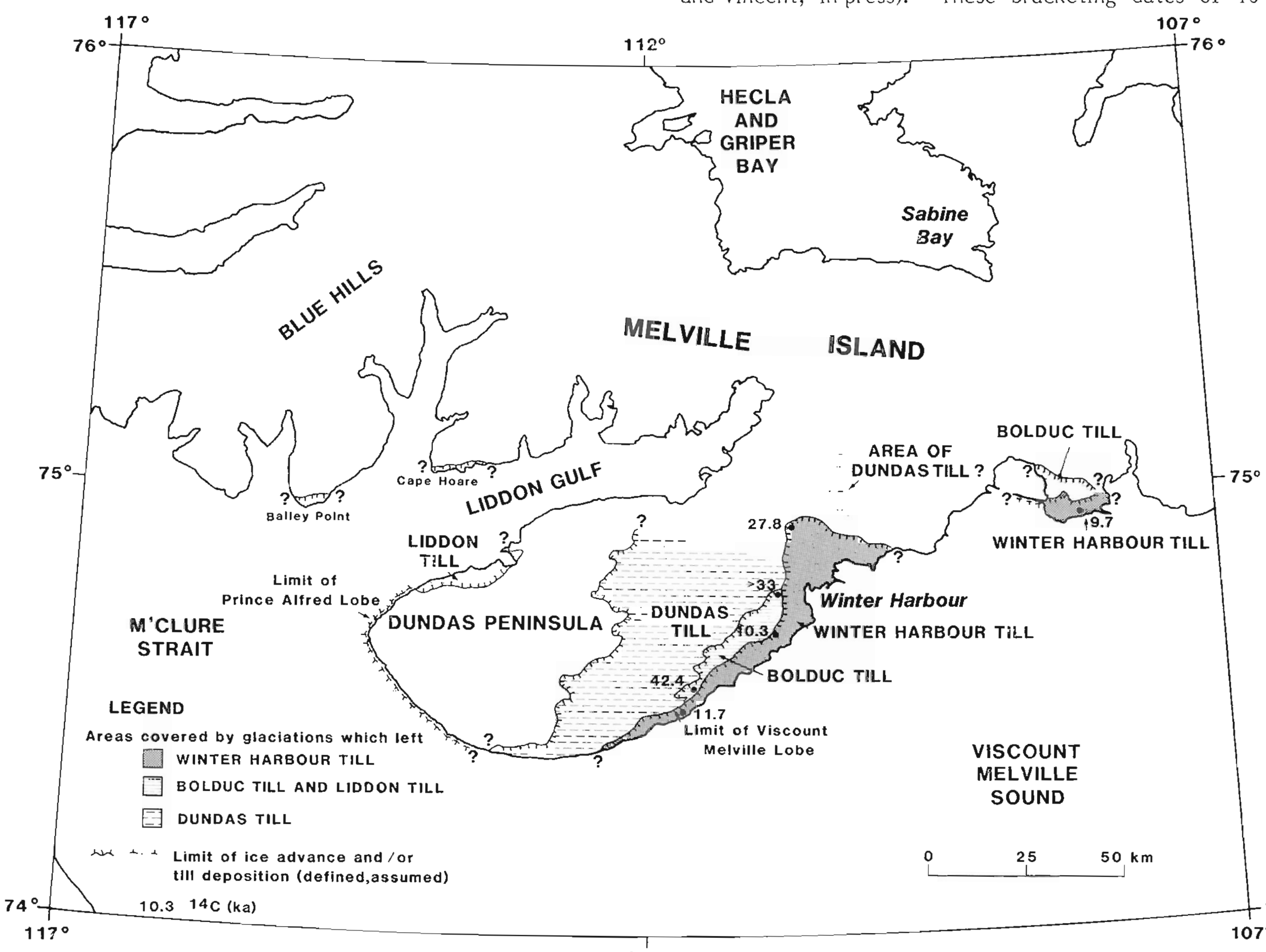

Figure 6. Distribution of till sheets and proposed glacial limits on central Melville Island (after Hodgson et al., in press).

and 9670 are extremely important because they permit reliable dating of the time at which Late Wisconsinan Laurentide ice reached its limit in this area of North America.

The distribution of ice marginal channels and locally derived till veneers on the uplands of western Melville Island north of Liddon Gulf, and of fiord-like inlets farther west (Tozer and Thorsteinsson, 1964) indicates that local ice covered these areas at undetermined times in the past.

Apart from the evidence for the two limited advances of continental ice from the southeast on the south coast and for the likely existence of local glaciers on eastern and western uplands, there is no direct evidence for an extensive Wisconsinan ice sheet (such as the Innuitian Ice Sheet suggested by Blake (1970) and depicted on maps by Prest (1969) or Denton and Hughes (1981)), north of Viscount Melville Sound.

QUATERNARY UNITS OF PRINCE PATRICK, EGLINTON, BROCK, BORDEN, AND MACKENZIE KING ISLANDS

Evidence collected by Tozer and Thorsteinsson (1964) and Fyles (1965) indicates that the westernmost Queen Elizabeth Islands were once in part at least covered by continental(?) ice. Some of the evidence, such as the striated sandstone surfaces at the head of Mould Bay on Prince Patrick Island (Robitaille, 1960; Tozer and Thorsteinsson, 1964), may reflect a locally centred glacier. Other features, such as the widespread erratics on the Beaufort Formation (Tozer and Thorsteinsson, 1964) and the glacial landscapes (Fyles, 1965) of Prince Patrick Island (moraine-like topography, kame-like hills, eskers, misfit channels) and of Brock Island (ice thrust moraine), point towards a more widespread (continental?) ice cover.

On the basis of the geographical distribution of the farthest glacial limits of clearly continental ice on Banks Island (extent of Bernard Till) and central Melville Island (extent of Dundas Till), it is evident that the only continental ice thick enough to have reached and covered part of these coastal plain islands was pre-Wisconsinan and most likely equivalent to the extensive Banks Glaciation. Even in the case of the most powerful continental glaciation, ice flow was probably entirely controlled by the interisland channels and the ice was likely not thick enough to extend far onto land. Again, no evidence exists for a widespread Late Wisconsinan ice cover (locally centred ice may have been present; Tozer and Thorsteinsson, 1964; Fyles, 1965) like that shown by Prest (1969) or by Denton and Hughes (1981).

Shell-bearing marine deposits are found at low elevation along the coasts of the islands. The oldest shells in the area, collected from beaches 3-6 m a.s.l. by J.G. Fyles on southern Prince Patrick Island, are 11 660 ± 370 years old (GSC-354; Blake, 1972) whereas the highest shells (30 m), also collected by J.G. Fyles on east-central Prince Patrick Island, are 11 160 ± 150 years old (GSC-260; Lowdon et al., 1967). It appears therefore that the sea that flooded extensive marginally depressed coastal areas of Banks and Melville islands before the advance of Viscount Melville Sound Ice Shelf also covered the westernmost Queen Elizabeth Islands. Depression of the crust is likely due to the combined effect of Late Wisconsinan M'Clintock Dome continental ice to the southeast on Victoria Island and possibly to the presence of local glaciers on Prince Patrick Island and eastern and western Melville Island and to the expansion of other local ice caps to the east on Bathurst and adjacent islands. Other factors such as the gravitational attraction of the ice sheets upon the oceans (Clark, 1976) or latitudinal compressive tectonic forces (see discussion in Hodgson, 1981) may also account for some of the observed "uplift".

SUMMARY

In the western Canadian Arctic Archipelago, the best Quaternary stratigraphic record is found on Banks Island. Continental ice sheets, spreading from dispersal centres on the mainland to the southeast, reached their limit on at least three occasions on this island. Sediments in numerous exposures document these three glacials as well as preglacial and intervening interglacial periods. Most of Banks Island and possibly extensive areas of the western Queen Elizabeth Islands were covered by the oldest recognized Banks Glaciation. The subsequent pre-Wisconsinan Thomsen Glaciation was less extensive. It may have partially covered the southwestern Queen Elizabeth Islands, but it is impossible at this time to separate its sediments from the Banks Glaciation sediments. Two glacial stades are recorded during the Wisconsinan-age Amundsen Glaciation. During the older M'Clure Stade on Banks Island (possibly early Wisconsinan Substage), ice covered most of Victoria Island, except for parts of Prince Albert Peninsula and the Shaler Mountains, and flowed into Amundsen Gulf impinging on the southwest and east coast of Banks Island and into M'Clure Strait impinging on the north coast of Banks and the south coast of Melville Island. Ice from the M'Clintock Dome advanced again in Late Wisconsinan time (Russell Stade of Banks Island) over Victoria Island into eastern Amundsen Gulf and Viscount Melville Sound. This ice impinged on the northeast coast of Banks Island and the south coast of Melville Island, leaving large areas of Wollaston, Diamond Jenness, and Prince Albert peninsulas, and the Shaler Mountains of Victoria Island unglaciated. The climate was warmer during the Morgan Bluffs Interglaciation (between Banks and Thomsen glaciations) and the Cape Collinson Interglaciation (between Thomsen and Amundsen glaciations) than during the present interglaciation.

ACKNOWLEDGMENTS

This report is part of the reporting process for studies dealing with the Quaternary geology of Banks Island, central Melville Island, and western Victoria Island. Field logistics over six summers were very efficiently handled by the Polar Continental Shelf Project. This report greatly benefited from critical reading by J.T. Andrews, R.J. Fulton, and D.A. Hodgson.

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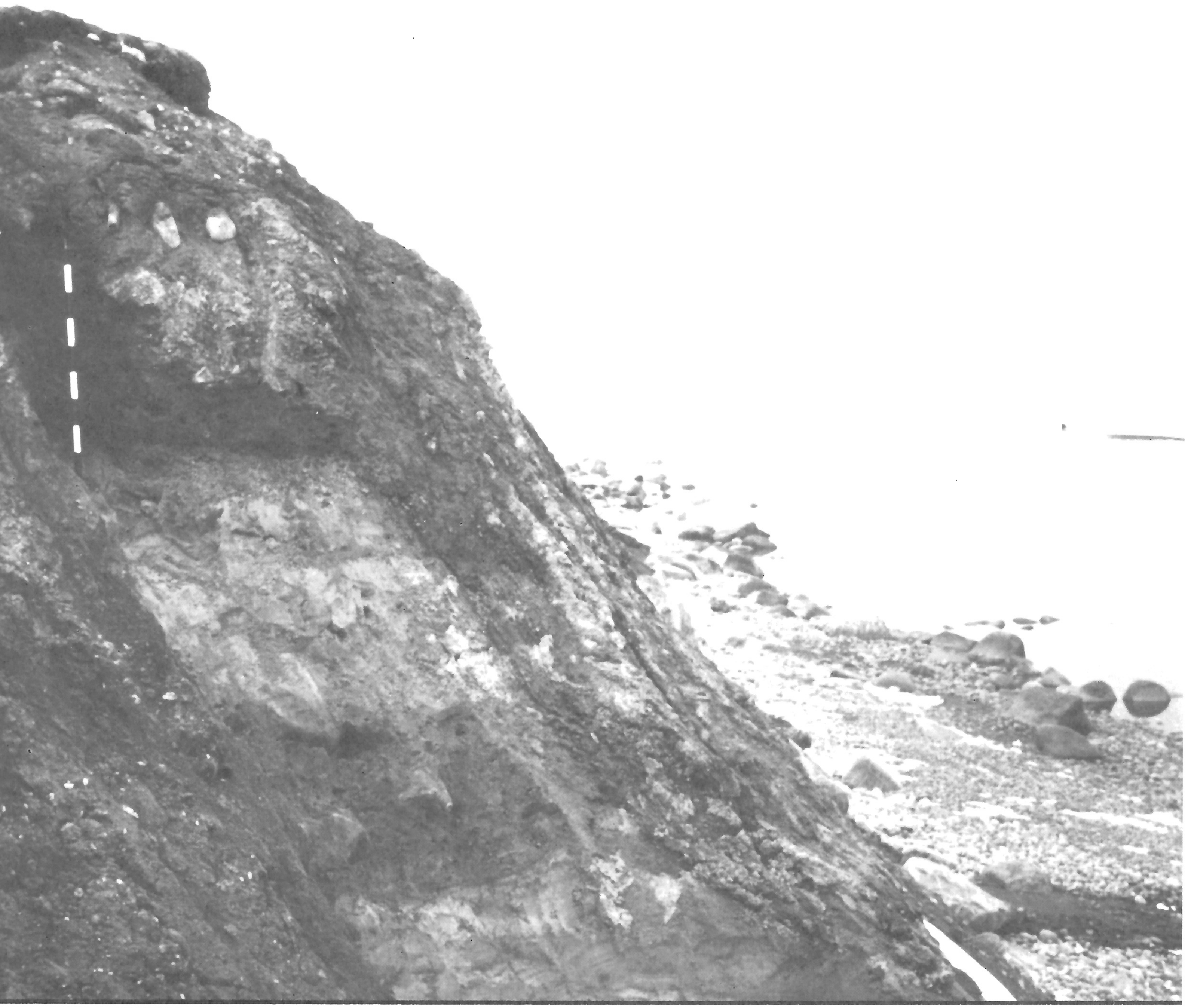

Qivitu Peninsula, east-central Baffin Island: Section contains lithofacies representing three glaciomarine sedimentation cycles which, according to interpretation of amino acid ratios, range in age from about 9 ka to older than 190 ka. Photo and stratigraphy by A.R. Nelson, GSC 202881-P.

QUATERNARY GLACIAL AND NONGLACIAL CORRELATIONS FOR THE EASTERN CANADIAN ARCTIC

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Andrews, J.T. and Miller, G.H., Quaternary glacial and nonglacial correlations for the Eastern Canadian Arctic; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 101-116, 1984.

Abstract

The Eastern Canadian Arctic includes the 450 000 km² Baffin Island and the northern areas of Labrador-Ungava Peninsula. Quaternary research in these areas during the last century traditionally concerned itself with the mapping of major moraine systems and the recognition of weathering zones. Of late more attention has focused on the extensive exposures of Quaternary sediments in wave-eroded cliffs along much of the outer coastline that fronts Baffin Bay and Labrador Sea. These exposures contain fossiliferous glacial marine sediments and buried soils; tills are reported in a few sections. Absolute radiometric dates have been obtained from several units using both ^{14}C and U-series methods. In many areas the upper sediment is an eolian unit that dates from the last 5 ka; this is underlain by distal glacial marine and beach sediments which consistently date at between 8 and 10 ka. On the outer coast of eastern Baffin Island these sediments represent the Eglinton Member of the Clyde Foreland Formation; they overlie sediments of the Kogalu Member which is older than 54 ka on the basis of ^{14}C and is probably between 70 and 120 ka old judging from U-series dates and amino acid racemization estimates. In northernmost Labrador and on southern Ellesmere Island good evidence exists for a deglacial event with finite ^{14}C dates close to 40 ka. Despite several years of investigation and several hundred ^{14}C dates, there is still no evidence for an 18 ka glacial maximum. In southern Baffin Island, however, the outer Hall moraines within Frobisher Bay are ^{14}C dated at ca. 10.7 ka and are thus distinctly older than moraines of Cockburn age (8-9 ka) which appear to represent the maximum late Wisconsinan ice margin from Cumberland Sound northward. Beneath the Kogalu Member are as many as eight additional sedimentary sequences that represent the effects of glacial isostatic loading and unloading. These units can be distinguished on the basis of their amino acid ratios and broadly "dated". The Quaternary record in the Eastern Canadian Arctic probably spans 1 to 2 million years.

Résumé

La partie est de l'Arctique canadien englobe l'île de Baffin, d'une superficie de 450 000 km², et les régions nordiques du Labrador et de la péninsule d'Ungava. Depuis un siècle, les études quaternaires dans ces régions ont surtout été consacrées à la cartographie des principaux systèmes morainiques et à l'identification des zones d'altération. Depuis peu, on s'intéresse davantage aux vastes couches de sédiments quaternaires contenus dans des falaises érodées par les vagues le long d'une bonne partie de la côte extérieure donnant sur la baie de Baffin et la mer du Labrador. Ces affleurements renferment des sédiments glaciomarins fossilifères et des sols enfouis; on signale même la présence de tills dans quelques coupes. Plusieurs unités stratigraphiques ont été datées au carbone radioactif et par la méthode des isotopes de l'uranium. À de nombreux endroits, les couches supérieures de sédiments forment une unité éolienne vieille de 5 ka; elles reposent sur des sédiments glaciomarins et littoraux de nature distale dont les âges se situent entre 8 et 10 ka. Sur la côte extérieure de l'île de Baffin, ces sédiments représentent le niveau Eglinton de la formation de Clyde Foreland; ils recouvrent des sédiments du niveau Kogalu qui ont plus de 54 ka d'après la datation au carbone radioactif et dont l'âge se situe vraisemblablement entre 70 et 120 ka si l'on en juge d'après les dates déterminées par la méthode des isotopes de l'uranium et par les estimations de la racémisation d'acides aminés. Dans l'extrême nord du Labrador et dand le sud de l'île d'Ellesmere, on trouve de bons indices d'une déglaciation vieille de 40 ka d'après les résultats de la datation au carbone radioactif. Malgré plusieurs années d'études et plusieurs centaines de datations au carbone radioactif, les chercheurs n'ont pas encore trouvé la preuve que le maximum d'extension glaciaire a eu lieu il y a 18 ka. Dans le sud de l'île de Baffin, toutefois, les moraines extérieures de la formation de Hall, à l'intérieur de la baie Frobisher, datent de 10,7 ka (^{14}C) et sont donc nettement plus anciennes que les moraines de la phase Cockburn (8 à 9 ka) qui représentent, semble-t-il, la limite d'extension maximale de la marge du glacier de la fin du Wisconsinien; cette marge s'étendait du détroit de Cumberland vers le nord. Le niveau Kogalu repose sur non moins de huit autres successions sédimentaires, qui représentent les effets des pressions et allégements isostatiques. Ces unités peuvent être reconnues d'après leurs rapports d'acides aminés et datées très approximativement. Les formations de l'est de l'Arctique canadien rendent compte probablement de 1 à 2 millions d'années d'histoire du Quaternaire.

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Manuscript received: 1981-11-18
Final version approved for publication: 1983-05-24

INTRODUCTION

The status of Quaternary stratigraphy and chronology for the area of the Eastern Canadian Arctic (Fig. 1) has been reviewed in previous reports to IGCP Project 24 (Andrews et al., 1976; Andrews, 1977). This report summarizes current knowledge and hypotheses about the land-based glacial and raised marine stratigraphy and chronology and compares these with the increasing number of records that are coming from other stratigraphic contexts, such as the δO^{18} records from the Devon Island Ice Cap (Paterson et al., 1977; Fisher and Koerner, 1981) and the δO^{18}, biostratigraphic, and lithostratigraphic records from deep-sea cores in Baffin Bay and northern Labrador Sea (Aksu and Piper, 1979; Aksu, 1980; Fillon and Duplessy, 1980; Fillon et al., 1981). The latest area where preliminary Quaternary records are forthcoming is from the nearshore zone of Baffin Island and northernmost Labrador (Fillon, 1978; Osterman, 1980, 1981; Osterman et al., 1980). Because of the increased activity in the Eastern Canadian Arctic due to hydrocarbon exploration, we feel that major advances in the near future will be from continued analysis of both the nearshore and deep-sea marine records.

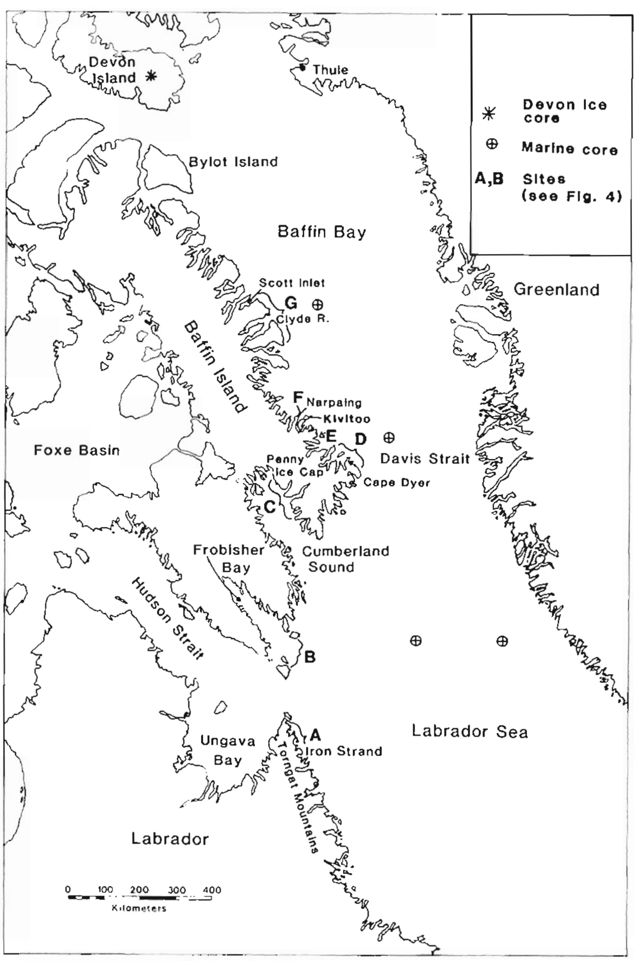


Figure 1. Location of place names and sites reported in this study, including deep-sea cores and Devon Island Ice Cap stable oxygen record (Paterson et al., 1977; Aksu, 1981; Fillon and Duplessy, 1980). A, B, C, etc. indicate sites on which columns of Figure 4 are based.

Figure 1 shows the study area and the location of some of the critical ice and marine cores. The physical setting is discussed below, followed by a summary of current knowledge of the Quaternary stratigraphy and chronology of glacial and raised marine units (e.g., Andrews et al., 1976; Miller et al., 1977). The current chronological framework is based in large part on Miller's continued work on the kinetics of amino acid racemization for shells of the taxa **Hiatella arctica** and **Mya truncata.** We also compare our results with other chronologies from Hudson Bay (Andrews et al., 1983) and from Ellesmere Island (England et al., 1978, 1981; Blake, 1980a, b).

LOCATION AND BACKGROUND

The Eastern Canadian Arctic is a critical area in any assessment of Quaternary correlations between glaciated areas. It is probably one of the first areas to be glaciated during a climatic deterioration (Ives et al., 1975; Andrews and Mahaffy, 1976; Williams, 1978a, b) and was certainly affected by cooling during the "Little Ice Age" (Ives, 1962; Bradley and Miller, 1972; Williams, 1978b; see, however, Koerner, 1980). Of considerable importance to the entire Laurentide Ice Sheet is the presence of Hudson Strait – the major trough that connects Hudson Bay, James Bay, and Foxe Basin with the North Atlantic. This trough figures prominently in many discussions on the stability of and controls on glaciation and deglaciation of the Laurentide Ice Sheet (e.g., Andrews and Falconer, 1969; Denton and Hughes, 1981), but little work has been carried out along the outer coast near the mouth of Hudson Strait.

The high plateaus of the uplifted rim of the Canadian Shield form the major topographic element of the region. Elevations exceed 1500 m in a few places, but vast areas lie about 600 m a.s.l. The interior basins of Foxe Basin, Hudson Bay, and Ungava Bay are floored primarily by Paleozoic limestones, and similar units floor Hudson Strait, Frobisher Bay, and Cumberland Sound (MacLean and Falconer, 1979). Paleozoic limestone also underlies part of the southeast Baffin Island continental shelf. Paleozoic outliers occur on southwestern Baffin Island, and a wide variety of sedimentary units outcrops in the northern part of the island. The distribution of Paleozoic limestone erratics and the carbonate content of tills are thus potentially important indicators of ice movement throughout the area.

The environment of the Eastern Canadian Arctic is harsh. July temperatures range from about 10°C in southern Labrador to about 4°C in northern Baffin Bay. Winter snow accumulation is poorly documented for the region but probably ranges between 20 and 100 cm H_2O. The glaciation level (Andrews and Miller, 1972; Miller et al., 1975) varies between 600 and 800 m a.s.l. at the east coast of Baffin Island, although it is higher across the Torngat Mountains of Labrador, and rises inland (westward) to maximum elevations of 1100 to 1200 m a.s.l. in the vicinity of the Penny Ice Cap (Fig. 1). Present glaciation consists of small cirque glaciers, valley glaciers, mountain ice caps, and plateau ice caps (e.g., Barnes Ice Cap).

Baffin Bay and the northern Labrador Sea are ice covered for several months of the year. The most severe sea ice conditions exist along the eastern coast of Baffin Island between Cape Dyer and Clyde River (Fig. 1). Maximum surface water temperatures occur in August when the 7°C isotherm extends northward from off Labrador towards northern Greenland near Thule. This isotherm serves to delimit two basic water masses which are important in any Quaternary study of the region. Along the coast of Baffin Island and Labrador, cold water from the Canadian Current flows southward with maximum surface temperatures between 0° and 7°C (Fig. 2). Offshore and extending northward along the coast of West Greenland is the mixed

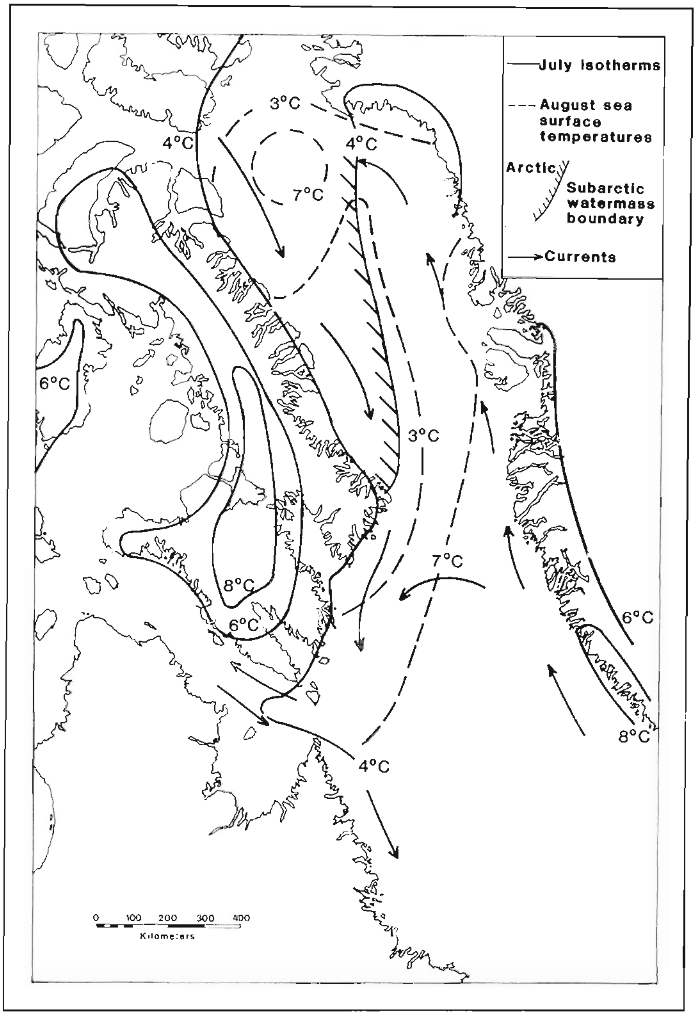


Figure 2. *Some environmental parameters that are important in the interpretation of the Quaternary history of the region, namely, July land temperature (°C), major currents, arctic/subarctic watermass boundary.*

Arctic/North Atlantic water of the West Greenland Current. These two currents fundamentally modulate the environment of Baffin Bay, Baffin Island, the islands in northern Baffin Bay, and the coast of West Greenland.

Quaternary glaciation of the Eastern Canadian Arctic involved different ice types and ice sources: (1) local cirque and valley glacier complexes, e.g., Cape Dyer-Merchants Bay area of Baffin Island (Fig. 1; Miller, 1975; Locke, 1980; Hawkins, 1980); (2) local ice caps of substantial size, e.g., Penny Ice Cap (Pheasant and Andrews, 1973; Miller, 1973; Dyke, 1979) and Devon Island Ice Cap, (Paterson et al., 1977); (3) areas of interaction between local and regional ice sources, e.g., Bylot Island (Klassen, 1981), southeast Baffin Island (Blake, 1966; Miller, 1980; Muller, 1980); (4) areas dominated by ice flowing from dispersal centres of the Laurentide Ice Sheet, e.g., central east coast of Baffin Island (Hodgson and Haselton, 1974; Miller et al., 1977; Mode, 1980); and (5) ice flowing onto or even generated on the continental shelf (R.H. Fillon, personal communication, 1981; B. MacLean, personal communication, 1981; J.T. Andrews and G.H. Miller, unpublished data).

QUATERNARY STRATIGRAPHIC NOMENCLATURE AND RECORDS

We have been concerned over the last several years with the problems of Quaternary nomenclature for our study area (Andrews, 1977; Andrews and Ives, 1978; Miller et al., 1977; Andrews et al., 1981). During the past 20 years of research in the Eastern Canadian Arctic, several approaches and nomenclatures suited to local problems have evolved. This process of evolution is far from complete, and in this final report we will suggest a major change in our existing terminology (e.g., Miller et al., 1977). First, however, our methods of correlation, dating, and nomenclature are briefly discussed:

1. In areas of local cirque glaciation, we have been forced to rely on lichenometry as a means of dating the last 8 ka of record (Miller, 1973; Andrews and Barnett, 1979) whereas for the nonfossiliferous pre-Holocene deposits, researchers have investigated a wide range of relative dating methods primarily related to rock weathering and pedogenic processes (e.g., Isherwood, 1975; Dyke, 1977; Birkeland, 1978; Bockheim, 1979; Locke, 1979, 1980).
2. In coastal areas affected glacio-isostatically by fairly large ice loads, workers have developed a glaciomarine facies model which emphasizes the role of glacial isostasy in producing a sequence of marine transgressions and regressions (Miller et al., 1977; Andrews, 1980; Mode, 1980; Brigham, 1980; Nelson, 1981).
3. Most of the units formed by repeated marine transgressions and regressions are fossiliferous. Molluscs and foraminifera have been studied and used to infer paleoenvironmental conditions in the inshore water of western Baffin Bay (Andrews, 1972; Feyling-Hanssen, 1976a, b, 1980; Mode, 1980; Miller, 1980; Andrews et al., 1981). The marine regressions and transgressions are interpreted as resulting from glacial events, hence the glacial marine stratigraphy forms a major corner-stone in the chronology of Quaternary glaciations.
4. The marine molluscs from the sediments noted in points 2 and 3 above can be used to provide absolute(?) and relative ages of the units through a variety of dating methods, most commonly: ^{14}C dating; U-series dating; and amino acid racemization (e.g., Miller et al., 1977; Nelson, 1978; Miller, 1979; Mode, 1980; Brigham, 1980; Szabo et al., 1981). In this report ^{14}C dates are used to date the events of the last 11 ka and to provide minimum dates on older deposits; U-series dates provide minimum age estimates on deposits older than 40 ka; and amino acid ratios are used as the major link in correlating local stratigraphies and as a tool for providing a first approximation to an "absolute" chronology based on some specific knowledge of the racemization rates of specific molluscan genera (Miller and Hare, 1980; G.H. Miller, unpublished data).
5. Relatively detailed local correlations have used raised marine shorelines to develop patterns of regional isostatic warping and local glacial retreat (Andrews et al., 1970; Dyke, 1974, 1979; Miller, 1980; Andrews, 1980).

There has been considerable discussion about appropriate Quaternary nomenclature for the Eastern Canadian Arctic (Table 1). The early work based stratigraphic interpretation on the observed elevational differences in the weathering of bedrock, surface boulders, and soil development. This work resulted in the recognition of weathering zones which have been largely interpreted in terms of time. Sugden and Watts (1977) and Denton and Hughes (1981), however, have suggested that some of these zones might be better explained as the result of differences in thermal conditions at the base of glaciers and ice sheets.

Table 1. Trends in Quaternary studies and nomemclature - Baffin Island and northernmost Labrador

1898	Tyrrell published a map showing separate ice divides over Labrador and western Baffin Island.
early 20th century	Observations and discussions by early geologists on the extent of glaciation along the Labrador coast; recognition of differences in weathering and implications to Quaternary studies (Ives, 1978, for review).
1943	Flint (1943) developed theory for the growth of the Laurentide Ice Sheet: ice thickens from the mountains of Labrador and Baffin Island and finally moves radially outward from a single centre over Hudson Bay.
middle and late 1950s	Glacial geomorphological studies, centred on McGill University, commence in northern Labrador and Baffin Island (e.g. Mercer, 1956; see Ives, 1978, for review). Recognition of vertical differences in the degree of weathering and preservation of glacial features. In early 1960s use of the terms Saglek, Koroksoak, and Torngat for major weathering/morphological zones in Torngat Mountains south to Kiglapait Mountains.
1960s	Development of research programs on Baffin Island and the first extensive application of airphoto studies and radiometric dating. Ives and Andrews (1963) reintroduced the notion of a Foxe Basin centre of ice dispersal; they also recognized two major moraine units – the Clyde moraines along the outer coast and the Cockburn moraines near the fiord heads. Falconer et al. (1965) discussed the extent of the Cockburn moraines and suggested an interval of time for their formation (8-9 ka). Løken (1966) first published on the existence of "old" radiocarbon dates along the outer east coast of Baffin Island. Andrews (1965) introduced the concept of Foxe Glaciation of north-central Baffin Island.
1970s	Reintroduction of the importance of vertical differences in weathering and soil formation as a means of subdividing Quaternary sediments on Baffin Island (Boyer, 1972). Weathering Zones I, II, and III were described by Pheasant and Andrews (1973) and Zone III was equated with the Wisconsin Glaciation. Extensive descriptions of the Quaternary sediments exposed in wave-cut cliffs led to the recognition of repeated sea level cycles associated with glaciation and deglaciation (Miller et al., 1977). Amino acid racemization studies first started in the mid 1970s and proved a powerful method of correlation along the complex coastal sections (Miller et al., 1977; Nelson, 1978). U-series dates on molluscs were also forthcoming (eg., Szabo et al., 1981). Miller et al. (1977) suggested that the term Foxe Glaciation be used for events of the last glaciation on Baffin Island. Amino acid ratios were used to subdivide Clyde Foreland Formation (Feyling-Hanssen, 1976a) into members namely, the Cape Christian, Kuvinilk, Kogalu, and Eglinton. Andrews and Ives (1978) reviewed the confused "Cockburn" nomenclature and suggested a geochronological subdivision of the Holocene in the Eastern Canadian Arctic with the Cockburn substage radiocarbon dated between 8 and 9 ka.
1980s	Work continued on the application of amino acid geochronology (Brigham, 1980; Mode, 1980) and more attention was paid to the pre-Cape Christian members both near Clyde River and farther south. Further work on amino acid kinetics and on interpretation of U-series dates (Szabo et al., 1981; Andrews et al., 1981) indicated that the Cape Christian Member could not be last interglaciation in age. Thus Foxe Glaciation (cf. Miller et al., 1977) may include about 300-500 ka. Andrews and Miller (this volume) suggest return to original intent i.e., Foxe Glaciation is the last glaciation and includes event of the last 120 ka.

This explanation may be true in a few cases, but we reject it categorically for differences based on soil development and surface boulder weathering of glacial deposits (e.g., Birkeland, 1978; Locke, 1979). These techniques have been used extensively in Antarctica and suprisingly are accepted uncritically in the Denton and Hughes (1981) chapter on Antarctica despite extensive criticism of their application in Arctic Canada.

In the early 1970s the term "Wisconsin Glaciation" was retained for the last major glaciation of Baffin Island. During the latter part of that decade, however, workers favored the use of "Foxe Glaciation" as a term that included glacial events since the last global interglacial which was taken to have occurred about 125 ka (Miller et al., 1977). Thus, Foxe Glaciation was defined by Miller et al. (1977) as the glacial event(s) following the last major interglacial unit which contained high **Betula** pollen, that is, the Cape Christian soil. Thus, we believed that Foxe Glaciation included events of the last 120 ka. However, our most recent age assessment of the Kuvinilk Member, which overlies the Cape Christian soil (Szabo et al., 1981; Nelson, 1981), indicates that it is much older than 125 ka and thus as it was defined by Miller et al. (1977), Foxe Glaciation covers the events of the last 500 to 300 ka.

The original use of Foxe Glaciation was given in Andrews (1965, 1968) but it was not strictly defined. However, it is clear from the context of these publications that the Foxe Glaciation was considered to be broadly correlative with the Wisconsin Glaciation, and indeed, this was the intention of Miller et al. (1977). Given that the Kuvinilk Member is much older than previously thought, we propose that Foxe Glaciation be redefined on Baffin Island so that it keeps the original concept and the later intention. Although no one has successfully traced the weathering zone boundaries into the raised marine records of the outer coast, a workable definition of the Foxe Glaciation is that it included the glacial events of the last major continental glaciation of Baffin Island (Fig. 3). Nowhere can we specifically date the start of this period with any degree of certainty, but our best estimate is that the onset of Foxe Glaciation is recorded by the transgressive marine sediments of the lower Kogalu Member (G of Fig. 4). Amino acid data indicate that this glaciomarine event is probably correlative with the deposition of major lateral moraine systems in the fiords and outer coast which have been called variously the Duval moraine (Dyke, 1977), the Ayr Lake moraine (Miller et al., 1977), the Sunneshine moraine (Locke, 1980), and the Alikdjuak moraine (Nelson, 1980, 1981) as well as

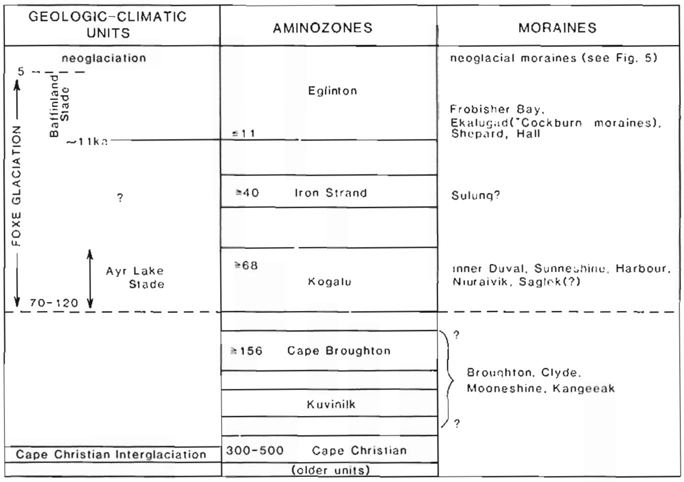
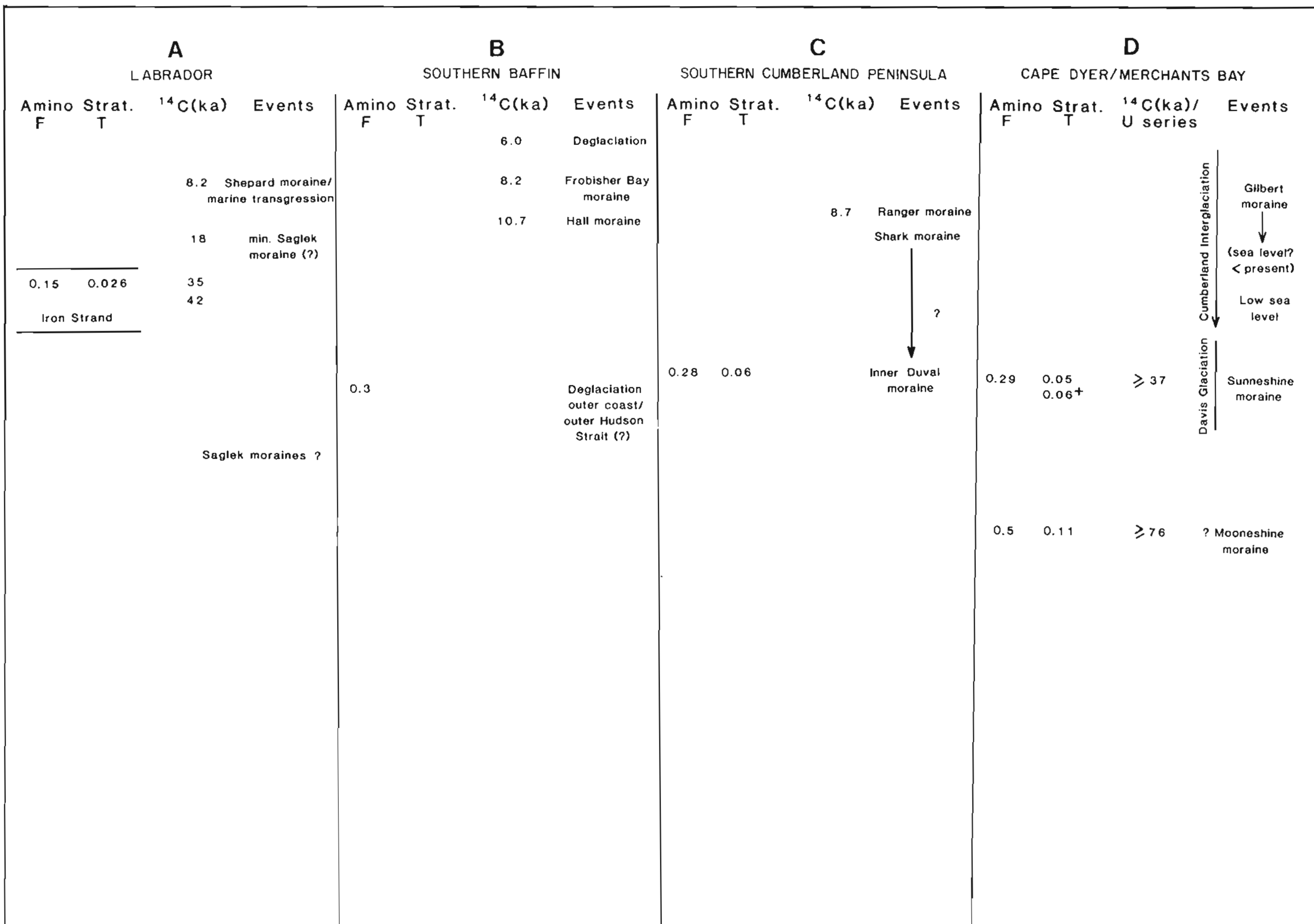


Figure 3. Summary of Quaternary nomenclature for Baffin Island/Northern Labrador; dates are in 10^3 years.

moraines in outer Clyde Fiord (Fig. 3). These moraines are probably correlative with at least part of the Clyde moraines of the central east coast (Ives and Andrews, 1963; Mode, 1980). In the past, these moraines had been thought to be of mid-Foxe age, but under the current usage are of early Foxe age.

The termination of Foxe Glaciation has not been defined. It is suggested here that the effective end of the Foxe Glaciation be marked by the disintegration of the Baffin Island ice cap into a series of distinct land-based ice masses, ca. 5-6 ka ago (Blake, 1966; Bryson et al., 1969; Dyke, 1974). Subsequent advances of local glaciers and the local ice caps are considered later in this report as the local expression of global neoglaciation (e.g., Miller, 1973). Holocene terminology has been discussed by Andrews and Ives (1978) and Andrews (1982) (see Fig. 5).



In column E the named members are part of the Broughton Island Formation (Brigham, 1980, p. 115); the number to the right of the total (T) amino acid ratio refers to the sequence of amino acid zones (Brigham, 1980).

In column F the members are part of a number of formations that are outlined in detail by Nelson (1981).

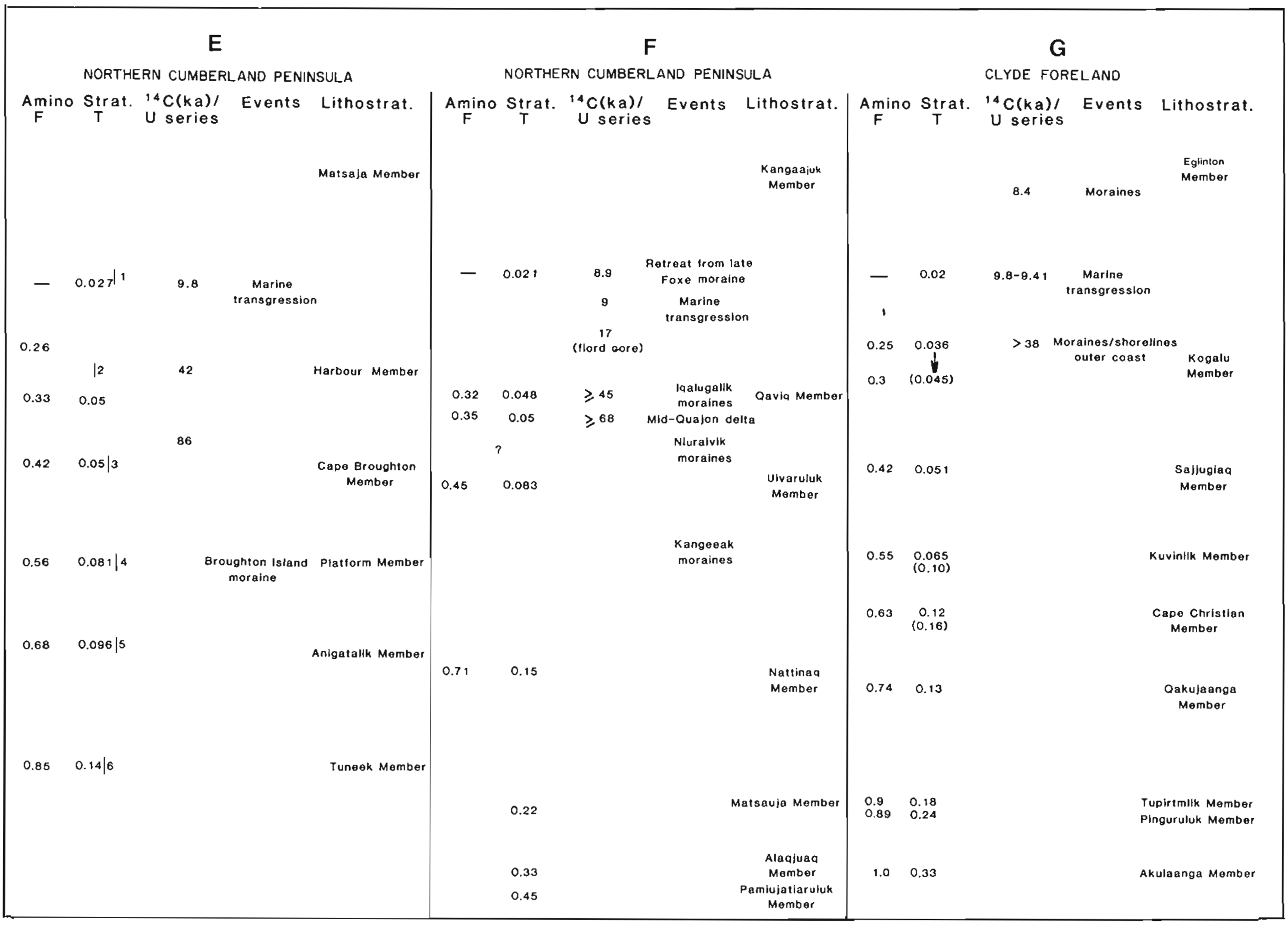
In column G the members are part of the Clyde Foreland Formation (Feyling-Hanssen, 1976a; Miller et al., 1977).

Figure 4. Quaternary glacial and raised marine sequences from northern Labrador northward. Under "Amino Strat." F is the free aIle:Ile ratio and T is the total aIle:Ile ratio. See text for references.

QUATERNARY (PRE-NEOGLACIAL) GLACIAL CHRONOLOGIES

The framework for our regional correlations is based on similarities in the alle:Ile[1] amino acid ratios in shells from raised marine units along the coast (Fig. 4). Fundamental to the interpretation of the Quaternary stratigraphy along the outer Baffin Island coast is the concept of repetitive sedimentary sequences associated with glacial isostatically controlled fluctuations in relative sea level (Miller et al., 1977; Nelson, 1978, 1981). In the ideal complete sequence, a period of sea level close to present level is marked by a surface soil. During ice build-up to the west, relative sea level rises and a marine transgressive sequence ensues to be followed by a regressive event as the ice retreats and relative sea level falls. Different sequences of this type can be recognized and dated in a relative manner by amino acid racemization techniques (Miller et al., 1977). Because the rate of racemization is a function of temperature, amino acid ratios on materials of the same age will only be the same within areas that experienced similar thermal regimes. Because of the cold offshore Canadian Current (Fig. 2), most of the outer coast from Cumberland Peninsula northward to Bylot Island experiences similar summer temperatures with only a slight increase in temperature southward to Labrador. Therefore, as a first approximation, amino acid ratios can be used to correlate units along this stretch of coastline.

Our studies indicate that individual sequences can be correlated laterally by their specific amino acid ratios and that superimposed sequences of sediments show a consistent trend for the ratios to become progressively lower (younger) upwards within a section. We call a sequence or series of beds that is characterized by a relatively narrow range of amino acid ratios an "aminozone" (Fig. 3). These aminozones, or characteristic amino acid ratios, are then used as a means of correlating between sections because it has not been possible to base correlations on lithological criteria. Where the sediments that are grouped as an aminozone can be correlated with moraines or ice-marginal deposits (e.g., Nelson, 1980), these are included in the stratigraphic columns as glacial events (Fig. 3, 4).



[1] Ratio of the non-protein amino acid D-alloisoleucine to its protein diasteriomer L-isoleucine in the carbonate matrix of pelecypod fossils (previously abbreviated as allo/iso ratio). This ratio increases from an initial value near zero to an equilibrium ratio of approximately 1.3.

Figure 3 illustrates the geologic-climate and amino acid units that have been recognized on Baffin Island and northern Labrador. The ages of these various units are based on radiocarbon, uranium series, and amino acid dating methods. Limitations of these various techniques have been discussed by Szabo et al. (1981). Table 2 presents the average ratios for each aminozone.

In the next sections composite stratigraphies from the northern Torngat Mountains to Scott Inlet (Fig. 1, 4) are described.

Northern Torngat Mountains (A of Fig. 4)

The glacial chronology of this region is poorly understood; some progress is being made and ongoing research by a number of investigators from Canada and United States will add materially to our scanty knowledge within the next few years. The age of the Saglek moraine (Ives, 1976) is not known with certainty. By analogy with Baffin Island it may predate the late Wisconsinan glacial maximum. Løken's work on the raised marine shorelines (1962, 1964) has not been rivalled, nor has his tracing of the various moraine systems. Some amino acid ratios and ^{14}C dates are presently available (Ives, 1977; Andrews et al., 1981; Short, 1981; Clark, 1982). Shells from a diamicton at Iron Strand gave ^{14}C ages of $42\,730 \pm ^{6680}_{9970}$ (DIC-517; Ives, 1977) and 34 360 ± 850 BP (SI-4131; Short, 1981). Interpretation of finite dates on marine shells in this age range are notoriously difficult, but in this case we have done extensive work on the amino acid ratios in **Hiatella** and **Balanus.** The ratios in both the free (F) and total (T) fractions are low, with average alle:Ile ratios close to 0.15 (F) and 0.026 (T). These ratios can be reconciled with the ^{14}C dates so our interpretation is that these shells date to the Middle Wisconsinan interval.

Radiocarbon dates of 16 800 ± 2300 (GX-6387), 18 210 ± 1900 (GX-6362), and 11 160 ± 520 BP (GX-5522) have been obtained on basal lake sediments from lakes high in the Torngat Mountains (Short, 1981). These dates may represent minimum ages for the Saglek moraine system, but because they are from the distal side of the moraines their relationship to the glacial event is uncertain. Similar "old" dates, however, have also been obtained on several lake cores from the centre of the Labrador-Ungava Peninsula (Stravers, 1981; Short, 1981), and Stravers has argued that these dates represent contamination by organics carried by the ice sheet.

The best age estimate on the Shepard moraine of northern Labrador (Løken, 1964) is that it represents a glacial advance or stillstand during the Cockburn stage.

Southern Baffin Island (B of Fig. 4)

Detailed work on this area only started four years ago. Prior to this, publications of note were those by Mercer (1956) and Blake (1966); Blackadar (1967), in the course of regional bedrock mapping, also made a substantial contribution to our limited knowledge. More recently, Miller (1980), Muller (1980), and Osterman (1980) have added new data.

The area has had a complex glacial history. Ice movement down Frobisher Bay, along and/or across Hudson Strait (from Ungava Bay?), off the surrounding plateaus of Hall and Meta Incognita peninsulas, and possibly on the shelf makes this an interesting area.

Column B of Figure 4 summarizes current data on the timing and extent of glaciation. Marine cores from within outer Frobisher Bay serve to document the readvance of ice during the deposition of the Hall moraine (Miller, 1980) just prior to 10.7 ka. Local glaciers on Meta Incognita Peninsula advanced during the Cockburn substage (Andrews and Ives, 1978), but continental ice was restricted to the head of Frobisher Bay at this time. Radiocarbon dates and amino acid data from molluscs in marine deposits on Loks Land and Allen Island indicate that pre-late Foxe glacial and marine sediments extend outside the limit of the Hall moraine. Extensive rock weathering and soil development at higher elevations in the outer part of the bay indicate that southeastern Baffin Island may have never been fully glaciated during the Foxe Glaciation, or may have been mantled by a thin, cold-base ice cap.

Southern Cumberland Peninsula (C of Fig. 4)

Studies on southern Cumberland Peninsula (Dyke 1977, 1979; Birkeland, 1978; Locke, 1979; Bockheim, 1979; Davis, 1980) have relied heavily on geographic position, regional mapping, relative weathering, and soil development as a means of erecting a sequence of glacial events. However, these studies combined with a single stratigraphic site in outer Kingnait Fiord do enable us to suggest a correlation between southern Cumberland Peninsula, Cape Dyer, and northern Cumberland Peninsula (Fig. 4). The Ranger moraine at the head of Cumberland Sound represents the ice margin during the Cockburn Substage and is dated close to 8.6 ka at one site (Dyke, 1977). The age of the next older moraine/weathering unit is not known. These moraines have been called the Shark and Usualuk moraines by Dyke (1977) and were tentatively assigned a middle Foxe age. Given the age of the Hall moraine as ca. 10.7 ka, it is possible that these moraines represent a correlative ice margin. The marine limit at the Shark moraine is 100-120 m a.s.l. compared with 90 m a.s.l. at the Ranger moraine. There is a difference in weathering between the two units and the question remains, are the Shark and outer Usualuk moraines correlatives of the Hall moraine or might they be considerably older, possibly coeval with the Iron Strand aminozone? Amino acid ratios indicate that the inner Duval moraine is correlative with the Kogalu aminozone.

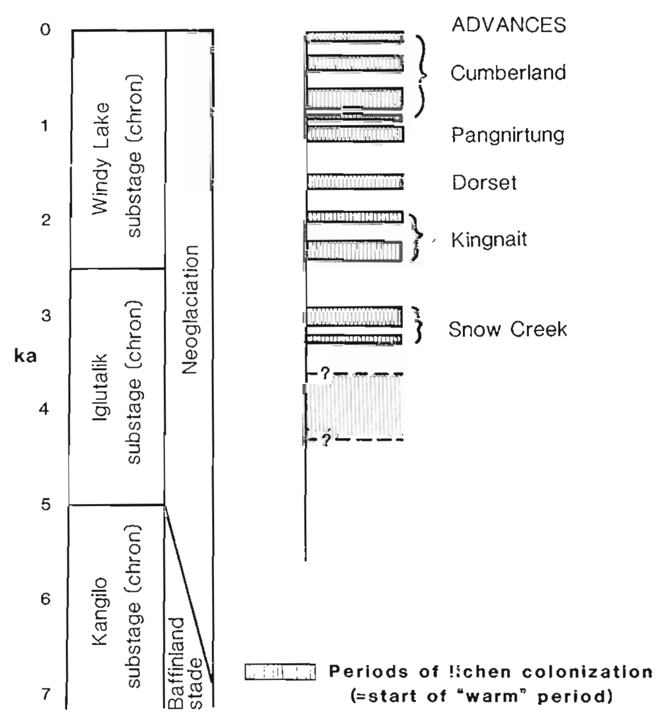


Figure 5. *Neoglacial record for Baffin Island (compiled from Miller, 1973; Andrews and Barnett, 1979; Davis, 1980); chronostratigraphy from Andrews (1982).*

Cape Dyer/Merchants Bay (D of Fig. 4)

Cape Dyer and the area of Merchants Bay extend well eastward of the influence of both Laurentide and Penny ice. They thus constitute a record of local glacial activity – a fact that Locke (1980) has noted and incorporated into his Quaternary glacial/nonglacial nomenclature. Hawkins (1980) confirmed several aspects of Locke's work at Cape Dyer. Miller and Andrews (Miller, 1975; J.T. Andrews, unpublished data) have also worked in the area. Unfortunately, severe sea ice conditions have prohibited the study of major sections, visible on aerial photographs, on western Padloping Island and on the tip of a large peninsula due west.

Correlations between southern Cumberland Peninsula and the Merchants Bay area are possible because a major trough, Kingnait Fiord and Padle Fiord, cuts southwest-northeast across the peninsula. In addition, raised marine sediments at Cape Dyer and Merchants Bay allow for a direct amino acid correlation between parts of the Duval moraine and the Sunneshine moraine. Locke (1980) named the last series of glacial events in that area the Davis Glaciation. Evidence exists for glacial advances of inferred earliest Holocene/latest Pleistocene age from local valley glaciers in the western part of the Cape Dyer region and within Merchants Bay (Miller, 1975; Hawkins, 1980), although these deposits are associated with glaciomarine deltas that are now situated below present sea level (Miller, 1975; Andrews, 1980) and hence cannot be dated directly. Nevertheless, the relative weathering and soil data strongly support the inference that these represent a glacial maximum broadly correlative with the Baffinland Stade of the Foxe Glaciation (Andrews and Ives, 1978).

Northern Cumberland Peninsula (E and F of Fig. 4)

Intermittent work on the glacial geology and chronology of Broughton Island and the sea cliff exposures on that island northward to Quajon Fiord were placed on a firm footing by the studies of Nelson (1978, 1980, 1981) and Brigham (1980). Broughton Island was glaciated from the outflow of local ice caps to the west; these might have merged with an expanded Penny Ice Cap during a glacial maximum. One or two small cirque glaciers also developed on the west coast of the island. The sediments exposed north of Broughton Island at Kivitoo ("Qivitu") represent glacial/marine interactions related to an expanded Penny Ice Cap plus local ice flowing off the mountains east of the Narmak Trough (Pheasant and Andrews, 1973). Nelson (1980) was able to use amino acid ratios in marine shells to date the highest marine beaches in the area and thus to correlate these littoral units with the associated lateral moraines and the offshore marine facies now exposed in the Kivitoo foreland (Nelson, 1978, 1981; Feyling-Hanssen, 1980).

Table 2. Average ratios for the most recent aminozones recognized along the coast of the Eastern Canadian Arctic

Aminozone (cf. Fig. 3)	Species [1]	Total alle:Ile	Free alle:Ile
"Modern"	Mt/Ha	0.018 ± 0.002	ND [2]
Eglinton (ca. 9 ka)	Mt/Ha	0.18 ± 0.002	ND
Iron Strand	Mt	0.026 ± 0.01	0.15 ± 0.04
Kogalu	Ha	0.045 ± 0.01	0.29 ± 0.04
Cape Broughton	Ha	0.055 ± 0.015	0.44 ± 0.03
Kuvinilk	Ha	0.09 ± 0.01	0.55 ± 0.04
Cape Christian	Ha Mt	0.15 ± 0.02 0.14 ± 0.02	0.66 ± 0.05 0.66 ± 0.05

[1] Mt = **Mya truncata**; Ha **Hiatella arctica**
[2] ND = not detectable

Local cirque moraines lie inland from the Kivitoo foreland (Dugdale, 1972; Miller, 1973) and by their position must be younger than the youngest lateral moraines along the outer coast. Few absolute ages are available for these moraines, and the ages of those in the Narmak Trough (Boyer, 1972; Isherwood, 1975) are unknown, although the soil data of Isherwood and Dugdale suggest that the outer moraines are certainly pre-late Foxe. On both Broughton Island and the Kivitoo foreland there is good stratigraphic evidence of an early Holocene marine transgression that reached its maximum sometime between 10 and 9 ka. Moraines at the head of Quajon Fiord date close to 9 ka. Local cirques and outlet glaciers retreated from late Foxe maxima between 9 and 8 ka (Pheasant and Andrews, 1973; Miller, 1973).

Clyde Foreland (G of Fig. 4)

Work on this pivotal area is contained in reports by Løken (1965, 1966), Ives and Buckley (1969), King (1969), Hodgson and Haselton (1974), Andrews (1975), Feyling-Hanssen (1976a), Miller (1976), Miller et al., (1977), and Mode (1980). The sea cliffs along the Clyde Foreland constitute the type area for the Clyde Foreland Formation and it is here that the various lithostratigraphic units of Miller et al. (1977) were first defined; Mode's (1980) work serves to expand the last noted paper. Of specifc interest in Mode's (1980) work is the presence of a second peak of amino acid ratios within the Kogalu aminozone. This also occurs at Broughton Island and may represent a distinct glacial/sea level event. Sediments at the surface that are beyond the range of radiocarbon dating require that ice from interior Baffin Island has not reached the outer coast for at least the last 35 ka. In addition, Miller (1976) has pointed out that the present local cirque glaciers crosscut lateral moraines that are at least 47 ka old suggesting that this local ice has not been more extensive than present for the last 47 ka or more. Ice-contact glaciomarine deltas at the outer coast, both to the north and south of Clyde, contain shells with amino acid ratios that fall within the Kogalu aminozone and yield a ^{14}C date of >54 ka (Løken, 1966), and include the maximum recorded marine transgression against the outer coast (60 to 80 m a.s.l.).

Moraines of the Baffinland Stade of the Foxe Glaciation occur extensively on the uplands between Clyde and Sam Ford fiords (Ives and Andrews, 1963; Hodgson and Haselton, 1974; Andrews and Ives, 1978). Available ^{14}C dates place many of these moraines within the Cockburn Substage (8-9 ka) although there are younger sets of moraines.

Northern Baffin Island and Bylot Island

Klassen (1981) has published preliminary data on the glacial geology and aminostratigraphy of this area. He concluded (p. 325) that "The channels between Bylot and Baffin islands have not been occupied by grounded ice for at least 35 000 radiocarbon years." Amino acid ratios on shells associated with the last glacial maximum in this area indicate a correlation with the deposits of Kogalu aminozone farther south (Fig. 3).

NEOGLACIATION

Neoglaciation on Baffin Island is represented by moraines and outwash deposits around the margins of ice caps, valley glaciers, and cirque glaciers. Some ^{14}C control on neoglacial events has been reported (Miller, 1973; Stuckenrath et al., 1979; Davis, 1980) but the major technique for dating the sequences of nested and commonly ice-cored moraines has been lichenometry. This work has been well summarized by Davis (1980) and Locke (1980). Additional observations on the age of glacial moraines around the Terra Nivea Ice Cap in southern Baffin Island (Muller, 1980) do not change the overall picture.

Miller (1973), Andrews and Barnett (1979), and Davis (1980) have discussed the question of the regional applicability of the growth curve for **Rhizocarpon geographicum** s.l. The correspondence in maximum diameters of **R. geographicum** on moraines from these different areas suggests that the growth rate is, as a first approximation, similar all the way from the northern Torngat Mountains (W.D. McCoy, personal communication, 1981) to the Barnes Ice Cap. This general statement is not grossly contradicted by existing weather station data (e.g. Fig. 2). Figure 5 represents the major episodes of neoglaciation for Baffin Island and probably for the Torngat Mountains. Neoglaciation commenced ca. 3.5 ka; the most extensive advance was the one that terminated within the last 100 years.

ABSOLUTE AGE ESTIMATES FOR GLACIAL EVENTS

Løken (1966) first documented that the most recent phase of extensive continental glaciation to reach the east coast of Baffin Island occurred prior to 54 ka (beyond the limit of radiocarbon dating). Since then many additional ^{14}C dates >35 000 BP have been obtained from shells in ice-proximal or deglacial marine deposits along the outer coast of the island. Attempts to date marine molluscs from "old" marine units by the U-series method met with mixed success and are summarized by Szabo et al. (1981). Based primarily on the available U-series dates and the presence of interglacial flora at two stratigraphically controlled sites, Miller et al. (1977) made preliminary age assignments to the aminostratigraphic units in the Clyde Foreland Formation. The Cape Christian Member was thought to correlate with marine isotope stage 5e or the end of stage 6, whereas the overlying Kuvinilk Member was deposited during an early Foxe glacial event. Further analysis of the U-content in shells from this region has led to a revision of the earlier dates (Szabo et al., 1981) and the Cape Christian marine sands are now ≥190 ka as opposed to an initial estimate of 130 ka. In addition, recent work on the temperature-dependence of the isoleucine epimerization reaction in the pelecypod genera **Mya** and **Hiatella** allow us to put constraints on the ages for measured alle:Ile ratios. Shells from Iron Strand, Labrador (Ives, 1977; Clark, 1982), Cape Storm, Ellesmere Island (Blake, 1980a), and Loks Land (G.H. Miller, unpublished data) have yielded the lowest alle:Ile ratios for any shell collections with ^{14}C dates >35 000 BP. As a first approximation, we can assume that the finite dates of 40 ka for these sites are approximately correct. We calculate an effective diagenetic temperature (EDT) of -9°C for the reported alle:Ile ratio (0.026 total for these sites). The current mean annual temperatures are approximately -12°C for Cape Storm, -7°C for Iron Strand, and -8°C for Loks Land. As noted previously, however, the summer temperatures, which are the primary racemization rate-controlling temperature, are similar for these sites. Because of the insulation by seasonal snow cover, mean annual arctic sediment temperatures always exceed mean annual air temperatures (MAT) (note, for example, that the southern limit of permafrost coincides with the -7°C rather than 0°C annual air isotherm) (Brown, 1978).

Based on all available data, we conclude that sites above the sea have most likely experienced diagenetic temperatures between -6 and -9°C. Applying these temperatures to the measured alle:Ile ratios, results in preliminary amino acid age estimates for the primary depositional intervals on eastern Baffin Island (Table 3). Table 3 also shows the original age estimates from Miller et al. (1977) and the thermal term required to allow the observed epimerization in the postulated time. Clearly, the Cape Christian marine sands would have to have had an EDT of 0°C throughout the last 130 ka if the original age estimate were correct. This thermal model cannot be reconciled with paleoclimate and sea level reconstructions.

Table 3. Amino acid ratios (T), radiometric determinations, and amino acid age estimates

MEMBER	D/L	EFFECTIVE DIAGENETIC TEMPERATURE (°C) -1	-4	-6	-9	-11	^{14}C AGE	Th-130 AGE
Kogalu	0.045	24	37	70	130	180	35-54 (≥54)	21-70 (≥70)
Kuvinilk	0.10	73	100	200	380	550		78-156 (≥130)
Cape Christian	0.15	130	210	315	580	900		120-190 (≥190)
Clyde MAT is -11°C		AMINO ACID DERIVED AGES (ka)						

Miller et al (1977)

current best estimates

Our current best estimates of the chronology of eastern Baffin Island is that **Mya** or **Hiatella** shells with alle:Ile ratios that fall in the Kogalu aminozone (0.035 to 0.055 total; 0.25 to 0.32 free) or lower were probably deposited within the last 130 ka. The Kogalu aminozone may span much of marine isotope stage 5 and represent more than one depositional event. The difference in alle:Ile ratios within this aminozone are so slight that refinement by our current methods is difficult. Table 2 represents our current best estimates of the average amino acid ratios for each of the aminozones currently recognized.

REGIONAL CORRELATIONS

Over the past five years, increasing attention has been given to continuous Quaternary records in the Eastern Canadian Arctic. Of special note are the stable oxygen-isotope studies on the ice core through the Devon Island Ice Cap (Paterson et al., 1977; Fisher and Koerner, 1981); the stable isotope records from one core in Baffin Bay and one in Davis Strait (Aksu, 1981); and the stable oxygen isotope records from a series of cores in the northern Labrador Sea (Fillon and Duplessy, 1980; Aksu, 1981). These sites are shown in Figure 1. Figure 6 represents an attempt to synthesize the information of the events of the last (Foxe) glaciation in the Eastern Canadian Arctic. Also included in Figure 6 are the dates of deglaciation of Hudson Bay Lowland and James Bay Lowland (Shilts et al., 1981; Andrews et al., 1983) and the inferred deglacial record from southern and northern Ellesmere Island (England et al., 1978; Blake, 1980a, b; England et al., 1981).

A suggested correlation between the Iron Strand and Cape Storm amino acid ratios indicates a probable deglacial event in the Labrador Sea and northern Baffin Bay about >40 ka. The alle:Ile ratios (free) of about 0.3 and 0.28 from raised marine strata in both southern and northern Ellesmere Island (Blake, 1980b; England et al., 1978) suggest a correlation between the Kogalu Member of the Clyde Foreland Formation and these units.

In the suggested chronology of Figure 6 the last interglaciation of Baffin Island lies between the sediments of the Cape Broughton (.44 F) and Kogalu (0.29 F) aminozones. Buried soils with high **Betula** pollen spectra have been reported from several sites on Baffin Island from beneath the Kogalu or correlative units (Mode, 1980; Brigham, 1980). A major early Foxe ice advance to the outer coast, well documented at several sites on eastern Baffin Island (Fig. 4), is represented by the Duval, Ayr Lake, Sunneshine, and Alikdjuak moraines and is correlative with the Ayr Lake Stade (Fig. 3) at Clyde River. Based on a reasonable thermal history, the Ayr Lake Stade of the Foxe Glaciation possibly dates from early in marine isotope stage 5 (Fig. 6).

Benthic foraminifera in marine sediments thought to have been deposited at this time indicate ameliorated inshore marine conditions (Feyling-Hanssen, 1976a, 1980). Aksu (1981) came to a similar conclusion based on his analysis of the subpolar planktonic foraminifera in cores from Baffin Bay and Davis Strait (Fig. 6). The Devon Island Ice Cap record is also suggestive of seasonal open water during isotope stage 5 with δO^{18} values close to -25‰ throughout the majority of this interval except for two short, sharp excursions to more negative values (Fig. 6).

Alle:Ile (free) ratios in shells from early Foxe marine units on Broughton Island and Clyde Foreland (Brigham, 1980; Mode, 1980) cluster into two discrete groups (E, Fig. 4), with average ratios (F) of about 0.26 and 0.33. To account for this on Figure 6, we suggest that the Kogalu aminozone includes two episodes of glaciation of the outer coast. On Clyde Foreland a radiocarbon date indicates that this younger Kogalu episode is older than 39 ka (Mode, 1980).

The stratigraphy of central eastern Baffin Island does not include (at present) any depositional interval of marine sediments above present sea level at any time between the

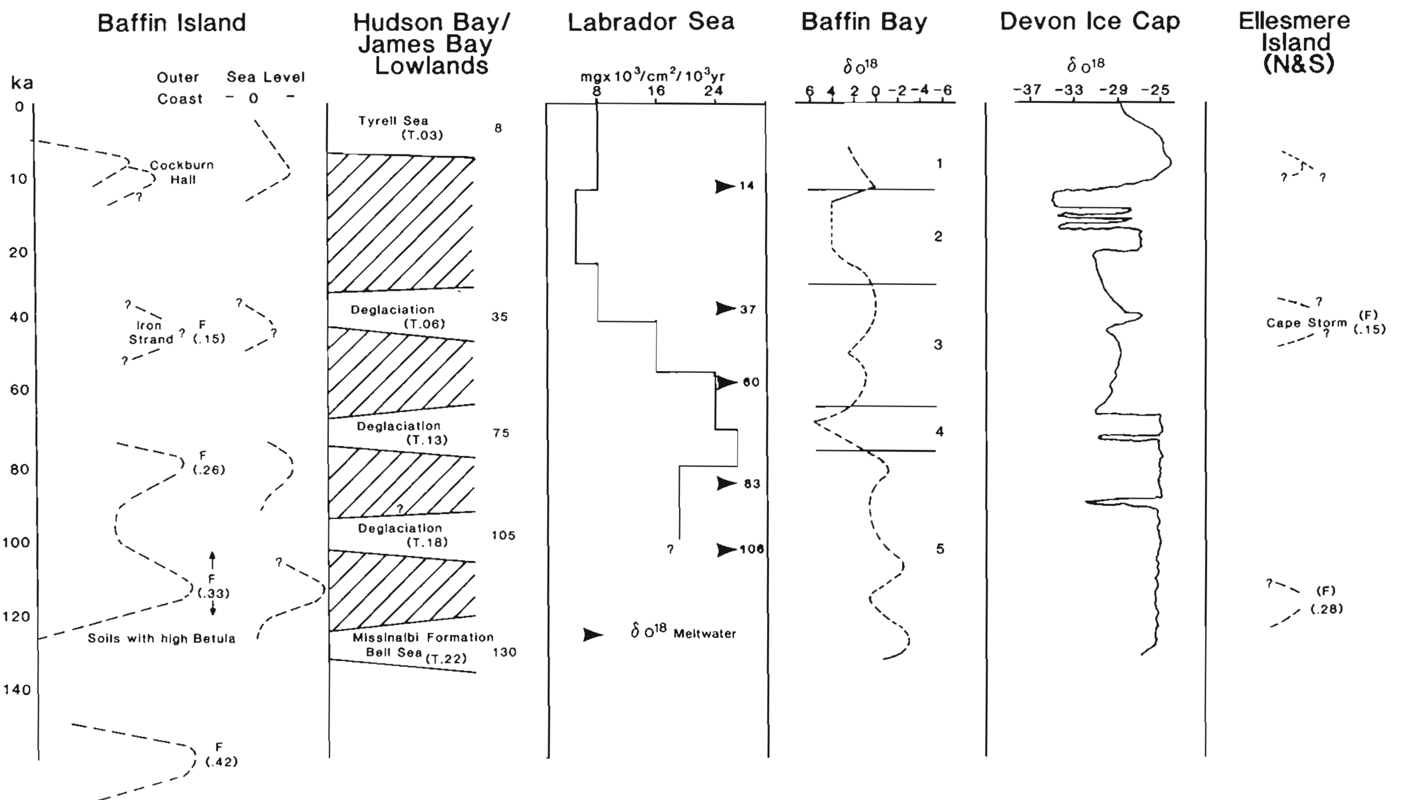


Figure 6. *Comparison of the Baffin Island glacial and sea level record for Foxe Glaciation with various records from neighboring regions; this figure has been compiled from the literature as follows:*

1) *Baffin Island: a composite reconstruction based primarily on the work of Miller et al. (1977), Andrews and Ives (1978), Mode (1980), Brigham (1980), and Nelson (1981) with the Iron Strand glacial/deglacial event of Labrador taken from Ives (1977) and Andrews et al. (1981). The curve on the left reflects the movement of the ice sheet (advance to the right). The figures in parentheses are approximate average free (F) amino acid ratios for these events. The Iron Strand sediments represents nonglacial deposition following a period of ice expansion (see Regional Correlations).*
2) *Hudson Bay/James Bay Lowlands (from Andrews et al., 1983): striped areas represent times of glacial expansion. The figures in parentheses are average values for total (T) amino acid ratios for each unit.*
3) *Labrador Sea: terrigenous sand input record and meltwater spikes. Influx of sand into marine cores in northeastern Labrador Sea (Fillon et al., 1981) is a measure of the intensity of ice rafting across this part of the ocean. The black arrows are specific spikes in the marine isotopic record (δO^{18}) which denote periods of light (meltwater) influx into the Labrador Sea; the figures refer to estimated dates (ka) of these events (R.H. Fillon, personal communication, 1981).*
4) *Baffin Bay: marine planktonic oxygen isotopic record from cores in Baffin Bay with suggested isotopic stage boundaries (Aksu, 1981).*
5) *Devon Ice Cap: oxygen isotope record from the Devon Island Ice Cap (Paterson et al., 1977; Fisher and Koerner, 1981).*
6) *Ellesmere Island: approximate position of glacial/deglacial events on Ellesmere Island (Blake, 1980a, b; England et al., 1978; England et al., 1982). Free (F) amino acid ratios are average values for the different events. The sediments at Cape Storm and Iron Strand represent nonglacial events but the presence of these raised marine sediments indicates that deposition was preceded by glaciation and glacial isostatic depression.*

Kogalu and Eglinton aminozones (Fig. 3; Hodgson and Haselton, 1974; Andrews, 1975). At present we see no alternative to the argument (Denton and Hughes, 1981, notwithstanding) that the extent of glaciation in the Eastern Canadian Arctic was sufficiently reduced that glacial isostatic loading of the outer coast never exceed the global lowering of sea level. It is important however to note that raised marine sediments have been located both south and north of Baffin Island which have amino acid ratios strongly indicative of a middle Foxe (Wisconsinan) glacial and deglacial event (Ives, 1977; Blake, 1980a; Andrews et al., 1981). The deposits at Iron Strand and Cape Storm indicate some glacial and deglacial activity close to 40 ka. It is intriguing to note that the Devon Island stable oxygen record has values close to present values about 40 ka (Fig. 6) and that the Baffin Bay/Davis Strait marine isotope record is marked by a decrease in the stable oxygen values at about this time (Aksu, 1981).

No evidence exists in the Eastern Canadian Arctic for a major glacial/deglacial event 18-20 ka; indeed the Devon Ice Cap record (Fig. 6) suggests that seasonal open water may have been present in Baffin Bay at that period. Although ice may have been stable during the late Foxe (Andrews, 1975), the maximum recorded glacial advances are dated at between 8 and 11 ka (Miller, 1980; Osterman, 1982).

Of extreme interest to the continental glacial record is the occurrence of meltwater spikes in the isotope records from cores from the northern Labrador Sea (Fillon and Duplessy, 1980) and their correlation with the Baffin Island glacial record, the Hudson Bay Lowland record, and the input of terrigenous sand into the northern Labrador Sea (Fig. 6; Fillon et al., 1981; Andrews et al., 1983). Considering the various errors inherent in the chronologies of Figure 6 it is noteworthy how closely the various records match.

Further work is clearly required. Of special importance is the glacial and marine record of the northern Torngat Mountains, the outer coast of southern Baffin Island, the north shore of Hudson Strait and the nearshore marine environment. Further refinements to the regional Quaternary stratigraphy will result from an in-depth examination of Quaternary records from Baffin Island, Baffin Bay, and West Greenland.

ACKNOWLEDGMENTS

Support for University of Colorado field and laboratory studies in the Eastern Canadian Arctic have been provided by the Geology Program of the National Science Foundation. We acknowledge with gratitude financial travel assistance from the Canadian IGCP Committee which has enabled us to attend and benefit from the annual Canadian IGCP Project 24 meetings. A. Dreimanis' interest in the Canadian Arctic is gratefully acknowledged.

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POSTSCRIPT

After this manuscript had been written, we uncovered a step in the sample preparation procedure that fractionated the total fraction, preferentially removing L-amino acids. Representatives of each aminozone have been reprepared; details of the fractionation and analyses are in Miller (in press). In the Table below we give the current best number for the aminozones and for contrast, the old numbers that are cited in the text. Note that the free ratios are essentially unchanged. Repreparation of our calibration samples has led to the derivation of a new series of Arrhenius parameters for the equations relating D/L, time, and temperature. The "old" alle/Ile ratios used with the "old" equations produce similar results as the "new" ratios with "new" equations; hence, all of the conclusions on thermal histories remain unchanged.

	Current Values		Old Values	
Aminozone	Total	Free	Total	Free
Modern	0.011 ± 0.001	ND	0.018 ± 0.002	ND
Eglinton	0.013 ± 0.001	ND	0.018 ± 0.002	ND
Loks Land (Iron Strand)	0.020 ± 0.004	0.14 ± 0.02	0.026 ± 0.010	0.15 ± 0.04
Kogalu	0.029 ± 0.005	0.30 ± 0.02	0.045 ± 0.010	0.29 ± 0.04
Cape Broughton	0.045 ± 0.002	0.43 ± 0.04	0.055 ± 0.015	0.44 ± 0.03
Kuvinilk	0.060 ± 0.004	0.54 ± 0.03	0.09 ± 0.01	0.55 ± 0.04
Cape Christian	0.092 ± 0.012	0.64 ± 0.02	0.15 ± 0.02	0.66 ± 0.05

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Missinaibi River, Hudson Bay Lowland, northern Ontario: Type section of the last interglacial Missinaibi Formation; the peaty member (>72.5 ka) of Missinaibi Formation is the dark band near the top, left centre of the section. The peat is overlain by a varved lacustrine member which grades upwards into a single Wisconsinan-age clay till. Four lithologically distinct tills underlie the Missinaibi Formation here, forming the most complete pre-Missinaibi stratigraphic record in the Hudson Bay-James Bay Lowlands. The upper two pre-Missinaibi tills are separated from the lower two tills and from each other by fluvial sand and gravel (indicating an open Hudson Bay), the bedding of which can be seen in the lower part of the section. Stratigraphy by O.L. Hughes, J. Terasmae, B.C. McDonald, R.G. Skinner, W.W. Shilts; photo by B.C. McDonald, GSC 204150-A.

QUATERNARY EVENTS - HUDSON BAY LOWLAND AND SOUTHERN DISTRICT OF KEEWATIN

W.W. Shilts[1]

Shilts, W.W., Quaternary events – Hudson Bay Lowland and southern District of Keewatin; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 117-126, 1984.

Abstract

The abundant stratigraphic sections in the Hudson Bay Lowland expose deposits of three to four glaciations beneath deposits of the last interglacial (Sangamon?) Missinaibi beds. Both physical stratigraphic relationships and aminostratigraphic data suggest that two or more glacial events postdate the Missinaibi and that Hudson Bay may have been ice free at least once during the time traditionally assigned to the Wisconsinan. Tills of the southwestern Hudson Bay – James Bay Lowlands likely were deposited by a glacier flowing from Labrador-Nouveau Quebec, except for the upper till or upper part of the youngest till in the north part of the Lowland, which may have been deposited by ice from a Keewatin dispersal centre. Although deposits of multiple glaciations are present in the District of Keewatin and northern Manitoba, their age and relationship to deposits in the Hudson Bay Lowland are obscure at present.

Résumé

Les affleurements stratigraphiques abondants des basses-terres de la baie d'Hudson font voir des dépôts de trois ou quatre glaciations sous les couches de Missinaibi dont la mise en place date du dernier interglaciaire (Sangamonien?). Tant les relations stratigraphiques que les données aminostratigraphiques semblent indiquer que le Missinaibi a été suivi de deux ou plusieurs épisodes glaciaires et que la baie d'Hudson s'est peut-être trouvée libre de glace au moins une fois au cours de la période généralement attribuée au Wisconsinien. Les tills de la partie sud-ouest des basses-terres de la baie d'Hudson et de la baie James ont vraisemblablement été mis en place par un glacier en provenance de la région du Labrador et du Nouveau-Québec, à l'exception du till supérieur ou de la partie supérieure du till le plus récent de la partie nord des basses-terres, dont la présence est peut-être attribuable à un glacier provenant d'un centre de dispersion du Keewatin. Il existe apparemment des dépôts laissés à la suite de nombreuses glaciations dans le district de Keewatin et dans le nord du Manitoba, mais leur âge et leurs liens avec les sédiments des basses-terres de la baie d'Hudson demeurent obscurs.

INTRODUCTION

This report provides a summary of the Quaternary stratigraphy of southwestern Hudson Bay Lowland and adjacent parts of northwestern Manitoba and southern District of Keewatin (Fig. 1). Because these interpretations are in a state of flux, no attempt will be made to treat the stratigraphy in an exhaustive manner.

It is important to bear in mind that, because the region is at or near the geographical centre of the Laurentide Ice Sheet, any deposit of nonglacial (fluvial, lacustrine, organic, marine, eolian) sediment is paleoclimatologically very significant. Nonglacial or proglacial sediments, locally weathered and oxidized, in the Hudson Bay Lowland or in District of Keewatin require that the Laurentide Ice Sheet be severely reduced in size or dissipated altogether. Also, occurrence of buried marine sediments in Hudson Bay Lowland necessitates an open Hudson Bay during their deposition, implying major deterioration of the Laurentide Ice Sheet. Thus, the terms "interstadial" and "interglacial" become almost synonymous in Keewatin and Hudson Bay Lowland, since any oscillation of the edge of the Laurentide Ice Sheet through these areas implies such severe deterioration of the ice sheet that interglacial conditions probably were prevalent over much of the continent.

HUDSON BAY LOWLAND

Hudson Bay Lowland is poorly drained, low, flat, and underlain by Paleozoic and upper Mesozoic formations, the Paleozoic section being characterized by limestones, dolomites, and minor clastic units. Into this swampy, relatively featureless plain, rivers and streams have cut postglacial trenches which have become progressively deeper over the last 7 ka as base level (relative sea level) has fallen because of isostatic uplift. Perhaps because of this continual downcutting, which is presumably going on now, there is an extraordinary number of well exposed sections, many of which reveal tens of metres of Quaternary sediments. I would estimate that, despite the large amount of work done on the Quaternary stratigraphy of the Lowland during the late 1960s and early 1970s, less than 50% of the available exposures have been visited; of those visited, probably fewer than 50% have received more than rudimentary study, and many were visited when high river levels or slumping obscured important stratigraphic units. Furthermore, descriptions of the stratigraphy were done when the model of the Laurentide Ice Sheet was that of a single dome over Hudson Bay, a model that biased the descriptions and interpretations of the sections that were being examined. In short, there is a vast amount of Quaternary stratigraphic exposure in the Hudson Bay Lowland, and only a small part of the potential Quaternary information has been obtained.

Currently a widespread debate exists concerning the configuration of the centre or centres from which ice was dispersed to form the Laurentide Ice Sheet (for example,

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Manuscript received: 1982-11-09
Final version approved for publication: 1984-02-10

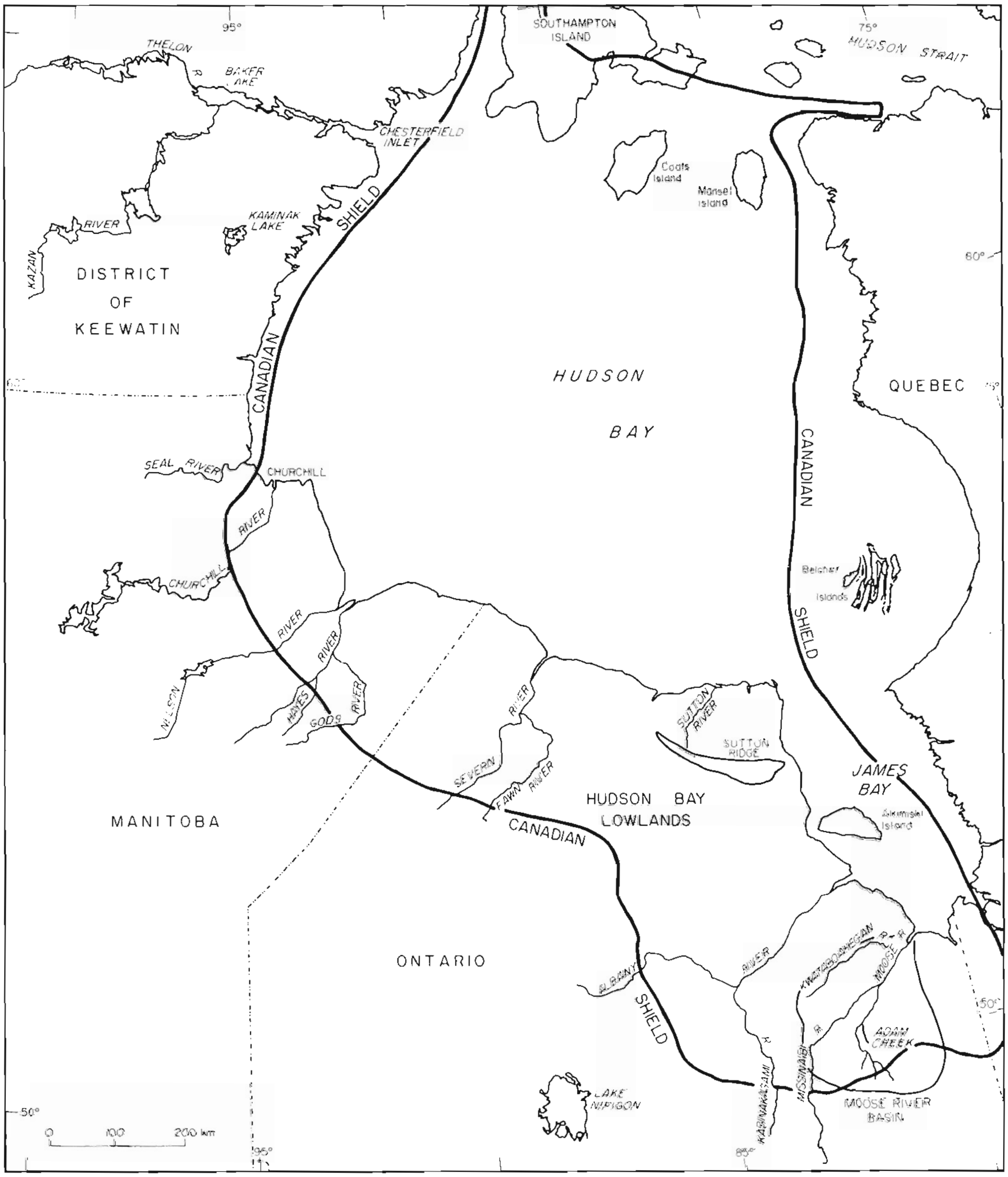

Figure 1. *Hudson Bay region showing features mentioned in text. Most of the area outside the heavy line is underlain by igneous and metamorphic rock of the Precambrian Shield.*

Hughes et al., 1977; Shilts et al., 1979; Andrews and Miller, 1979; Shilts, 1980; Denton and Hughes, 1981; Dyke et al., 1982). The composition of glacial sediments and the history of their deposition in Hudson Bay Lowland and District of Keewatin are critical factors constraining the models proposed for reconstructing the last and older Laurentide ice sheets. For example, if the Laurentide Ice Sheet had a simple, long-lived single centre of dispersal, centred on what is now Hudson Bay, as suggested by Flint (1943), Hughes et al. (1977), or Denton and Hughes (1981), erratics of Paleozoic limestone and other older rocks that underlie Hudson Bay should be dispersed landward all around it. In fact, these lithologies are only dispersed southward and southwestward in an immense dispersal train that continues far onto the Canadian Shield from a line drawn south from James Bay to a line drawn west approximately from Churchill, Manitoba (Fig. 2; Shilts, 1980, 1982). Clearly, unless some special dynamic conditions are invoked for the base of the last and older Laurentide ice sheets to explain the lack of dispersal of these distinctive erratics elsewhere around Hudson Bay, the "single dome" theory must be regarded as unworkable.

All of the other authors cited above propose that the Laurentide Ice Sheet comprised a number of contiguous domes or centres of ice dispersal which in concert formed the last Laurentide Ice Sheet. Major long-lived domes have been identified in M'Clintock Channel (*M'Clintock Dome* of Dyke et al., 1982), in Foxe Basin (*Foxe Dome* of Andrews and Miller, 1979), in central District of Keewatin (*Keewatin Ice Divide* of Lee et al., 1957; Shilts et al., 1979), and in Labrador-Nouveau Quebec (*Labrador Sector, Laurentide Ice Sheet* of Prest, 1970, this volume). In addition, Dyke et al. (1982) have proposed an additional dome – *Hudson Dome* – in the southwestern part of Hudson Bay and on Hudson Bay Lowland.

The history, location, and relative glacial contributions of these proposed domes must be clearly understood before interpretations of the stratigraphy of the Hudson Bay

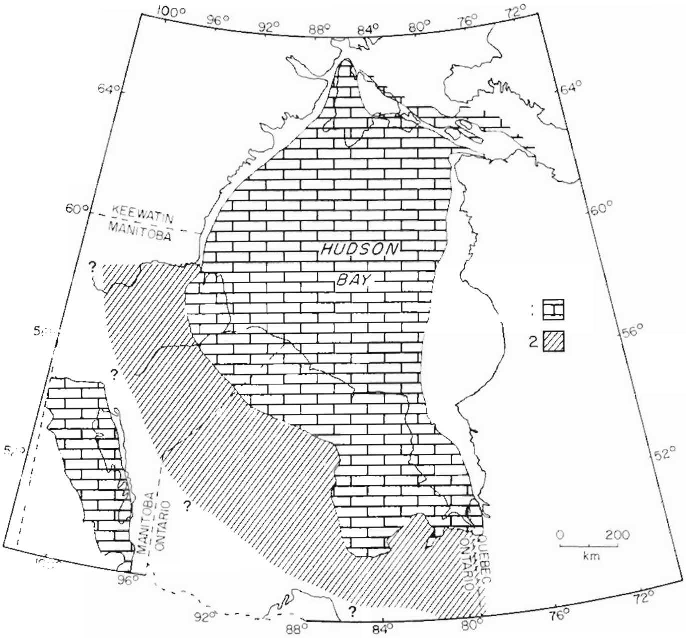

Figure 2. Dispersal pattern of Paleozoic erratics southwest of Hudson Bay: (1) the area underlain by Paleozoic carbonates and minor clastic rocks; (2) the area of dispersal of carbonate rocks, Proterozoic rocks from east side of Hudson Bay, and of calcareous, generally fine grained till. The dispersal pattern reflects the combined effects of all glacial events to affect the region.

Lowland and adjacent parts of Keewatin and Manitoba can be made. Conversely, the stratigraphy and petrography of the glacial sediments in the Lowland and Keewatin can shed considerable light on the location and interrelationships of the domes. Thus, the present controversial nature of interpretation of data on both the domes and the stratigraphy of the Lowland and Keewatin makes a definitive discussion of either aspect alone difficult. The following discussion of stratigraphy should be read, therefore, with these presently largely unresolved controversies in mind.

It should be evident from this preamble that, because of geographic location and extensive exposures of Quaternary sediment, many of the secrets of the Laurentide Ice Sheet and of North American paleogeography of the last 1 to 2 million years will be resolved by systematic study of the Hudson Bay Lowland. The stratigraphic picture and correlations presented here should be regarded as but a preliminary glimpse of the stratigraphy that may ultimately be defined for this region. With the application of multiple correlation techniques, particularly till petrography, aminostratigraphy, and heavy mineral studies, the Quaternary history of the central part of the Laurentide Ice Sheet has undergone and will continue to undergo significant conceptual changes.

The main unit on which the Quaternary stratigraphy of the Hudson Bay Lowland has been hung is the Missinaibi Formation (Skinner, 1973). Correlations between deposits older or younger than the Missinaibi have been made traditionally by "counting" down or up from these interglacial beds. Therefore, rather than discussing the regional stratigraphy from oldest units to youngest, the important nonglacial sediments that comprise the Missinaibi Formation will be discussed first.

Missinaibi Formation

The Missinaibi Formation, probably the best known Quaternary stratigraphic unit in the Hudson Bay Lowland, was first described by Bell (1877). Early workers had some difficulty in separating the Missinaibi beds, as presently defined, from Cretaceous lignite that occurs in the Moose River Basin south of James Bay. According to Terasmae and Hughes (1960), the confusion over the ages of the various buried organic horizons in the Lowland was resolved by McLearn (1927).

The first modern description of the Missinaibi beds was made by Terasmae and Hughes (1960). They concluded from palynological evidence that the Missinaibi beds were probably interstadial in rank because pollen assemblages indicated that the nonglacial interval was not "warmer than present" and "was rather short". They did not discuss the implication that the presence of peat and fluvial sediments at low elevations adjacent to Hudson Bay suggests a severely reduced Laurentide Ice Sheet, making the application of the term "interstadial" to any low-elevation, nonglacial deposit in this region questionable.

McDonald (1969) further discussed the Missinaibi beds and described 21 general areas where buried peat or associated waterlain sediments, thought to be correlative with the Missinaibi, occurred throughout the Hudson Bay Lowland. He cited a number of reasons that led him to believe that the Missinaibi sequence represented interglacial deposition, but later, McDonald (1971) reconsidered his evidence and concluded that the Missinaibi represented an interstadial sequence, correlative with the St. Pierre beds of the St. Lawrence Lowlands. In McDonald's original work (1969) he described three major sediment facies that occur within the Missinaibi beds: (1) a lower fossiliferous marine silt or sand, (2) peat and wood that overlie the marine beds on Kwataboahegan River and that occur as isolated beds elsewhere, and (3) fluvial sands and gravels, some of which contain abraded fragments of Pleistocene marine shells.

McDonald (1969) made some important points about constraints that the composition and physical setting of the Missinaibi beds place on interpretations of the stratigraphic history of Hudson Bay Lowland:

"...these subtill, nonglacial strata are considered to be interglacial because:

1. They are underlain and overlain by till;
2. They include marine strata which require that Hudson Bay and Hudson Strait be sufficiently glacier free to allow the influx of sea water;
3. Subaerial environments at low altitudes and streams, also at low altitudes, flowing toward the bay both require that Hudson Bay and Hudson Strait be glacier free;
4. Assuming that the earlier ice caps developed and shrank in a manner similar to that of the Wisconsin ice cap, disappearance of glacier ice in Hudson Bay would indicate sufficient diminution of the ice caps to merit calling the condition interglacial; and
5. The pollen record in the Missinaibi River peats has lead Terasmae and Hughes (1960, p. 11) to conclude that vegetation during the nonglacial was 'similar to that now present in the region'."

In addition to these points, McDonald (1969, p. 89-90) made three additional observations:

"1. The presence of interglacial marine beds in the Lowland indicates that Hudson Bay was a depression occupied by the sea at least as early as Sangamon time. Also, west of 86°W longitude Pleistocene marine shell fragments are present in all the tills. Whether these were transported inland from Hudson Bay or were picked up from local subtill marine strata, the sea had to have occupied the Hudson Bay Basin prior to the glaciation.

2. The similarity of interglacial facies relationships to postglacial sedimentary facies suggests that events during the interglacial were grossly similar to those of the past 8000 years.

3. There is a crude separation between interglacial stream gravel in the northwest part of the Lowland, and peat beds in the southeast portion. Although this may in part reflect the dilute sampling, it could also indicate that the major rivers in the northwest have largely reoccupied their interglacial valleys, whereas the rivers in the southeast have cut new channels in postglacial time."

Skinner (1973) completed the most thorough study of the Missinaibi beds in their type region – Moose River basin, south of James Bay. He observed the same units that McDonald and his predecessors had described but presented a comprehensive facies model of the deposits of this time interval. Briefly, in the Missinaibi Formation, Skinner included a lower marine unit, which he named the Bell Sea beds, a middle complex of fluvial gravels, peat, and forest beds, and an upper laminated glaciolacustrine organic silty clay, deposited in a proglacial lake dammed by the first glacier to cross Hudson Bay and enter the Lowland after the Missinaibi interval. Skinner considered the Bell Sea beds to be a post-Illinoian analogue of the Tyrrell Sea sediments, the latter being deposited when Hudson Bay flooded isostatically depressed land at the end of the Wisconsinan glaciation(s).

Skinner presented convincing palynological, paleogeographical, and sedimentological evidence that confirmed the interglacial rank of the Missinaibi interval. He found that some of the previously reported palynological evidence for cold climates during the Missinaibi was derived from sequences collected from the proglacial lake facies, deposited when glaciers first entered the Lowland and when climate would be expected to be in a state of deterioration.

Since McDonald and Skinner's work, little research has been done on the Missinaibi beds. Netterville (1974) described Missinaibi-equivalent peat and fluvial sediments (God's River sediments) along God's River, Manitoba. Nielsen and Dredge (1982) described organic beds, presumably correlative with the Missinaibi, in the Nelson River system. Stuiver et al. (1978) attempted to obtain a ^{14}C date on wood, using special enrichment techniques, collected (by Skinner?) from the Missinaibi type section. As with previous attempts, the age was beyond the range of radiocarbon dating, in this case greater than 72.5 ka.

Although no marine or peat beds have yet been shown to occur higher in the section, it is also entirely possible that some of the waterlaid or forest bed units presently correlated with the Missinaibi on the basis of physical similarity, may, in fact, be younger (or older).

Currently the Missinaibi interval is thought by some to be "interstadial" in rank, but it is my opinion that Skinner's (1973) careful study has established beyond the shadow of a doubt that at and near its type section it is interglacial, probably correlative with the Sangamon of the mid-continent and with part of oxygen isotope stage 5.

Pre-Missinaibi Deposits

Although tills underlying Missinaibi-type beds have been found throughout the Hudson Bay Lowland, the number and rank of glacial events they represent are presently unclear. Nielsen and Dredge (1982) described two pre-Missinaibi tills separated by a weathered surface along Nelson River. McDonald (1969) and Netterville (1974) both described single till units beneath Missinaibi-type beds, and Terasmae and Hughes (1960) described "lower and middle drift" (at least two tills) beneath the Missinaibi at its type section on Missinaibi River.

Skinner (1973) described pre-Missinaibi tills from many sites in the Moose River Basin and discussed their provenance and ice flow history. He was the first to point out significant concentrations of siderite in the older tills; this mineral has since been found to be ubiquitous throughout the Lowland (Shilts, 1980; Paré, 1982; Henderson, 1983) and to have considerable potential as an indicator to differentiate tills of eastern (Labradorean) provenance from those of western or northwestern (Keewatin) provenance.

Skinner (1973) also reported that till beneath Missinaibi beds contained shell clasts at other places in the Moose River Basin. Unfortunately, no shell collections or shell-bearing older tills have been found among his samples, and visits to several sites where he reported shell-bearing older tills yielded only a few fragments from a probable pre-Missinaibi till at the mouth of Adam Creek[1]. Nielsen and Dredge (1982) also reported that amino acid ratios (aspartic acid) were obtained for shell fragments from tills underlying Missinaibi-equivalent beds on Nelson River.

At the type section, Missinaibi peat and forest beds lie near the top of a 40 m-high bluff on Missinaibi River (Skinner, 1973). This bluff (section 24 M of Terasmae and Hughes, 1960) exposes the most complete record of pre-Missinaibi glacial and nonglacial events in the Lowland. Skinner recognized three tills below the Missinaibi at this section, the lowest of which has a distinctive reddish (mauve) colour. During a very low water stage of Missinaibi River in 1982, I discovered a fourth, light grey till, oxidized or iron stained in its upper metre, lying beneath and in sharp contact with the red till. The red till is overlain by 30 cm of varves, which is in turn overlain by about 7 m of coarse grained, oxidized, crossbedded sand with lenses of pebbly silt clay reminiscent of slump deposits presently found at the toes of sections in this region. The sand also contains clasts of the underlying varves, and in one 20 cm-thick sand bed near the top, abundant, small (<1 cm) charcoal or lignite fragments were found.

The next highest till is grey to grey-brown, sandy, and very compact. It is overlain by sand which contains diamicton lenses similar to those in the sand below this till. According to Skinner (1973), current structures in the sand units separating these tills are southeast to west, indicating a current opposite to the present flow direction of the river. Although Skinner interpreted the intertill units to be glaciofluvial on the basis of these crossbedding measurements, the two intertill sands at section 24 M are tabular, significantly more weathered than the enclosing tills, and certainly have the appearance of beds of nonglacial fluvial gravel, similar to the fluvial sands and gravels of the younger Missinaibi beds. The sand is overlain by dark grey sandy till which is more friable and highly oxidized than the two underlying tills.

In summary, as many as four glacial advances may have occurred in the southern part of Hudson Bay Lowland before deposition of the Missinaibi interglacial beds (Fig. 3). The rank of these events and the origin of the intertill waterlaid sediments are not known. The low elevation (<100 m a.s.l.) and apparent weathering of the fluvial gravels separating the

[1] Recent isoleucine data (total) on these fragments, obtained by a revised laboratory technique, yielded an alle:Ile ratio considerably higher (0.67) than ratios for fragments from the overlying gravel (0.3) and Adam Till (0.31). (J.T. Andrews, personal communication, 1983).

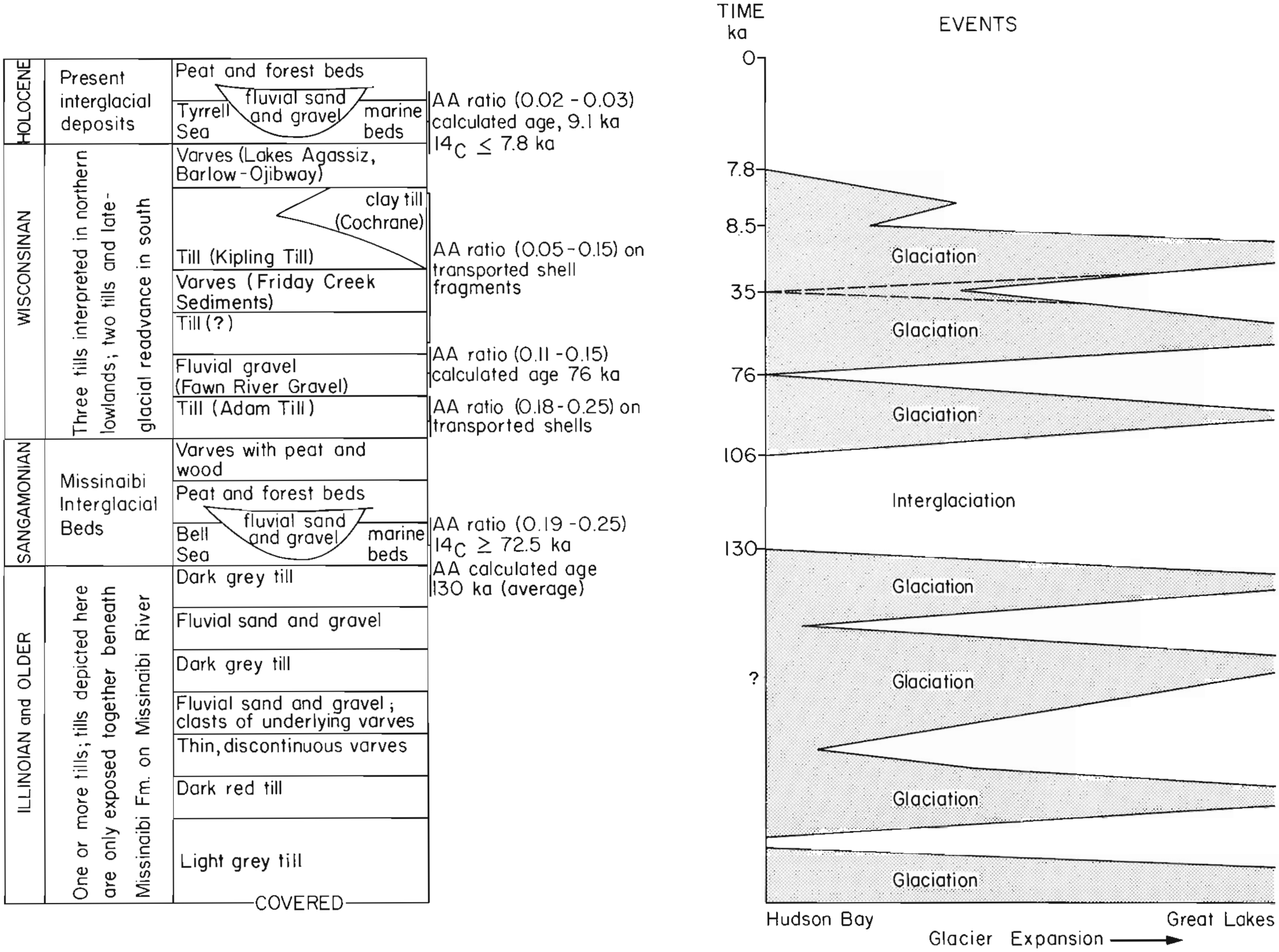

Figure 3. Possible stratigraphic interpretation of glacial sediments presently exposed in Hudson Bay Lowland. Ages (other than for Tyrrell Sea) are approximate and speculative, based on recent amino acid (AA) data (total ratios).

red (mauve) and grey tills at section 24 M on Missinaibi River suggest two major deglaciations predating the Missinaibi interglacial. The highly oxidized upper part of the pre-Missinaibi lower grey till of Nielsen and Dredge (1982, p. 19) suggests "a lengthy period of nonglacial conditions". The occurrence of this till at low elevation (<150 m a.s.l.) along lower Nelson River, about 100 km from Hudson Bay, strongly suggests that an interglacial period occurred before deposition of the overlying (middle) grey till, which is also older than the Missinaibi. Any weathering event in Hudson Bay Lowland requires an ice-free Hudson Bay, for if Hudson Bay was blocked by ice, these low-elevation sites would have been covered by ice or proglacial lake waters.

Thus, several glacial events apparently predate the Missinaibi interglaciation, but no comparable terrestrial organic and marine beds have been identified within the pre-Missinaibi sequence. It is probable that any further developments in understanding of the pre-Missinaibi record will come only through drilling to depths below present river levels.

Post-Missinaibi Deposits

All recent works in the Hudson Bay Lowland have recognized at least two till sheets overlying the Missinaibi beds. Netterville (1974) and I.M. Kettles and P.H. Wyatt (personal communication, 1983, 1984) have studied three post-Missinaibi tills in God's River valley (Manitoba) and adjacent Fawn-Severn River valleys (Ontario), respectively. Shilts et al. (1981), Shilts (1982), and Andrews et al. (1983) have also proposed three glacial events based on a reinterpretation of McDonald's original field notes and on total isoleucine aminostratigraphic evidence derived from shell fragments from tills (Fig. 3).

The colour and texture of the post-Missinaibi tills vary throughout Hudson Bay Lowland, depending on provenance and the nature of the unconsolidated sediments immediately underlying them. In general they are calcareous, grey to brown grey, and fine grained with few clasts larger than cobbles. They are commonly interrupted by distinctive boulder pavements, and both McDonald (1969) and Skinner (1973) used orientations of striae on the upper faceted surfaces of stones in these pavements as indicators of ice movement directions. Post-Missinaibi tills in the Moose River Basin are generally clayey due to the incorporation of underlying varved clays, which were deposited during the final stages of the Missinaibi interglaciation, and to the incorporation of kaolin from the extensive, unconsolidated, lignite-bearing kaolin deposits of Cretaceous age. In this same region, the lowermost till is commonly dark grey or brown where it is charged with organic debris reworked from the Missinaibi peat and forest beds and from the Cretaceous lignites. In many places throughout Hudson Bay Lowland the post-Missinaibi tills contain fragments of Pleistocene-age marine shells, mostly the robust pelecypod **Hiatella arctica.**

Finally, all tills sampled by McDonald, Skinner, Wyatt, Kettles, and myself contain abundant erratics derived from the Proterozoic beds of the Circum-Ungava Geosyncline which underlies the eastern part of Hudson Bay and the Sutton ridge in Ontario. These erratics suggest an eastern Hudson Bay-Quebec provenance for most or all of the tills sampled from Churchill southward and eastward to the Quebec-Ontario border. Recent geochemical and mineralogical evidence (Shilts, 1980; Paré, 1982) suggests a northerly or northwesterly provenance for the upper part of the uppermost till north of the Ontario-Manitoba border. The latter mineralogical data are consistent with observations of northwest-southeast oriented striae reported by McDonald (1969) on boulder pavements and bedrock at several places in Hudson Bay Lowland.

Where multiple tills occur together above the Missinaibi Formation, they are commonly separated by proglacial lake sediments in the southern and northern part of Hudson Bay Lowland (McDonald, 1969; Skinner, 1973). Skinner named the laminated silty clays separating the post-Missinaibi Adam (lower) and Kipling (upper) tills in the Moose River basin the Friday Creek sediments. He speculated that they may represent a significant Middle Wisconsinan deterioration of the Laurentide Ice Sheet but recognized that they may also represent northward extension of the late glacial Barlow-Ojibway system, the overlying Kipling Till then being equivalent to the Cochrane Till of Hughes (1965). The Cochrane and Kipling tills, if correlative, would have been deposited during the short-lived, but areally extensive, Cochrane readvance near the end of the Wisconsin Glaciation.

In the central part of Hudson Bay Lowland, at least two tills, commonly with distinctly different colours, overlie beds correlated with the Missinaibi and lie directly on one another with no intervening waterlaid sediments or evidence of weathering on the lower till. Examination of McDonald's original field notes on his traverses of the Fawn-Severn rivers and Hayes River (Manitoba) has led me to believe that the shell-bearing, low-elevation fluvial gravels described by McDonald as equivalent to the fluvial member of the Missinaibi Formation may actually postdate the first till above the Missinaibi. If this assumption is correct, then three tills and corresponding glacial events may postdate the Missinaibi in this part of Hudson Bay Lowland, a conclusion also reached by Netterville (1974) for the God's River area.

In the Nelson River to Churchill River segment of Hudson Bay Lowland, siderite occurs as a dominant heavy mineral in all tills so far examined, except for the youngest till or uppermost part of the youngest till (Shilts, 1980; Paré, 1982). As siderite is thought to have an eastern provenance in this region, being derived from Devonian formations underlying Moose River Basin and Hudson Bay (Skinner, 1973; Henderson, 1983), it is probably associated with till deposited from a Labradorean or, less likely, southern Hudson Bay (Dyke et al., 1982) ice centre. The absence of siderite in the youngest till may reflect northern or northwestern provenance and deposition by ice from a Keewatin centre – the Keewatin glacier displacing the Labradorean (or Hudson Bay) glaciers in this part of the Lowland towards the end of the Wisconsinan. Much more petrographic work will be required to confirm the continuity of these mineralogical differences.

Late glacial sedimentation

As the last glaciers retreated from Hudson Bay Lowland, fresh water from proglacial lakes Agassiz and Barlow-Ojibway, ponded between retreating ice and Hudson Bay and Great Lakes-Mississippi River drainage divides, invaded the southern and western parts of Hudson Bay Lowland. Laminated sediments from these lakes overlie the uppermost till in sections southward from Churchill River. When the ice dam in Hudson Bay broke, approximately 7.8 ka, the sea rushed in and the immense glacial lakes drained catastrophically. The laminated sediments are overlain by offshore marine silts of the Tyrrell Sea (Lee, 1960) which are commonly overlain by nearshore sediments formed as wave base migrated downslope towards Hudson Bay during isostatically induced offlap of the Tyrrell Sea. The contact between the freshwater sediments and overlying marine sediments is marked in the southern part of Hudson Bay Lowland by a disrupted and oxidized zone first interpreted by Skinner (1973) to have been formed during catastrophic drainage of the glacial lakes into the Tyrrell Sea.

Summary of Wisconsinan events

At least two major glacial events affected Húdson Bay Lowland during the Wisconsinan. Waterlaid sediments separating tills in the southern and northern part of the Lowland further suggest that the Laurentide Ice Sheet reached a state of advanced decline at least once during the Wisconsinan. In the next section are discussed the implications for the physical stratigraphy described above of recent aminostratigraphic studies of marine shell fragments found in tills and waterlaid sediments.

Aminostratigraphy

The widespread occurrence of organic remains in deposits of the Hudson Bay Lowland, mostly beyond the range of ^{14}C dating, has led to attempts by various researchers to apply amino acid dating techniques to the stratigraphic problems. Andrews et al. (1983) have studied the isoleucine epimerization rates of marine molluscs found in situ in marine deposits and as erratic clasts in till and fluvial gravel in an attempt to deduce both relative and rough absolute ages for the deposits in which they are found using total alle:Ile[1] ratios. For the relatively young shells analyzed, total or combined ratios yield more discriminative results than the free ratios, which were also measured.

Collections of shells (**H. arctica**) from interglacial Bell Sea deposits and shells from late glacial Tyrrell Sea deposits yielded total (combined) alle:Ile ratios of 0.20 to 0.25 and 0.01 to 0.03, respectively. Shells (**H. arctica**) from low-elevation, nonglacial fluvial gravels separating tills on Fawn River (Ontario) and Hayes River (Manitoba) yielded ratios of 0.11 to 0.15. Shell fragments (**H. arctica**) from a waterlaid silty clay underlying 13 m of ice-contact gravel overlain by 5 m of till on Kabinakagami River (Ontario) yielded ratios of 0.05 to 0.08.

Shell fragments (mostly **H. arctica**) collected from tills throughout Hudson Bay Lowland were found to have ratios characteristic of one or more of the groups collected from the waterlaid sediments. Lowermost tills or tills known to overlie Missinaibi beds directly, consistently had ratios in the 0.20 to 0.25 range. Five samples collected from a vertical profile through the Adam (lowermost Wisconsinan) Till at its

[1] Ratio of the non-protein amino acid D-alloisoleucine to its protein diasteriomer L-isoleucine in the carbonate matrix of invertebrate fossils.

type section at the mouth of Adam Creek (Ontario) yielded ratios of 0.18 to 0.25 for **Hiatella arctica** shell fragments. A two-till section on God's River (Manitoba) yielded ratios of 0.19 to 0.25 for the lower till and 0.054 to 0.120 for the upper till.

Considering the total alle:Ile amino acid ratios for shells from more than 40 sites throughout Hudson Bay Lowland, Shilts et al. (1981) and Andrews et al. (1983) concluded that there was at least one and possibly two significant groupings of ratios falling between 0.20 to 0.25, which represents the Bell Sea and associated interglacial sediment, and 0.01 to 0.03, which represents the postglacial Tyrrell Sea sediments. The best documented intermediate group comprises ratios in the 0.11 to 0.15 range; these were obtained for shells occurring as clasts in the intertill fluvial gravels on Fawn and Hayes rivers, gravels correlated by McDonald (1969) with the Missinaibi but considered to be a younger stratigraphic unit and informally named the Fawn River gravels by Shilts et al. (1981), Shilts (1982), and Andrews et al. (1983), largely on the basis of amino acid data. Another, more tenuous, conclusion by these same authors was that there is a still younger group in the 0.05 to 0.09 range, tentatively associated with the silty clay on Kabinakagami River (Varves -- Friday Creek sediments in Fig. 3).

Assuming that the shells from Hudson Bay Lowland were subjected to maximum diagenetic shifts of temperature of a few degrees on either side of 0°C, Andrews et al. (1983) have attempted to calculate rough absolute ages of each of the groups by applying kinetic equations to the amino acid data (Miller and Hare, 1980). Using this technique, approximate ages of 106-135 ka (mean 121 ka) are obtained for the 0.20 to 0.25 group, 76 ka for the 0.11 to 0.15 group, 35 ka for the 0.05 to 0.09 group, and 9.1 ka for the 0.01 to 0.03 (Tyrrell Sea) group. The Tyrrell Sea ages are slightly too old, the oldest ^{14}C dates in the region being of the order of 7.8 ka; a date of 7540 ± 140 BP (GSC-915) was determined for one of the samples for which amino acid ratios were calculated. Amino acid "ages" calculated from Tyrrell sea shells are, however, close enough to the ^{14}C age to warrant accepting the ages calculated for the older shells.

Amino acid ratios suggest that Hudson Bay was at least partially deglaciated once and possibly twice during the Wisconsinan (Fig. 3). The erratic marine shells from which the data were obtained indicate that marine waters penetrated to the southern part of Hudson Bay, and the shells were reworked later into glacial and fluvial deposits. If the ages calculated from the amino acid data are valid, the periods of severe deterioration of the Laurentide Ice Sheet in the vicinity of Hudson Bay correspond roughly to major Wisconsinan interstadial events documented in southern Canada at about 76 and 35 ka. Whether the ages are valid or not, it does seem appropriate to question the common notion that the central part of the Laurentide Ice Sheet comprised a relatively stable ice cover over and adjacent to Hudson Bay throughout the Wisconsinan.

SOUTHERN DISTRICT OF KEEWATIN

The character of the terrain and the compositional characteristics of till sheets north of Hudson Bay Lowland on the west side of Hudson Bay are different from those of the Lowland. This is in part due to the rolling nature of the topography which has developed on hard crystalline rocks of the Canadian Shield, but is more closely related to the fact that north of Seal River, Manitoba, all tills were deposited by ice emanating from a Keewatin dispersal centre (Shilts et al., 1979; Shilts, 1980). Consequently, unlike tills southwest of Hudson Bay, they contain none of the fine grained, carbonate-rich components from the Paleozoic basin that underlies Hudson Bay.

Few natural sections have been cut by postglacial rivers in this area. The low relief and resistance of the bedrock to glacial erosion probably precluded the formation of thick drift units and increased the likelihood that drift deposited during one glaciation would be removed during subsequent glaciations. Thus, only a handful of localities are known to be underlain by drift predating the last glaciation.

Multiple Till Sections in Keewatin and Northern Manitoba

Multiple till sections are known from exposures along Kazan and Thelon rivers near Baker Lake and in the vicinity of Kaminak Lake (Shilts, 1971; Ridler and Shilts, 1974). In these areas two tills of sharply contrasting geochemical composition, lithology, and texture are superposed but are not separated by intervening waterlaid sediments or weathering zones. Although these sections may represent deposition during separate glaciations, it is just as likely that they represent either deposition from a single ice sheet that shifted ice flow trajectory with time or that they represent a single basal meltout till, the layers of varying composition representing debris bands of varying composition that were stacked vertically in the ice.

In a few of the deep boreholes drilled by the Polargas consortium to provide geotechnical data on a proposed gas pipeline, multiple till units of contrasting geochemical and lithological composition were encountered (Shilts, 1980). Although the same difficulties exist in assigning these tills to separate glaciations as were cited for natural river exposures, three boreholes were drilled in southern District of Keewatin and northern Manitoba in till separated by fluvial or glaciofluvial sediments. In a 10 m-deep Polargas hole located about 15 km south of the Keewatin-Manitoba border, at least two geochemically contrasting tills are separated by a complex of deformed gravel and till a few metres thick. Whether this gravel is fluvial or glaciofluvial, it represents deposition during a period when the glacier that deposited the underlying till was either confined to the Keewatin mainland west of the Hudson Bay depression or had melted away altogether. This locality is only a few hundred kilometres from the heart of the Keewatin ice sheet (Shilts et al., 1979) and any waterlaid sediments at this location imply severe diminution or total destruction of the western sector of the Laurentide Ice Sheet.

Near the Polargas borehole mentioned above, at least two till units, separated by waterlaid sand reported by the drillers to be rich in plant fragments, were intersected in another Polargas borehole. Although this would appear to support the interpretations of a nonglacial period in this region, the upper "till" may be merely colluvium which covered a postglacial alluvial site as a result of downslope movement associated with solifluction, a common phenomenon in this area of deep continuous permafrost.

Several of the eight boreholes drilled by Polargas on Thelon River, just west of Baker Lake, intersected at least two till units of contrasting colour and geochemical composition. The boreholes were drilled a few kilometres west of the last position of the Keewatin Ice Divide in an area where geochemically distinctive bedrock units could have provided compositionally contrasting debris, depending on azimuth of ice flow over the site. Although it is easy to see how the geochemical contrasts in the tills might have resulted, the holes are too few and the history of the ice flow too complex near the eastwardly migrating divide to establish the provenance or stratigraphic importance of the tills. Nevertheless, in one borehole on Thelon River, two geochemically and lithologically contrasting tills are separated by 2 m of fluvial sand of provenance that contrasts sharply with the provenances of underlying and overlying tills. At this location, almost on the Keewatin Ice Divide, any such nonglacial deposit must be regarded as interglacial.

Summary

Unfortunately, because of the paucity of stratigraphic exposures and the lack of any dated material in or between the tills of District of Keewatin and northern Manitoba, it is impossible at this time to correlate the units observed with the stratigraphic units in the Hudson Bay Lowland. It can be concluded that at least two major glacial events, separated by a relatively glacier-free interval, occurred in southern Keewatin and northernmost Manitoba. Whether these events occurred within the Wisconsinan or whether they represent pre-Wisconsinan and Wisconsinan glaciations is not known. The last glaciation in District of Keewatin is known to have terminated by about 6.6 ka based on radiocarbon dates on marine shells collected from the marine sediment/till contact a few tens of kilometres east of the final position of the Keewatin Ice Divide (Ridler and Shilts, 1974).

CONCLUSION

Hudson Bay Lowland was subjected to as many as four glacial events prior to deposition of the interglacial sediments of the Missinaibi Formation. The Missinaibi interval is considered to be equivalent to the Sangamon Interglaciation of the mid-continent region based on the similarity of its sediment facies to those of the present interglacial, its palynological record, and the amino acid ratios of marine shells from sediments deposited during it. The Wisconsin Glaciation was interrupted at least once by a major shrinkage of the Laurentide Ice Sheet that allowed marine waters to penetrate to the southern part of Hudson Bay. Tills from at least two and possibly three glacial events are identified overlying the Missinaibi Formation. Throughout the southwestern part of Hudson Bay Lowland from James Bay to Churchill, Manitoba, composition of most till units suggests derivation from a Nouveau Quebec-Labradorean centre of dispersal. The youngest till or uppermost part of the youngest till from Nelson River northward appears to have been deposited by ice flowing from a Keewatin centre of dispersal. A separate centre of dispersal – the Hudson Dome – has been proposed over southwestern Hudson Bay (Dyke et al., 1982) because of problems of ice sheet reconstruction related to apparent asymmetry of length of flow lines from a Nouveau Quebec-Labrador centre, because of the necessity of a centre of outflow from which the late glacial Cochrane surges could have originated, and because of anomalous gravity data from southern Hudson Bay. However, there is no known petrological or stratigraphic evidence that supports this model.

Multiple glacial events are recognized in District of Keewatin and northern Manitoba, but whether they represent provenance shifts through a single glaciation or deposits of separate glaciations is not known. In two deep boreholes in northern Manitoba and on the Keewatin Ice Divide near Baker Lake, fluvial or glaciofluvial sediments separate tills, suggesting that interglacial conditions are represented by the interval separating the tills. It is impossible at present to establish whether this interglacial interval is equivalent at both sites, and it is equally impossible to say whether it correlates with the Missinaibi or with one of the Wisconsinan interstadials apparently recorded in the Hudson Bay Lowland.

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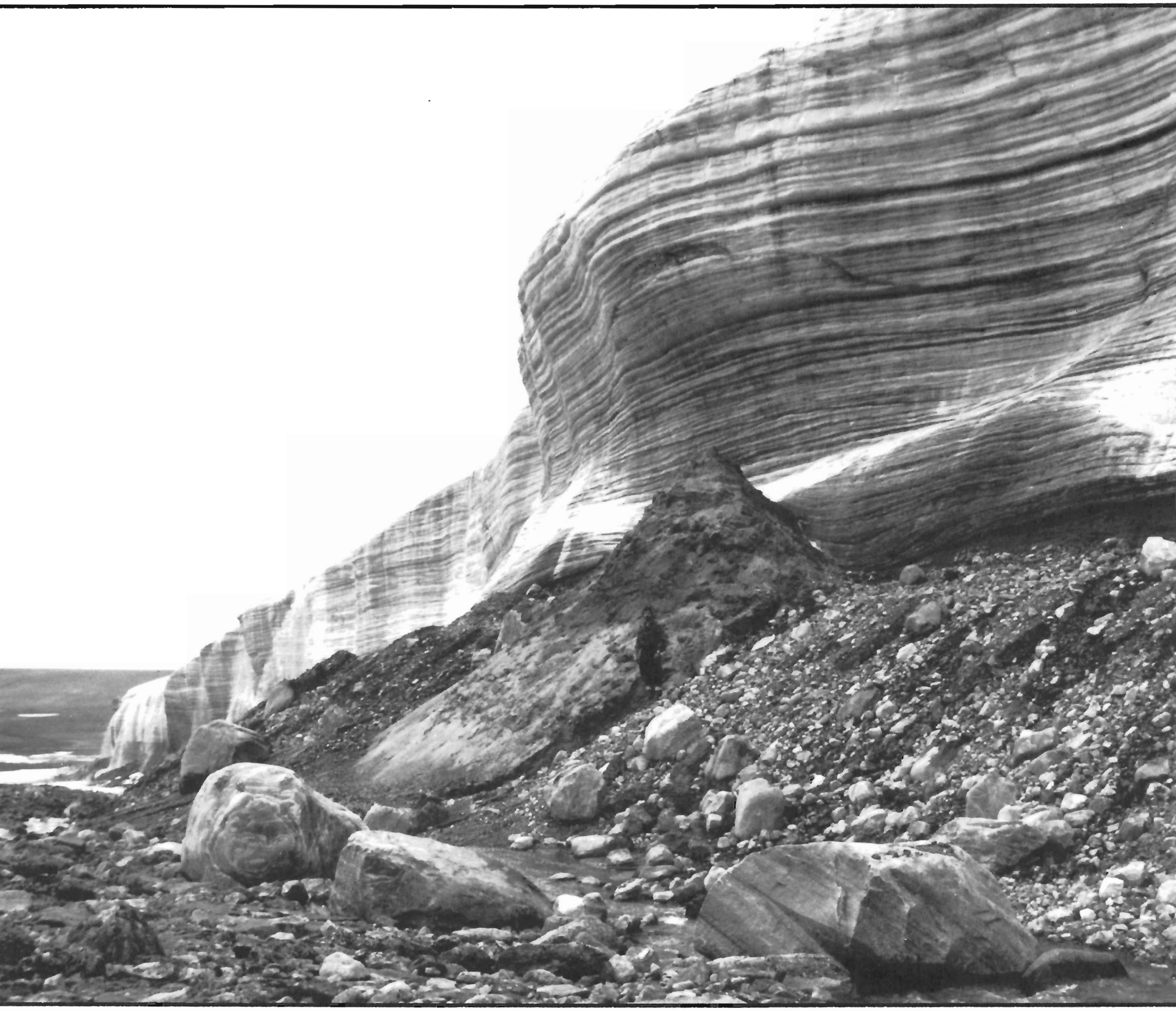

Aktineq glacier, Bylot Island: Coarse, crystalline debris forming a lateral moraine is derived from bedrock several kilometres up ice. The debris has been transported within the basal zone of the glacier and is melting out of the ice forming a debris-covered apron. A bedded sand and gravel deposit capped by in situ organic material (adjacent to standing figure) occurs at the upper part of the basal zone and has been glacially transported as a frozen intact block. Glacier ice is nearly debris-free and appears foliated in section as a result of internal flow. Photo and stratigraphy by R.A. Klassen, GSC 204126.

QUATERNARY CORRELATIONS IN ARCTIC CANADA

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Andrews, J.T., Miller, G.H., Vincent, J-S., and Shilts, W.W., Quaternary correlations in Arctic Canada; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 127-134, 1984.

Abstract

In the Hudson Bay/James Bay Lowlands, along the coasts of Banks Island, and along the eastern coast of Baffin Island are continuous and extensive sections in Quaternary sediments. These sections are rich in marine fossils, buried peats, and soils and contain a wide variety of glaciagenic sediments together with glacial marine units and littoral deposits. Lake muds are also fairly common. All three areas possess very long records that may extend to the early Quaternary and Pliocene.

The events of the last glaciation (Wisconsinan, Foxe, Amundsen) are interpreted in terms of lithostratigraphy, biostratigraphy, and aminostratigraphy. Relative and "absolute" dating control is provided by radiocarbon dating of events that span the last 50 ka, and in particular the last 11 ka, and some age control is also provided by several U-series dates on marine molluscs. Regional correlations are based on comparisons of amino acid ratios from marine shells. Suggested correlations during the last glaciation (Wisconsinan, Foxe, Amundsen) are:

ka	*Banks Island*	*Hudson Bay Lowland*	*Baffin Island*
8		*Tyrrell Sea sediments*	*Inugsuin regression*
10	*Russell Stade*	*Upper tills*	*Baffinland Stade*
40	*?*	*Friday Creek sediments*	*Iron Strand event*
		till	*?*
80	*?*	*Fawn River gravels*	*Quajon Interstade*
	M'Clure Stade	*Adam Till*	*Ayr Lake Stade*
120	*Cape Collinson Interglaciation*	*Missinaibi Formation*	*Kogalu/Cape Broughton interglaciation*

Résumé

Dans les basses-terres de la baie d'Hudson et de la baie James, le long des côtes de l'île Banks et sur la côte est de l'île de Baffin, les sédiments du Quaternaire peuvent être observés le long de coupes continues. Ces coupes naturelles abondent en fossiles marins, en tourbes enfouies et en sols, et renferment une grande variété de sédiments d'origine glaciaire ainsi que des unités glaciomarines et des dépôts littoraux. Les boues lacustres y sont assez répandues. Les trois régions se partagent une très longue histoire qui remonte parfois au début du Quaternaire et au Pliocène.

Les événements de la dernière glaciation (Wisconsinien, Foxe, Amundsen) sont interprétés des points de vue de la lithostratigraphie, de la biostratigraphie et de l'aminostratigraphie. La méthode de datation au carbone radioactif a servi pour établir l'âge relatif et «absolu» des événements survenus depuis 50 ka, et en particulier depuis 11 ka, et l'application de la méthode des isotopes de l'uranium aux mollusques marins a également donné certaines dates. Les corrélations régionales sont basées sur la comparaison des rapports d'acides aminés déterminés à partir des coquillages marins. Les auteurs proposent les corrélations suivantes pour les événements qui datent de la dernière glaciation (Wisconsinien, Foxe, Amundsen):

ka	*Île Banks*	*Basses-terres de la baie d'Hudson*	*Île de Baffin*
8		*Sédiments de la mer Tyrrell*	*Régression d'Inugsuin*
10	*Stade de Russell*	*Tills supérieurs*	*Stade de Baffinland*
40	*?*	*Sédiments de Friday Creek*	*Episode d'Iron Strand*
		Tills	*?*
80	*?*	*Graviers de Fawn River*	*Interstade de Quajon*
	Stade de M'Clure	*Till d'Adam*	*Stade d'Ayr Lake*
120	*Interglaciaire de Cape Collinson*	*Formation de Missinaibi*	*Interglaciaire de Kogalu et de Cape Broughton*

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Manuscript received: 1982-02-17
Final version approved for publication: 1982-11-10

INTRODUCTION

In this volume we have individually discussed the Quaternary glacial history of our areas of responsibility. Thus, Andrews and Miller (this volume) reported on the findings from the Eastern Canadian Arctic, which includes northern Labrador, Baffin Island, Bylot Island, and Foxe Basin. Vincent (this volume) outlined the increasing wealth of stratigraphic data that has become available for the islands of the Western Canadian Arctic, with emphasis on Banks, Melville, and Victoria islands. Finally, Shilts (this volume) outlined the glacial history of the southern District of Keewatin and the Hudson Bay region. Our combined area of study thus includes a significant part of the northern sector of the Laurentide Ice Sheet (Fig. 1). It excludes the islands of the High Arctic where work has been recently completed (Blake, 1970, 1975, 1980a, b; England, 1976; England et al., 1978; Hodgson, 1981, 1982; England and Bradley, 1981; Hodgson et al., in press) and the region between Victoria and Bylot islands (Craig, 1965; Dyke, 1979, 1983, 1984; Klassen, 1981).

It is appropriate at this point to stress the importance of the evidence for oscillations in not only ice extent, but also the associated variations of local sea level. In the three areas under consideration here, the recognition of major "sea level events" (cf. Andrews et al., 1981) provides two major pieces of data: 1) It provides lithostratigraphic units which can be associated with times of glacial advance and retreat (e.g., Miller et al., 1977; Nelson, 1978, 1980, 1981; Vincent, 1982, 1983; Vincent et al., 1983). 2) The marine faunas in the various facies provide material suitable for ^{14}C, U-series, or amino acid determinations (e.g., Miller et al., 1977; Blake, 1980a, b; Szabo et al., 1981; Shilts et al., 1981; Vincent, 1982, 1983; Vincent et al., 1983). Information from marine molluscs can also be complemented by ^{14}C and amino acid studies on wood which in some areas, such as Banks Island, is a common component of interglacial units.

Long (in terms of time) records of Quaternary glacial and sea level events are available from several areas of Arctic Canada, most notably sections on Banks Island, along the eastern coast of Baffin Island, and within the Hudson Bay/James Bay Lowlands (Vincent, this volume; Andrews and Miller, this volume; Shilts, this volume). Immense difficulties occur, however, in correlating between three areas geographically remote from each other (Fig. 1); in all three areas Quaternary sediments occur that may span much of the Quaternary and indeed may include some Pliocene sediments (Feyling-Hanssen, 1980; Szabo et al., 1981; Nelson, 1981; Vincent et al., 1983).

CORRELATIONS FOR THE LAST INTERGLACIAL/GLACIAL CYCLE

Because of the above-mentioned problems, there is great uncertainty in correlation of old units and so our survey focuses on the correlations that can be made for sediments and events of the last interglacial/glacial cycle (Fig. 2). In the southern regions of Hudson Bay the last interglacial is marked by sediments of the Missinaibi Formation (McDonald, 1969; Prest, 1970; Skinner, 1973) whereas the overlying glacial and nonglacial sediments were deposited during the Wisconsin Glaciation (Prest, 1970) which ended about 8 ka with the incursion of the Tyrrell Sea into Hudson Bay (Lee, 1960; Craig, 1969; Hardy, 1976).

On Banks Island the last interglacial sediments have been assigned to the Cape Collinson Interglaciation (Vincent, 1982, 1983), which is characterized by a climate much warmer than present in which **Betula** was dominant. Glacial and marine sediments stratigraphically above Cape Collinson deposits are assigned to the M'Clure and Russell

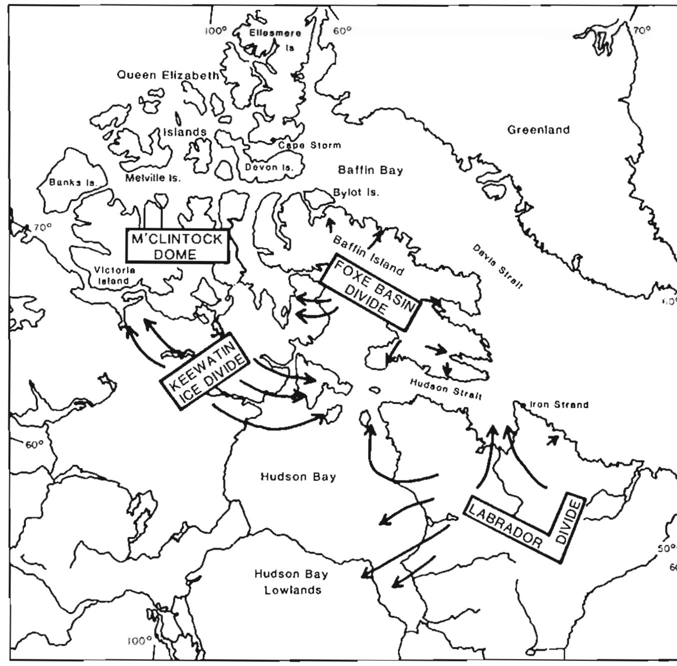

Figure 1. Map of northern Canada showing the three areas covered in this review, the location of ice divides and ice domes of the Wisconsinan Laurentide Ice Sheet, and general directions of ice flow.

stades of Amundsen Glaciation which ended shortly after 10 ka as the ice retreated towards mainland Canada (Craig and Fyles, 1960; Prest, 1970; Vincent, 1982, 1983).

On Baffin Island the Foxe Glaciation (cf. Miller et al., 1977) was the last glaciation and has recently been redefined to exclude glacial events that occurred prior to the deposition of the Kogalu Member of the Clyde Foreland Formation (Andrews and Miller, this volume). Prior to the redefinition, Foxe Glaciation extended back to the Cape Christian Interglaciation (Miller et al., 1977), which had been considered to represent the "last interglacial", but recent analysis of the probable ages of sediments along the east coast of Baffin Island suggested that this was of the order of 300 to 600 ka (Szabo et al., 1981; Nelson, 1981; Andrews et al., 1981). The last interglacial has not been formally or informally named but a warm interglacial climate is marked by **Betula**-dominated pollen spectra from buried soils and muck beneath units of the Kogalu Member (Mode, 1980; Brigham, 1980). Thus Foxe Glaciation is now defined to include the Kogalu Member and glacial and nonglacial sediments that occur stratigraphically above the Kogalu until the termination of the Foxe Glaciation about 5 ka (Andrews, 1982). Subsequent glacial expansion is assigned to an unnamed episode of "neoglaciation" (Fig. 2).

Thus the following conclusions appear valid:

1. The Cape Collinson, Missinaibi, and buried soils beneath the Kogalu Member are broadly time-correlative units that are probably "last interglacial" in age and thus may date in the interval between 130 and 100 ka.
2. The glacial and nonglacial sediments that lie stratigraphically above these units and below the "postglacial" marine sediments or the surface are broadly time equivalent, and thus as a first approximation the Amundsen, Wisconsin (of Hudson Bay), and Foxe glaciations are comparable (i.e. coeval) geologic-climate units.

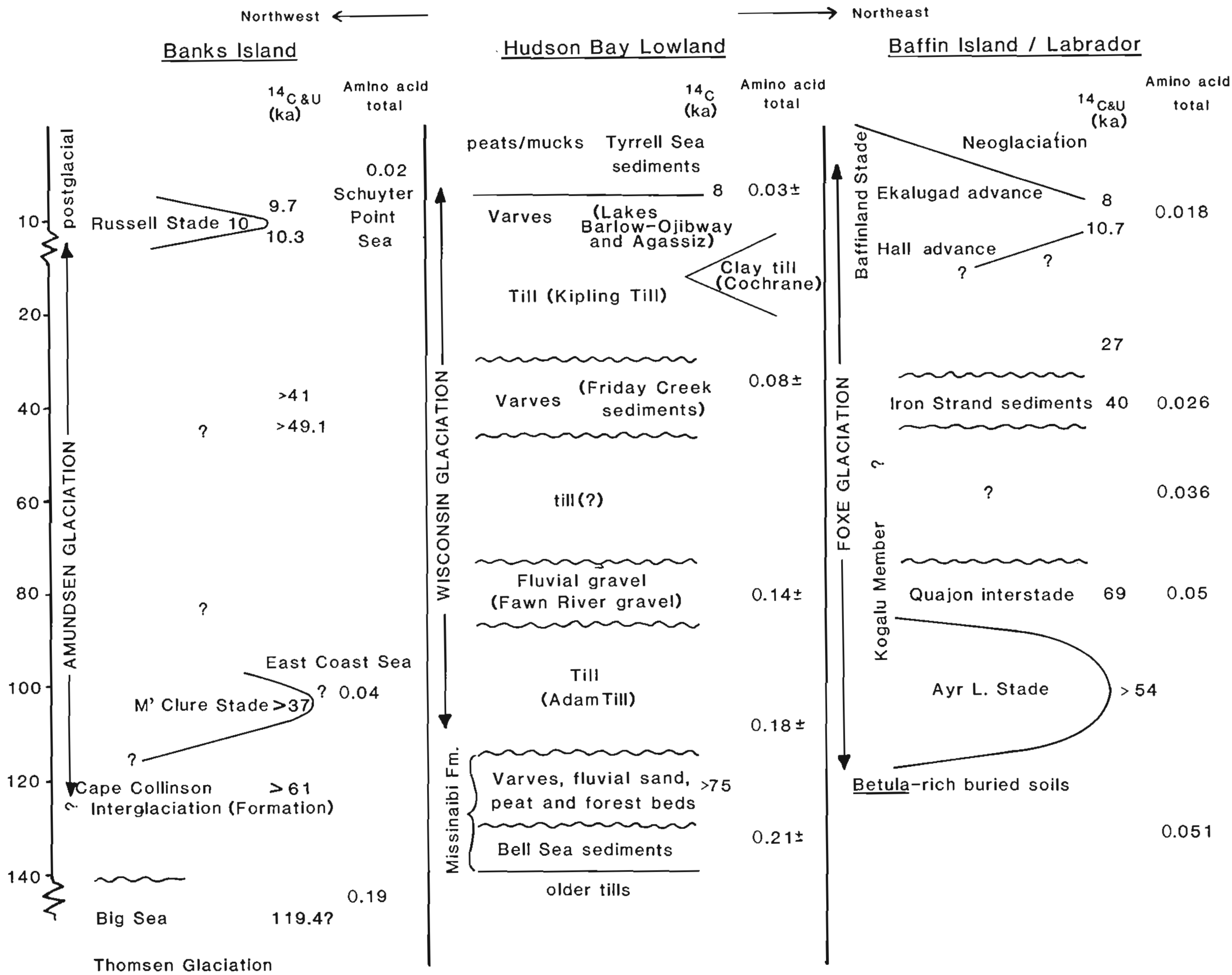

Figure 2. *Correlation diagram for the last interglacial/glacial cycle showing lithological units and geologic-climate events. Available radiometric dates and amino acid ratios are also presented. Banks Island – Vincent (this volume), Hudson Bay Lowland – Shilts (this volume), Baffin Island/Labrador - Andrews and Miller (this volume).*

The specific interest in this report is a comparison of and contrast between the records of the Wisconsin-Foxe-Amundsen glaciations. Although these glaciations are probably approximate time-equivalents, it should be stressed that the thinking in Canada now strongly supports the notion that the Laurentide Ice Sheet was not a single, stable-cored ice sheet (cf. Andrews and Barry, 1978) but was significantly more complex and more dynamic, with at least three or four major centres of growth and dispersal that did not necessarily act synchronously (Shilts, 1980; Dyke et al., 1982). The three areas under discussion here were influenced by different ice centres: (1) most of the deposits of the Hudson Bay Lowland are clearly associated with ice transportation from the northeast, that is from the Labradorean centre of Tyrrell (1898; Fig. 1); (2) Foxe Glaciation on eastern Baffin Island is associated with ice growth and decay stemming from an ice divide over Foxe Basin or possibly over the extreme western coast of Baffin Island (Ives and Andrews, 1963; Andrews and Miller, 1979; Dyke et al., 1982); and (3) Amundsen Glaciation is associated with both the Keewatin centre and the M'Clintock Dome postulated by Dyke et al. (1982). These interrelationships are shown in Figure 3.

The early stages of the Wisconsin-Foxe-Amundsen glaciations (hereafter termed the Wisconsin Glaciation for ease of reference) are probably represented in all three areas by glaciagenic sediments. All units are beyond the limit of ^{14}C dating; U-series dates on marine molluscs in Kogalu sediments (Szabo et al., 1981) from Baffin Island have not clarified the chronology. We suggest that Adam Till and other "lower tills" in the Hudson Bay Lowland (Andrews et al., 1983; Shilts, 1982) represent the first advance of Wisconsinan ice across the Lowland; Skinner (1973) noted that this ice flow was from the northeast. Shell fragments in stratigraphically unambiguous lower tills gave some amino acid total ratios for aIle:Ile typical of the Bell Sea (Fig. 2) but also resulted in a distinct cluster of ratios close to 0.18 (Fig. 2). Andrews et al. (1983) have presented an argument that enables an estimated age to be associated with specific amino acid ratios in the Hudson Bay Lowlands. The essence of the argument is as follows: 1) the age of the Bell Sea is 130 ka and 2) first-order linear kinetics can be used to provide ages for amino acid ratios less than those that typify the Bell Sea with a long term average effective diagenetic temperature for the Lowlands of 0.6°C.

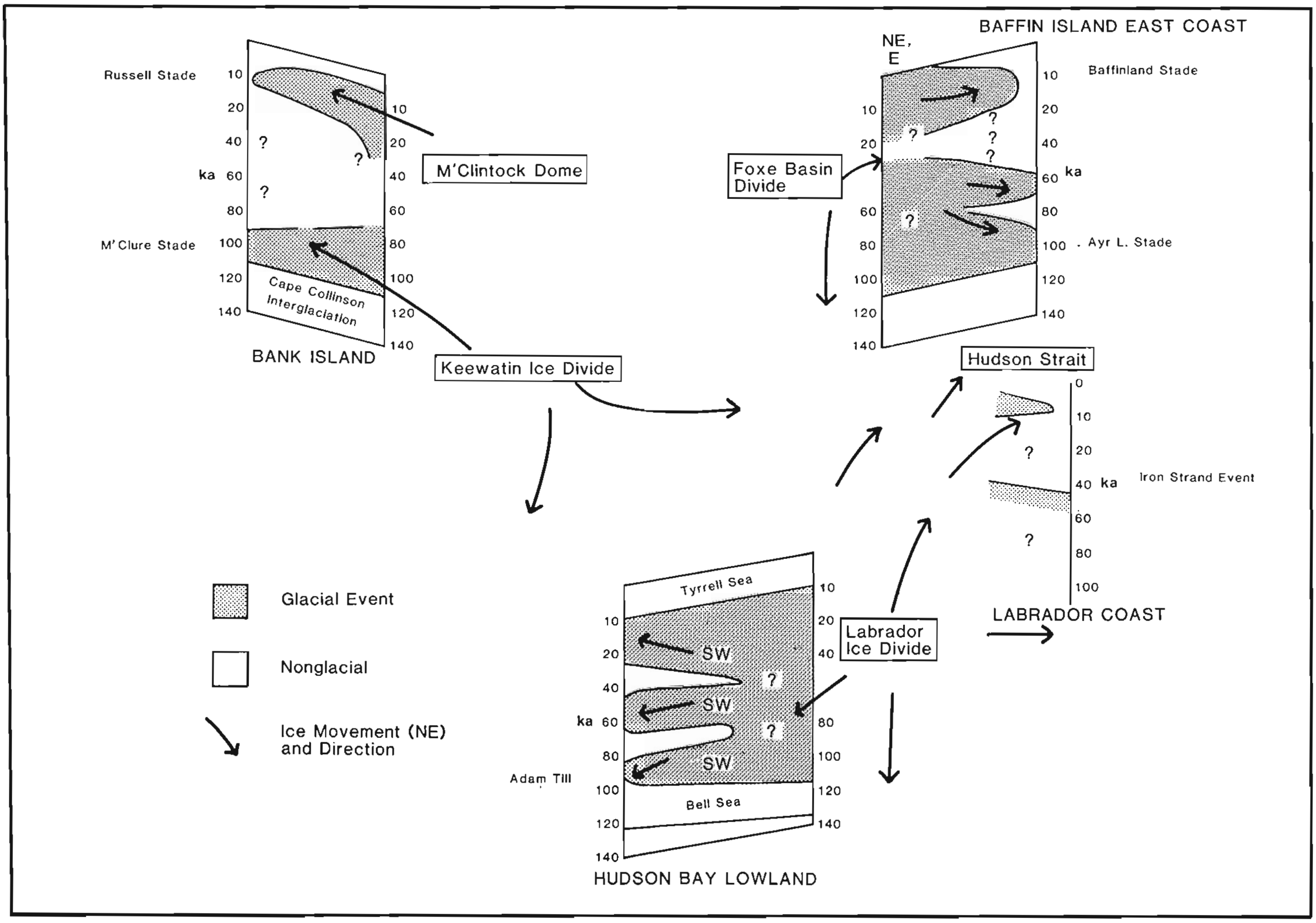

Figure 3. Fence diagram showing suggested time/distance correlations and possible correlations with southern records.

With these assumptions, a chronology for events in the Hudson Bay Lowlands can be developed (Fig. 2, 3, 4). Thus the alle:Ile ratios from the lower tills indicate that ice overrode marine sediments in Hudson Bay some time close to 105 ka.

On Figures 2 and 3 it is suggested that the Ayr Lake Stade on Baffin Island and the M'Clure Stade on Banks Island are correlative and date from within marine isotope stage 5. The Ayr Lake Stade represents the only episode during the Foxe Glaciation during which ice from the Foxe Basin divide reached the continental shelf of eastern Baffin Island (Miller et al., 1977; Nelson, 1981; Klassen, 1981). Amino acid ratios (total) on shells associated with the Kogalu Member associated with the Ayr Lake Stade average 0.045±; for the East Coast Sea Sediments of the M'Clure Stade, Vincent (1982, 1983) noted that ratios ranged between 0.04 and 0.09. The lower ratios from Banks Island would certainly permit the proposed correlation because the mean annual air temperature (MAT) on Banks Island is, and was, probably colder than along the eastern coast of Baffin Island. The MAT along the eastern coast of Baffin averages about -11°C whereas at Sachs Harbour on Banks Island the MAT is

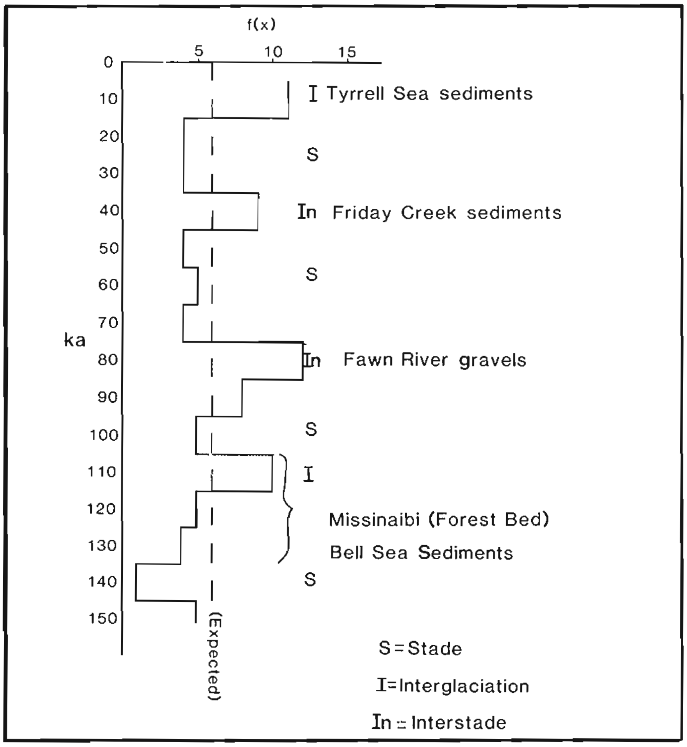

Figure 4. Frequency diagram of amino acid ratios (total alle:Ile) and suggested ages from the Hudson Bay Lowland (data from Andrews et al., 1983).

closer to -13.7°C. Hence we might expect time-equivalent units on Banks Island to have somewhat lower ratios than those on Baffin Island.

The early stadial deposits of the Wisconsin Glaciation in Hudson Bay are overlain by fluvial gravels which Shilts et al. (1981) and Andrews et al. (1983) informally called the Fawn River gravels after sections on Fawn River. Marine shell fragments in fluvial deposits and current structures, indicating flow of water towards Hudson Bay, are used as proof that Hudson Bay was open at this time. The estimated age based on amino acid ratios of a distinct cluster of samples (Andrews et al., 1983; Fig. 4) is 76 ka. If Hudson Bay was deglaciated then it can certainly be inferred that Hudson Strait was ice free and that deglaciation would also have affected the other major ice centres. On Baffin Island the Quajon interstadial deposit is characterized by total alle:Ile ratios of 0.05 and has a U-series age of $\geq$69 000 years (Szabo et al., 1981). An age of 80 ka for the Quajon Interstade is reasonable in light of these data but cannot be supported conclusively.

The timing of the M'Clure Stade, although it probably occurred before 50 ka, is not known – the suggestion on Figure 2 that it too terminated ca. 80 ka must be viewed as hypothesis.

The next glacial advance/retreat that has been recognized along most of the eastern coast of Baffin Island and on Banks, Victoria, and Melville islands dates from between 11 and 10 ka (Fig. 2). However, in the Hudson Bay Lowland and at sites at either end of Baffin Island, northernmost Labrador, and southern Ellesmere Island evidence exists for an event having ^{14}C dates and amino acid ratios suggestive of a Middle Wisconsinan age – 50 to 40 ka (Ives, 1977; Blake, 1980b; Klassen, 1981; Clark, 1982; Andrews et al., 1983). In addition, the clustering of amino acid ratios for the Kogalu Member on eastern Baffin Island (Mode, 1980; Brigham, 1980) suggests high relative sea levels (ice advance?) on two occasions during deposition of this member; the younger of these, having total ratios of about 0.036, is older than 38 ka (Mode, 1980). Thus we argue for some glacial activity for parts of eastern Baffin Island after 80 ka but before 40 ka.

Data from the Hudson Bay Lowland (Shilts, 1982; Andrews et al., 1983) indicate that some sediments along Kabinakagami River have average amino acid ratios of 0.08 (total) and an estimated age of 40 to 35 ka. These sediments are tentatively correlated by Shilts (this volume) with the Friday Creek sediments of Skinner (1973). We hypothesize that these are correlative. The age of these is approximately correlative with that of raised coastal/marine sediments at Iron Strand, Labrador (Fig. 2; Ives, 1977; Clark, 1982) and probably also that of the Cape Storm unit, noted by Blake (1980b) on Ellesmere Island (Fig. 1), which yielded finite radiocarbon dates and amino acid total ratios of 0.026. If marine waters were inshore along the Labrador coast and southern Ellesmere Island at this time we might also expect that widespread deglaciation of the channels and sounds of the Arctic Islands might have occurred. England et al. (1978) and England and Bradley (1981) also reported units from northern Ellesmere Island that have low amino acid ratios, comparable with those from Cape Storm and Iron Strand. Correlation problems, however, are compounded by the fact that the present MAT in the area is close to -17°C, several degrees lower than sites on Baffin Bay.

A lack of appropriate amino acid ratios in the Hudson Bay Lowland suggests this area, near the centre of the Laurentide Ice Sheet, was ice covered from ca. 30 ka until the transgression of the Tyrrell Sea at about 8 ka. No data have been found to indicate the extent of ice cover during the early part of the period in Baffin Island and western Arctic areas (near the margin of the ice sheet). There are however considerable data that indicate that ice in these areas was advancing to the Late Wisconsinan glacial maximum between 11 and 10 ka (Miller, 1980; Osterman, 1982; Hodgson et al., in press; Hodgson and Vincent, in press; Vincent, this volume; Fig. 2). On Banks Island this late stade is termed the Russell whereas to the east it has been called the Baffinland (Andrews and Ives, 1978). The earliest dated expression of the Baffinland Stade in Frobisher Bay is the Hall moraine (Miller, 1980). Farther north on Baffin Island no ice advance positions have been dated in the 10 to 11 ka range but there are numerous radiocarbon dates from within the fiords to indicate that during the Cockburn Substage (Andrews and Ives, 1978), between 9 and 8 ka, substantial glacial advances took place. It is interesting, however, that along the outermost coast of Baffin Island a large number of radiocarbon dates from low elevation, raised marine deposits indicate that the highest Holocene marine transgression along this stretch of coast occurred between 9.5 and 10 ka (cf. Nelson, 1978; Andrews, 1980); it is possible that these dates represent, or mark, the glacial isostatic response of the outer coast to glacial advances that have not been successfully identified within the fiords.

During the Russell Stade, in the western Arctic, ice advanced northward and westward through inter-island channels to impinge on the northeast coast of Banks Island depositing Passage Point Sediments; on the north coast of Victoria Island; and on the south coast of Melville Island depositing Winter Harbour Till (Vincent, 1982, 1983, this volume; Hodgson et al., in press). Based on ^{14}C dating of shell-bearing marine sediments underlying and overlying glacial sediments of the Russell Stade, the ice advance occurred about 10 ka (Hodgson and Vincent, in press). Much of the western arctic coastal areas (east coast of Banks, northwest Victoria, Melville, and other islands of the western Queen Elizabeth Islands) were isostatically depressed over a period of 2 to 3 ka before the Russell Stade ice advanced (Vincent, this volume).

The timing of deglaciation from the late Wisconsinan maximum varied throughout the Arctic. On Baffin Island retreat was generally slow and has in fact continued through to the present. The period between 8.5 and 3 ka was one of glacial isostatic emergence across eastern Baffin Island; this event is termed the Inugsuin regression (Andrews, 1980). Tidewater glaciers from a remnant of the Laurentide Ice Sheet were still active on eastern Baffin Island between 5.6 and 4.7 ka (Dyke, 1979; Andrews, 1982). Deglaciation of Hudson Strait and southern Hudson Bay was rapid and essentially complete 8 to 7 ka (Lee, 1960; Skinner, 1973).

CONCLUSIONS

The correlations presented here (Fig. 2, 3) will provide a framework for investigations of the events of the Wisconsin Glaciation. Studies of the stratigraphy and sediments in the Hudson Bay Lowland should provide important controls not only for arctic Quaternary chronology but also for the chronology of glacial and nonglacial events in the Prairies and the Great Lakes area. Events in the St. Lawrence Lowlands and the Atlantic Provinces may not be as easily correlated with this record. Our evidence suggests that the major or largest Wisconsinan glacial advance in two regions of the Canadian Arctic occurred during an early stade. On both Banks Island and Baffin Island the retreat of glaciers from the Late Wisconsinan glacial maximum lags that along the southern Laurentide Ice Sheet margin by several thousand years but appears to be correlative with glacial advances in other arctic regions such as northwest Greenland (Kelly, 1980), east Greenland (Hjort, 1981), and Spitsbergen (Boulton, 1979).

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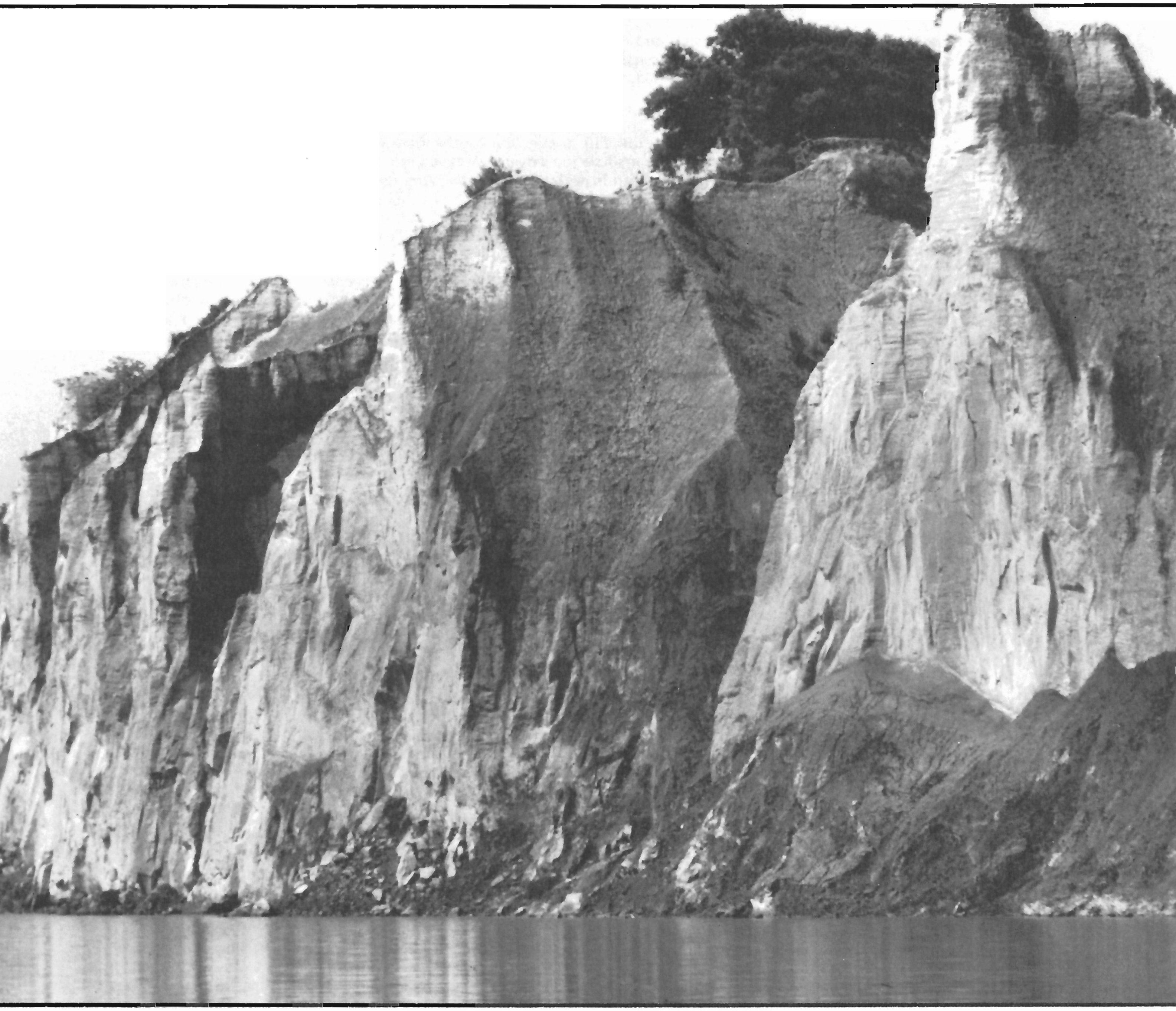
EASTERN CANADA

QUATERNARY STRATIGRAPHY AND HISTORY, GREAT LAKES — ST. LAWRENCE REGION



Scarborough Bluffs, Lake Ontario, southern Ontario: Glacial lake deposits dating from the end of the Sangamonian and beginning of the Wisconsinan; Scarborough Formation deltaic sands and silts at the base of the exposure are truncated by the massive Sunnybrook Till which is overlain by stratified sand and silt of the Thorncliffe Formation. Photo and stratigraphy by D.R. Sharpe, GSC 203504-V.

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Karrow, P.F., Quaternary stratigraphy and history, Great Lakes – St. Lawrence region; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 137-153, 1984.

Abstract

At Toronto, Ontario, the Illinoian York Till is overlain by the fluvial Don Formation containing warm climate fossils. Oldest Early Wisconsinan ice advances deposited the Bécancour and Johnville tills of Quebec and dammed the Ontario basin in which the Scarborough delta, containing cool climate fossils, was deposited. Ice retreat allowed deposition of the fluvial St. Pierre Sediments in Quebec and Pottery Road Formation at Toronto. The major Early Wisconsinan ice advance then covered the region and deposited the Chaudière and Gentilly tills in Quebec, Sunnybrook Till at Toronto, and Bradtville Till near Lake Erie.

Early Middle Wisconsinan Port Talbot interstadial deposits are represented in southeastern Quebec by the Gayhurst Formation, at Toronto by the Thorncliffe Formation, and at the type locality on Lake Erie. Ice advances then extended over Toronto to central Lake Erie and separated the Port Talbot from the later Plum Point Interstade (known from Toronto and Lake Erie). St. Lawrence River valley remained ice covered through the Middle Wisconsinan.

Late Wisconsinan ice advances covered the region and the fluctuating retreat deposited many named tills in the Great Lakes area. Concurrent with this retreat, a complex series of glacial lakes developed with outlets initially southwestward but later eastward as deglaciation progressed. The downwarped St. Lawrence valley was temporarily flooded by the Champlain Sea but isostatic upwarp restored terrestrial conditions. The northward retreating ice left this region about 10 ka but upwarp caused continuing drainage changes well into postglacial time.

Résumé

A Toronto, en Ontario, le till de York d'âge illinoien, repose sous la formation fluviale de Don, qui renferme des fossiles de climat chaud. Les avancées glaciaires du Wisconsinien inférieur ont mis en place les tills de Bécancour et de Johnville, au Québec, et barré le bassin de l'Ontario dans lequel a eu lieu la mise en place de la formation deltaique de Scarborough, qui contient des fossiles de climat froid. Au cours de leur retraite, les glaciers ont mis en place les sédiments fluviale de St. Pierre au Québec et la formation de Pottery Road à Toronto. Lors de l'importante avancée du Wisconsinien inférieur, les glaciers ont envahi la région et mis en place les tills de Chaudière et de Gentilly au Québec, le till de Sunnybrook à Toronto et le till de Bradtville près du lac Erié.

Les dépôts de l'interstade de Port Talbot, mis en place au début du Wisconsinien moyen, sont représentés dans le sud-est du Québec par la formation de Gayhurst, à Toronto par la formation de Thorncliffe et à la localité type en bordure du lac Erié. Les glaciers ont ensuite envahi Toronto jusqu'au centre du lac Erié au cours de la période séparant l'interstade de Port Talbot de celui de Plum Point (connu d'après Toronto et le lac Erié). La vallée du Saint-Laurent est demeurée couverte de glace pendant tout le Wisconsinien moyen.

Au Wisconsinien supérieur, les fronts glaciaires ont complètement envahi le territoire et, au cours de leur recul marqué par des fluctuations, ont laissé dans la région des Grands lacs de nombreux tills qui ont tous reçu des appellations. Simultanément, s'est formé un réseau complexe de lacs glaciaires duquel se détachaient des émissaires d'abord vers le sud-ouest, plus dans la direction est à mesure que progressait la déglaciation. La vallée du Saint-Laurent, affaissée, a temporairement été inondée par la mer Champlain, mais un bombement isostatique l'a asséchée. Reculant vers le nord, la glace a abondonné cette région il y a environ 10 ka, mais la transformation du réseau hydrographique sous l'effet des bombements isostatiques s'est poursuivie au cours de la période post-glaciaire.

INTRODUCTION

The Great Lakes – St. Lawrence region is the southernmost part of Canada and was affected by glaciation from the Labradorean centre of the Laurentide Ice Sheet. It is an area of mainly low relief, but nevertheless topography created a lobate ice margin in the Great Lakes area. Because of the gentle topography and southern latitude, the ice surface probably had a low gradient; slight changes in ice mass resulted in substantial fluctuations in areal extent of the ice. Some ice advances left till sheets without any marginal moraines, whereas others built large end moraines. Overridden older landforms commonly show through younger deposits and affect the present landscape.

The nonglacial record comprises interglacial fluvial sediments, indicated by fossils associated with a warm climate or deep weathering, and interstadial fluvial and lacustrine sediments, indicated by included organic deposits of cool or cold affinities. The organic component is of crucial importance in establishing past environmental conditions and chronology, particularly in Middle Wisconsinan time.

The region includes the long-standing classic sections at Toronto (Coleman, 1933) and more recently described, but now classic, sections at Port Talbot on Lake Erie (Dreimanis et al., 1966) and the St. Pierre beds near Trois-Rivières, Quebec (Gadd, 1971). The Quaternary history of

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Manuscript received: 1982-03-01
Final version approved for publication: 1982-10-29

the area has been previously reviewed by Goldthwait et al. (1965), Prest (1970), McDonald (1971), Terasmae et al. (1972), Dreimanis and Goldthwait (1973), Gadd (1976), Dreimanis (1977a, b), and Occhietti (1982). Because it was developed through studies in this area and remains the most relevant of existing schemes, the Wisconsinan time classification of Dreimanis and Karrow (1972), with modifications, will be followed herein (Fig. 1).

More discussion is centred on southern Ontario than on the rest of the Great Lakes-St. Lawrence Lowlands because of the abundance of information for this area. Northern Ontario and southern Quebec are less intensively studied (see LaSalle, this volume) and according to present knowledge were generally ice covered for a much longer part of the late Quaternary.

Acknowledgments

Helpful comments on the manuscript were provided by A. Dreimanis, J.T. Andrews, and R.J. Fulton. Illustrations were prepared by N. Bahar.

Brief History of Study

The region under consideration includes some of the earliest settled parts of Canada. The record of scientific study is long and diverse, but only selected major steps in the evolution of our present knowledge can be mentioned here. The reader is referred to reviews of earlier work by Karrow (1967, 1969), Gadd (1971), and Dreimanis and Goldthwait (1973) for additional detail.

J.J. Bigsby travelled widely and described many features of the Great Lakes area in several papers published between 1821 and 1852, among which may be mentioned his description of the deposits of the bluffs east of Toronto (Bigsby, 1829). Observations by Bayfield (1837) on elevated marine deposits near St. Lawrence River and by Roy (1837) on raised beaches north of Toronto attracted the attention of Lyell, who visited the area in 1841-42 and described his travels and observations in 1845, as well as in several more specific papers before and after 1845.

	?		
WISCONSINAN	LATE	North Bay Interstade	
		Greatlakean Stade	
		Two Creeks Interstade	11.85 ka
		Port Huron Stade	
		Mackinaw Interstade	13.3 ka
		Port Bruce Stade	
		Erie Interstade	
		Nissouri Stade	
	MIDDLE	Plum Point Interstade	28 ka
		Cherrytree Stade	
		Port Talbot Interstade II	45 ka
		unnamed stadial (Dunwich Till)	
		Port Talbot I	
	EARLY	Guildwood Stade	
		St. Pierre Interstade	75 ka
		Nicolet Stade	
SANGAMONIAN			
ILLINOIAN			

Figure 1. *Time classification adapted from Dreimanis and Karrow (1972); ages from dated sites are indicated.*

The founding of the Geological Survey of Canada in 1842 brought about much new exploration and many progress reports by its geologists, summarized in Logan's (1863) report on the geology of Canada. This monumental report included a map of the surface materials of Eastern Canada and attempted a stratigraphic classification of some of these. Agassiz (1850) described raised beaches and other features of the Lake Superior area.

Although buried fossils were previously known to occur at Toronto, the first detailed description of the strata of Scarborough Bluffs and some of their fossils was presented by Hinde (1878). The interglacial fossils at Toronto became well known through the work of Coleman (1894) who continued work in the area for several decades and made available extensive detail on the stratigraphy (Coleman, 1933).

In numerous papers starting in 1857, J.W. Dawson described many aspects of the Quaternary geology of St. Lawrence valley. He is best known for his paleontological study of the Champlain Sea marine sediments. Dawson (1893) discussed a floating ice origin for glacial deposits, as well as the history of the Champlain Sea. In contrast, Chalmers (1898) accepted the theory of continental glaciation and described multiple-till sequences in southeastern Quebec.

The complex succession of glacial lakes in the Great Lakes area has long attracted considerable attention and was subjected to a great upsurge of study in the late 1800s. Several former lake levels were identified in each of the Great Lakes basins and their interrelationships and relationship to the retreating ice lobes were the subject of many papers (e.g., Spencer, 1890b, 1891; Taylor, 1896; Goldthwait, 1910; Coleman, 1922, 1936). A major synthesis of glacial lake history by Leverett and Taylor (1915) included many observations in Ontario; not only were the geomorphic relationships studied, but the warping and uplift of the shorelines were considered in relation to crustal dynamics and the Earth's interior. The evolution of the Niagara River gorge was correlated with drainage changes in the glacial lakes and the recession of the Falls became a geochronometer (Gilbert, 1890; Spencer, 1908). Glacial lake varves were studied as a geochronometer by Antevs (1925) and rates of ice retreat in Eastern Canada were worked out.

During the first half of the present century, there was major emphasis on surface landforms in deriving the history of ice retreat, whereas earlier events were commonly ignored. Taylor (1913) described moraines of southwestern Ontario and Chapman and Putnam (1951) made available a major report with maps of the landforms of southern Ontario. The mapping of Quaternary geology was carried out in a few scattered areas early in this century by the Geological Survey of Canada with an emphasis on surface sediments. With the establishment of the Pleistocene section in the late 1940s work was expanded in Ontario (e.g., Deane, 1950; Gravenor, 1957) and Quebec (e.g., Gadd, 1971; McDonald and Shilts, 1971). Later reports placed much more emphasis on stratigraphy, supplementing earlier emphasis on landform interpretation. In the 1950s stratigraphic studies were undertaken by Dreimanis along Lake Erie bluffs and resulted in the discovery of the Port Talbot and Plum Point interstadial deposits (Dreimanis et al., 1966). Concurrently, the Ontario Department of Mines (now Ontario Geological Survey) mapped glacial geology in connection with groundwater studies and investigated stratigraphic aspects (e.g., Watt, 1957; Karrow, 1963). By the 1970s this work had been greatly expanded so that almost all of southern Ontario has been mapped at least at 1:50 000 scale, although several areas are as yet without published maps and reports;

individual reports and maps are too numerous for listing here. This work has resulted in the discovery of additional buried organic deposits and a much improved appreciation of the history of Late Wisconsinan glaciation.

As a result of the great increase in construction activity after 1945, unprecedented opportunities have been available for the gathering of stratigraphic information in urban areas. Unfortunately, only a small fraction of the available exposures have been geologically studied; notable exceptions include the subways in Toronto (Watt, 1954; Lajtai, 1969) and a major compilation on the Montreal area (Prest and Hode-Keyser, 1977).

In connection with the expanded mapping by the Geological Survey of Canada in the 1950s, paleontological work was undertaken by Wagner (1970) on the Champlain Sea invertebrate faunas and by Terasmae (1958, 1960) on the palynology of buried and surface peat deposits, including the St. Pierre and Toronto sections. The availability of radiocarbon dating after 1950 made it possible to set up a chronological framework for the last 50 ka and allowed the establishment of correlations. Thus deVries and Dreimanis (1960) established the age of the Port Talbot interstadial deposits and Dreimanis and Terasmae (1958) revised the age of the previously described sequence at Toronto. With the rapid growth of university geology departments in the 1960s and 1970s, great expansion of Quaternary studies of all types has taken place. The greatly expanded volume of literature cannot be fairly and adequately reviewed here but some of the publications will be mentioned below where relevant to the present discussion.

Regional Geological Setting

The northern part of the Great Lakes – St. Lawrence region is underlain by Precambrian igneous and metamorphic rocks of the Canadian Shield, whereas the southern part is underlain by Paleozoic sedimentary rocks which are nearly flat-lying, except along the southeastern edge in Quebec where affected by Appalachian folding (Fig. 2). Lake Superior, the largest, deepest, and northernmost of the Great Lakes, is almost completely within the Precambrian Shield, whereas Georgian Bay and northern Lake Huron are bordered by the Shield on the northeast. Lakes Ontario and Erie are wholly within the area of Paleozoic rocks, as is Lake Michigan – the only Great Lake entirely within the territory of the United States.

St. Lawrence River crosses a narrow belt of Precambrian rocks in the Thousand Islands at the outlet of Lake Ontario then flows on flat-lying Paleozoic sedimentary rocks to Quebec city, where it crosses onto the Appalachian fold belt. To the east it follows the border between the Shield to the north and the Appalachians to the south.

The Precambrian rocks are complex lithologically and structurally. Relief on the Shield varies between 500 m north of Lake Superior and St. Lawrence River and 50 to 200 m east of Georgian Bay. Till on the Shield is generally coarse textured (Scott, 1976). Paleozoic rocks consist mainly of interbedded carbonates and shales, with the carbonate belts forming the more resistant bedrock highs separated by shale-based lowlands. Relief on the Paleozoic rocks is generally 30-50 m but with escarpments reaching 300 m. Tills on the Paleozoic rocks range from sandy to clayey, with the finest commonly derived from the reworking of lacustrine clays.

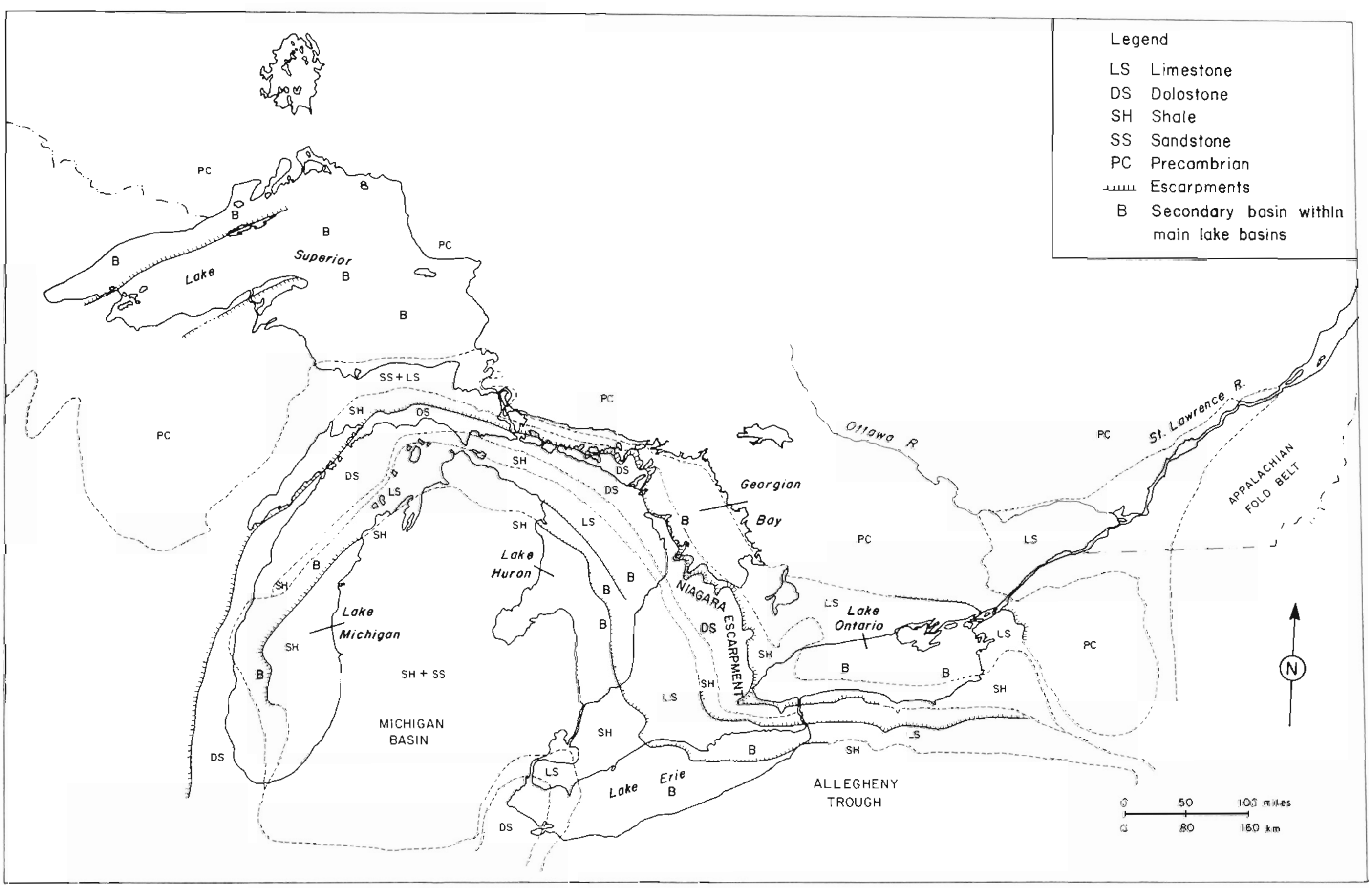

Figure 2. *Map of region showing bedrock lithology, escarpments, and lake basins.*

Differential erosion of the carbonate-shale sequences of the Michigan Basin and Allegheny Trough created the basins in which most of the Great Lakes developed (Fig. 2); Lake Superior was formed in a Precambrian sedimentary trough. Later glacial erosion accentuated the basins, and the effect of the topography was to create ice margins that were strongly lobate. Each lake basin was occupied by separate ice lobes which acted more or less independently. The lobes may also have been at times areas of major snow accumulation, generating strong outflows from the basins. Glacial lakes developed marginal to the lobes in the basins. This lobation and formation of marginal lakes is well known from study of the retreat of the last ice sheet, but it is believed to have occurred during earlier glaciations as well (Dreimanis, 1969).

The region is dominated by the effects of the last glaciation, which largely erased the record of earlier events. Where old sediments remain, they are only in protected locations, such as buried valleys, or underlie a thick cover of younger deposits. Exposures of the old sediments are limited and little is known of the materials in the buried valleys.

ILLINOIAN(?) AND OLDER

The oldest known Quaternary deposits occur at Toronto, where they are widely distributed under the metropolitan area (Karrow, 1969). The classic section at the Don Brickyard (Fig. 3) shows two till sheets separated by fluvial sediments, the lower part of which contains a rich assemblage of warm climate fossils attributed to the last or Sangamon Interglaciation. The lower 'York Till' is considered to be of Illinoian age (Terasmae, 1960). At the brickyard it is a discontinuous clayey sandy till up to 1 m thick, containing abundant shale pebbles and directly overlying Ordovician shale. Striae on the underlying bedrock indicate ice flow northward out of the Ontario basin (Terasmae, 1960).

At Woodbridge (Fig. 3) four Wisconsinan tills overlie cool climate peaty sediments with a minimum age of >49.7 ka, and sands containing molluscs of probable interglacial age. A till at the base of the section, of which some 5 m is exposed, is considered to be York Till. Borings indicate that 30 m of gravel with till layers underlies York Till at this site; these sediments are of unknown age but pre-Illinoian deposits could be present. Similarly, about 10 km northeast of Woodbridge a 200 m-deep well into the Laurentian buried valley (White and Karrow, 1971) encountered tills, which could be of Illinoian or greater age and which underlie probable interglacial beds (Coleman, 1933).

York Till was encountered in both the Yonge and University subway tunnels in downtown Toronto (Watt, 1954; Lajtai, 1969) where it was interbedded with or overlain by lacustrine clay, giving a combined thickness of 6 to 9 m. Watt (1954) noted the presence of two somewhat contrasting till layers, but their significance is unknown. The lacustrine clay suggests that marginal lakes occupied the area between ice lying in the Ontario basin and higher ground to the north.

At Woodbridge, lenses of ice-contact sand and gravel and a diamicton (colluvium), showing some evidence of weathering, overlie York Till (White, 1975). The weathering is likely a result of exposure during subsequent interglacial(?) time.

SANGAMONIAN

Stratified clay and sand of the Don Formation, commonly about 7 m thick, form the next younger unit at Toronto (Karrow, 1967, 1969). They have long been famous for the warm climate fossils (plants, molluscs) that they contain (Coleman, 1933). Terasmae (1960) has shown that the

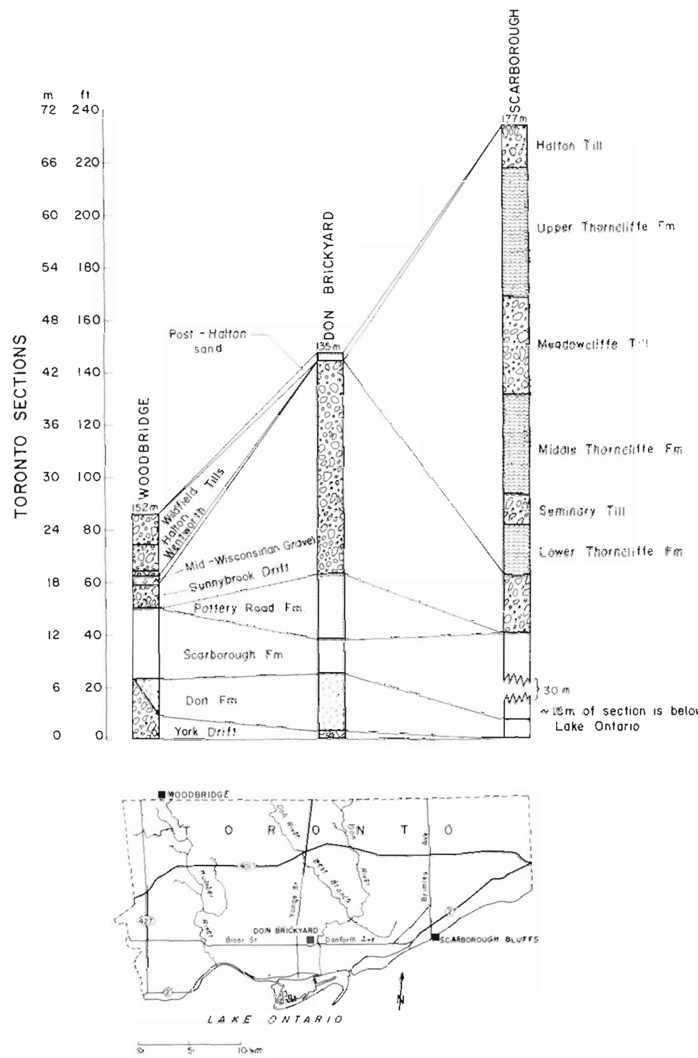

Figure 3. *Principal sections at Toronto (Karrow, 1967, 1969). Numbers at top of sections are elevations above sea level. Scale at left margin is height above base of section. About 15 m at the base of the Scarborough column is derived from borehole data from below the level of Lake Ontario.*

sequence at the Don Brickyard records warm climate at the base, with cooling upward. The Don Formation has been widely recognized in the Toronto area, particularly in borings and excavations in downtown Toronto (Watt, 1954; Lajtai, 1969), below the level of Lake Ontario at Scarborough Bluffs (Fig. 3), and along the Laurentian buried valley north of Toronto (Karrow, 1970). A metre or two of fossiliferous sand in the Woodbridge cut also seem to be correlative.

Pollen and other plant fossils from the Don Formation have been described by Terasmae (1960), the diatoms by Duthie and Mannada Rani (1967), the caddisflies by Williams and Morgan (1977), and the ostracodes by Poplawski and Karrow (1981). Few vertebrates have been recorded, but they include groundhog, deer, bison, bear, giant beaver, catfish, and pike (Karrow, 1969); additional fish remains are currently under study. A climate 2°C warmer than present is indicated by the basal beds (Terasmae, 1960) and this is the basis for the interglacial assignment; that they are of last interglacial age has been the accepted interpretation in recent years. They are too old for radiocarbon dating, but amino acid analysis of wood has yielded results

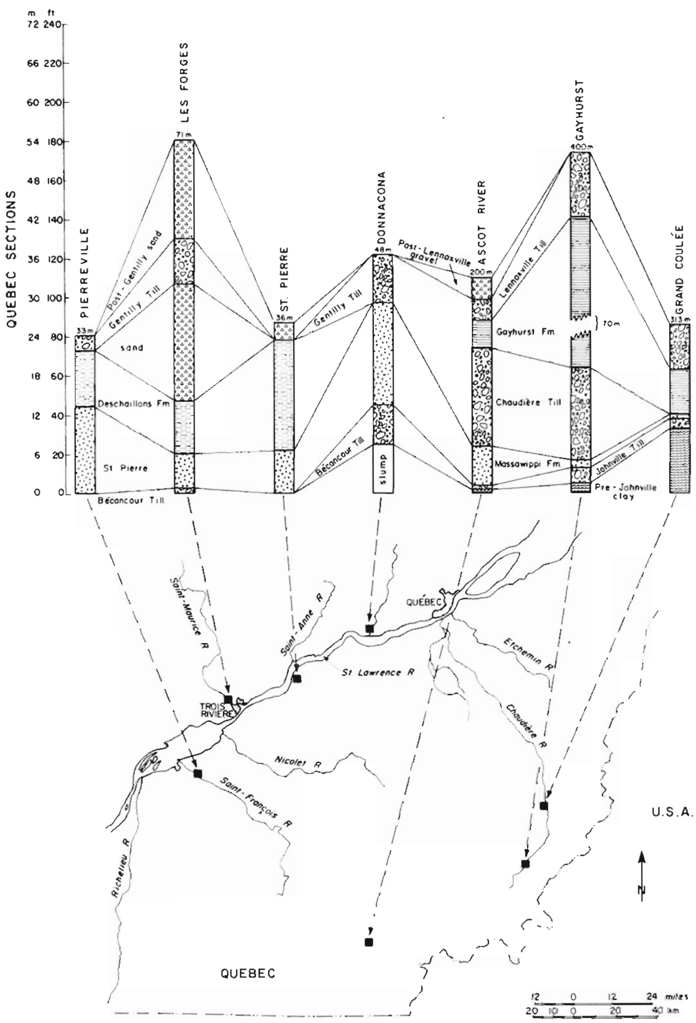

Figure 4. *Principal sections in southern Quebec. (Gadd, 1971; McDonald and Shilts, 1971; Occhietti, 1980). Numbers at top of section are elevations above sea level. Scale at left margin is height above base of section.*

compatible with a Sangamonian age (N.W. Rutter, personal communication, 1980). Amino acid analyses of freshwater shells from the Don Formation and from interglacial beds near Ithaca, New York, suggest they are of similar age (P.E. Hare, personal communication, 1973).

The Don Formation apparently represents mainly fluvial deposition at the Brickyard but estuarine and shallow lacustrine conditions were also present or nearby. This suggests that water in the Ontario basin was as much as 20 m higher than the present Lake Ontario level. Higher water level in the Ontario basin may reflect an isostatically upwarped eastern outlet during Sangamonian time; Wisconsinan glacial erosion of the outlet area may have made possible the lower present day water level; or both processes may have been involved. The top of the Don Formation is strongly weathered at the brickyard (Terasmae, 1960) and evidence exists of an erosional break between this formation and the next major sedimentary unit – the Scarborough Formation. This suggests that the water level in the Ontario basin fell during or after deposition of the Don Formation.

WISCONSINAN

Deposits of the last major glaciation are well represented in the region, although those of Early and Middle Wisconsinan age are commonly not present, or are deeply buried, because of the effects of Late Wisconsinan glaciation. Because radiocarbon dating generally extends back only through the later Middle Wisconsinan, the timing of events of earlier Middle Wisconsinan and Early Wisconsinan remains poorly known.

Early Wisconsinan

Early Wisconsinan history includes the transition from interglacial to glacial conditions as ice spread across the region. It was a time of dominantly cooling or cold climate and extensive glaciation.

Early Wisconsinan deposits are particularly well exposed and studied at Toronto and in St. Lawrence Lowlands. Because these deposits are beyond the range of radiocarbon dating, correlation has to be based mainly on stratigraphy and inferred geological history.

Nicolet Stade

In central St. Lawrence valley, Bécancour Till (Gadd, 1960) rests directly on Ordovician bedrock; incorporated red shale gives it a distinctive red colour in its type area. Locally, masses of varved clay are found in places above or below the till. No evidence of interglacial weathering or warm climate fossils has been found in the lowlands, and consequently all deposits are considered to postdate the last interglaciation. Bécancour Till is thought to be Early Wisconsinan, but could be older (Gadd, 1976). In southeastern Quebec (Fig. 4), Johnville till overlies weathered glacial gravel (weathering thought to be interglacial) and is believed to be equivalent in age to and to have been deposited by the same substantial ice advance as Bécancour Till (McDonald and Shilts, 1971).

Scarborough Formation is a large (approximately 25 km by 40 km by 50 m) deltaic mass of sand over clay evidently formed by a large river flowing from the north. The lake in which the delta was built (Lake Scarborough) stood some 45 m above present Lake Ontario level. A lake at that level would have to have been held up by ice occupying St. Lawrence valley, causing water to spill southeastward across New York State in a similar way to that of Lake Iroquois, a postglacial lake in the Lake Ontario basin. The damming ice mass may have been the one that deposited Bécancour Till and Johnville Till of southern Quebec. Abundant plant fossils in the Scarborough Formation indicate a climate 6°C colder than present (Terasmae, 1960), which is compatible with the idea of ice present in St. Lawrence valley. Molluscs, ostracodes, and diatoms are also present in the Scarborough Formation and support the above cooler climate interpretation. Peaty sands in the Woodbridge cut also contain cold climate plant remains and, although probably a local and separate deposit, they are considered to be roughly contemporaneous with the Scarborough Formation (Karrow, 1969).

St. Pierre Interstade

Several valleys, up to 50 m deep, are cut into the Scarborough Formation. The dropping of water level which permitted the erosion of these valleys is correlated with the disappearance of ice from St. Lawrence valley. The St. Pierre Sediments (Gadd, 1960) – fluvial sands, containing logs, and floodplain peat bogs – are considered to have been deposited under fluvial conditions which developed in St. Lawrence valley subsequent to deposition of Bécancour Till. These sediments are known from numerous exposures near St. Lawrence River between Sorel and Québec City (Fig. 4). Terasmae (1958) has described the plant remains as indicative of a climate about 2° to 4°C cooler than present; they have been dated most recently as having an age of about 75 ka (Stuiver et al., 1978).

Fluvial sediments – the Pottery Road Formation (Karrow, 1974; and Fig. 3) – occupying valleys cut in the Scarborough Formation at Toronto are correlated with the St. Pierre Sediments. These contain a varied assortment of animal remains; vertebrates include deer, bison, bear, and muskox; molluscs include several species that have not been found in older beds. Sparse pollen is the only evidence of plants and represents cool climate types (Churcher and Karrow, 1977). The limited exposure of the Pottery Road Formation has left it as a poorly understood facet of the stratigraphy at Toronto.

In southeastern Quebec, fluvial sediments of the Massawippi Formation (Fig. 4) contain plant remains with minimum ages of >54 ka (McDonald and Shilts, 1971); they indicate regional drainage like the present, northward to the St. Lawrence, and are correlated with the St. Pierre Sediments.

Guildwood Stade

Overlying the St. Pierre Sediments in central St. Lawrence valley and extending over an area of 80 by 20 km is some 25 m and 5 ka (Hillaire-Marcel and Page, 1981) of varved clay and silt believed to have been deposited in a large glacial lake (Lake Deschaillons) during a major ice advance (Gadd, 1971; Occhietti, 1980). According to previous interpretations, this lake formed when the advancing post-St. Pierre interstadial ice dammed the St. Lawrence and continued ice advance overwhelmed the area, covering the older deposits with sandy Gentilly Till in the central St. Lawrence Lowlands and Chaudière Till in southeastern Quebec (McDonald and Shilts, 1971; Gadd, 1971, 1976). Continued southwestward advance eventually brought ice over the Toronto area and deposited the Sunnybrook Drift. Recently published radiocarbon dates on concretions (Lamothe et al., 1983) have been used to suggest that the Gentilly Till was deposited after 35 ka. As mentioned in the following discussion of the Port Talbot Interstade, Sunnybrook Till at Woodridge is overlain by gravel containing peat dated at 45 ka. Either the correlation of Sunnybrook Till with the lower part of the Gentilly Till is incorrect or there is a problem with the dates.

Sunnybrook Till (lowest member of Sunnybrook Drift, Terasmae, 1960) forms an extensive sheet throughout the Toronto area and overlies Scarborough and Pottery Road formations (Fig. 3). It is commonly a clayey or silty till, with low stone content, which is interpreted as being derived from reworked lacustrine sediments (Lake Scarborough and probably proglacial-Sunnybrook lakes) of the Ontario basin. (For an alternative view on the origin of the Sunnybrook Till see Eyles and Eyles, 1983). It underlies sediments that have high finite (Middle Wisconsinan age) or minimum (>53 ka) radiocarbon ages.

Borings along the north shore of Lake Erie show that below the bluffs at Port Talbot (Fig. 5), the Bradtville Till, which rests on Devonian bedrock, underlies Middle Wisconsinan deposits and probably was deposited during Early Wisconsinan glaciation (Dreimanis et al., 1966). Similarly, at Guelph, Ontario, till below peat dated as >45 ka may be Early Wisconsinan or older (Karrow et al., 1982). Canning Till, of lower Nith River valley, may also be a deposit formed by the Early Wisconsinan advance (Karrow, 1963) although Cooper (1975) has suggested it may be an early Late Wisconsinan till.

Present evidence suggests that the major Early Wisconsinan ice advance completely covered the St. Lawrence – Great Lakes region; in some places it extended beyond the Late Wisconsinan ice marginal position, whereas it was less extensive elsewhere (Dreimanis and Goldthwait, 1973). During its subsequent retreat, ice marginal lakes are recorded at Toronto by the presence of extensive varved clays of the Bloor Member, Sunnybrook Drift (Karrow, 1969). Continued ice retreat then ushered in the nonglacial deposition that prevailed in the area during most of Middle Wisconsinan time.

Middle Wisconsinan

The Middle Wisconsinan was mainly a time of contraction of the Laurentide ice; most of the Great Lakes area was ice free through much of the interval from 70 to 25 ka with a brief expansion of ice into part of the Great Lakes area about 40 ka. Part of southeastern Quebec also was ice free through part of this interval, but St. Lawrence valley apparently remained ice covered.

A number of organic sites have been discovered in southwestern Ontario (Table 1, Fig. 6). For several, only minimum radiocarbon ages are available, or they remain undated. Within each time interval finitely dated successions are discussed first because their chronological position has been at least tentatively defined. For most of the sites, pollen, commonly accompanied by plant macrofossils, is the only identified fossil remains. At some sites, molluscs, ostracodes, and insects have also been identified, whereas vertebrates are quite rare.

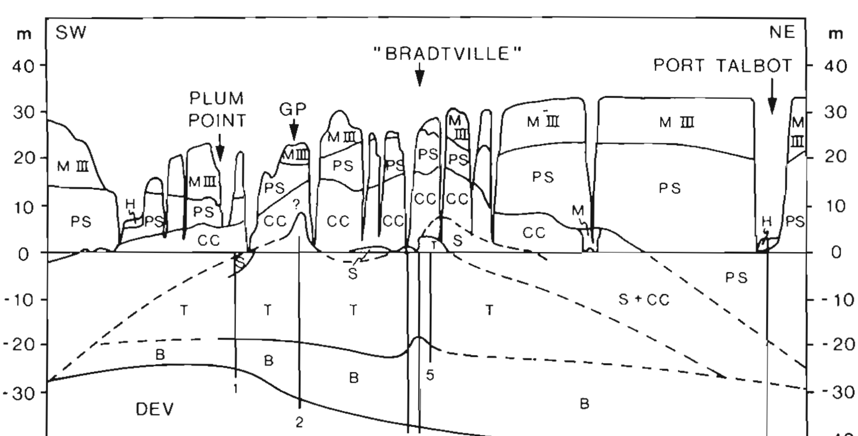

Figure 5

Port Talbot section, Lake Erie (after Karrow et al., 1978). Vertical lines extending below the level of Lake Erie indicate the location of boreholes.

B = Bradtville Drift
CC = Catfish Creek Drift
DEV = Devonian limestone
H = alluvium
M = Erie interstadial beds
MIII = Lake Maumee III silt and clay
PS = Port Stanley Drift
S = Southwold Drift
T = Port Talbot interstadial beds

Table 1. Organic sites in southwestern Ontario (Middle Wisconsinan or older, excluding Toronto interglacial sequence) (Karrow et al., 1978)

Site (cf. Fig. 6)	Radiocarbon Age	Fossils present*
Finite ages:		
Port Talbot II	13 dates av. 44 ka	P, PM, M, O, I, V
Woodbridge	45 ka	P, PM, M, I, V
Waterloo	40 ka	P, PM, M, O, I
Scarborough		
Cathedral Bluffs	28 ka, 32 ka	P, PM, M, I
Amber	24.6 ka, 34 ka	P, PM
Plum Point	4 av. 27.2 ka	P, PM
St. Davids	22.8 ka	P, PM
Minimum ages:		
Scarborough		
Cudia Park	>53 ka	P, PM, M, I
Innerkip	>50 ka	P, PM, M, O, I, V
Guelph	>45 ka	P, PM, M, O, I, W
Glen Allan	>41 ka	P, PM, W
Brampton	>41.2 ka	P, PM
Clarksburg	>36 ka	P, PM
Toronto, Jackes Ave.	>30 ka	P, PM, W
Undated		
Avonton		P
Port Talbot I		P, W

*Fossils
P - pollen
PM - plant macrofossils
M - molluscs
O - ostracodes
I - insects
V - vertebrates
W - weathering

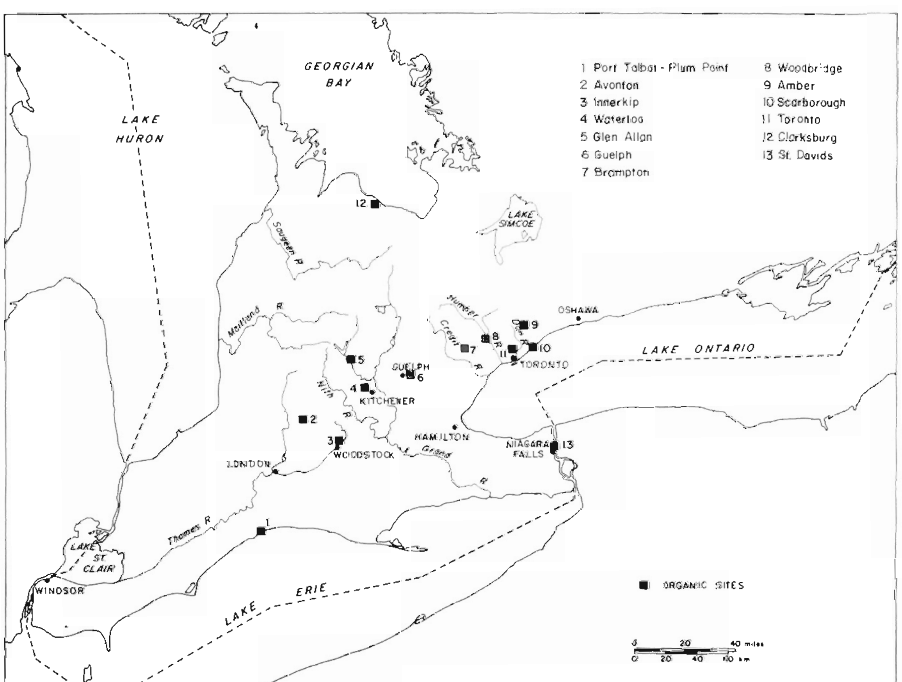

Figure 6. Subtill organic sites, southwestern Ontario.

Port Talbot Interstade

The oldest well dated organics are those of the Port Talbot II Interstade (Table 1). Material from the main location on Lake Erie, south of London (Fig. 5, 6) has been dated repeatedly by several laboratories, yielding a high degree of consistency, averaging near 44 ka, with the oldest date being 47 690 ± 190 (GSC-217; Terasmae et al., 1972). Berti (1975) has described the plant record in detail and Dreimanis et al. (1966) have given additional detail. The sediments are waterlaid sand and silt including a gyttja layer. Peat balls are often washed up on the Lake Erie shore and those that have been dated give ages similar to those on the gyttja; they are apparently derived from a nearby underwater source. These materials indicate cool climate and a low water level in the Erie basin. A similar finite date has only been obtained at Woodbridge (Fig. 3, 6) where peat in gravel overlies Early Wisconsinan Sunnybrook Till and underlies Wentworth, Halton, and Wildfield tills of Late Wisconsinan age (White, 1975).

Underlying the Port Talbot II sediments at the type section on Lake Erie are varved clays, suggesting a brief ice advance into the Erie basin (Dreimanis et al., 1966). Although such an ice advance should also have affected other areas, such as Toronto, no such evidence has been discovered. Underlying these clays is a weathered green clay (Quigley and Dreimanis, 1972) – the Port Talbot I sediments - containing a rich pollen assemblage suggestive of milder conditions than prevailed during Port Talbot II time but still cooler than an interglacial (Berti, 1975). Although no suitable materials have been found for dating Port Talbot I sediments, their age can be estimated to be between 65 and 50 ka. Other sites with similar minimum ages include the Cudia Park section at Scarborough, Innerkip, and Guelph (Table 1).

At Toronto, stratified sand, silt, and clay of fluvial and lacustrine origin (lower member, Thorncliffe Formation) separate Early Wisconsinan Sunnybrook Till from Middle Wisconsinan Seminary Till (Fig. 3). High water level in the Ontario basin is indicated during this interval. At Cudia Park, detrital plant matter near the base of the Thorncliffe Formation is >53 ka. At Innerkip (Fig. 6), the best exposed and thickest interstadial deposit in southern Ontario (Cowan, 1975) has an age of >50 ka. Unfortunately, it is not closely confined stratigraphically; a long gap is present in the record as indicated by the directly overlying late Late Wisconsinan Port Stanley and Tavistock tills. A similar situation exists at the Guelph site (>45 ka; Karrow et al., 1982) and the Waterloo site (40 ka) where the superjacent till is Late Wisconsinan Catfish Creek Till.

The Guelph site is unusual because of the presence of a well developed paleosol under the dated plant layer; the degree of weathering is intermediate between the interstadial Sidney soil of Ohio and typical Sangamonian soils of the Mid-West United States (Karrow et al., 1982).

Sites having younger minimum ages or that are undated but considered to be of Port Talbot age include Glen Allan (P.F. Karrow, unpublished data), Clarksburg, Jackes Avenue in Toronto (Dreimanis and Terasmae, 1958), and Avonton (Karrow, 1977). Because of the incomplete information on the age and correlation of these sites, only tentative conclusions can be reached; it appears that Port Talbot I was the warmest interval, with presumably the maximum ice recession of Middle Wisconsinan time, and with cooler conditions and perhaps somewhat more extensive ice cover in Port Talbot II time. It is apparent, however, that during Port Talbot time generally, at least most of the southern Great Lakes area was free of ice.

In southeastern Quebec (Fig. 4), interstadial sediments of the Gayhurst Formation (McDonald and Shilts, 1971; >20 ka) record a Middle Wisconsinan ice retreat. This was not extensive enough to uncover St. Lawrence valley, which may have been occupied by the ice that deposited Gentilly Till from the end of the St. Pierre Interstade until Late Wisconsinan deglaciation (Gadd, 1976). Because maximum interstadial warmth is indicated by Port Talbot I sediments, perhaps the Gayhurst Formation was deposited during that interval. It overlies Chaudière Till which was deposited between St. Pierre and Gayhurst time and is capped by a single till – Lennoxville Till – which apparently represents deposition through the rest of the Wisconsinan (Gadd, 1976).

Cherrytree Stade

At Scarborough Bluffs, Toronto, the lower Thorncliffe Formation (Fig. 3) is separated from the upper Thorncliffe Formation by Seminary Till, middle Thorncliffe Formation, and Meadowcliffe Till (Karrow, 1967), which record advances of the Lake Ontario ice lobe referred to the Cherrytree Stade. The time span involved is bracketed by dates of >53 and 45 ka, and dates of 32 and 28 ka, so its age may be estimated at 40 to 35 ka. At Port Talbot on Lake Erie, Dunwich Till, which was apparently derived from the Georgian Bay lobe, may represent the Cherrytree Stade (Dreimanis, 1981). The farthest south that ice of Cherrytree age is now considered to have advanced is into the central Erie basin (A. Dreimanis, personal communication 1981).

Of the two Cherrytree tills at Toronto, the Meadowcliffe is more extensive and thicker. Like the Sunnybrook, it is a massive clayey till, apparently composed of reworked lacustrine clay. Correlative till has been identified in bluffs along Lake Ontario 80 km east of Toronto (Karrow et al., 1978; Brookfield et al., 1982).

Plum Point Interstade

Plum Point Interstade was recognized on the basis of wood, which was dated at about 27 ka, in the base of the overlying Catfish Creek Till at the Plum Point section (Dreimanis et al., 1966). It thus corresponds with the well dated Farmdalian Substage of the Illinois classification (Frye and Willman, 1960) and represents a widely recognized interval of reduced ice coverage in the Great Lakes region (Dreimanis and Goldthwait, 1973). It is represented at Toronto by the upper Thorncliffe Formation stratified silt, sand, and clay, containing plant detritus dated 28 and 32 ka (Morner, 1971). Peat balls included in gravel at Amber, north of Toronto, have yielded ages of about 25 and 34 ka and are believed to be correlative.

Near Niagara Falls, the 100 m-deep buried St. David's gorge marks an earlier course of Niagara River; wood from the fluvial fill of the buried gorge was dated about 23 ka (Hobson and Terasmae, 1969), so this succession is also included in the Plum Point Interstade. This is the youngest pre-Late Wisconsinan date in the area and requires a lack of ice cover in the Niagara area at that time. Soon after, however, the major Late Wisconsinan ice advance had extended over the Erie basin.

The climate inferred for the Plum Point Interstade is very cool (Berti, 1975), and judging from the few sites of this age, and the substantially greater number of sites of Port Talbot age, ice cover may be inferred to have been greater than during the preceding interstade.

Late Wisconsinan

Beginning with the Late Wisconsinan ice advance, the record is much better documented because sequences are more complete and better exposed. Mapping has shown that the ice fluctuated many times during overall retreat, commonly depositing lithologically distinctive till sheets which elucidate ice movements and serve as stratigraphically recognizable units. Also, surface landforms become increasingly important in the interpretation of the younger events.

In contrast to the relatively few isolated, known occurrences of the older units, Late Wisconsinan tills are widespread and relatively easily traced over large areas. On the other hand, between the Plum Point Interstade and local postglacial time, with one exception, no datable organics have been found in the region to provide a chronology and one must depend on sites south of the Great Lakes to estimate the timing of events.

Nissouri Stade

The sandy Catfish Creek Till (deVries and Dreimanis, 1960), deposited in part by ice flowing from the northeast, occurs under much of the interlake peninsula of southwestern Ontario. The flow direction is interpreted as that of the glacier during its maximun thickness and extent when lobation associated with thinner ice was not present in the region. This ice advanced southward across Ohio as early as 21 ka and then the margin fluctuated near its maximum limit for an about 4 ka, while the region north of the Great Lakes remained ice covered (Dreimanis and Goldthwait, 1973).

From the presence of dated Plum Point deposits at Toronto, and probably correlative deposits east of Oshawa, it can be inferred that most of the Ontario and all of the Erie basins were ice free during preceding Plum Point time. The Nissouri advance must have originated at least as far east as the eastern Lake Ontario basin. The extent of the advance in the Huron basin is largely unknown but is assumed to have also been substantial.

During subsequent retreat, extensive lakes were ponded at least in the Erie basin, and on land glaciofluvial deposits suggest stagnation. Because the next ice advance (Port Bruce Stade) almost completely covered southwestern Ontario, only a few small windows of the Nissouri deposits are left exposed along the interlobate zone near Woodstock, which lay between the Huron-Georgian Bay lobe and the Erie-Ontario lobe. These small areas were greatly modified by later meltwaters.

Erie Interstade

The interval of ice retreat that separates the maximum Late Wisconsinan advance which deposited sandy Catfish Creek Till and the next younger important ice advance, which deposited the generally fine textured Port Bruce stadial tills, is best known from the Erie basin (Dreimanis, 1958). During this interval, glacial lakes (including Lake Leverett, the lowest one, at or below the level of Lake Erie) formed in the Erie basin, and fine lacustrine sediment was deposited over a large area, providing the source material for the fine grained tills of the subsequent Port Bruce ice advance. Buried beach deposits occur near London, Ontario, from near present Lake Erie level up to the level of postglacial Lake Maumee (Mörner and Dreimanis, 1973). Evidence of low water stages during the interval indicates ice retreat sufficient to allow drainage to the east over the Niagara Escarpment.

No datable organic deposits have been found in sediment deposited during this interval, but its age is interpolated and estimated to be about 16.5 to 15.5 ka (Mörner and Dreimanis, 1973). Near St. Mary's, Ontario, the pollen-bearing Wildwood Silts, likely of this age, contain typical interstadial pine-spruce assemblages (Sigleo and Karrow, 1977). The Wildwood Silts are considered to represent deposition in a local lake not part of the major lakes of the Erie basin.

Although the lacustrine interval is clearly recorded in the Erie basin, events in the Huron basin are much more obscure at this time. Because initial Huron and Georgian Bay lobe tills of Port Bruce age are fine textured, a similar pattern of retreat with lacustrine sedimentation and readvance is envisaged there. Unfortunately, the later Port Huron stadial advance completely filled the Huron Basin and destroyed or covered deposits of Erie and Port Bruce age near the lakeshores. The lack of fine grained tills intervening between Nissouri and Port Huron stadial deposits southwest of Owen Sound, has suggested to Sharpe and Edwards (1979) that in the area affected by Georgian Bay lobe ice, the Erie interstadial retreat did not extend as far north as Chesley.

Port Bruce Stade

Deposits of this age are at or near the surface over much of southwestern Ontario, consequently much more detail is known about Port Bruce ice fluctuations and the extent of resulting deposits. Also, associated with the fluctuating retreat of Port Bruce ice is the complex series of ice marginal lakes whose history begins about 14 ka with Lake Maumee in the Erie basin and continues into later time intervals. In view of their impact on the present landscape, events of Port Bruce age are the most important in southwestern Ontario (Fig. 7).

The initial Port Bruce advance incorporated large quantities of lacustrine silt and clay in the Erie basin to produce the fine grained, nearly stone free, Port Stanley Till (deVries and Dreimanis, 1960). The ice fluctuated, depositing interbedded clay till and varved or stratified lacustrine silt and clay near Lake Erie. Details of the advance are not well known, but a series of moraines were formed during the retreat, including the Ingersoll (Taylor, 1913), Westminster (Chapman and Putnam, 1951), St. Thomas (Taylor, 1913), Norwich (Chapman and Putnam, 1951), Sparta (Dreimanis, 1959), and Tillsonburg (Taylor, 1913) moraines. On the northeastern flank of the Erie lobe, where it merged with the western Ontario lobe, little lacustrine material was available for overriding and so the Port Stanley Till, by lateral facies change near Kitchener, becomes sandy to the north (Karrow, 1974). Near Kitchener, a locally recognized clayey Maryhill Till (Karrow, 1974) apparently represents early ice thrust into glacial lakes which were perhaps confined near Grand River valley.

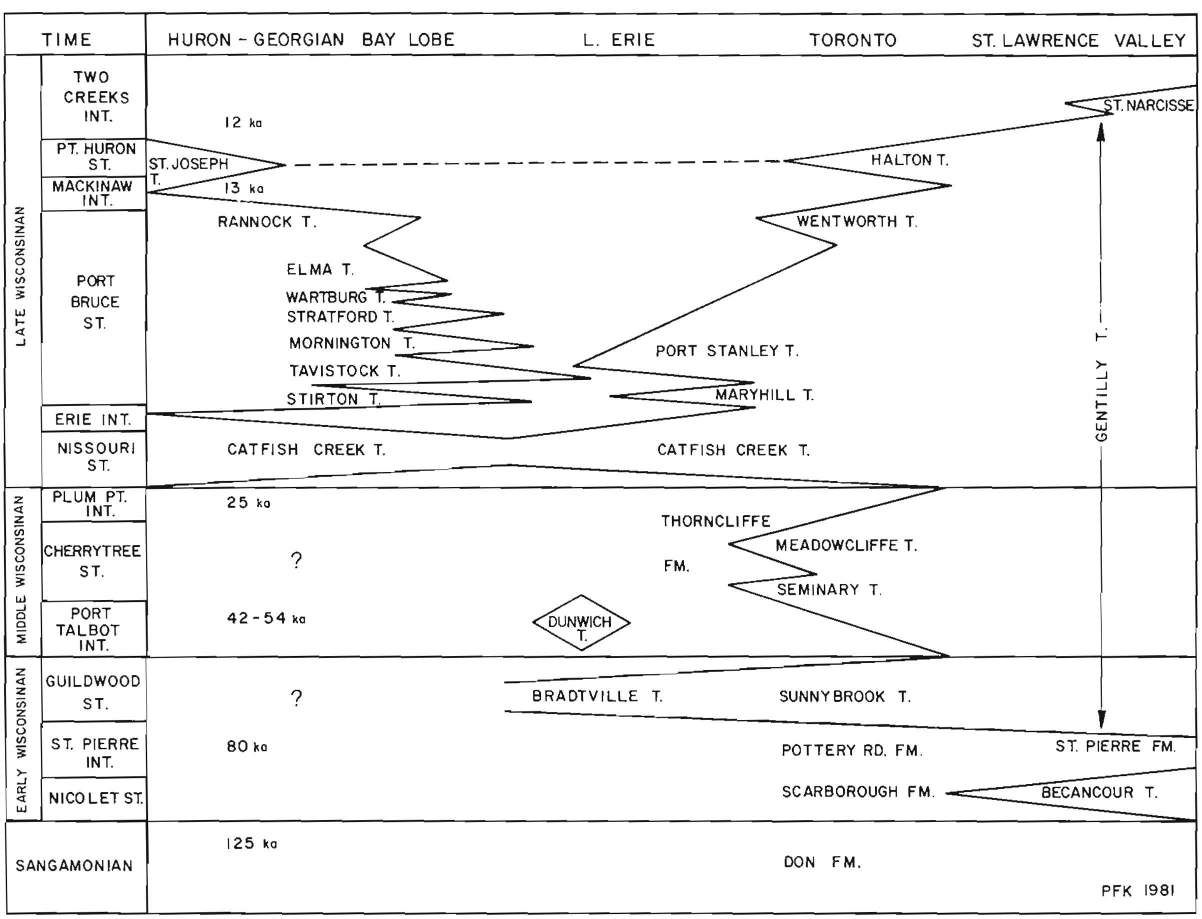

Figure 7. *Tills and ice fluctuations, Lake Huron to St. Lawrence valley. Note variable time scale in radiocarbon years.*

A later Port Bruce event can be recognized in the Erie-Ontario lobe deposits because a distinct sandy till (Wentworth Till; Karrow, 1959) extends eastward nearly to the Niagara Escarpment. The Paris and Galt moraines (Taylor, 1913) were formed near the western edge of this till sheet and large outwash deposits are associated with its margin. Drumlins are common on the sandy facies of Port Stanley Till and on the sandy Wentworth Till (Guelph drumlin field).

While the Port Bruce stadial fluctuations of the Erie lobe deposited only two distinctive till sheets (Port Stanley and Wentworth) in Ontario (in contrast three – Lavery, Hiram, and Ashtabula – are recognized in northeastern Ohio; White, 1982), the Huron and Georgian Bay lobes acted in a more complex fashion. In the earlier part of the interval they acted as a combined lobe which advanced to deposit the silty Tavistock Till (Karrow, 1974) over a large area extending from London to Shelburne (Cowan, 1975, 1976). An earlier local fluctuation during the advance formed the clayey Stirton Till (Karrow, 1974) in Conestogo valley north of Kitchener. Tavistock Till is closely similar in age to Port Stanley Till and the two overlap in limited areas near the interlobate line. Additional local fluctuations deposited sandy Stratford Till (Karrow, 1974) near Stratford and clayey Mornington Till in Conestogo valley (Karrow, 1974). Unlike the Erie lobe, which formed several large moraines during its retreat, the earlier action of the Huron-Georgian Bay lobe laid down till sheets unmarked by large end moraines. The first significant moraines formed were the Arva (Dreimanis, 1964) and Milverton (Taylor, 1913) moraines, formed of clayey to silty Tavistock and Wartburg tills (Karrow, 1977) north of London and Stratford, respectively.

Another sandy till sheet – Elma Till – was deposited over a substantial area by the Georgian Bay lobe (Karrow, 1974; Cowan, 1979). It nearly covered the Wartburg Till, leaving it exposed only along its marginal moraine. Deposition of Elma Till marked the first clearly independent action by the Georgian Bay lobe, moving from the northwest to form the Teeswater drumlin field in southern Bruce County. All the lithologically distinct Port Bruce tills of the Huron-Georgian Bay lobe so far mentioned were apparently deposited in the same time span as the Port Stanley Till, but in contrast, while the Erie lobe built several end moraines, its till remained generally uniform.

In late Port Bruce time the Huron lobe became separately active; the separation of the Huron and Georgian Bay lobes probably took place because of the growing influence of topography on the thinning ice. Several moraines – Mitchell (Taylor, 1913), Dublin (Karrow, 1977), Lucan, and Seaforth (Taylor, 1913) – mark the spasmodic retreat of the Huron lobe as it deposited the silty Rannoch Till (Karrow, 1977).

To the northeast, the Simcoe lobe becomes distinguishable about this time through its deposition of the sandy Newmarket Till (Gwyn, 1972) which is closely related

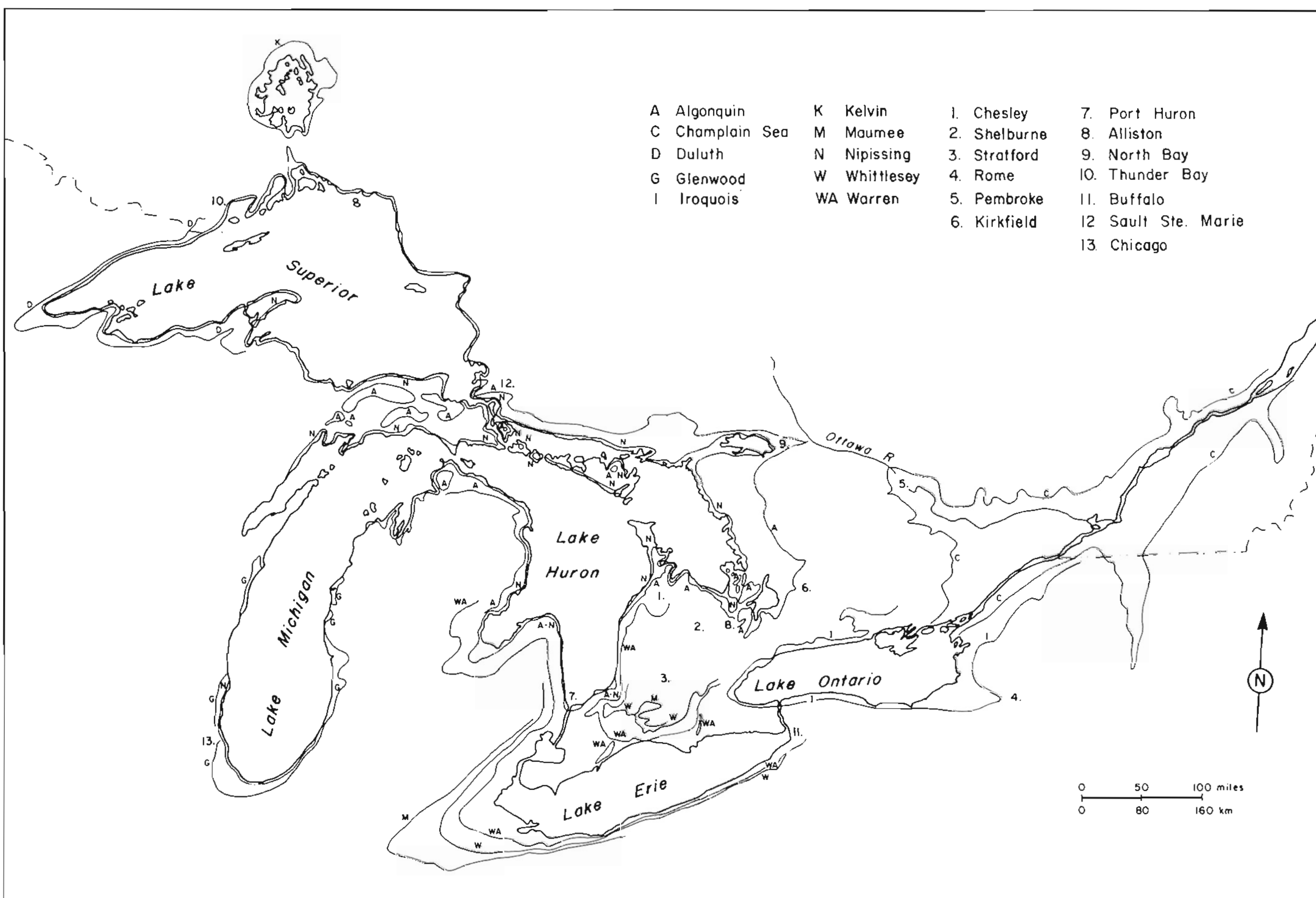

Figure 8. *Great Lakes area, showing selected shorelines of glacial lakes and Champlain Sea. Place names relate to section of text describing Late Wisconsinan events.*

in age to the Port Stanley and Wentworth tills (Cowan, 1976). No doubt its southwestward advance was hindered by the Niagara Escarpment, which it barely surmounted.

During the interlobate separation of the ice and retreat eastward by the Erie-Ontario lobe and northward by the Huron-Georgian Bay lobe, innumerable local bodies of meltwater were trapped along the margin and coalesced to form larger glacial lakes. Eventually these became the well known large lakes whose history has occupied much attention over the past century. Their history has been dealt with at length by Hough (1958, 1963), Chapman and Putnam (1966), Prest (1970), and Fullerton (1980).

The first dry land to appear in southwestern Ontario was the high ground northwest of the interlobate zone which was referred to as "Ontario Island" by Taylor (1913) because it was bounded by retreating Port Bruce stadial ice to the north and east and by glacial lakes to the southwest.

The first major lake formed during Port Bruce retreat was Lake Maumee (Fig. 8), which has three or four recognized levels around Lake Erie but is only represented in Ontario by beaches between London and Simcoe (Barnett, 1978). Maumee drainage alternated between Wabash River, in Indiana, to the southwest and across Michigan to the west and northwest. Continued retreat allowed water level to lower some 30 m to the Arkona level, recorded by beaches in the Erie and southernmost Huron basins (Dreimanis, 1964; Cooper, 1979). Lake Arkona also had its outlet westward across Michigan.

Substantial retreat of the ice northward into the Huron basin and eastward into the Ontario basin marks the end of the Port Bruce Stade.

Mackinaw Interstade

Mackinaw Interstade is a time when the Michigan and Huron lobes retreated from at least most of the area south of Mackinac Straits, Michigan. The type locality has yielded a small moss flora dated 13.3 ka, and a few similar dates have been obtained on drift logs from widely scattered localities (Dreimanis and Goldthwait, 1973; Gravenor and Stupavsky, 1976); overall, however, organic remains and radiocarbon dates are rare.

The western Ontario basin was temporarily free of ice. This marks the first recorded break in ice cover at Toronto since the main Late Wisconsinan advance (Karrow, 1969).

By this time, all of southwestern Ontario was likely ice free and southern Ontario had largely acquired its present form. As mentioned, Lake Arkona formed during the earlier part of this ice retreat; even lower water levels were reached in the Erie basin (Lake Ypsilanti?) as eastward drainage was opened up. The Oak Ridges moraine (Taylor, 1913) separated the Ontario lobe from the Simcoe lobe to the north and blocked the southward drainage of the upper Great Lakes basins, which formerly followed the Laurentian Valley to Toronto (Spencer, 1890a; White and Karrow, 1971).

This interval of ice retreat was undoubtedly brief and was followed by another ice advance, the last to affect the Erie basin and probably the last to affect the Ontario basin directly.

Port Huron Stade

Ontario lobe ice readvanced rapidly to fill the Ontario basin and spill into easternmost Erie basin, while the Huron lobe filled that basin and built the massive Wyoming moraine (Taylor, 1913) a few kilometres beyond the present basin margin (Cooper, 1979). The clayey St. Joseph Till (Cooper and Clue, 1974), deposited by this advance, overlies Lake Arkona beaches. The silty Halton Till (Karrow, 1959) is the Ontario lobe equivalent. Although the ice managed to cross the Niagara Escarpment in the south, where it is relatively low, it closely paralleled it north of Hamilton then swung eastward along the southern flank of the Oak Ridges moraine.

The Georgian Bay lobe thickened greatly and was able to surmount the highest part of the Niagara Escarpment and advance southward to form the Banks (Chapman and Putnam, 1951) and Williscroft (Sharpe and Edwards, 1979) moraines. The Simcoe lobe advanced a lesser distance, depositing the clayey Kettleby Till (Gwyn, 1972) north of the interlobate Oak Ridges moraine, and extended its margin west along the base of the Escarpment (Cowan, 1976).

When the Port Huron advance was at its maximum about 13 ka, waters in the Erie and southern Huron basins rose to the Lake Whittlesey level (Fig. 8). This lake drained to the west across Michigan. A segment of its northern shoreline is prominent from east of Cambridge (Karrow, 1963) to Exeter, Ontario (Cooper, 1979).

Two Creeks Interstade

Major and widespread ice retreat deglaciated the Ontario basin, most of the Huron and Georgian Bay basins, and probably the western part of the Superior basin. During this retreat falling lake levels in the Erie and Huron basins were stabilized at several different levels; these included three levels of Lake Warren, which drained westward across Michigan, and lakes Grassmere and Lundy, which may have drained eastward around the south side of the Ontario basin. Because its outlet at Buffalo was isostatically depressed, further retreat of the Ontario lobe drained the Erie basin to below present lake level and established early Lake Erie.

In the Ontario basin, glacial Lake Iroquois (Fig. 8) was formed, with its outflow southeastward through the Rome outlet in New York State. This lake has an age of 12 ka (Karrow, 1969) and although it developed a prominent shoreline, it could not have lasted more than several hundred years.

Deglaciation was also evident by this time in southeastern Quebec, with the ice retreating downslope towards St. Lawrence River valley. At one stage of this retreat part of the area within the Appalachian Fold Belt was affected by northward ice flow for a short period (Gadd, 1976). This may have been associated with the development of a calving bay in St. Lawrence valley.

The conventional interpretation of glacier retreat from upper St. Lawrence valley (Prest, 1970) has the ice retreating off the north flank of the Adirondack Mountains of New York allowing a step-wise dropping of levels in the Ontario basin and confluence with lakes of the Lake Champlain basin. Ice retreat in central St. Lawrence Lowlands allowed the sea to flood the depressed land. At its maximum, the Champlain Sea (Fig. 8) entered the Lake Champlain basin, extended up Ottawa valley to Pembroke, and may have entered the Ontario basin, at least temporarily. The confluence of Champlain Sea and waters in the Ontario basin occurred after the end of Lake Iroquois but ^{14}C dates on shells from the Ottawa area are older than dates on wood related to Lake Iroquois (Karrow, 1981).

To account for the conflict, Gadd (1980) has proposed that by rapid calving westward, the Champlain Sea flooded central St. Lawrence valley and Ottawa valley about 13 ka (based on shell dates) while ice remained in upper St. Lawrence valley to the south, retaining Lake Iroquois in the Ontario basin until after 12 ka (radiocarbon dates on wood). It is debatable whether the marine shell dates can be properly compared to the wood dates on Lake Iroquois (Karrow, 1981) and hence it may not be necessary to invoke a calving bay in Ottawa valley to explain this discrepancy.

With opening of upper St. Lawrence valley, Lake Ontario was established and because the outlet was isostatically depressed relative to the western end of the basin, water levels fell much below present levels.

The interstade type locality at Two Creeks, Wisconsin, on the west shore of Lake Michigan, records water levels low enough to require opening of the Trent valley drainageway between Georgian Bay and the Ontario basin (Hough, 1963). The Two Creeks forest bed has an average age of 11.9 ka (Broecker and Farrand, 1963) and the site was apparently drowned by the rising waters ahead of the subsequent ice advance. No similar sequence has been identified in Ontario.

Greatlakean Stade (formerly Valders Stade)

In the Lake Michigan basin a rapid ice advance, perhaps a surge, overrode the Two Creeks forest bed and deposited a red clay till by the reworking of red lacustrine clay. The margin of the advance has been traced across Michigan eastward to Lake Huron (Burgis and Eschman, 1981). A corresponding ice advance has not been identified in Ontario, but the ice margin must have extended across southern Georgian Bay and in the general direction of Montreal. Based on marine shell dates, the Champlain Sea existed during this advance, but no equivalent ice advance event has been identified with any assurance in the St. Lawrence Lowlands. Both the St. Narcisse moraine (LaSalle and Elson, 1975) and the Drummondville moraine (Dreimanis, 1977a) have been suggested as equivalents, but the former is probably younger and the latter is undated. It is possible that the contemporaneous ice margin in the east may have been stable or if it readvanced, it did not build an end moraine.

This readvance, or isostatic uplift, closed the Kirkfield outlet (Trent valley) to the Ontario basin and water level rose in the Michigan and Huron basins to the Main Algonquin level, with southward drainage at Port Huron (Hough, 1963). The Algonquin shoreline is cut into the youngest till, including that deposited during the Greatlakean advance, throughout the Michigan and Huron basins. The prominent Algonquin shoreline is present around the Michigan, Huron, and Georgian Bay basins, suggesting that this lake was relatively long lived and that the Kirkfield outlet was not in operation during the subsequent ice retreat.

North Bay Interstade and Algonquin Stade

Subsequent retreat led to the complete withdrawal of the ice from the Huron and Georgian Bay basins. As the ice withdrew onto the Shield north of Lake Huron, Lake Algonquin expanded northward to include the Sudbury basin (Burwasser, 1979). In the south fossiliferous fine sediments were deposited in many places, including the Alliston embayment and valleys near Lake Huron; dates on wood in these sediments indicate the continued existence of Lake Algonquin up to between 10.5 and 10 ka (Karrow et al., 1975).

A prominent event in Great Lakes history is the opening of the North Bay outlet and draining of Lake Algonquin. In detail, a series of interconnected channels crossing the highlands south of North Bay was used, and the water level fell in closely spaced stages to far below the present Lake Huron level (Harrison, 1972), creating Lake Hough in the Georgian Bay basin and Lake Stanley in the Huron basin. The numerous shorelines thus created are recorded around the Huron and Georgian Bay basins. A pause in the retreat about this time has been postulated by Saarnisto (1974) and Dreimanis (1977a), which may also have involved short readvances (Algonquin Stade).

The pattern and timing of the retreat of the ice across the Superior basin and the Precambrian Shield north of Lakes Superior and Huron are known almost entirely from generalized reconnaissance work (Zoltai, 1965, 1967; Boissonneau, 1968; Farrand, 1969; Saarnisto, 1974). The region is a difficult one to study because of its abundant rock outcrop and discontinuous glacial deposits, limited road access, and general forest cover.

Retreat of the ice from the western Superior basin was accompanied by a succession of dropping water levels – Lake Duluth and several post-Duluth levels – which successively drained south into the Michigan basin, then into the Huron basin as the St. Mary's River area at the east end of the lake became ice free about 10.5 ka. A readvance about 10 ka has been documented in the south-central Superior basin but equivalents to the north and east remain speculative (Drexler et al., 1983). The isostatically depressed outlet at Sault Ste. Marie created low water levels during ice retreat (Minong and Houghton stages; Farrand, 1969). More detailed mapping of the Thunder Bay area has recorded several local fluctuations of the ice there as Lake Superior lobe ice became separated from the Patrician lobe, creating interlobate deposits between them. Prominent Superior basin shorelines are recorded near Thunder Bay in deltaic deposits of Kaministikwia River, which prograded during the dropping water levels (Burwasser, 1977).

Deglaciation of the Superior basin was probably completed by about 9.5 ka (Saarnisto, 1974). Around this time Lake Kelvin was created in the Nipigon basin and it drained south into the Superior basin. Various outlets of Lake Agassiz, centred in Manitoba, drained into the Superior basin, sometimes via Lake Kelvin (Zoltai, 1965; Teller and Thorleifson, 1983).

In St. Lawrence valley, northward recession of the Laurentian ice led to full deglaciation of the Lowlands for the first time since the St. Pierre Interstade. A small readvance into the Champlain Sea built the St. Narcisse moraine along the north edge of the Lowlands shortly after 11 ka; near Trois-Rivières this moraine overlies and is overlain by marine sediments (Gadd, 1971; Occhietti, 1980). As the ice retreated northward into the Laurentian Highlands, the Champlain Sea followed it. Complex sedimentation in the marine environment produced a full spectrum of glaciomarine drift (Karrow, 1961). At its northwestern extremity up Ottawa valley, Champlain Sea received the outflow from the North Bay outlets when Lake Algonquin was being drained.

Champlain Sea was created by the marine flooding of isostatically depressed lowlands. Even though sea level rose as the ice continued to melt, the land rose faster, thus causing the sea to regress. It had largely receded from St. Lawrence valley by about 10 ka, to be replaced by freshwater fluvial conditions (Gadd, 1971). During its existence, thick and commonly highly fossiliferous sand, silt, and clay were deposited. Its invertebrate fossils have been described by Elson (1969), Wagner (1970), and Cronin (1977). Their work suggests several stages, defined in terms of water salinity and temperature, during the sea's existence. The varied vertebrate fauna of the Champlain Sea has been described by Harington (1977).

Later Events

By about 9 ka, glaciers had retreated completely from the Great Lakes – St. Lawrence region, and subsequent events mainly involved the continued isostatic uplift and tilting of the whole region. Low-water stages in all the basins resulted from the unblocking by ice retreat of isostatically depressed outlets, generally located in the northeastern parts of the basins.

Through uplift of the outlet at Buffalo, the water in the Erie basin rose and flooded large areas at the west end which had been dry land (Lewis, 1969). Likewise the outlet of the

Ontario basin rose and raised its water level, flooding land areas at the west end of the basin at a gradually decreasing rate (Karrow et al., 1961). Thus Early Lake Erie and Early Lake Ontario evolved into present Lake Erie and Lake Ontario, respectively, over a period of about 12 ka.

Subsequent changes in the Georgian Bay, Huron, and Superior basins were more complicated. After the opening of the North Bay outlet about 10 ka, isostatic uplift of the outlet raised water levels and caused widespread transgression all around the Georgian Bay and Huron basins. When it was high enough to spill southward again at Chicago and Port Huron about 5.5 ka, the Nipissing phase was created (Lewis, 1969; Karrow, 1980). Subsequent erosion at Port Huron lowered the water below the other outlets and eventually to the present Lake Huron-Georgian Bay level. Meanwhile, after the Houghton stage in the Superior basin, uplift of the outlet at Sault Ste. Marie caused the water level to rise within the basin. Rapid rise of the North Bay outlet overtook that of the Sault area, flooding the sill between the two basins so that both shared the Nipissing phase. As the levels fell in the Huron basin, the Sault sill once again emerged and through its subsequent rise created present Lake Superior (Farrand, 1969).

In St. Lawrence valley, uplift drained off the Champlain Sea shortly after 10 ka and the progressively constricted estuary evolved into the terraced St. Lawrence River valley (Gadd, 1971). The strong isostatic tilting has raised the marine limit much higher on the north side of the valley than on the south.

CONCLUSIONS

1. The stratigraphic record provides evidence of two glaciations, separated by an interglacial stage believed to be of Sangamonian age.
2. The last glaciation is divisible into three parts: early and late glacial substages are separated by a long, cool interstadial complex.
3. The precise age of most interstadial deposits believed to be of Middle Wisconsinan age is unknown; some are undated and several have only minimum ages.
4. Radiocarbon dating provides a limited chronological framework, generally extending only to about half way into Middle Wisconsinan time. Other dating methods are needed to decipher the earlier history.

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Aston Junction, southern Quebec: The well stratified sand at the base is part of the St. Pierre Sediments; the overlying crudely stratified unit is Gentilly Till (Middle to Late Wisconsinan); the dark grey stratified material is Champlain Sea clay (Late Wisconsinan to Holocene); and the surface massive unit is alluvial sand. Photo and stratigraphy by N.R. Gadd, GSC 203193-X.

QUATERNARY STRATIGRAPHY OF QUEBEC: A REVIEW

Pierre LaSalle[1]

LaSalle, P., Quaternary stratigraphy of Quebec: A review; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 155-171, 1984.

Abstract

The stratigraphy of the St. Lawrence Lowlands of Quebec is centred around the nonglacial St. Pierre Sediments composed mostly of freshwater peat, sand, and some gravels. They are underlain by Bécancour Till and overlain by Gentilly Till. Varved sediments underlie Bécancour Till and separate Bécancour Till from the St. Pierre Sediments; the Deschaillons varved sediments are intercalated between the St. Pierre Sediments and the overlying Gentilly Till. In southeastern Quebec, the same general sequence is repeated, except that a partial deglaciation (Gayhurst episode) separated the Gentilly Glaciation into two phases – Chaudière and Lennoxville. Evidence for this same break in the last glacial sequence is present in the Montreal area but in the Central and Quebec City parts of the lowland there is evidence of only a single advance and retreat of the last ice sheet.

The St. Pierre Sediments, which have yielded a finite date of 74 700 ± $^{2700}_{2000}$ BP (QL-198), are possibly of late Sangamonian age.

Deglaciation of the St. Lawrence Lowlands in Quebec was accompanied by a reversal of ice flow, south of the Laurentian channel, emplacement of the Highland Front Moraine, and when the ice disappeared about 12.7 ka, by marine invasion waters of the isostatically depressed areas. Conditions within this body of water, the Champlain Sea, gradually passed from an environment of accumulation to one of erosion, as glacial sediment sources retreated to the north and as the marine waters retreated because of isostatic rebound. Freshwater replaced marine waters as the basin shoaled and the St. Lawrence River may have attained its present configuration in the Montreal area by 6 ka.

Résumé

La stratigraphie des basses-terres du Saint-Laurent (Québec) se concentre sur les sédiments non glaciaires de St. Pierre, qui se composent de tourbe, de sable et d'une certaine quantité de gravier accumulés en eau douce. Ils recouvrent le till de Bécancour et sont sous-jacents au till de Gentilly. Les sédiments varvés sont généralement associés à des avancées et des retraites glaciaires; les sédiments varvés de Deschaillons se trouvent intercalés entre les sédiments de St. Pierre et le till de Gentilly sus-jacent. La même séquence générale se répète dans le sud-est du Québec, mais une déglaciation partielle (épisode Gayhurst) sépare la glaciation Gentilly en deux phases, soit les phases Chaudière et Lennoxville. Il semble que la séquence trouvée dans le sud-est du Québec se retrouve dans la région de Montréal. Dans la région de Québec, on ne trouve les mêmes unités que dans la partie centrale des basses-terres du Saint-Laurent.

La datation des sédiments de St. Pierre a donné un âge de 74 700 ± $^{2700}_{2000}$ BP (QL-198); ces sédiments datent donc vraisemblablement du Sangamonien récent.

Au Québec, la déglaciation des basses-terres du Saint-Laurent a été accompagnée d'une inversion de la direction d'écoulement de la glace au sud du chenal du fleuve, où l'on trouve la moraine frontale de Highland, et de l'invasion par les eaux marines des régions abaissées suite au phénomène d'isostasie il y a environ 12,7 ka. Les conditions à l'intérieur du bassin de la mer Champlain se sont transformées graduellement d'un milieu de sédimentation à un milieu d'érosion, à mesure que le soulèvement isostatique de la terre refoulait les eaux marines et à mesure que la quantité d'eau douce augmentait. Le fleuve Saint-Laurent a vraisemblablement réalisé sa configuration actuelle dans la région de Montréal il y a 6 ka.

"We really ought to see the message rather than become lawyers – our responsibility is to the facts rather than our clients"

C.L. Drake
Geology, 1982, v. 10, p. 127

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Manuscript received: 1982-01-06
Final version approved for publication: 1983-03-23
* Published with permission of the Deputy Minister, ministère de l'Énergie et des Ressources, Québec

INTRODUCTION

Several reviews dealing with Quaternary stratigraphy of Quebec or Eastern Canada have appeared in the last ten years (Prest, 1970, 1977; McDonald and Shilts, 1971; Gadd, 1976; Dreimanis, 1977; Occhietti, 1982). Some of the data and interpretations presented in these earlier papers will be discussed here.

This report reviews briefly the literature dealing with the stratigraphy of the Quaternary sediments in Quebec, while adding some unpublished data to the already well documented sequence. For this purpose, Quebec has been subdivided into seven regions (Fig. 1): 1) Central St. Lawrence Lowland, 2) southeastern Quebec area, 3) Quebec City area, 4) Montreal area, 5) James Bay Lowland, 6) Lac Saint-Jean area, and 7) Gaspésie Peninsula.

Radiocarbon dates have been quoted without corrections. Radiocarbon dates obtained from shells or any other material, except perhaps wood, must be subjected to cautious appraisal and should not be used indiscriminately. It is my opinion that ^{14}C dates within the study area have been generally consistent with field interpretation, which means that good field geology is not generally replaced by dates, but that dates may help to clarify some problems (Terasmae, 1980).

CENTRAL ST. LAWRENCE LOWLAND

Gadd (1960, 1971) and Karrow (1957) have proposed a stratigraphic sequence comprising two tills separated by the nonglacial St. Pierre Sediments. Varves occur above and below the two tills. The entire stratigraphic sequence is described in Gadd (1971, p. 32-33) and is summarized in Table 1.

The stratigraphic framework in the Central St. Lawrence Lowland has centred around a rock-stratigraphic unit known as the St. Pierre Sediments (Gadd, 1955, 1971), deposited during the St. Pierre Interstade, which was characterized by fluvial sedimentation and erosion. The drainage system was very much like the present one and flow was towards the Gulf of St. Lawrence as is indicated by current structures in the sediments. The present elevation of St. Pierre deposits in the Quebec City area also suggests that sea level may have been higher than that

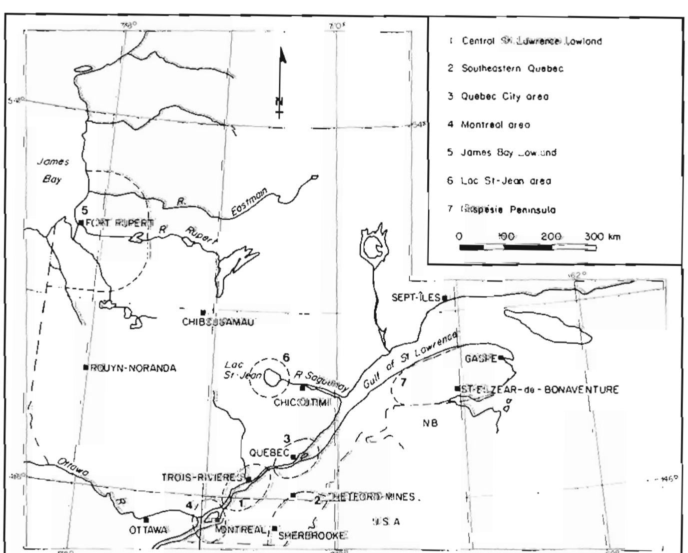

Figure 1. *Outline of the seven subregions of the study area.*

Table 1. Stratigraphy – Central St. Lawrence Lowland

Quaternary	Holocene	Sediments of Lampsilis Lake (Elson, 1969a) and early St. Lawrence River
		Champlain Sea sediments
	Wisconsinan	Varved sediments
		Gentilly Till
		Deschaillons Formation
		St. Pierre Sediments
		Pierreville Varves
		Bécancour Till
		Varves

at present. No evidence exists, however, for the presence of sea water in the St. Lawrence Lowlands during the St. Pierre Interstade. Hence, the sediments that accumulated are principally freshwater peat and fluvial sands and gravels.

St. Pierre Sediments are underlain by Bécancour Till and associated varves (Gadd, 1955; Karrow, 1957) and are overlain by Deschaillons Formation and Gentilly Till. In their type areas, Bécancour Till is generally reddish and calcareous whereas Gentilly Till is also calcareous, but grey (Gadd, 1955, 1971); colour is not, however, an infallible criterion for separating the two tills. Their textures vary from sandy to silty (Gadd, 1971), but some clayey facies may be encountered.

There is evidence both in the Quebec City and in the Bécancour (Gadd, 1955) areas, that ice advanced from the northeast towards the southwest at the end of the St. Pierre Interstade at the inception of Gentilly Stade. Two-dimensional till fabrics in Chaudière Till of the southeastern Quebec area also suggest that ice advanced from the northeast at the beginning of the glaciation that followed the St. Pierre Interstade (McDonald and Shilts, 1971; see below). When the advancing Laurentide Ice Sheet reached the escarpment on the south side of St. Lawrence valley or met the ice advancing from the northeast, drainage to the Atlantic Ocean was blocked and a lake formed to the southwest of the advancing ice sheet. Proof of this sequence of events is found in the varved clays underlying till in the Beaupré area, approximately 30 km east of Quebec City, and in the Deschaillons Formation in the Bécancour area (Gadd, 1955, 1971). Glacial Lake Deschaillons (and older glacial lakes which were associated with each ice advance) probably extended southwest to the Montreal area and Lake Champlain valley. During the waning of the Gentilly ice mass (and older ice), the sequence was repeated in reverse, i.e. glacial lakes appeared first in the valleys of the Appalachians and in Lake Champlain valley and extended northward and eastward as St. Lawrence valley was deglaciated. Following that, when the entrance to the St. Lawrence Lowlands (in the Quebec City area) became free of ice, the Champlain Sea inundated the isostatically depressed areas. At that point in time, drainage to the Atlantic was reestablished.

Finite dates were obtained on the St. Pierre Sediments in the early sixties, using a method of ^{14}C dating developed at Groningen by H. DeVries: 65 300 ± 1400 BP (GrN-1977) and 67 000 ± 2000 BP (GrN-1711) (Dreimanis, 1960; Vogel and Waterbolk, 1963). The most reliable date, however, appears to be 74 000 $\pm\,^{2700}_{2000}$ BP (QL-198; Stuiver et al., 1978).

Attempts to date the time of emplacement of the sediments of Lake Deschaillons using concretions collected in the varves have yielded finite dates of the order of 30 to 40 ka (Hillaire-Marcel, 1977; Occhietti, 1980; Barrette et al., 1981; Lamothe et al., 1983). There are contradictory statements concerning the potential of the method, but it is outside the scope of this paper to review its merits and apparent deficiencies.

SOUTHEASTERN QUEBEC

The stratigraphic sequence, summarized in Table 2, for southeastern Quebec (Fig. 1), is somewhat similar to that for the Central St. Lawrence Lowland (cf. Table 1) and is largely taken from McDonald and Shilts (1971) and Shilts (1981).

O'Malley Pond Saprolite

The O'Malley Pond saprolite is exposed in the vicinity of the O'Malley Pond, south of Mont Orford. It is a reddish material and includes smectite and lepidocrocite, which are probably secondary minerals (C.R. DeKimpe, personal communication, 1983), and is developed on basic metavolcanics rich in chlorite (DeRomer, 1960). Other occurrences of deep oxidation zones developed in situ on bedrock have been reported in Quebec (Dejou et al., 1982; LaSalle et al., 1983) and in adjacent New England (Borns and Calkin, 1977). Newton (1978) has also reported deep oxidation developed on a buried till (Thomaston till) in the New England states. It is possible that the O'Malley Pond saprolite, as well as other saprolites in Quebec, developed during either an interglacial stage or a preglacial period (Tertiary).

Cemented Gravels and Varves

McDonald and Shilts (1971) reported two occurrences of deeply oxidized gravels in southeastern Quebec. Their presence as clasts in the Johnville Till (next unit above) in their oxidized and cemented state suggest strongly that they had acquired those characters before being overridden by the glacier (McDonald and Shilts, 1971, p. 685). Their emplacement by fluvial processes in a nonglacial environment is suggested by current structures indicating the same direction of flow as the modern fluvial system. Consequently, northeast drainage to the Atlantic Ocean was in existence at the time of their deposition (McDonald and Shilts, 1971, p. 685). These gravels postdate at least one advance of Laurentide ice because they contain Precambrian erratics (McDonald, 1971, p. 338).

Johnville Till

Johnville Till is the oldest till known in southeastern Quebec. At one of its two occurrences, it directly overlies the cemented gravels and is overlain by the Massawippi Formation which has an age greater than 54 ka (McDonald and Shilts, 1971, p. 686). McDonald and Shilts (1971) used a high magnetite content in the fine sand fraction, high content in volcanic pebbles (sources to the northwest), and strong southeast two-dimensional fabrics as evidence that the ice moved from the northwest. Because of the age of the overlying Massawippi Formation, Johnville Till is considered as Early Wisconsinan or pre-Wisconsinan in age. It has been correlated with Bécancour Till of the Central St. Lawrence Lowland.

Massawippi Formation

Massawippi Formation consists of noncalcareous, compact, interstratified sands and silts. In the four exposures mentioned by McDonald and Shilts (1971), those sediments could be in part lacustrine and in part fluvial. The Massawippi Formation contains organic debris with ages greater than 54 ka. It has been correlated with the St. Pierre Sediments of the Central St. Lawrence Lowland dated at 74 700 $\pm\,^{2700}_{2000}$ BP (QL-198; Stuiver et al., 1978).

Table 2. Stratigraphy – Southeastern Quebec

Quaternary	Holocene	River alluvium
		Peat
	Wisconsinan	Champlain Sea deposits
		Lennoxville Till
		Gayhurst Formation: proglacial lacustrine sediments
		Chaudière Till
		Massawippi Formation: sands, silts, organic debris
		Johnville Till
	Pre-Wisconsinan	Cemented river gravels, direction of flow the same as today's present drainage
interglacial or Tertiary		subtill saprolite (O'Malley Pond, Mont Orford)

Chaudière Till

Chaudière Till has been observed at many exposures in southeastern Quebec, southeast of the Gayhurst ice front (see below). This till is grey, compact, and in many places can be distinguished from the overlying Lennoxville Till only by feldspar content, till fabric, and stratigraphic position. Till fabric and clast content (ultrabasic rocks, phyllites, volcanics, magnetite, derived from the Sutton Mountains located to the northwest) indicate that Chaudière Till was deposited by southeastward flowing ice (McDonald and Shilts, 1971). As a rock-stratigraphic unit, Chaudière Till is equivalent to the lower part of the Gentilly Till of the Central St. Lawrence Lowland.

Gayhurst Formation

Gayhurst Formation comprises 4000 varves or rhythmites deposited in a proglacial lake (Lake Gayhurst).

The formation is underlain by Chaudière Till and is overlain by Lennoxville Till. During the existence of proglacial Lake Gayhurst, through drainage to the Atlantic Ocean by the St. Lawrence estuary was blocked by ice which extended up St. Lawrence valley to approximately 60 km south of Quebec City. Disseminated organic debric collected from Gayhurst Formation varves (McDonald and Shilts, 1971) supplied a ${}^{14}C$ date of >20 000 BP (GSC-1137). It is certainly however younger than the Massawippi and St. Pierre formations, and consequently is younger than $74\,700 \pm {}^{2700}_{2000}$ BP (QL-198, Stuiver et al., 1978). It is clearly within the Gentilly Stade of the Central St. Lawrence Lowland terminology.

Lennoxville Till

Lennoxville Till is the youngest till recorded in southeastern Quebec. It overlies the Gayhurst Formation and is overlain in places by postglacial varved sediments. In many places it can be separated into two members, the significance of which is not clear at the present time and will be discussed further below. Shilts (1978) stated that, as exposed at Samson River, the upper member is brown, oxidized, not compact, sandy, weakly calcareous, and contains a large proportion of ultrabasics because of the favorable location of the section with respect to the ultrabasic rock outcrops farther to the northwest. The lower member is grey, clayey, compact, more strongly calcareous than the upper member, and shows jointing. Chauvin (1979), in a study of the unconsolidated sediments of the Thetford Mines area (Fig. 2), described the Thetford Mines Till (correlative with the Lennoxville Till) as having similar characteristics. Shilts (1978) reported that lacustrine sediments (clay and sand) are found between the two members at the Samson River section. Chauvin (1979) also observed stratified sands in many places between the two members of Lennoxville Till in the Thetford Mines area.

Three points concerning the above sequence of McDonald and Shilts (1971) require further mention: First, available evidence suggests that, at the time the Gayhurst glaciolacustrine sediments were deposited, the ice front was located no farther north than a line south of the present position of St. Lawrence River and about 50 km south of Quebec City (McDonald and Shilts, 1971, p. 691). Consequently, at that time there was no northward drainage like that of the present. The Quebec City area and the

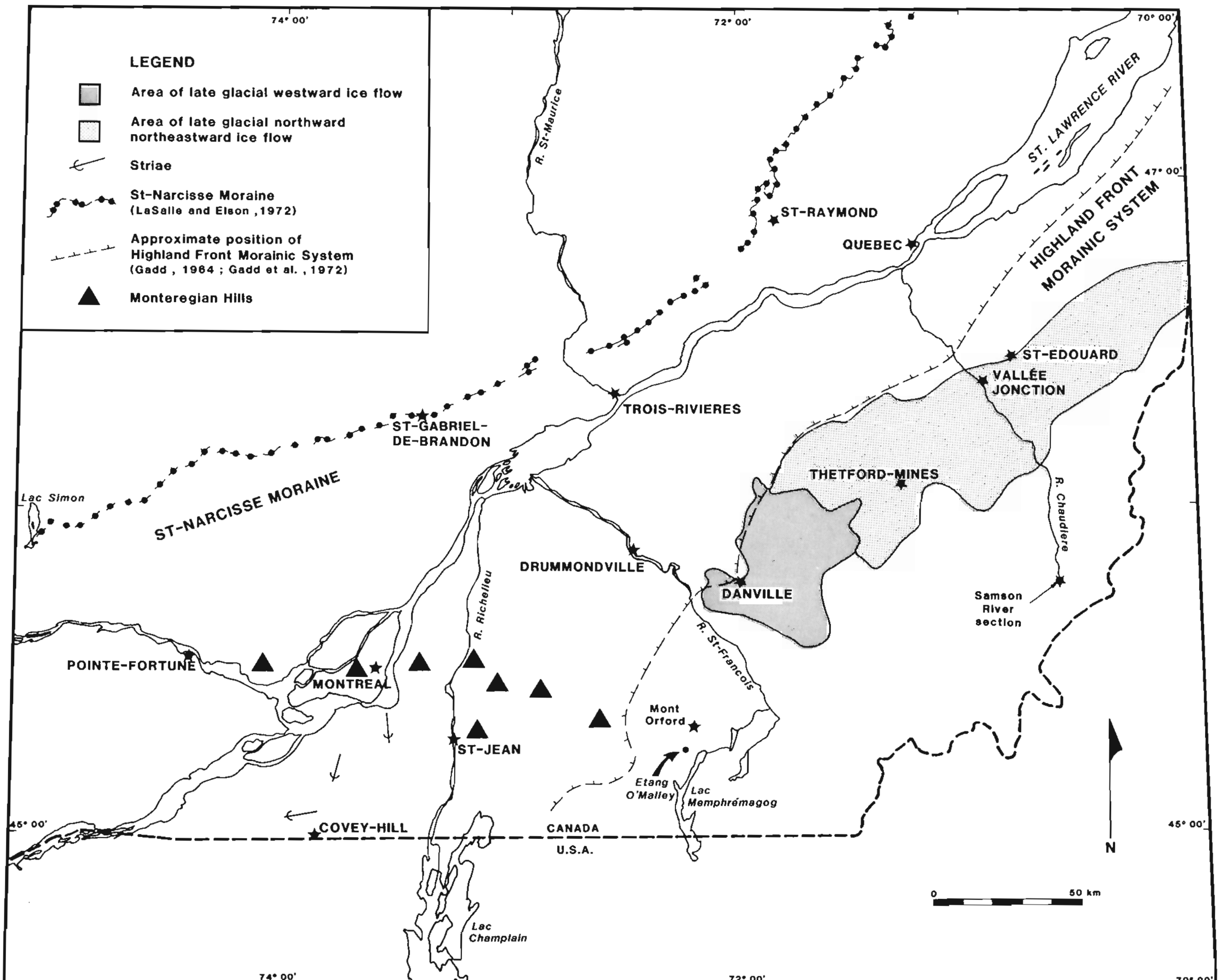

Figure 2. *The Central St. Lawrence Lowland with schematic outlines of several features discussed in the text.*

lower St. Lawrence were apparently covered by glacier ice. Indeed, no field evidence has been found that would suggest even partial deglaciation of the Quebec City area during the Gayhurst episode which lasted at least 4 ka. This means that even though the Gentilly Stade is represented by only one till north of the Gayhurst ice front, in southeastern Quebec it is represented by three units: Chaudière and Lennoxville tills, separated by Gayhurst glaciolacustrine sediments.

The second point requiring further discussion is the significance of the two members of Lennoxville Till. Shilts (1978) suggested that Lennoxville Till was deposited during the maximum of the glaciation and that the presence of the glaciolacustrine sediments between the two members can be attributed to an early fluctuation of the ice front. According to Chauvin (1979) Thetford Mines Till was deposited in two phases:

1. an active phase during deposition of the lower member when the ice moved southeastward to its maximum, and then northeastward and westward due to drawdown caused by calving bay(s) in St. Lawrence valley (Lortie, 1976);
2. a stagnating phase during which the upper member was emplaced either as a meltout or as an ablation till.

If this concept of stagnating ice is accepted, part of the Highland Front morainic system west of Chaudière River may have been deposited at the same time as deposits located south and east of this hypothetical late glacial Appalachian ice mass, but after the late glacial westward, northward, and northeastward movement had ceased.

The third point concerns the glacial sequence found in adjacent New England. According to Borns and Calkin (1977), evidence exists for at least two and possibly three Wisconsinan glaciations in west-central Maine. Newton (1978), in a study of tills along a transect from northern New Hampshire to Massachusetts, recognized two Wisconsinan tills and an older one, of unspecified age. Sirkin (1982) reported the presence of two drift sheets related to two Wisconsinan glaciations; there is evidence, in pollen diagrams, for a third, intervening cold period, but the ice did not reach Long Island at that time (Sirkin, 1982). Borns and Calkin (1977, p. 1782) have attempted a correlation of their sequence with southeastern Quebec. More work and better sections are needed to clarify all these correlations.

QUEBEC CITY AREA

Several good sections are present in the Quebec City area (Fig. 2) but have only been described summarily on the occasion of field excursions (Gadd et al., 1972a; LaSalle et al., 1977b). As new data are obtained a clearer picture of the stratigraphy is emerging. Table 3 gives a summary of dates on subtill organics in the Quebec City area, Figure 3 shows section locations, and Figure 4 shows a composite section. Several named units are introduced informally to facilitate the discussion. These units are described briefly below.

Charlesbourg Saprolite

Charlesbourg saprolite, exposed in a quarry in Charlesbourg north of Quebec City, is described by LaSalle and Ledoux (1975) and LaSalle et al. (1983). It is developed in part on a mylonite derived from a Precambrian biotite-hornblende gneiss and in part on the gneiss itself. Biotite has been altered to vermiculite and then to smectite, hornblende in the fine fractions has been transformed into swelling minerals, and kaolinite is abundant and associated with a

Table 3. Dates obtained on organic remains in the Quebec City area

^{14}C Age	Lab. Number	Locality	Comments and References
>44 000 BP	Y-463	Donnacona	Organic debris extracted from peaty sands and silts (Karrow, 1957, p. 35).
>39 000 BP	Qu-327	Vallée-Jonction	Bryophyte remains; assemblage probably grew in situ in shallow bay of a glacial lake. (LaSalle et al., 1977a, 1979b).
>39 000 BP	GSC-1539	Beaupré	Bryophyte remains possibly belonging to Tertiary floras (LaSalle et al., 1979b). Organic material has obviously been redeposited from older strata. Evidence of wearing and breaking in transport. (Gadd et al., 1972a; Lowdon et al., 1977).
>37 000 BP	GSC-1478	Beauport	Pieces of wood, **Picea** sp. and **Larix** sp., collected in glaciolacustrine sediments (Lake Deschaillons) overlain by till. (Gadd et al., 1972a; Lowdon et al., 1977).
36 560 ± 4690 BP 28 375 ± 775 BP >42 000 BP	Qu-439 UGa-463 GSC-3420	St-Nicolas	Mostly unidentifiable organic debris mixed with silt and fine sand at base of Anse-aux-Hirondelles Formation. Pieces of wood are common in the recently exposed sections. Pollen assemblage recovered suggests correlation with the St-Pierre. Finite dates considered minimal as explained in the text.

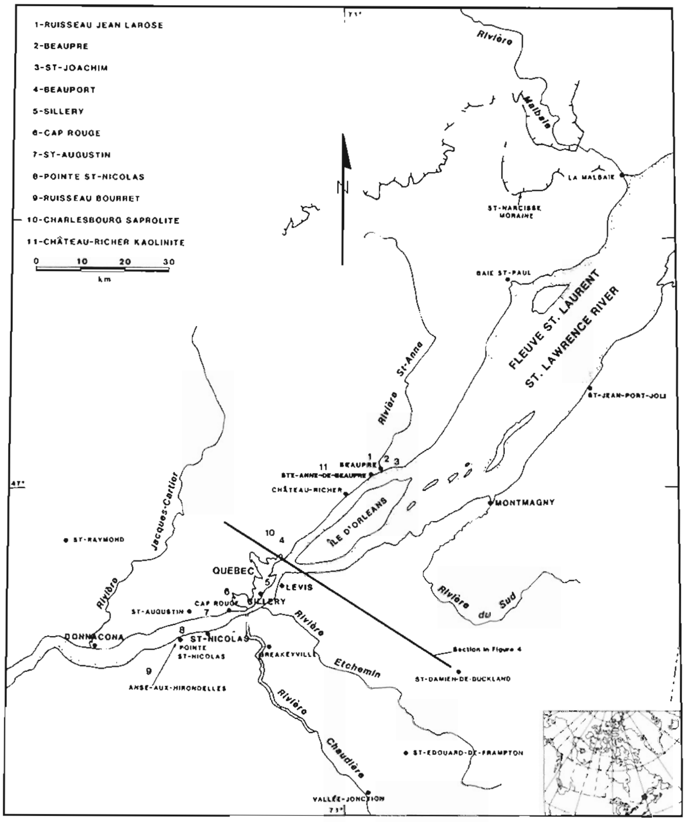

Figure 3. *The Quebec City area, showing locations of stratigraphic sections.*

degradation of the swelling minerals. In places, the alteration has reached the gibbsite stage. Depth of alteration reaches 15 m. The saprolite is located south of a bedrock knob, which has protected it from glacial erosion. It is probable that the Charlesbourg saprolite predates the earliest glaciation in the Quebec City area.

Château-Richer Kaolinite

The Château-Richer kaolinite is exposed in a small stream valley about 20 km northeast of Quebec City. It has developed on anorthosite and related rocks. The alteration reaches a depth of about 25 m in places. The white colour of the kaolinite is conspicuous in all the exposures. It is overlain by a sandy brown till, the lower part of which is enriched with glacially derived kaolinite. The Château-Richer kaolinite predates the last glacier advance in the Quebec City area and its development may date back to the Tertiary.

Pointe St-Nicolas Till

This, the oldest glacially derived sediment observed in the Quebec City area, is exposed at the base of a section at Pointe St-Nicolas about 15 km west of Quebec City on the south shore of St. Lawrence River. The till is greenish on fresh exposure because of the great abundance of chlorite, but it oxidizes rapidly. It is about 2.5 m thick and contains a minor proportion of rounded Precambrian clasts, but most clasts are locally derived. No stratified sediments have been observed underlying it and it appears to rest directly on bedrock. It is overlain by the Anse-aux-Hirondelles Formation.

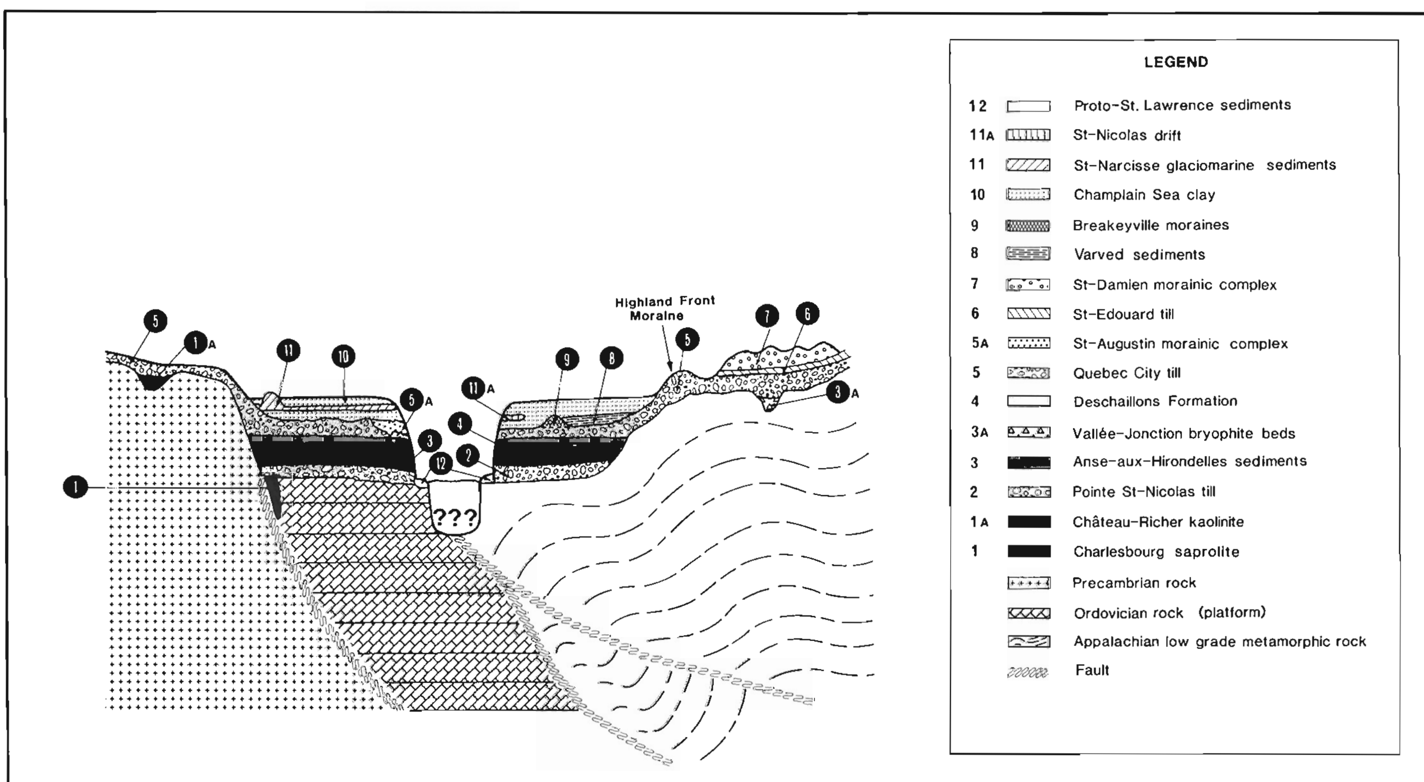

Figure 4. *Composite stratigraphic succession along a line running approximately from Quebec City to St-Damien-de-Buckland along the line shown in Figure 3.*

Anse-aux-Hirondelles Sediments

This stratigraphic unit is exposed at Pointe St-Nicolas, about 15 km west of the Quebec bridge, on the south shore of St. Lawrence River. It consists of horizontally stratified sand and gravel with organic beds. The organic beds are exposed at the base of the formation, immediately above Pointe St-Nicolas till. Wood fragments recovered from the organic beds have given a ^{14}C age of more than 42 ka (see discussion below). Cross-stratification indicates flow towards the present St. Lawrence River and parallel to the flow direction of the modern local streams. It is probable that the sediments exposed lie at the lower end of a buried side channel of the main river. It is also possible that the sediments at Anse-aux-Hirondelles occupy a local tributary valley eroded in rock. This ravine would have been formed before deposition of Pointe St-Nicolas till and its longitudinal profile might possibly be graded to the Micmac Terrace. The thickness of the Anse-aux-Hirondelles Sediments is of the order of 20-25 m. Deschaillons Formation varves overlie the Anse-aux-Hirondelles Formation.

Beaupré Varved Sediments

These sediments were exposed during construction in Beaupré at the foot of Mont Ste-Anne, 30 km east of Quebec City. About 10 m of silty varved sediment with load and glaciotectonic structures was present at one site and thicker coarser sediment, probably proximal varves, was exposed above and in a separate section. These deposits contain a bryophyte assemblage which is probably redeposited Tertiary material (see Table 3). The Beaupré varved sediments are presumably correlative with Deschaillons Formation. They are overlain by a grey calcareous till (Quebec City till).

Quebec City Till

Quebec City till overlies the varves of glacial Lake Deschaillons. In most places it is a very compact calcareous till containing mainly striated clasts of limestone and local rock types, but it is locally clayey where the depositing glacier overrode varved sediments. Precambrian erratics are present. This is the surface till in most of the Quebec City area.

The St-Augustin ice-contact drift complex, located about 6 km south of the village of St-Augustin on the north shore of St. Lawrence River is assumed to be a local facies of the Quebec City till. It is approximately 10 m thick and is composed of well rounded clasts of cobble to boulder size, exclusively of Precambrian origin, and a matrix of poorly sorted angular sand. Large clasts of till are also present near the base of the unit. It rests in part on bedrock, and in part on sands that are tentatively correlated with the Anse-aux-Hirondelles Sediments. It is overlain by sediments of the Champlain Sea.

The name St-Édouard Till is used to designate till that was remobilized or deposited during the late glacial episode of northward or northeastward ice flow on the northern flank of the Appalachians in Quebec. It is undistinguishable from other surface till in the area and could be considered only as a facies of the Quebec City till. It is named after the village of St-Édouard-de-Frampton, located about 50 km southeast of Quebec City. In that area, in a few places, till has been observed lying directly on bedrock which has northward trending striae.

St-Nicolas Drift

This term designates a poorly sorted, fossiliferous, and calcareous diamicton that has been observed at several localities in the Quebec City area. The sediment has an abundance of local lithologies and contains **Balanus hameri**, commonly with basal plates still attached to the clasts. Dates obtained on **Balanus hameri** are all in the range 11-11.2 ka (e.g., 11 200 ± 160 BP, GSC-1176). The deposition of this fossiliferous drift is associated with the St-Narcisse ice readvance into the Champlain Sea but predates the construction of the St-Narcisse Moraine and is considered equivalent in age to the St-Narcisse glaciomarine sediments.

Quaternary History

There is evidence in the Quebec City area for two major glacial events separated by one nonglacial event. The most significant stratigraphic interval, and the one about which the most information is available, is the succession between the Quebec City and Pointe St-Nicolas tills. Current structures in the sediments of this succession indicate flow towards the northeast. This indicates that St. Lawrence valley was open (not blocked by ice) and that drainage was similar to that of the present. The sediments in this interval consist of the Anse-aux-Hirondelles sediments and Deschaillons Formation. The Anse-aux-Hirondelles sediments may be subdivided into three subunits: the lower consists of a silty sand rich in organic materials, overlain by a thick well washed and well stratified sand, which in turn is overlain by gravel containing minor sand. The lower two subunits were deposited on a floodplain which occupied St. Lawrence valley (and a side channel or a tributary valley) and filled it to at least the present elevation of 30 m. The upward transition from organic-rich sediment to sand might have been due to a deterioration of climate which led to an increase in supply of sediment and a decrease in organic productivity or it could merely have been related to a shifting of channels in the floodplain. The gravel at the top lies with erosional uncomformity on the sand and, because it contains structures thought to have been caused by permafrost, it is considered to be related to a climatic deterioration. Deschaillons Formation varves, which overlie the gravel, are glacial lake sediments and were formed when ice dammed northeastward drainage in St. Lawrence valley. Radiocarbon dates on organic materials collected from the sediment related to this interval in the vicinity of Quebec City are listed in Table 3; all sites, with one exception, supplied material beyond the range of radiocarbon dating. A recent date on the material collected from the St-Nicolas site (>42 000 BP, GSC-3420), which originally gave the finite ages[1], has indicated that these probably should also be considered as beyond the radiocarbon dating range.

Late glacial deposits in the Quebec City area record fluctuations of the ice front during the retreat which followed deposition of the Quebec City till. Ice contact sediment east of Breakeyville, which do not contain marine fossils, and varved sediments underlying marine sediments on the south shore of the St. Lawrence suggest that the ice front in St. Lawrence valley had retreated downvalley from Quebec City probably as far east as Montmagny before the lowland was opened to marine invasion. The position of the ice front at the time of marine invasion is not known, but it must not have been far from Quebec City because the glacier was

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[1] The finite dates 36 560 ± 4690 (QU-439), and 28 375 ± 775 (UGa-463) were both obtained from laboratories using the benzene dating method. These are the only samples from this interval that have been dated by this method. Serious reservations are being entertained about finite radiocarbon dates in the 38 000 year range obtained by the benzene method (Radnell and Muller, 1980) and consequently, these dates from the St-Nicolas site should not be accepted as real. Also, QU-439 and UGa-463 were never published because of the strong possibility of contamination by modern rootlets. This was not the case for GSC-3420, which was collected from a recently exposed part of the section.

able to re-advance and cover marine sediments dated 12 400 ± 160 BP (GSC-1533) north of Quebec City (Lowdon and Blake, 1973).

Micmac Terrace

Micmac Terrace, which was first described by Goldthwait (1911), is a prominent rock platform that is well displayed on the north shore of the St. Lawrence between Quebec City and Ste-Anne-de-Beaupré; it is also present around l'Île d'Orléans and extends with some discontinuity along the south shore of the St. Lawrence from Quebec City down the lower St. Lawrence estuary and around the Gaspésie Peninsula. It is locally overlain by glacial drift or sediments deposited during a higher stand of the early Holocene St. Lawrence River; thickness of covering sediments varies from approximately 3 to 15 m. In the Quebec City area, varves of glacial Lake Deschaillons have been observed lying directly on the platform. Hence, it can be concluded that the Micmac Terrace predates Lake Deschaillons and is at least as old as the St. Pierre interval (time of deposition of Anse-aux-Hirondelles sediments in this area). The time required to erode the St. Lawrence channel, and consequently the rock platform that is called Micmac Terrace, is difficult to evaluate. If it is assumed that the St. Pierre Interstade is possibly correlative with the Sangamon Interglacial, it might also be assumed that most of the Micmac Terrace development occurred during that period. Development could also have occurred during earlier periods (interglacials) of higher sea level (Shackleton and Opdyke, 1973) and might even date back to the Tertiary – a time when erosional conditions prevailed in the area (Moore, 1958). LaSalle et al. (1982) believed that the St. Lawrence fluvial system and its early erosional features were probably formed during that time.

MONTREAL AREA

Prest and Hode-Keyser (1977, 1982) subdivided the Quaternary sequence of the Montreal area, into the five units listed below (the names Fort Covington and Malone tills are from MacClintock, 1958; MacClintock and Stewart, 1965; Terasmae, 1965).

Champlain Sea sediments

Glacial lake sediments

Fort Covington Till

Glacial lake sediments

Middle till complex
(upland and lowland phases)

Malone Till

The Malone, according to Prest and Hode-Keyser (1977), is a "dense lodgment till" lying directly on bedrock. It was deposited by southwestward flowing ice which reached a terminus in the vicinity of New York City. The middle till complex consists of an upland phase and a lowland phase. "The upland phase predominantly is composed of well stratified silt, sand, and gravel, whereas the lowland phase is made up mainly of rhythmically bedded finer sediments, massive silt, and fine sand (as lenses and pods), and interlayered till" (Prest and Hode-Keyser, 1977, p. 9). According to them these deposits are from an interstadial episode and the glaciolacustrine deposits indicate the presence of a glacial lake south of Montreal Island which in turn implies a glacial retreat of the ice margin from its terminal position to at least the north side of the St. Lawrence at Montreal. They suggest that the ice front at the time of deposition of the middle-till complex probably lay against the Appalachian Highland 80 km south of Quebec City, extended southwestward to Drummondville and westward to north of Montreal Island. The Fort Covington Till consists of variably clayey silt basal-type till, locally overlying substratified drift. It was deposited by an advance of the ice sheet which reoccupied St. Lawrence Lowland. Retreat of the Fort Covington ice towards the north was followed by deposition of thin varved clays and rhythmites (see also Terasmae, 1965) in a glacial lake ("younger glacial lake deposit") and opening of St. Lawrence valley which permitted marine waters to occupy the area to an elevation of approximately 170 m at Montreal and deposit Champlain Sea sediments.

LaSalle (1981), working in the area south and east of Montreal, established the succession presented in Figure 5. St-Jacques Till is the surface till of the area and, consequently, is correlated with Fort Covington Till of Prest and Hode-Keyser (1977, 1982). Lac Chateauguay sediments should then correlate with the middle-till complex, the Lac Chambly sediments with their "younger glacial lake deposit". No till unit was found which would be equivalent to Malone Till.

JAMES BAY LOWLAND

Compared with the Hudson Bay Lowland to the west (McDonald, 1969; Skinner, 1973; Shilts, this volume), little data are available on the Quaternary stratigraphy of the James Bay Lowland of Quebec. A sample collected from lower Rivière Harricanaw (Stuiver et al., 1963, p. 312) and brief mention of sediments underlying till in boreholes (Hardy, 1982a) indicate that materials which probably

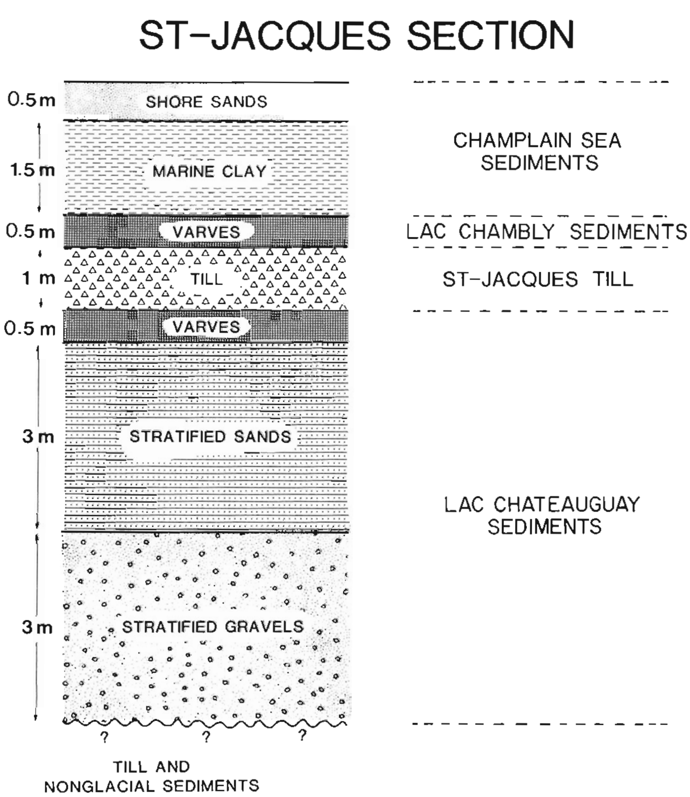

Figure 5. Stratigraphic sequence as shown in the St-Jacques section, about 50 km south of Montreal (after LaSalle, 1981).

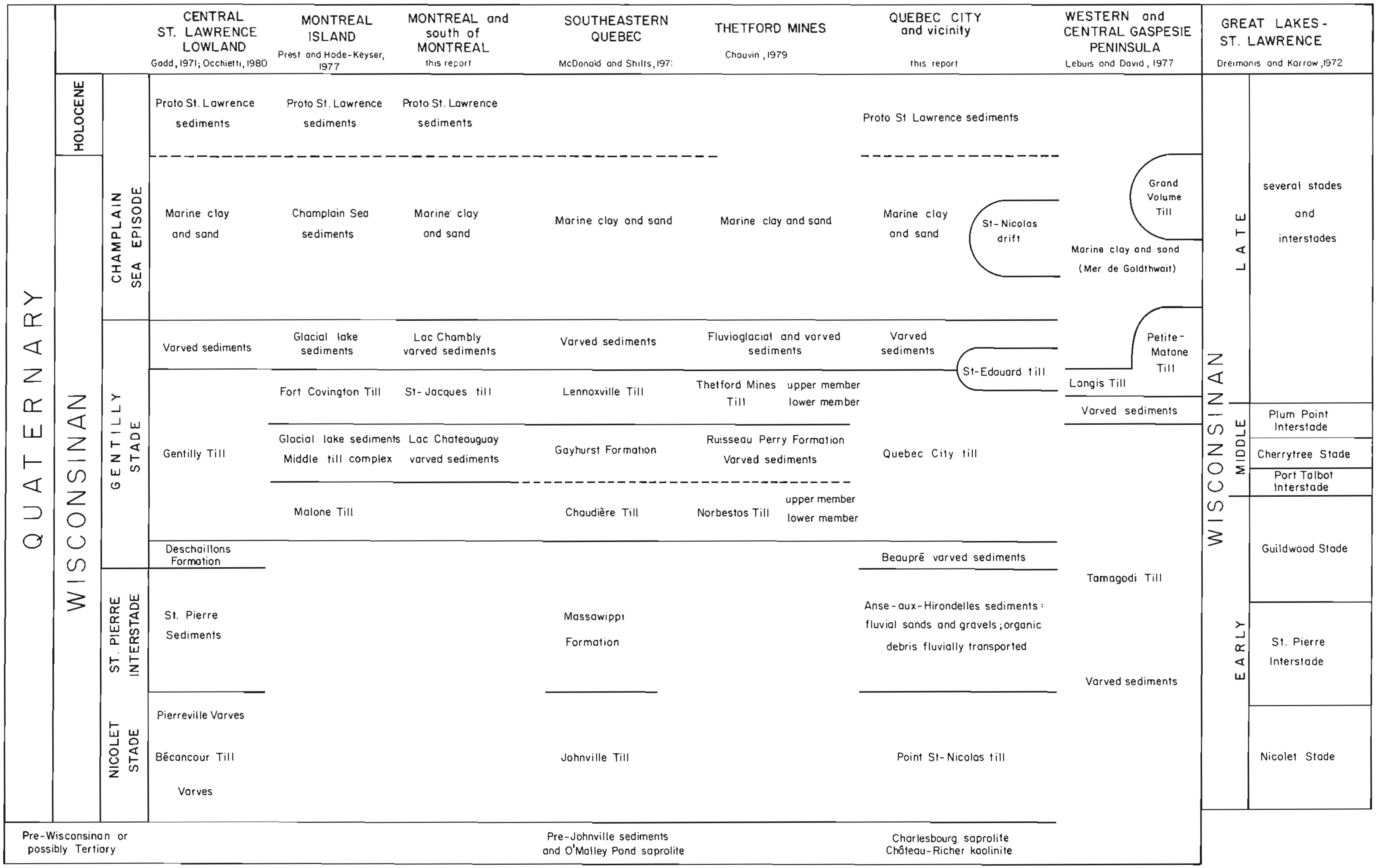

Figure 6. *Correlation chart.*

correlate with the Missinaibi Formation (Skinner, 1973) are locally present. The data available are not abundant but they do indicate that Quebec adjacent to James Bay was free of ice at the time of deposition of the Missinaibi Formation. Stuiver et al. (1978, p. 19) have reported an age >72 500 BP (QL-197) for a peat sample from the Missinaibi Formation in the Hudson Bay Lowland.

Data pertinent to subdivision of Wisconsinan-age deposits are not available but the timing and method of deglaciation are relatively well known. During ice retreat north of the Great Lakes-Hudson Bay drainage divide, an extensive glacial lake developed (Vincent and Hardy, 1979). Three surge-like advances (Cochrane I and II and Rupert) occurred in this lake basin (Hardy, 1977). The ice margin retreated quickly while the glacier was fronted by this deep lake; after about 7.9 ka, when the sea entered this part of Hudson Bay, the glacial lake drained and the ice margin, now on land or in shallow water, stabilized, and the Sakami Moraine was built (Hardy, 1982b).

LAC ST-JEAN AREA

Deposits older than Late Wisconsinan are not exposed in the Lac St-Jean area. They may, however, be present at depth because borings have revealed more than 100 m of Quaternary sediments in local basins. Isostatic depression was such that the sea invaded this area following ice retreat. Deglaciation was underway by 10.3 ka, as radiocarbon dates as old as 10 250 ± 350 BP (Gif-424, LaSalle et al., 1978, p. 37) have been obtained on shells from marine deposits. Final deglaciation took place after the formation of the St-Narcisse Moraine (see discussion below) so that this 10 250 BP date is a minimum for deposition of this feature (LaSalle, 1965).

GASPÉSIE PENINSULA

Lebuis and David (1977) recognized four different tills in the area of Gaspésie Peninsula. On the basis of lithology and till fabrics they have concluded that the Tamagodi Till was emplaced by a local ice sheet in central Gaspésie which expanded first towards the northeast and then flowed towards the southeast or northwest. The overlying Langis Till is associated with northwest to southeast flowing ice which was probably related to invasion of the area by Laurentide ice from the north shore of the Gulf of St. Lawrence. Even though these two tills are separated by varved clays, they might be related to the same glaciation. No datable material has been found in the Tamagodi or Langis tills or their associated sediments. It is assumed here that they were deposited during the last glaciation but they could equally well be the product of older glaciations (see also Grant, 1977; Grant and King, this volume).

Two other till units are described by Lebuis and David (1977). The Petite-Matane Till was deposited after the Laurentide Ice Sheet had been separated from Gaspésie ice by the incoming waters of the Goldthwait Sea. This event occurred before 13.5 ka, based on marine shell dates of 13 580 ± 350 BP (QU-83) and 13 450 ± 470 (QU-84, Lebuis and David, 1977). At this time a reversal of ice flow would already have occurred in the northern part of Gaspésie. Another till – the Grand Volume Till – likely was deposited by small ice masses (valley glaciers, cirque glaciers, and small isolated ice caps) after the break-up of the main Gaspésie ice cap. On the basis of maximum dates obtained on lake sediments, the Grand Volume Till was deposited before 9.8 ka (9810 ± 360 BP, GSC-1979, Lebuis and David, 1977).

Reconnaissance studies have been carried out by LaSalle (LaSalle and Guilday, 1980) in the area surrounding the entrance of the St-Elzéar-de-Bonaventure cavern, which is located on a plateau, at approximately 500 m elevation, on the south side of Gaspésie Peninsula. During the summer of 1983, erratics were found in the area surrounding the cave entrance. The flat bedrock surface is covered by rubble including rare rounded erratics (volcanics) of northern provenance. The rubble is composed of local bedrock on which glacial elements appear to have been superimposed or a less likely explanation is that the rubble is in part derived from weathering of a till. As the volcanics appear generally unweathered, it is likely that the rubble was present before the glacial elements were added. South of the cave entrance, erratics (volcanic rock and granite) have been found in the surface material (till, ice-contact sediments) as far as the coast of Baie des Chaleurs. Thus glacial striae found on the plateau north of the cave, together with the distribution of erratics, constitute good field evidence that glacier ice advanced over the area of the cave and south of it as far as the coast of Baie des Chaleurs at some time in the past. The material accumulated in the cavern (vertical entrance) has yielded no dates older than approximately 5 ka (e.g., 5110 ± 150 BP, GX-7017, hip bone of a moose collected from surface of talus, date courtesy of J.E. Guilday and Carnegie Museum, Pittsburgh, Pennsylvania). However, uranium-thorium dates in the range of 225 and 100 ka have been obtained on speleothems collected inside the cavern (Roberge and Gascoyne, 1978). Hennig et al. (1983) have shown that terrestrial calcite formation is clearly related to paleoclimatic fluctuations and these dates seem to correspond to interglacial periods as shown by the curves of Shackleton and Opdyke (1973).

CORRELATIONS

A correlation of Quaternary units from the different regions discussed in this report is given in Figure 6. The different units are positioned according to the geologic-climatic units of Gadd (1971) for central St. Lawrence valley and those of Dreimanis and Karrow (1972) for the Great Lakes – St. Lawrence region. The correlations are in general similar to those presented in other syntheses for the Quaternary of Quebec (e.g., Gadd, 1976; Dreimanis, 1977; Occhietti, 1982).

Pre-St. Pierre Interstade

Tills and varved sediments are locally found underlying the St. Pierre Sediments (Gadd, 1971) or correlative nonglacial sediments (McDonald and Shilts, 1971). In the Central St. Lawrence Lowland these consist of till lying between two units of varved sediments. This suggests deposition during a single advance and retreat with the lower varves having been formed when ice blocked normal northward drainage of the St. Lawrence and the upper varves having been deposited after the Central St. Lawrence Lowland had been deglaciated but before the downstream end of the St. Lawrence was opened. The upper varves grade upward into the overlying St. Pierre beds (Gadd, 1971, p. 43); a continuous change in climate from subarctic in the varved sediments to a climate slightly cooler than at present in the St. Pierre organic deposits was noted by J. Terasmae (as reported in Gadd, 1971, p. 56). The only thing known about the absolute chronology of those units is that they are older than 74 700 $\pm\,^{2700}_{2000}$ BP, QL-198 (Stuiver et al., 1978) – the date obtained on wood from the St. Pierre beds. Most regional correlations have referred these deposits to the Early Wisconsinan, but in presenting their data all authors have stated that these units could be pre-Wisconsinan in age.

St. Pierre Interstade

Continental sedimentation was widespread in southern Quebec during the St. Pierre Interstade (McDonald, 1971). Several dated sites in the adjacent New England States would appear to be correlative with the St. Pierre Sediments (Caldwell, 1959; Muller, 1965; Borns and Calkin 1977; LaSalle et al., 1979a). Gadd et al. (1981) reported fluvial sediments underlying till and containing organic materials dated >42 000 BP (GSC-2932) in Ottawa valley near Pointe-Fortune, Quebec (Fig. 2).

St. Pierre Sediments were deposited on an alluvial plain which was as large as 120 x 30 km and which had local base levels as much as 20 m above the present ones (Gadd, 1971; Occhietti, 1980, 1982). The direction of drainage on this floodplain was the same as that of the present St. Lawrence. This indicates that drainage of St. Lawrence valley was not controlled by ice at that time. Terasmae (1958) concluded, based on pollen studies, that climate during St. Pierre time was at least 2°C cooler than at present and that these deposits represented an interstadial rather than an interglacial stage. He deduced that the St. Pierre Interstade might have occurred during the onset of the Wisconsinan Stage before there had been sufficient time or the ice had reached a sufficient mass to depress St. Lawrence valley below sea level as was the case when ice receded from the valley in Late Wisconsinan time. Occhietti (1982) arrived at a similar conclusion, reasoning that the only period during which the environmental conditions indicated by the St. Pierre Sediments might have occurred, was during one or more of the periods of high "interstadial" sea level which have been postulated for oxygen isotope stage 5 (Shackleton and Opdyke, 1973).

Last Glacial Interval

The glacial deposits overlying the St. Pierre Sediments in the Central St. Lawrence Lowland have been referred to a single glaciation (Gentilly Stade of Gadd, 1971 and Trois-Rivières Stade of Occhietti, 1980). It is generally agreed that the oldest unit of the Gentilly, the Deschaillons Formation which overlies St. Pierre Sediments, was deposited when advancing ice blocked lower St. Lawrence valley. Considerable disagreement exists, however, on how the timing of this event and of the deposition of the overlying till fits in with the standard Wisconsinan time units established for the Great Lakes – St. Lawrence region by Dreimanis and Karrow (1972); they equated the advance of this ice with the start of the Guildwood Stade – an Early Wisconsinan event. Gadd (1976) referred Gentilly Till and underlying varves to the middle of the Middle Wisconsinan Substage. Occhietti (1982) placed the end of the St. Pierre at the boundary between Early and Middle Wisconsinan. These differences do not represent disagreement in the paleoenvironmental interpretation of the units or in the correlation between areas but indicate a difference in application of the Wisconsinan substage terminology.

Gadd (1971) found only one till overlying St. Pierre Sediments in central St. Lawrence valley and consequently concluded that this part of the valley was occupied continuously by ice from the end of the St. Pierre Interstade until deglaciation, which permitted the Champlain Sea to flood the St. Lawrence Lowland. In the vicinity of Montreal and in southeastern Quebec, three units – two tills separated by glaciolacustrine or glaciofluvial sediments – are ascribed to this interval. A date of >20 000 BP (GSC-1137, McDonald and Shilts, 1971) has been obtained for disseminated organic material from one of these intertill units. These stratified sediments have generally been correlated with one of the Middle Wisconsinan interstadials of the Great Lakes area (Dreimanis and Karrow, 1972) because of the date and the lack of other deposits in the area that might be correlated with the extensive ice retreat postulated for this interstadial (McDonald, 1971).

The ice responsible for deposition of Gentilly Till moved from north to south (Gadd, 1971). The correlative ice advance in the Montreal area (responsible for deposition of Malone Till) advanced southwestward up the St. Lawrence (Prest and Hode-Keyser, 1977; see also MacClintock and Terasmae, 1960). The ice in the eastern townships which correlates with this same advance (responsible for deposition of Chaudière Till) flowed initially from the northeast but by the end of deposition, ice flow was towards the southeast McDonald and Shilts (1971). This appears to indicate that the upper, middle, and western St. Lawrence valley was overriden by ice moving southward from the Canadian Shield whereas the eastern St. Lawrence valley was initially overridden by ice from Appalachian sources but later was overwhelmed by ice from the north and west.

Late Wisconsinan Retreat

The position of the southern limit of the Late Wisconsinan ice that covered Quebec is not clearly defined. MacClintock and Terasmae (1960) placed the limit of their last ice advance (Fort Covington) on the northern flank of Covey Hill; however, no dates are given for this advance. Others feel that the last advance reached the New Jersey-Long Island area (Connally and Sirkin, 1973; Sirkin, 1982); they refer this advance to the Woodfordian Substage during which the ice reached its terminal position by about 21.8 ka and had begun to retreat by 21.3 ka. It is sufficient for the purpose of this report to say that the Late Wisconsinan ice margin lay south of Quebec without becoming involved in speculation about the exact position or age of its limit (see Fullerton, 1980).

The style and pattern of retreat of the last ice sheet in Quebec have been the subject of considerable discussion. McDonald and Shilts (1971, p. 692) expressed the general view held up to that time that ice flow throughout the last glaciation was in general from north to south. Prest (1970), Lamarche (1971), and Gadd et al. (1972b, p. 7), however, mentioned northward flow from a late local dispersal centre in the vicinity of Thetford Mines; Lamarche (1974), Lortie (1976), and Chauvin (1979) further defined this area of late flow reversal (Fig. 2). The generally accepted explanation of this reversal is that a calving bay developed in and advanced up the Gulf of St. Lawrence and St. Lawrence River valley, eventually separating the ice on the east side of the valley from the main Laurentide Ice Sheet to the north. Development of this feature produced a north and westward gradient on the surface of the ice remaining on the Appalachian side of the valley and hence resulted in northward flow. Thomas (1977) presented a theoretical model for the development of a calving bay in the St. Lawrence.

A major deglaciation feature which has not been adequately explained is the Highland Front morainic system (Fig. 2). It was first mentioned by Gadd (1964) who suggested that this complex of ice-contact gravel and meltwater channels formed as the ice sheet readjusted its profile on retreating from the Appalachian Highlands to the St. Lawrence Lowlands, 100 to 200 m lower. Several important facts concerning the Highland Front morainic system are: (1) the youngest striae in its vicinity were produced by northward and westward moving ice, (2) the morainal complex was formed at the margin of a southeast-facing ice front with lakes ponded in valleys to the south and east (the area occupied by northward flowing ice), and (3) no evidence exists of a major readvance of Laurentide ice to the position of the Highland Front morainic system. The most plausible explanation is that drawdown occurred in St. Lawrence valley, resulting in flow of ice from the Appalachian Highlands towards the valley (towards the north, northeast, and west). This was then followed by a major southward and eastward advance of Laurentide ice to the position of the Highland Front morainic system. The main problems with this explanation are that there is no evidence for a major readvance, and it is highly unlikely that once a deep saddle and calving bay had developed in St. Lawrence valley, a late glacial readvance strong enough to reestablish a northwest to southeast gradient across the valley could have occurred. Furthermore, near Quebec City, the ice would have had to advance into the Champlain Sea when that body of water was at its maximum level.

Glacial lakes formed south of the ice margin in the Champlain-Hudson valley during ice retreat (Connally and Sirkin, 1973). At one stage during retreat these possibly extended northward into the St. Lawrence Lowlands as far north as Montreal (Prest and Hode-Keyser, 1977) or maybe as far as Danville (LaSalle, 1981; LaSalle et al., 1982). Prest (1970) suggested that the last ice dam, separating a St. Lawrence valley occupied by a glacial lake to the south from a St. Lawrence valley occupied by the sea to the north, was in the vicinity of Chaudière river valley near Quebec City. Field evidence indicates that a glacial lake occupied large valleys, such as the Chaudière and Etchemin, on the south shore of the St. Lawrence and reached at least as far east as Montmagny (Fig. 3). The oldest postglacial marine date on the Gaspésie coast of the Gulf of St. Lawrence is 13 540 ± 300 BP (QU-85, Lebuis and David, 1977). A date of 12 700 ± 100 BP (GSC-1859, Richard, 1978) was obtained for marine shells near Ottawa almost 800 km inland from the Gaspésie site. If these shell dates are an accurate indication of sediment age, inundation of St. Lawrence valley by the sea occurred quickly.

Elson (1962, 1969b; see also, Prichonnet, 1977; Hillaire-Marcel, 1979) has discussed the various phases of the Champlain Sea in the Montreal area, based on the abundance of marine pelecypods found in sediments at different elevations. He has recorded the following phases: 1) **Hiatella** phase – approximately 12.5 to 10.8 ka, deepest and coldest phase; 2) **Mya** phase – about 10.8 to 10.6 ka, gradually shoaling, intermediate boreal phase; 3) **Lampsilis** lake phase – after 10 ka, isostatic uplift led to formation of a lake upstream from Quebec City. With further differential uplift, the lake phase was gradually drained and St. Lawrence River became entrenched in the floor of the valley. Laurentide ice readvanced into the Champlain Sea shortly after 12.4 ka (12 400 ± 160 BP, GSC-1533, on shells of **Portlandia artica** underlying till, north of Quebec City; Lowdon and Blake, 1973) and glacier ice was still present north of Quebec City around 11.6 ka (11 600 ± 160 BP, GSC-1235, on shells of **Mya truncata**). Furthermore, field evidence and ^{14}C dating suggest that the ice readvanced into the Champlain Sea in the Quebec City area and west of it around 11-11.2 ka (11 100 ± 160 BP, GSC-1232; 11 200 ± 170 BP, GSC-1476; 11 200 ± 160 BP, GSC-1295; all three dates obtained on **Balanus** sp. or **Balanus hameri**) before the formation of the St-Narcisse Moraine (Fig. 2; see LaSalle et al., 1972; LaSalle and Elson, 1975).

The significance of the advance referred to as the St-Narcisse event (Fig. 2) which brought the Laurentide Ice Sheet locally into the St. Lawrence Lowland about 11 ka, has been debated for a number of years (Terasmae, 1959; LaSalle, 1965, 1966; LaSalle and Elson, 1975; Hillaire-Marcel et al., 1981). Only a short segment of the St-Narcisse Moraine between St-Raymond and St-Gabriel-de-Brandon and a segment in Malbaie river valley appear to have been built in the sea. On land, however, till ridges, ice-contact stratified drift, and outwash deltas related to this event have been traced from St-Siméon, near the mouth of Rivière Saguenay, more than 300 km to Lac Simon, north of Ottawa River. LaSalle and Elson (1975) argued that the St-Narcisse event represents a halt in retreat, with a period of equilibrium or minor readvance, which might correlate with the Valders Substage. Occhietti and Hillaire-Marcel (1977, p. 1, 2, 7) noted that the St-Narcisse advance corresponded in time with the cooling at the beginning of Dryas III (see also LaSalle, 1966). Hillaire-Marcel et al. (1981, p. 213) however played down the climatic significance of the feature and referred to it as a re-equilibrium moraine constructed on the southern margin of the Laurentide Hills, where the ice anchored itself following rapid retreat by calving in the Champlain Sea. The concept of equilibrium moraines may be valid for features such as the Sakami Moraine where the entire ice front terminated in the sea. It is questionable, however, whether the St-Narcisse Moraine could have formed by this mechanism because the ice margin was in contact with the sea in only two relatively restricted areas. Mott et al. (1981) suggested that tundra conditions still prevailed at some distance south of the ice front at the approximate time of the formation of the St-Narcisse Moraine in the Malbaie river area.

The ice had certainly retreated from the St-Narcisse Moraine by 10.3 ka (10 250 ± 250 BP, Gif-424, LaSalle and Tremblay, 1978) because the sea had entered the Lac St-Jean area on the proximal side of the moraine by this time (see discussion of Lac St-Jean area). Recently, Dubois and Dionne (1981) have reported on an ice frontal position (the Quebec North Shore frontal moraine system) that might be in part contemporaneous with the St-Narcisse Moraine ice frontal position; however, those frontal sediments, especially in the eastern part of the system, were probably deposited slightly after 10 ka.

Elson (1982) suggested that St. Lawrence River has occupied its present channel in the Montreal area since about 6.7 ka. In the Quebec City area, the surface waters appear to have been favourable for marine life until about 10 ka, (shown by the varied and abundant fauna at St-Nicolas, at an elevation of about 64 m: **Hemythyris psittacea**, 10 000 ± 150 BP, GSC-1451; **Mytilus edulis**, 9960 ± 150 BP, GSC-1508). Waters in the Quebec City area, however, appear to have been fresh enough by 9.7 ka to accommodate the freshwater species **Elliptio complanatus** (9730 ± 190 BP, GSC-1796).

CONCLUSIONS

Stratigraphic correlations are summarized in Figure 6 and are tied in with the basic stratigraphic sequence of Dreimanis and Karrow (1972).

Pre-Wisconsinan-age events are represented by the pre-Johnville sediments and paleosols which may be as old as Tertiary. Bécancour, Johnville, and Pointe St-Nicolas tills are thought to be Early Wisconsinan but they may be older. St. Pierre, Massawippi, and Anse-aux-Hirondelles sediments were probably deposited during an Early Wisconsinan interstadial but might be of late Sangamonian age. Gentilly and Quebec City tills in the middle and lower St. Lawrence valley are probably of Middle and Late Wisconsinan age but may in part be Early Wisconsinan; this suggests that these parts were continuously occupied by ice during Middle and Late Wisconsinan. Malone, Chaudière, and Norbestos tills of the upper St. Lawrence and Appalachian areas, are of Middle or late Early Wisconsinan age. The middle-till complex, Lac Chateauguay and Gayhurst sediments, and Ruisseau Perry Formation are possibly of Middle Wisconsinan age. Fort Covington, St-Jacques, Lennoxville, and Thetford Mines tills of the upper St. Lawrence and Appalachian areas are probably Late Wisconsinan. Varved sediments, Champlain Sea deposits, and a variety of ice-contact and local glacial deposits formed during Late Wisconsinan ice retreat.

The known Quaternary chronology is as follows: the St. Pierre and older units were deposited by at least 74.7 ka; the ice advance which followed St. Pierre probably did not occur before 74.7 ka but had possibly taken place by approximately 40 ka; the Middle Wisconsinan nonglacial events occurred before 20 ka; the Gaspé Bay coast was free of ice by 13.5 ka and the Champlain Sea had reached the Ottawa area by 12.7 ka; the Champlain Sea by 10 ka had been transformed into a shallow lake which was drained by 6.7 ka.

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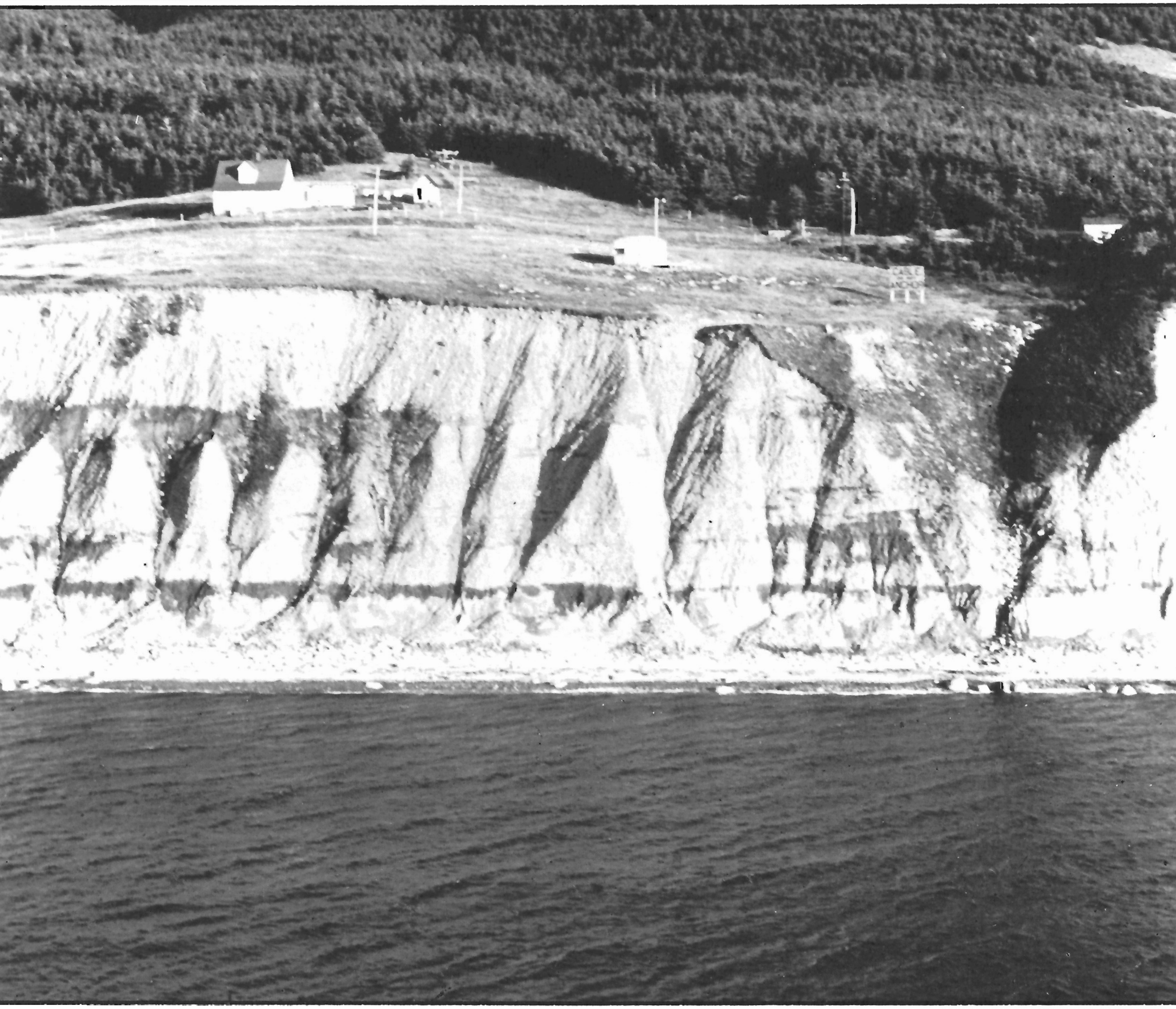
A STRATIGRAPHIC FRAMEWORK FOR THE QUATERNARY HISTORY OF THE ATLANTIC PROVINCES, CANADA



Bay St. Lawrence, northern Cape Breton, Atlantic Provinces: The dark toned unit near the base of the section is beach gravel and overlying peat, which is >38 ka old, with tundra/forest/tundra climatic cycle indicators. These sit on a raised intertidal platform (last interglacial?). The rest of the exposure consists mainly of rubbly gravel containing cold climate indicators with a silty sand lens containing allochthonous deepwater molluscs and microfossils occurring at the level of the top of the dark grey unit two-thirds up the section. Photo and stratigraphy by D.R. Grant, GSC 203504-J.

A STRATIGRAPHIC FRAMEWORK FOR THE QUATERNARY HISTORY OF THE ATLANTIC PROVINCES, CANADA

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Grant, D.R. and King, L.H., A stratigraphic framework for the Quaternary history of the Atlantic Provinces; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 173-191, 1984.

Abstract

Lithostratigraphic correlation of sedimentary sequences reveals a broadly parallel series of four glacial advances of varying provenance and vigour. In offshore sediments there is a comparable record in the form of calcareous foram-nanno ooze with intercalations of red and grey mud from which temperature conditions are inferred from microfauna, and glacial action is deduced from terrigenous input. Oxygen isotope variations provide chronometric control by correlation with the deep-sea standard back to stage 13.

Quaternary deposits are divided into three broad groups according to whether they underlie or overlie horizons assigned to the last interglacial stage.

Pre-last interglacial deposits are rare. On land they include patches of oxidized and cemented tills, sporadic remnants of deeply weathered bedrock as saprolites and colluvial beds on paleoplains, and degraded tills on ancient glacial terrains (termed Weathered Zones B and C) on summits above and beyond the reach of Wisconsinan glaciers. Offshore, pre-interglacial sequences are found on seamounts and abyssal hills, where the calcareous biogenic sediment is interrupted by two major effluxes of distinctive red terrigenous mud from Gulf of St. Lawrence during oxygen isotope stages 6 and 12. These signify the periods of greatest cooling and deepest glacial erosion, and are correlated with the tills of glacial maxima on land.

The last interglacial period onshore is recognized primarily by an elevated shore platform and associated littoral and fluvial gravels which grade vertically or horizontally to organic beds that indicate climates comparable to or warmer than those of the Holocene. Amino acid ratios on wood from 21 such deposits suggest that they all belong to one lengthy mild interval. Accordingly, the organic beds are referred to isotope stages 5a and 5e. An intervening cold phase, when small ice caps re-formed, is inferred from regression and weathering of marine beds, periglacial colluvium, and locally, thin tills. Offshore, core data reveal an interval when conditions were comparable to those of the Holocene in terms of microfaunal association; it spans a period as long as that of the last glacial stage and thus supports the hypothesis of a lengthy interglaciation of about 50 ka.

The last glacial stage onshore is represented in several areas by a consistent sequence of three superposed tills, locally separated by nonglacial sediments and truncated weathered horizons. The tills record three major glacial advances; the first is a distinctive red drift deposited by a regional (Shield-based?) ice sheet, the latter two are locally derived tills left by ice caps on uplands and emergent shelf areas. The advances are linked to cold stages 4, 3, and 2. Two major moraine-building phases are dated at 13 and 11 ka; a later climatic deterioration and/or readvance ca. 10-11 ka BP is inferred from diamicton over organics at 12 sites. Offshore the same three cool periods are inferred from alternations of arctic and subarctic microfaunal associations.

Thus both onshore and offshore sedimentary sequences represent broadly parallel series of glacial advances, retreats, and nonglacial intervals. Their inferred age and individual vigour seem to match the temperature variations recorded offshore by oxygen isotope fluctuations measured in core V30-97: a strong cooling in stage 6, two mild episodes of higher sea level with a cool interval during a lengthy stage 5, and three glacierizations in stages 4, 3, and 2. The correlation supports the hypothesis that northwestern Atlantic Ocean climate strongly influenced eastern North America glacier budgets, and both show an apparent 23 000-year cycle.

Résumé

La corrélation lithostratigraphique des séquences sédimentaires révèle une série plus ou moins parallèle de quatre avancées glaciaires dont la provenance et l'importance varient. Dans les sédiments marins, les vases calcaires à nannoforaminifères, dans lesquelles se trouvent des intercalations de boues rouges et grises, indiquent une histoire comparable; la microfaune révèle les conditions climatiques et les sédiments terrigènes, l'action des glaciers. La variation des concentrations en isotopes d'oxygène fournit un contrôle chronométrique en permettant d'établir une corrélation, jusqu'à l'étage 13, avec la normale océanique.

Les dépôts quaternaires se classent en trois grands groupes selon qu'ils sont sus-jacents ou sous-jacents aux horizons appartenant à la dernière période interglaciaire.

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Manuscript received: 1982-12-01
Final version approved for publication: 1984-02-24

Il est rare de trouver des dépôts accumulés avant le dernier interglaciaire. Sur terre, ces dépôts se composent de plaques de tills oxydés et cimentés, de restes épars de socle très altéré sous forme de saprolites et de colluvions dans les paléoplaines et de tills dégradés dans les anciens terrains glaciaires (appelés zones altérées B et C) sur les sommets hors de l'atteinte des glaciers du Wisconsinien. En mer, les séquences pré-interglaciaires se trouvent sur les guyots et les collines abyssales, là où deux grands écoulements de boue rouge terrigène caractéristique provenant du golfe Saint-Laurent ont coupé les sédiments biogéniques calcaires lors des étages 6 et 12 des isotopes d'oxygène. Ces sédiments représentent les périodes de refroidissement le plus marqué et de plus forte érosion glaciaire et correspondent aux tills des maximums glaciaires sur terre.

Sur terre, la dernière période interglaciaire est représentée principalement par une plate-forme littorale soulevée et par des graviers littoraux et fluviatiles associés qui se transforment verticalement ou horizontalement en couches organiques indicatrices d'un climat comparable à celui de l'Holocène ou encore plus chaud. Les rapports d'acides aminés déterminés à partir de morceaux de bois provenant de 21 de ces dépôts semblent indiquer que tous ces sédiments se sont accumulés au cours d'une seule période douce très longue. Les couches organiques sont donc baptisées étages 5a et 5e. Une période froide intermédiaire, caractérisée par le renouveau de petites calottes glaciaires, est déduite de la régression et de l'altération des couches marines, des colluvions périglaciaires et par endroits, de minces couches de till. Des carottes océaniques révèlent qu'il y a eu un intervalle caractérisé par des conditions semblables à celles de l'Holocène pour ce qui est des assemblages microfauniques; ce dernier a duré aussi longtemps que le dernier étage glaciaire, venant appuyer du fait même l'hypothèse selon laquelle se serait produit une longue période interglaciaire d'environ 50 ka.

Sur terre, le dernier étage glaciaire est représenté en de nombreux endroits par une séquence uniforme de trois tills superposés, séparés par endroits par des sédiments non glaciaires et coupés par des horizons altérés. Les tills révèlent qu'il y a eu trois grandes avancées glaciaires. Le premier till se compose de sédiments rouges distinctifs déposés par une nappe glaciaire régionale (provenant peut-être du Bouclier) et les deux derniers sont des tills dérivés localement et abandonnés par les calottes glaciaires sur les hautes-terres et les plates-formes émergentes. Les avancées sont liées aux étages froids 4, 3 et 2. Deux grandes étapes de formation de moraines datent respectivement de 13 ka et de 11 ka; une couche de diamicton recouvre les sédiments organiques à 12 endroits, indiquant que, par la suite, il y a eu détérioration du climat, nouvelle avancée de la glace ou les deux. En mer, les trois mêmes périodes froides sont déduites de l'alternance des associations microfauniques arctiques et subarctiques.

Les séquences sédimentaires terrestres et marines représentent donc des séries grossièrement parallèles d'avancées et de retraites glaciaires et d'intervalles non glaciaires. L'âge et l'importance de chaque événement semblent correspondre aux fluctuations de la température enregistrées en mer par la variation de la teneur en isotopes d'oxygène relevée dans la carotte V30-97; refroidissement marqué au cours de l'étage 6, deux épisodes plus doux marqués par un niveau plus élevé de la mer et séparés par un intervalle froid au cours du long étage 5, et trois épisodes glaciaires au cours des étages 4, 3 et 2. La corrélation appuie l'hypothèse selon laquelle le climat de la partie nord-ouest de l'océan Atlantique ait eu une forte influence sur les bilans glaciaires de l'est de l'Amérique du Nord; les deux séquences indiquent un cycle apparent de 23 000 ans.

INTRODUCTION

Scope and Purpose

This report correlates lithostratigraphic sequences on the land areas of the Atlantic Provinces. From the sedimentary succession a series of glacial and nonglacial intervals is inferred, and for these a number of local and regional terms for stades and interstades, glaciations and interglaciations is proposed. It also links the terrestrial sequence to various facies of marine sedimentation on the continental shelf and slope, and on seamounts on the abyssal plain. From this, three major temperature events can be discerned. The sequence is compared with the classical mid-continent climatostratigraphic scheme and certain significant differences emerge. Looking seaward, a better correlation is evident with the oxygen isotope temperature history based on deep-sea cores from the northwestern Atlantic Ocean.

The state of knowledge of Quaternary lithostratigraphy and the prevalent concepts of climatostratigraphic and chronostratigraphic correlation are outlined, based on the results of 100 years of geological exploration, although much of the evidence has been acquired comparatively recently. The work of many individuals has been incorporated in the body of data considered here, but only the major and most recent works and summaries can be acknowledged. As well, no attempt is made to consider and argue all the manifold possible hypotheses that bear on the topic. Presented here, therefore, is a synthesis of the critical facts and an interpretation of the broad lines of correspondence between the diverse records. King contributed the synthesis of the work on the Scotian Shelf by him and his colleagues, and Grant wrote the rest of the report.

Physiographic Setting

The Atlantic Provinces region belongs mainly to the Appalachian physiographic province. The land areas consist of two main terrains: One is characterized by broad rolling lowlands within 100 m of sea level that are developed largely on folded Carboniferous clastic rocks cut by tortuous valleys. The other rises abruptly from the lower terrains as fault-bounded pre-Carboniferous crystalline massifs that form steep-sided, deeply dissected uplands and highlands whose flat summits range from 400 m in the south to 1000 m in the north. The region is bounded on the north by the Precambrian Shield, and fringed by a broad shelf underlain mainly by flat-lying Mesozoic and Cenozoic strata. The resistant uplands have thin or absent glacial deposits, but nonglacial deposits are locally thick along their flanks. More voluminous deposits occur mainly over the lowlands, particularly over shaly and karstic areas; preglacial valleys oriented transversely to ice flow are deeply buried.

Surface features, however, give little evidence of the sequences that may lie at depth. Stratigraphic studies are thus dependent on sections resulting from fluvial dissection and coastal retreat, and on artificial excavations for gypsum, limestone, and coal.

Offshore, glaciated parts of the shelf have simple sedimentary sequences, with the addition of subaquatic facies reflecting changes from grounded glaciers to ice shelves to floe ice. Distal shelf areas which may not have been overrun by glaciers present an ambiguous record. Nonetheless, the stratigraphy has been well documented by means of systematic seismic profiling. Deep-sea areas contain mainly the distal products of terrestrial processes, notably glaciation; by links with the shelf record these sediments can be indirectly deciphered.

Chronometric Control

The nature and reliability of chronometric control vary regionally. On land, till members are linked to recognizable glacier-flow events and are correlated lithologically and with reference to intertill organic beds which, although beyond the limit of radiocarbon dating, can be provisionally correlated using aspartic acid racemization ratios (D.R. Grant, R.J. Mott, and N.W. Rutter; unpublished data). Offshore, additional control comes from microfaunal zonation and extinctions, paleomagnetic signature, and oxygen isotope variations.

Glacial Style

Three intrinsic features of the area, recognized in part as a result of stratigraphic studies, have determined the main attributes of the Quaternary sedimentary sequence and its particular preservation, and therefore have a bearing on the process of correlation. The distribution of surficial deposits and the preservation of older sequences is attributed to the style, vigour, and extent of glacierization and to its interplay with the topographic diversity of the region and with contrasting bedrock terranes. The prime factor has been the style of glacierization. It is now accepted by most that two ice domains affected the area during glacial periods. The southern part of the region supported the Appalachian Glacier Complex (Prest, 1970, this volume) – a family of local independent dispersal centres, two of which were centred offshore during early stages. These small maritime ice caps centred at a range of elevations, merged in complex ways at different times, and produced mainly locally derived tills. On the north, the inland continental Laurentide ice sheet invaded the area irregularly (northern Newfoundland, Magdalen Islands, Gaspésie) during maximal phases and joined the local ice cap complex so as to set up a regional ice gradient and leave thick tills of northern provenance. In contrast with the single ice-domain regime in mid-continent areas, the Atlantic region had several ice centres which created mainly local sequences which may not necessarily have developed contemporaneously.

Secondly, the number of small ice caps reflects the general weakness of glacierization. As a result, successive advances were of greatly varying extent. There is compelling but still circumstantial evidence that at times parts of the region were not overrun. In fact some uplands of Newfoundland and Gaspésie were never glaciated. This complicates correlation because sequences may start and end with different glacial events, and in places nondepositional conditions may have prevailed for lengthy periods.

Thirdly, the moderately high relief and the number of major topographic irregularities, particularly the deep marine embayments, produced greatly varying conditions of glacial erosion and deposition so that there remains a patchy mosaic of thick and thin till sheets of divergent provenance. As well, quite varied assemblages of several facies are found. Few marker beds occur, and the difficulty is thus to recognize regional similarities through a maze of local variations. On balance these three situations have produced a multiplicity of strata which, because of paucity of chronometric control, have complicated the correlations.

DEVELOPMENT OF A REGIONAL STRATIGRAPHIC SCHEME

This correlation is the latest and most ambitious in a series, which began with Grant (1963, 1976), Prest (1977), Dreimanis and Grant (1977), and Dreimanis et al. (1981); they were concerned solely with the terrestrial record from a smaller area. This report links diverse stratigraphic information from all parts of the region and advances certain new concepts on Quaternary processes peculiar to this maritime area.

The Terrestrial Sedimentary Record

Until recently the stratigraphic record consisted of a few scattered exposures of superposed sediments of unknown age and significance. Multiple tills and intercalated nonglacial sediments had been reported from Nova Scotia by Prest (1896), Wickenden (1941), MacNeill (1969), and Mott and Prest (1967), and from Newfoundland by Van Alstine (1948) and Widmer (1950). In New Brunswick and Prince Edward Island the sequence consisted simply of one till and its accompanying deglacial deposits. The advent of systematic surficial geological mapping in the four provinces however has made it possible to deduce, from the pattern of crosscutting glacier-erosional markings, a sequence of ice movements, each with its corresponding till deposit, for large areas within the region. To these could be related the rest of the fragmentary sedimentary record, including nonglacial deposits. With the help of several newly discovered exposures where several events are recorded, it has been possible to erect an internally consistent lithostratigraphic and climatostratigraphic sequence for the region.

The present process of stratigraphic synthesis and re-evaluation began with summaries mainly for Nova Scotia by Prest (1970) who catalogued the sequences and who, like Prest and Grant (1969), attributed all glacial movements and hence all deposits to the "Classical" or Late Wisconsinan period. Systematic mapping in Cape Breton Island and stratigraphic studies in southern Nova Scotia culminated in speculative correlation charts by Grant (1975a, 1976) and by Prest (1977) who assigned deposits to the last interglaciation and to several Wisconsinan substages. Nielsen (1976), however, argued that all deposits are "Classical" or Late Wisconsinan in age. Concurrent work in Newfoundland (Grant, 1975b, 1977a) and detailed studies of thick sections along the Yarmouth-Digby coast of Gulf of Maine (Grant, 1980) revealed evidence of subaerial exposure between tills in the form of truncated weathered profiles and nonglacial sediments which suggested a tripartite division of supposed Wisconsinan-age deposits. The assignment of these beds to the Wisconsinan was, and still is, based on the fact that all the beds, together with their corresponding ice-flow indicators, are superposed and inscribed on a marker horizon of assumed last interglacial age. Similar relationships are the basis of the glacial history of New Brunswick developed by Rampton et al. (1984).

That single datum which serves as the only reference point for chronostratigraphic control is a raised coastal rock platform, of intertidal origin with associated littoral gravel, that occurs throughout the region 2-6 m above present tide level. It has been found around much of Nova Scotia, southern Newfoundland, and in parts of New Brunswick and Gaspésie. In places such as the Magdalen Islands, Cape Breton Island, and Yarmouth area a lower platform and beach are inset into the main one. In view of the wide occurrence, the anomalous weathered condition at many places, and the parallelism with present interglacial sea level, the two paleoshores are assigned to the last interglacial period (Grant, 1981). On the basis of 1982 field work by Grant on the Magdalen Islands, which revealed that the higher beach is associated with a warm-climate organic bed, the beaches are referred, respectively, to the two mild phases of the last interglaciation, that is to stage 5e and stage 5a, respectively, which have been dated elsewhere in the world at approximately 125 and 80 ka.

Ice-free periods are recognized primarily by nonglacial sediments between or under tills. In the Atlantic region most such beds are organic and lie below a triple-layer till sequence. All are beyond the range of radiocarbon dating (>50 ka). Paleoecologically they range from as warm as, or warmer than, the present to cool, boreal-forest type conditions. Most of the deposits span relatively short intervals so it is uncertain how many separate events are represented. Stratigraphic relations point to two main periods of organic accumulation, the earlier being warmer than the second. Beds belonging to the cooler period outnumber those from the warmer by ten to one, but this may simply be a function of the fact that wet boreal paludal environments produce thicker, more extensive peat deposits than do deciduous forests. The stratigraphic position of the beds is inferred from three relationships: some of the peats are clearly of interglacial rank based on temperature; most are part of, or overlie, the marine littoral formations of assumed last interglacial age; all underlie the sequence of three tills which are thought to record the last full glacial stage. All, therefore, predate the Wisconsinan glacial stage and are presumed to belong to the last interglacial stage. According to its local stratigraphic relation, each organic bed is referred to one or the other of the two mild intervals, corresponding to oxygen isotope stages 5a and 5e.

The distribution of nonglacial indicators gives a general idea of the extent of ice retreat. This in turn can be compared to hypotheses of ice limits based on glacier-marginal deposits that abut more mature, i.e. more weathered and hence longer exposed glacial terrains beyond. By this "weathering zone concept" three major ice advances are recognized: the last is Late Wisconsinan; the first (and greatest) failed to overtop the highest summits in Newfoundland and Gaspésie (Fig. 1). This zonation has not been adequately tested by pedostratigraphic studies and, although there is evidence of subaerial exposure between the till sheets in the form of truncated paleosols, the weathering intervals are not yet linked conclusively to the nonglacial depositional intervals.

The Submarine Sedimentary Record

On the continental shelf the Quaternary sequence differs from that on land in composition and structure and has been studied in different ways, with different results. Systematic seismic profiling over most of the shelf has provided a well controlled conception of the total Quaternary sequence. Sampling has largely confirmed the textural and genetic interpretations. In some respects, then, the marine Quaternary is better known than its terrestrial counterpart. The coverage is more uniform and consistent, and sedimentary units can be identified reliably, their horizontal and vertical contacts located precisely, and their extent traced visually. To date, deposits of the last glacial stage are well known, and one earlier event has been identified. The extent of ice, whether as a grounded glacier, ice shelf, ice rise, or drift ice has been inferred from the various facies of glacial, glaciomarine, and marine sediment that have been mapped and sampled. Although the glaciers moved generally from land to sea, the respective tills are not yet linked between the two areas.

From the continental slope and rise, from seamounts, and from the abyssal plain comes perhaps the most crucial component of the correlation scheme. These deep-ocean records provide a good approximation of the absolute temperature change of which glaciation is the most dramatic terrestrial manifestation. Moreover, because they are far removed from local continental influences, they provide an independent representation of the tempo, vigour, and extent of glaciation in terms of the provenance and biotic composition of the fine pelagic detritus. The sedimentation rate is slow, particularly on seamounts where a few cores have a record that spans the last several hundred thousand years. While the chronometric control is loose because of few definitive age determinations, the sequence is nonetheless fairly well documented by a variety of independent criteria, such as paleomagnetic and microfaunal markers, and oxygen isotope variations. By these means the upper part of the slope and seamount sequences is calibrated against the record of the last 100 ka of sedimentation on the shelf and has been extrapolated back to oxygen isotope stage 13 (ca. 500 ka). Thus these deep-sea records give evidence of the last several full glacial stages which can be semi-quantitatively compared in style and vigour to the last glaciation as it is known from the land and from the continental shelf. The final component and step in the correlation is a comparison of the lithostratigraphy of the continental margin with the oxygen isotope temperature history from the deep-sea abyssal plain. The rationale for setting a temperature curve against the sediment sequences is the assertion by Ruddiman and McIntyre (1981, p. 623) that because the southeastern extremity of the Laurentide ice sheet is the most proximal to the northwestern Atlantic core site, and because that part is most sensitive to insolation cycles, then the growth and decay of ice in Atlantic Canada could be related to the tempo of sea-surface temperature responses, as recorded by oxygen isotope analysis of foraminifera in deep-sea cores. Indeed, a correspondence seems evident; its basis is outlined in Table 1.

The Correlation Table

This report is primarily a discussion of sedimentary sequences from which is derived Table 1 which lists all published stratigraphic terms, plus some new informal appellations introduced for discussion purposes. Also included are: offshore microfaunal lithofacies zones; certain morphostratigraphic features such as dated major end moraines; pedostratigraphic horizons in the form of buried, and commonly truncated, alteration profiles; and a hybrid class, called Weathered Zones, which are variably degraded glacial terrains that represent the areas covered by pre-Late Wisconsinan glaciers at several different times. All provide corroborative evidence of a series of glacial and nonglacial events. To this event sequence a number of local climatostratigraphic labels are applied.

In the absence of finite dates (all are either late glacial or "greater than"), age assignment of the entire column has depended on the inferred age of a littoral marker horizon and associated organic beds, which are believed to be coeval and to date from the acme of the last interglacial stage (i.e. the type Sangamonian and oxygen isotope stage 5e) ca. 125 ka. Beds indicating slightly cooler climate and lower paleoshores in the same general stratigraphic interval represent other phases in the range of conditions that prevailed until stage 5 ended ca. 73 ka. Hence the Sangamon Interglaciation is broadly equated with oxygen isotope stage 5. On that basis deposits and events are treated under three main categories: those that predate the last interglaciation; those of the last

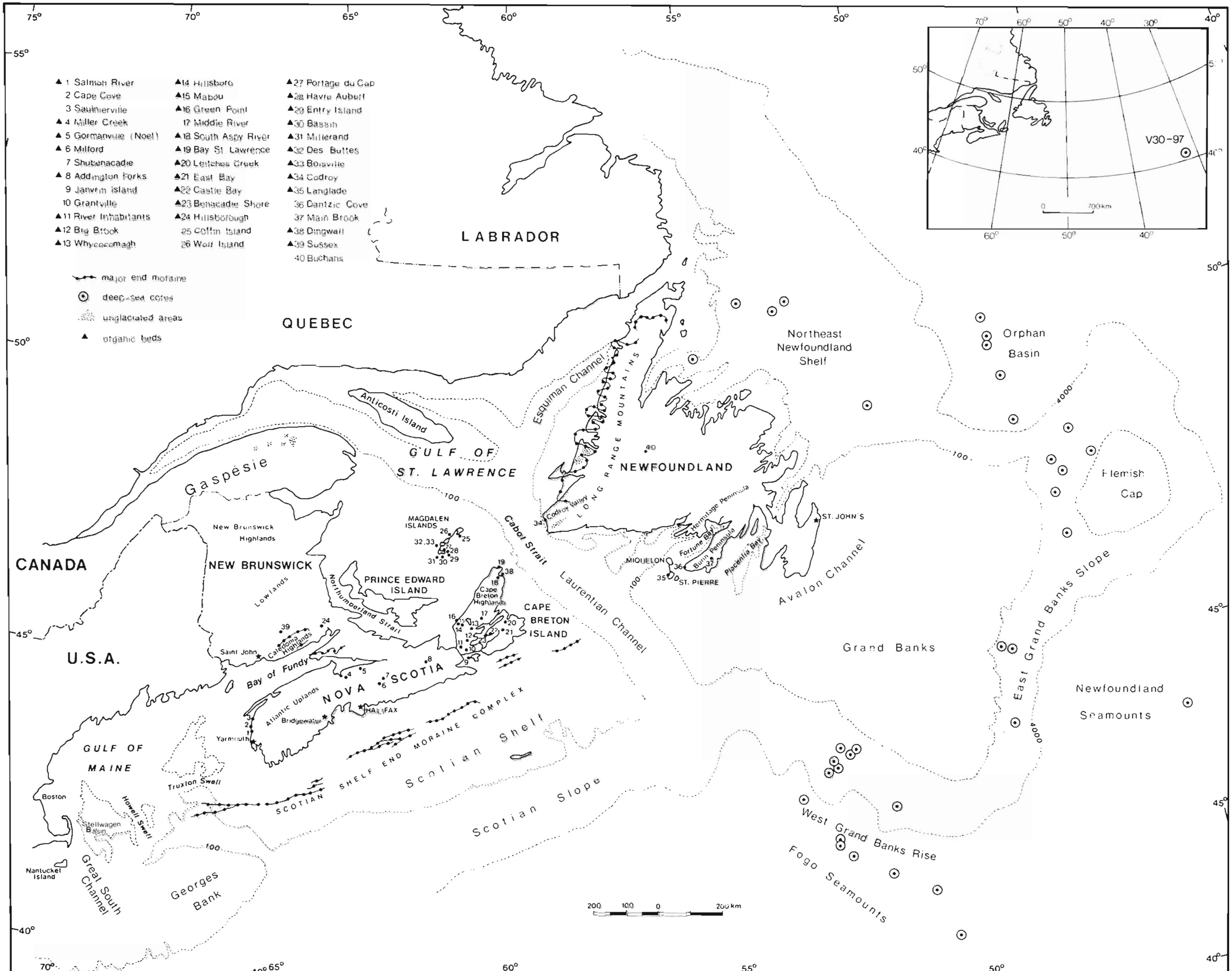
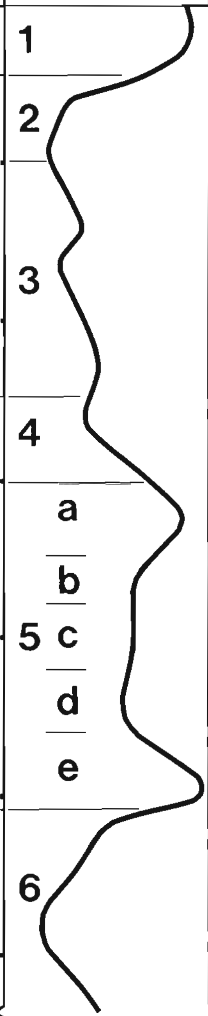


Figure 1. *Index map showing locations of major studied stratigraphic sections including offshore core sites, major end moraines, and selected physiographic features.*

Table 1. General correlation chart of lithostratigraphic units in the region



CHRONOLOGY: ka	OXYGEN-ISOTOPE Stages [1]	CONT'L SLOPE, SEAM'TS [2] (Unit)	SCOTIAN SHELF [3]	NOVA SCOTIA [4]: SOUTHWEST	NOVA SCOTIA: CENTRE	NOVA SCOTIA: CAPE BRETON ISLAND	NEW BRUNSWICK [5]	MAGDALEN ISLANDS [6] GULF ST. L.	NEWFOUNDLAND [7]: WEST COAST	NEWFOUNDLAND: BURIN PEN.	LABRADOR [8] TORNGAT MTS. SHELF	CLIMATO STRAT. [9]: N.S.	CLIMATO STRAT.: NL.	CHRONO-STRAT. [10]
0–11	1	A	Lahave Clay / Sable Is Sand and Gravel	Amherst Silt	Amherst Silt; diamicton; organic beds: 10 – 11 ka	diamicton; organic beds: 10 – 11 ka			Ten Mile Mor; Robinson's Head, Piedmont and Bradore Moraines		Shepard Moraines	ACADIAN GLACIATION	TERRA NOVAN GLACIATION	HOL.
11–25	2	B1 (arctic); B2 (subarctic)	Sambro Sand; End Moraine (ice shelf)	Port Maitland Gravel; Beaver River Till	Five Is Fm Rawdon Till; Bennett Bay Till	Till	Saint John End Moraine; BANTALOR PHASE		St. Georges Bay Drift	Till	Tasiuyak Mor.; Saglek Mor.	Scotian Stade	Burin St.	WISCONSINAN: LATE
25–62	3	B3 (arctic); B4 (subarctic)	Emerald Silt; Scotian Shelf End Moraines	Soil; Salmon River Sand 38.6?; Saulnierville Till; Soil; Cape Cove Gravel	Hants Till; Eagles Nest Clay	Big Brook Organic 36.2? mastodon 31.9ka?; Shelly Till; Soil	Hillsborough mastodon 37.3 ka?; CHIGNECTO PHASE; Soil	Coffin Island Moraine; Demoiselle Drift	Weathered Zone A	Langlade Silt?	Cartwright Mor.; Saglek W.Z.	Digby St.; St. Clare I/st.		WISCONSINAN: MIDDLE
62–75	4	B5 (arctic)	Scotian Shelf Drift (ice sheet)	Red Head Till	East Milford Till	Richmond Till	CALEDONIA PHASE	Till	Weathered Zone B	Garnish Till; Upper Burin Till	Mid-Bank Moraines	Fundy St.	Fortune Stade	WISCONSINAN: EARLY
75–	5 a, b	B6 (subarctic, Holocene)			ORGANIC BEDS Miller Creek, East Milford ?	ORG. BEDS: Dingwall, Bay St. Lawrence, Eskasoni, Leitches Ck B, Mabou, River Inhabitants, Benacadie, Hillsboro		ORG. BEDS: Bassin, Havre Aubert, Entry I, Millerand, Des Buttes, Boisville; raised beach				Cabot St.; D'Or I/st.; Bras		SANGAMONIAN
100	5 c			Little Brook Till	Miller Creek Till	Colluvium Till		Soil	Soil	Soil		MAGDALEN I/GL.; Isle Royale Interstade		SANGAMONIAN
	5 d	B7 (<arctic)		ORGANIC BEDS Barton Silt, Salmon R. Sand Sandford Gravel	ORGANIC BEDS East Milford, Addington Forks, Noel ?	ORGANIC BEDS Green Pt, Mabou, East Bay, Leitches Ck A, Big Brook A, raised beach		ORGANIC BEDS Portage du Cap, Wolf Island Conglomerate, raised beach	Codroy Beds	Langlade Silt				SANGAMONIAN
125–128	5 e	?							raised beach	raised beach				SANGAMONIAN
128–150	6	RED MUD (coldest water)				Colluvium		erratics in lag gravels	Weathered Zone C	Main Brook Till	Shelf Edge Mor.; Koroksoak W.Z.		VINLANDIAN GLACIATION	ILLINOIAN: LATE
	12, 13	RED MUD; *P. lacunosa* zone		Bridgewater Conglomerate	Bridgewater Conglomerate	Mabou Conglomerate					Torngat W.Z.		VINLANDIAN GLACIATION	ILLINOIAN

References:

[1] Ruddiman and McIntyre (1981)
[2] Alam and Piper (1977)
[3] King (1980)
[4] General: Grant (1963, 1975), Prest (1977)
West: Grant (1980)
Centre: Stea (1982)
CBI: Grant (unpublished)
[5] after Rampton and Paradis (1981a,b,c), Rampton et al. (1984)
[6] D.R. Grant, V.K. Prest, R.J. Mott, L.A. Dredge (unpublished data);
[7] after Grant (1977a,b), Brookes (1977), Tucker and McCann (1980)
[8] Grant (1980)
[9] Dreimanis and Karrow (1972)

For comparison the oxygen isotope (or "ice-volume proxy curve") and ^{14}C-U/Th time scales are set separately, showing the correlation proposed in this report. A tentative climato-stratigraphic scheme for the region is given, set against the classical mid-continent chronostratigraphic subdivision of the Quaternary.

interglaciation in the sense of isotope stage 5, and those of the last glacial stage, or younger than 73 ka. The oldest group consists of scattered, deeply weathered deposits, mainly tills of obscure age. The interglacial group includes various nonglacial sediments, mainly a suite of organic beds, which indicate climatic conditions or sea levels with ranges comparable to the Holocene interglacial stage. The last glacial group comprises most of the deposits and is mainly in the form of till sheets stacked upon the last interglacial beach.

DEPOSITS PREDATING THE LAST INTERGLACIATION

Offshore Areas

Deposits most reliably assignable to this age are largely confined to submarine areas. They are known mainly from cores in sediments on the continental slope off the Grand Banks and on nearby seamounts and abyssal hills (Alam and Piper, 1977; Alam et al., 1983). They correlated individual beds by lithological and biostratigraphic markers, by warm-cold cycles in microfossil assemblages, and by two magnetic events. The lower parts of several cores are referred to oxygen isotope stage 6, and a few are as old as stage 13 on the basis of limited oxygen isotope and ^{14}C data. They recognized a marker bed of thick red terrigenous mud deposited during oxygen isotope stage 6 when foraminifera indicate the coldest water conditions. They attributed the red layer to major glacial excavation of the Gulf of St. Lawrence which is mainly underlain by Permo-Carboniferous redbeds. Deep-sea sedimentation thus suggests that the Illinoian Stage was a time of maximal glaciation in the region. A comparable glacierization evidently occurred in stage 12. The above authors depict glaciers as having extended well out onto the shelf at least twice in pre-Sangamonian times, but no tills produced by these events have yet been recognized in submarine areas.

Terrestrial Areas

On land there are few deposits that are known with certainty to predate the last interglaciation. All indications of their antiquity are indirect. The most familiar candidate is the Bridgewater Conglomerate - an iron-cemented glacial drift and outwash found in patches along the Nova Scotia Atlantic coast. Its age has been variously inferred as Carboniferous (Honeyman, 1882; Poole, 1903), Tertiary (Sage, 1959), and Recent (Bailey, 1896). Its northern erratics and striated stones led Prest (1898) to assign an "early Pleistocene" age. Grant (1963) and Prest et al. (1972) showed that it had been lithified before being truncated by, and incorporated as clasts in, the oldest of three Wisconsinan tills. The several metres of deep oxidation and kaolinization, compared to 0.5 m-thick Holocene soils, indicate that it has passed through at least one lengthy period of interglacial pedogenesis. For this reason it is considered pre-Sangamonian. At Green Point (16 of Fig. 1) in Cape Breton Island a similar iron-rich lithified gravel, the Mabou Conglomerate, is truncated by a marine abrasion surface and is overlain by warm-climate peat, both of which are presumed to be of last interglacial age.

Indirect evidence of pre-Sangamonian glaciation and attendant tills is given by the erratics of northern provenance which occur in a raised beach of presumed last interglacial age on Magdalen Islands. Ancient tills, recognized by deep oxidation and weathering are known mainly on Burin Peninsula, Newfoundland (Van Alstine, 1948; Walthier, 1948; Grant, 1975b); 'Main Brook Till' is the best example. As the alteration is several times deeper and more advanced than that on Late Wisconsinan tills in the same area, Tucker and McCann (1980) proposed an Early or pre-Wisconsinan age. The latter is more likely in view of the lengthy nonglacial interval implied by the more than 5 m of pervasive chemical degradation.

On similar grounds, deposits of comparable antiquity are inferred to underlie certain high areas and, by virtue of their mature and degraded surface condition and position above and beyond the inferred glacial limit of the Late Wisconsinan, they are considered to predate the Late Wisconsinan (Grant, 1977a; Brookes, 1977). Two such pre-Late Wisconsinan terrains, including degraded till beds, designated Weathered Zones B and C, are recognized. Estimates of their age vary; the younger has been provisionally given an Early Wisconsinan age, and the older pre-Wisconsinan.

It may be noted that the oldest relicts, although not strictly deposits, are found on the uppermost of these ancient glaciated (or locally never glaciated) surfaces (Coleman, 1926; Brookes, 1977). Forms of strongly altered bedrock such as deep saprolites and regolith have been found on the Cape Breton Highlands (Grant, 1975a; McKeague et al., 1983) and on New Brunswick Highlands (Gauthier, 1980b; Wang et al., 1981; Rampton et al., 1984). Their situation on largely unmodified Tertiary peneplains (Mathews, 1975) and similarity to soils normally associated with warm temperate to tropical climates suggest perhaps that they were formed under conditions differing significantly from those of Quaternary interglaciation. Hence they are probably pre-Wisconsinan and may be pre-Quaternary. On the other hand it may be argued that they represent the result of longer-continued, less vigorous Quaternary alteration. The question is thus whether the alteration represents antiquity or longevity.

In summary, from the fragmentary sedimentary evidence of probable pre-last interglacial age, both onshore and offshore, it has been inferred that maximal glaciations, during which ice reached almost to the highest summits and almost to the edge of the continental shelf, occurred during oxygen isotope stages 6 and 12.

DEPOSITS OF THE LAST INTERGLACIATION

The basic premise is that the last interglaciation in climatostratigraphic terms is considered to equate with oxygen isotope stage 5 of the deep-sea chronology and hence to span a lengthy interval between 125 and 75 ka ago. With reference to the temperature curve on Table 1 this interval comprised two warm interludes which were separated by a distinctly cool period that, all other things being equal, was evidently comparable to conditions at about 11-12 ka when small ice caps lingered in the region. In a stable maritime area, sea level position is also relevant, so an elevated shore, corresponding to oxygen isotope stage 5e when world sea level is known to have stood some 4-6 m above present, is also to be expected. Every part of the region, both onshore and offshore shows clear evidence of this long warm interval of higher sea level. In this scheme deposits are therefore assigned to the last interglaciation providing they predate or underlie the oldest tills of the last glacial stage and also meet the criteria of mild climate and high sea level.

Offshore Areas

The only record of pre-Wisconsinan sedimentation comes from cores from the Fogo Seamounts and Newfoundland Basin where the facies alterations have been correlated with the standard North Atlantic temperature curve at least back to oxygen isotope stage 6 (Alam et al., 1983). The last interglaciation is thus bracketed between two cold periods and is recognized as a biostratigraphic interval comparable to the Holocene in terms of foraminiferal assemblages. Specifically, the interglacial muds are calcareous foram-nanno ooze whereas the glacial-age sediments are mainly red, brown, and grey terrigenous muds. As further support for their stratigraphic assignment the biogenic sediments reflect generally the same current and water-mass distribution as prevails during the present interglaciation. Moreover, they make up about one-half of the sediment thickness since stage 6, which is consistent with the hypothesis of a 50 ka warm period and an equally long glacial period. Finally, most cores show clearly that there were two temperate periods of deposition separated by a period of arctic character; this accords with the general structure of stage 5. On all points the last interglaciation seems well documented in deep sea muds and thus provides a primary horizon for the subdivision of the Late Quaternary offshore.

Terrestrial Areas

The differentiation of the last interglaciation from the last glaciation is even more conspicuous on land. The lowest tills of the surface succession in many places rest on a variety of organic beds of both warm and cool character, and upon an elevated littoral rock platform and associated pebble beach. The raised shoreline is perhaps the more useful regional stratigraphic datum because of its wide regional extent. Its 2-6 m elevation accords well with the global average elevation of the last interglacial highest sea level, as dated in many parts of the world. There are however vague indications, such as in southwestern Nova Scotia and Cape Breton Island, that two platforms may actually be involved -- a lower one at about present tide level which is inset into the higher one. On Magdalen Islands, where the high interglacial sea is recorded by tombolo formations comparable to the modern ones, there are two superposed raised beach-gravel units, separated by organics and/or lagoonal silt; the lower, older gravel is much more weathered than the younger (D.R. Grant, unpublished data). Thus, both high sea level events of the last interglaciation, corresponding to oxygen isotope stages 5a and 5e, may be represented.

Only two marine beds contain fossils that indicate interglacial or warm-temperate climatic affiliation. Unfortunately neither can be tied to the assumed interglacial paleoshore or to terrestrial organic beds. The most controversial deposit is the Salmon River Sand near Yarmouth (1 of Fig. 1). Its molluscan fauna, including the extinct gastropod **Atractodon stonei**, indicates a sea that was warmer and higher than at present. Accordingly the bed was first assigned to the Sangamon Interglaciation by Clarke et al. (1972), notwithstanding a finite radiocarbon date of 38 600 ± 130 BP (GSC-1440). Later, a concordant U/Th date of 40-44 ka and studies by Miller (1973) and Nielsen (1974), which revealed that the sand bed is interbedded with the upper part of the Red Head Till, led Grant (1980) to re-assign it to a Middle Wisconsinan, deglacial submergence. A closer examination of the sand/till contacts, however, has revealed that the sand bed had been glacio-tectonically emplaced along a parting plane in the upper part of the till. This reconciles its warm paleoecological affiliation with its apparent intratill position and supports the original interpretation that the sediment was deposited offshore during a warm marine interval. It is here correlated (by DRG) with the acme of the last interglacial period (stage 5e); on the other hand, it may represent a Middle Wisconsinan event (LHK). The other is a silt at Langlade (35 of Fig. 1), Miquelon Island (France), and correlatives at nearby Dantzic Cove (36 of Fig. 1), Burin Peninsula, Newfoundland. Tucker and McCann (1980) refer the Langlade silt (35) to the Middle Wisconsinan on the basis of an apparent similarity of foraminifera with the Salmon River Sand which they presume to date ca. 38 ka. The correlation may be valid, but in view of present ideas on the age of the Salmon River Sand (see above), the Langlade silt is more likely last interglacial (or older).

The organic beds however represent a more definitive stratigraphic interval because they are more numerous, underlie the main till sequence, and provide direct sedimentary and paleoecological information on climatic variation during the period. There are 32 such occurrences (Fig. 1) and all are beyond the range of radiocarbon dating (ca. 55 ka). All either underlie the lowest till of supposed Wisconsinan age or overlie the raised platform (or related fluvial gravels) and are part of the associated littoral sediments. Some 100 racemization ratios on aspartic acid in wood from these beds suggest that indeed they all belong to a single lengthy period (D.R. Grant, R.J. Mott, and N.W. Rutter, unpublished data). The organic beds are thus regarded as a single suite; each represents a short interval within the two relatively warm episodes of high sea level, either when paludification of coastal regions was at a maximum or when boreal peat was accumulating over the exposed, poorly drained, foreshore flats during the early phases of cooling and regression.

In support of the notion, gained from the Magdalen Islands where two raised beaches and both warm and cool organic sediments are found, that the last interglaciation is represented by a complex of organic beds from two mild interludes separated by a cold period, is the record from two boreholes which penetrate two organic beds separated by till. Prest (1970, p. 680) reported that at Leitches Creek (20 of Fig. 1) the lower organic unit is interglacial in character and the upper is "interstadial" (cool climate). At Noel (5 of Fig. 1) a comparable record is cited by Stea (1982, p. 156). As to the intervening till, it may be noted that glacial conditions could have prevailed during the long cool interval in the middle of the last interglaciation if temperatures during oxygen isotope stages 5b, c, and d were indeed as frigid as during 11-12 ka, as the oxygen isotope record (Table 1) suggests. Stea and Hemsworth (1979) have interpreted the deposit at Miller Creek (4 of Fig. 1) while Mott et al. (1983) documented the best known deposit, that at Milford (6 of Fig. 1) which they said records the 'end of an interglacial period, when a temperate hardwood forest was replaced by a coniferous forest as the climate deteriorated'. It is therefore tentatively concluded that most if not all the subtill organic beds in Atlantic Canada belong to the last interglaciation and that they mainly relate to the two major periods of climatic amelioration ca. 80 and 125 ka.

In consideration of the good stratigraphic basis for recognition of the last interglaciation in Atlantic Canada, new climatostratigraphic terms are proposed. Because the most definitive evidence of two warm episodes of higher sea level comes from the Magdalen Islands, the nonglacial interval corresponding to stage 5 may be termed the Magdalen Interglaciation. The two mild phases, which are the main features of the interglaciation, are best expressed by the numerous organic beds so well exposed in Cape Breton. Therefore for the earlier interstade, Isle Royale, as the original name of the island, is favoured; for the latter Bras D'Or, after the lake around which many are exposed, is chosen.

DEPOSITS FROM THE LAST GLACIAL STAGE

Sediments representing the last glaciation, traditionally referred to as the Wisconsin, are recognized by their superposition on deposits assigned to the last interglaciation. Providing the latter have been correctly identified and dated as outlined in the foregoing section, a thick sequence of tills together with intertill sediments appears to record several Wisconsinan-age glacial fluctuations. In the Maritime

Provinces and southern Gulf of St. Lawrence region an internally consistent sequence of three glacial advances has been recognized in several widely separated areas on the basis of superposed ice-flow indicators, and separate till sheets related to each event have been found in several areas. These are the basis of the hypothesis that the last glaciation featured separate accumulation centres. For Newfoundland only the beginnings of a comparable ice flow and till sheet sequence is emerging, mainly from work on the Burin Peninsula by Tucker (1979) and in the central uplands by Vanderveer and Sparkes (1982). Correspondence with the sequence in the Maritime Provinces therefore remains conjectural. Consequently each part of the region is discussed separately and from this, regional climatostratigraphic intervals are proposed.

Nova Scotia

The generalized stratigraphic section for Nova Scotia, shown in Table 1, should be regarded as provisional until relationships and age assignments can be proven by more quantitative information. It is a synthesis of relationships observed throughout the province, and a composite of beds seen in several type and reference sections in three main areas. With reference to Figure 1, in the first area – the central part of the mainland – prime exposures in gypsum quarries at East Milford (6; Mott et al., 1983), Shubenacadie (7), and Miller Creek (4; Stea and Hemsworth, 1979), together with a deep borehole near Noel (Gormanville) (5), were the first to be investigated in any detail. Hughes (1957) reported near Shubenacadie (7) two tills, the upper of more local derivation, separated by clay. Stea (1982) presented an interpretation and correlation of these deposits and these have been used here without modification. Recently, a three-till, three-phase glacial sequence has been outlined for northern Nova Scotia by Stea (1983) and Stea and Finck (1984). The second area is the Gulf of Maine coast between Yarmouth and Digby, where Grant (1980) constructed an independent local lithostratigraphic and climatostratigraphic scheme; data for that area are drawn mainly from sections at Salmon River (1), Cape Cove (2), and Saulnierville (3). In the third control area – Cape Breton Island – the succession is based on largely unpublished data from less well understood sections that have been tentatively organized into a reasonably internally consistent sequence. Pioneer work in this area was done by Mott and Prest (1967) who reported on exposures at Whycocomagh (13), Bay St. Lawrence (19), Hillsboro (14), and a borehole at Leitches Creek (20) and by Newman (1971). Mapping and stratigraphic studies by Grant during 1970-81 yielded crucial information (unpublished data) from sections at Big Brook (12), River Inhabitants (11; Mott, 1971), Green Point (16), Mabou (15), Dingwall (38), and from several places along the East Bay shore, notably at Castle Bay (22) and Benacadie Shore (23). R.J. Mott, S. Occhietti, and colleagues are conducting further analytical studies, e.g. De Vernal et al. (1983).

Early Wisconsinan

The sequence, as developed from the three widely separated regions, has remarkable similarities. Below the Holocene surface organic cover and the late glacial fluvial and marine beds are three major till sheets. The lower one is the thickest, most extensive, and most distinctive member – a reddish brown compact silty clay till having a southeastward fabric and a characteristic suite of foreign stones of northern provenance. In the central region it has been termed the East Milford Till (Stea, 1982). In Cape Breton Island and Yarmouth areas, where it is further distinguished by an admixture of marine shell fragments, it has been termed the Richmond Till and Red Head Till, respectively (Grant, 1980). Clearly this lower red drift is the product of a massive ice sheet moving from a broad ice shed north of Nova Scotia across the submerged Carboniferous redbed terrane towards the continental margin. At that time, but not since, the Caledonian Highlands in southern New Brunswick were overridden (Rampton et al., 1984). The gradient of this ice was sufficient to produce a uniform trajectory, irrespective of relief, and a thickness sufficient to overtop the Cape Breton Highlands (500 m). Consequently the terminus was probably far out on the continental shelf. On this basis, it was the major stade of the last glaciation, and because of the number of glacial and nonglacial events that followed, it is assigned to the Early Wisconsinan Substage, and thus to oxygen isotope stage 4, a period of intense and rapid cooling.

Evidence that the ice retreated, at least from coastal parts of Nova Scotia, is given for example by fluvial beds, such as the Cape Cove Gravel (2) which was graded to a lower sea level, then cryoturbated and deeply leached and oxidized (Grant, 1980). The gravel and its alteration represent a period of ice retreat, at least from the coastal area, while relative sea level was low.

Middle Wisconsinan

There are some indirect indications of Middle Wisconsinan time and conditions in Nova Scotia. All are contentious and some may be spurious, e.g. the Salmon River Sand. This supplied a finite radiocarbon date of 38 600 ± 130 BP (GSC-1440) but as described above (see section *Deposits of the Last Interglaciation*) is considered to be Sangamonian in age.

Other finite radiocarbon dates in the range 25-50 ka further complicate the argument. From northern Cape Breton Island, an area inferred to have been beyond the reach of Late Wisconsinan glaciers, a mastodon femur from a modern floodplain at Middle River (17) gave an age of 31 900 ± 630 BP (GSC-1220) and total carbon in silt from surface outwash on South Aspy River (18) gave an age of 24 900 ± 700 BP (I-3414; Newman, 1971). Both could be spurious in view of the materials used. Similarly, shells in an esker at Grantville (10), which date 32 100 ± 900 BP (GSC-1408), may be contaminated in view of the fact that shells from the surrounding tills on Janvrin Island (9) are beyond the range of radiocarbon dating (>34 000 BP, GSC-1639). In addition, peat at Bay St. Lawrence (19), originally dated as older than 38 270 BP (GSC-283, Mott and Prest, 1967), has been redated as 44 200 ± 820 BP (GSC-3636).

At present then there is mainly circumstantial evidence that part of inland Nova Scotia became ice free during the Wisconsinan. Otherwise, stratigraphic evidence of supposed Middle Wisconsinan events comes mainly from southern and central regions. The lower red till of inferred Early Wisconsinan age is overlain by a thick compact silty intermediate till of hybrid lithology that points either to an interplay of local glaciers and external ice or, more probably, to a change from foreign glaciers to local ice caps. It is represented by the Saulnierville and Hants tills in the Yarmouth and central districts, respectively. Vague signs of truncated weathered horizons in the upper part of the till in coastal sections suggest that the outer fringes of the landmass were subjected to subaerial exposure during an ice free period that intervened between the two glacial phases. The till and the weathering interval are tentatively assigned to the Middle Wisconsinan Substage (oxygen isotope stage 3, Fig. 1) (Grant, 1980).

In sum, the Middle Wisconsinan in Nova Scotia was mainly a time of glacierization, perhaps with some retreat from coastal areas, while glaciers were becoming reorganized into upland-centred ice caps.

Late Wisconsinan

The dating of the last glacial phase remains largely indirect. Stratigraphically it is represented by the surface till within the area believed to have been ice covered on geomorphic grounds. The upper drift sheet is represented by Rawdon Till of Stea (1982) and Beaver River Till of Grant (1980). This member is typically thin, loose, sandy, and locally derived. On the basis of provenance, striations and fabric, it was evidently deposited by glaciers flowing coastward from ice caps centred on the Atlantic Uplands. Its age is presumed to be Late Wisconsinan (oxygen isotope stage 2) because it grades laterally to deglacial marine and fluvial beds which have been dated directly and indirectly to the period 12-14 ka. Stea (1982) also recognized a younger drift in central Nova Scotia – Bennett Bay Till – which he related to final re-organization of remnant ice as marine waters invaded Bay of Fundy, caused drawdown and local westward flow.

In summary, Wisconsinan deposits in Nova Scotia consist of three distinctive till sheets of contrasting provenance which were evidently produced by separate advances of glaciers which came initially from distant northern sources and which later shrank to, and remained on, local uplands during an interval which is thought to span the entire Wisconsinan Stage.

New Brunswick

In this large inland part of the region thick sedimentary sequences consisting of more than the youngest till are extremely rare and virtually undated. This is a crucial deficiency because the area occupies a position between that affected solely by the inland continental Laurentide Ice Sheet and Nova Scotia where a complex of maritime satellite ice caps existed. Several indirect lines of evidence summarized by Rampton et al. (1984) suggest that this area too was subject to distinct glacial expansions from several separate ice centres which varied in position and activity throughout the Wisconsinan (Table 1). Moreover there are indications that parts of New Brunswick remained unglaciated at various times. This in itself imparts or implies a range of stratigraphic ages for the surface deposits in these areas.

Current hypotheses on the sequence of Quaternary events and processes are derived from a long history of study. This began with the work of Chalmers (1884, 1886, 1887, 1888, 1890, 1895, 1900), who described the surface deposits and interpreted the location, deployment, and extent of the glaciers and high level seas that produced them. He recognized an early flow from the west, local centres in the southern lowland, and "unglaciated" coastal and highland regions. His hypotheses remain generally valid today. Among numerous more recent reports, Lee (1955, 1957, 1959a,b, 1962) and Gadd (1973) described ice retreat in the southwestern part of the province. Gauthier (1978, 1979, 1980a,b) presented important new information on the northern highlands; argued against their role as an ice centre; postulated that the deep surficial weathered rock mantle required occupation by cold-based glaciers; called for an ice-free enclave in the highlands with a system of proglacial lakes while lowland ice lobes deployed around the flanks; and documented northward ice flow from a New Brunswick centre towards the Laurentide Ice Sheet.

The most complete accounts of the succession of till-forming events are by Rampton and Paradis (1981a,b,c) and Rampton et al. (1984). They postulated three main periods of glacier expansion which are assigned to the Wisconsinan because they postdate a raised intertidal rock platform for which they accept Grant's (1981) last-interglacial age designation. The first movement had a strong southeastward trajectory and came from a far northern source. It crossed the Caledonian Highlands, the highest parts in the south, which were not later overrun, and is therefore termed the Caledonian phase. They assigned it an Early Wisconsinan age because they assumed it correlated with the similar early strong movement over Nova Scotia (Grant, 1980). A long period of periglacial weathering and fluvial dissection followed, before the Chignecto phase when two local ice caps re-formed: one on the lowlands (the Gaspereau Ice Centre) and one offshore in Gulf of St. Lawrence (the Escuminac Ice Centre). These fed into Bay of Fundy as two lobes deploying around the Caledonian Highlands which remained a nunatak. They suggested that the Chignecto phase occurred prior to 18 ka. Near Hillsborough in the area overrun by Chignecto ice but not by later glaciers, a sinkhole contains a complete mastodon. Although a femur dated 13 600 ± 200 BP (GSC-1222) and the enclosing peat dated >43 000 BP (GSC-1680), the animal seems more reliably dated by the coprolites which yielded an age of 37 300 ± 1313 BP (GSC-2469). If the find signifies ice-free conditions at that time, then it seems to require that the Chignecto phase be followed by a nonglacial interval of Middle Wisconsinan age. Three subsequent advances are assigned to the Late Wisconsinan: The first, which predated 12.5 ka, radiated out from the southern lowlands and terminated in Bay of Fundy near the position proposed by Grant (1977b) as the Late Wisconsinan maximum. The second attained slightly lower levels against the Caledonian Highlands and had retreated from a major morainal stand at Saint John prior to 14.4 ka. The last came out of Gulf of St. Lawrence and must have climaxed before 12.5 ka – the age of deglacial marine submergence in that area.

There thus appears to be a general correspondence (Table 1) in number and timing of the latest glacial events in New Brunswick and in Nova Scotia. All postdate the last interglacial marker horizon and are thus Wisconsinan. The first had striking similarities in trend and vigour. In New Brunswick, too, at least one major intra-Wisconsinan nonglacial or deglacial period is corroborated by the weathering and by the Hillsborough mastodon occurrence.

Gulf of St. Lawrence – Magdalen Islands

The Quaternary history of this vast inland sea has been virtually unknown owing to the paucity and short span of stratigraphic information. Inferences on the glaciation of this area have therefore been speculative and based largely on results from surrounding areas. The question of when and how the area was glaciated remains largely unresolved. For the submarine area, only two major works bear on the Quaternary history. Conolly et al. (1967) studied nine cores up to 12 m long from Laurentian Channel, and noted two thin (10-20 cm) brick-red so-called "tills" within and on top of mainly glaciomarine mud. In view of the thickness and content of red Carboniferous debris, these layers are more probably ice shelf deposits related to a grounded glacier on Magdalen Shelf. Their age is unknown. In contrast, Loring and Nota (1973) studied provenance of surficial sediment and concluded that only a major ice sheet emanating from the Shield had crossed the area in Late Wisconsinan time. There are no dates to support this contention, so to reconcile their interpretation with those from surrounding areas, the event is assigned an Early Wisconsinan age; no subsequent glacial action has occurred to disturb the dispersal pattern.

As summarized by Prest (1970), the mature aspect of the Magdalen Islands and the lack of clear glacial features led to much speculation over the last 100 years as to whether they were ice covered, and, if so, at what times. New unpublished data from the Magdalen Islands, however, with their crucial location near the centre of the Gulf and on the edge of the great glacial trough of Laurentian Channel, shed new light on the glaciation in the region. The results of Prest et al. (1976), together with field work by D.R. Grant, V.K. Prest, R.J. Mott and L.A. Dredge in 1982 (unpublished), have revealed several significant relationships (Table 1). Firstly, there is clear evidence of two superposed emerged beach gravels, notably on Wolf Island and at Portage du Cap. The older is cemented and much more oxidized. Both are composed largely of Shield erratics. This constitutes good indirect evidence of an earlier invasion by Laurentide ice. Organic beds are associated with both beach deposits at Portage du Cap (27 of Fig. 1), Havre Aubert (28), Bassin (30), and Millerand (31) which have both cool- and warm-climate affiliations. The two raised paleoshores are correlated with the two high interglacial sea levels corresponding to oxygen isotope stages 5a and 5e even though their elevation exceeds that of the ancient rock platforms elsewhere in the Atlantic region by 10 m; the difference is considered to result either from lesser recent crustal subsidence or from salt and gypsum diapirism on the Magdalen Islands. The oxidation and cementation of the older beach material is attributed to regression and weathering during the intervening cool interval.

One bona fide till with a northern provenance overlies the raised beaches in three places (Havre Aubert, Bassin, Millerand). Providing the beach and organic beds are correctly assigned to the Sangamonian, this proves conclusively that the Laurentide ice sheet reached at least as far south as the Magdalen Islands during the Wisconsinan. Associated with the emplacement of the till, there is glaciotectonic deformation of the underlying sandstone bedrock, and wholesale transport of interglacial littoral beds uphill to 45 m at Des Buttes (32) and Boisville (33). The direction of overthrusting is southeastward, similar to the trend of the earliest glacial movement over New Brunswick and Nova Scotia. This ice flood is therefore assigned to the maximal Early Wisconsinan glacial stade. Overlying the interglacial beds, and transitional with the till sheet, is a pebbly substratified diamicton (Demoiselle Drift) which covers most of the land surface up to a fairly sharp limit at about 40 m. Its substratified texture, dropstones, and gradational contact with the underlying till suggest that it may be a marine sediment which accumulated under an ice shelf that followed the grounded glacier phase. There is, however, the dynamical problem of too little range between the +40 m upper limit and the -50 m depth of the present sea floor, in which to accommodate such an ice shelf.

Crosscutting all of the above, and restricted to the northern islands, is a massive ice-marginal deposit – on Grande Entree (Coffin) Island, first reported by Alcock (1941) – which is composed almost entirely of huge crystalline Shield erratic boulders in a sandy matrix. Clearly deposited at the margin of a southward-moving ice sheet, the moraine is attributed to an advance by an ice lobe that probably occupied Laurentian Channel. This ice advance occurred after the main Early Wisconsinan advance because the moraine apparently was not affected by the +40 m submergence associated with the older drift beyond. It must have occurred before the -62 m paleoshore, assumed to be of Late Wisconsinan age (Loring and Nota, 1973, p. 46, 134) which encircles the islands. The Coffin Island Moraine is thus attributed to a Middle Wisconsinan event.

There is no evidence that Late Wisconsinan glaciers touched the islands. Indeed, their anomalous appearance, characterized by mature, solifluction-graded slopes, deep dissection, and broad periglacial "vallons", suggests that this landscape has undergone lengthy subaerial exposure under glacial climates (Laverdière and Guimont, 1974).

It is thus clear that the stratigraphic evidence from the Magdalen Islands has broad implications for the glacial history of the Gulf of St. Lawrence, as well as corroborating the general sequence and timing of the major Quaternary events inferred for the surrounding mainland areas. Table 1 summarizes the sequence which includes two high sea levels during the last interglaciation, one major passage of Laurentide ice early in the Wisconsinan Stage, a secondary moraine-building advance presumably during the Middle Wisconsinan, and no clear sign of Late Wisconsinan glacial action.

Newfoundland

The history of interpretations on the glacial history of Newfoundland is traced in several recent reviews by Grant (1977b), Tucker (1976), Rogerson (1981, 1982, 1983), and Brookes (1982). Debate began with hypotheses about the relative importance of local glaciers spreading from centres on the island versus invasion by Laurentide ice from Labrador. There is now general agreement among those working in the area that local ice was responsible for essentially all deposits and features. Attention is now focused on reconstructing the areal and vertical extent of ice cover and on trying to distinguish and date the separate glacial expansions.

Most of the stratigraphic evidence for a multiphase glacial sequence comes from two main areas: (1) the western highlands and adjacent coastal lowlands where high relief and deep glacial channels produced clear vertical separation of successive ice sheets and (2) the southeastern coast including Burin and Hermitage peninsulas where superposed tills and nonglacial beds, together with a corroborative sequence of intersecting ice-flow markings, demonstrate the succession and course of glacial expansions. Additional data from the central uplands (Vanderveer and Sparkes, 1982) support the inferences in the coastal areas.

The present phase of systematic studies began with mapping and stratigraphic studies by Brookes (1974) who followed up the results of MacClintock and Twenhofel (1940) and documented the effects of an upland-centred ice cap on the lowlands around Stephenville. He attributed all features to Late Wisconsinan ice which be believed had terminated offshore. Differentiation of three major advances, separated by prolonged nonglacial periods of weathering was inferred for a part of the western highlands by Grant (1977a) on the basis of distinct mappable differences in the degree of postglacial dissection, slope degradation, and disintegration of bedrock. The youngest so-called "weathering zone" corresponds to the latest expansion which is dated to ca. 13 ka. The intermediate zone was referred to an earlier Wisconsinan stade; the highest, most degraded zone was thought to predate the last interglaciation. Comparison with analogous zones in other areas of Eastern Canada, notably Baffin Island and Labrador, suggests that they may be much older. The same three zones were found also in the highlands bordering Codroy valley by Brookes (1977) who also recognized a summit zone which bore no evidence of ever having been glaciated. These upper glacial limits, in particular the unglaciated summits above 400 m near Cabot Strait, place fundamental constraints on the outer limit of Pleistocene ice sheets. Evidence from offshore supports the hypothesis of limited glacierization throughout the Quaternary.

Meanwhile, mapping along the southeastern coast by Grant (1975b) elicited evidence of several ice movements and their limits, as well as a supposed interglacial littoral platform beneath the tills. The first glaciers (Early Wisconsinan) evidently advanced out onto the shelf from an inland centre and left a patchy till that has since been deeply oxidized. The next advance was from a centre that was localized on the seafloor of Placentia Bay; the ice flowed onshore over proglacial silts. The final phase involved small ice caps that radiated from the uplands of Burin and Hermitage peninsulas. The outer limit of this last advance, the Late Wisconsinan, from the main ice cap over interior Newfoundland, was placed by Grant (1977b) along a prominent end moraine that skirts the coast and crosses the top of Burin Peninsula.

Tucker and McCann (1980) largely corroborated these views but placed the Late Wisconsinan ice limit somewhat farther inland. They also presented additional stratigraphic evidence which showed that there were two major early advances outward from a Newfoundland centre: the first is represented by the cemented Main Brook Till which, because of its deep oxidation, predates the last interglaciation; the second is assigned to the major event of the Wisconsinan -- its early stade. In either case, there is a broadly parallel sequence of glacial advances of declining vigour in two widely separated parts of the island which strongly resembles that recognized in Nova Scotia. The Quaternary sequences in both provinces are therefore correlated without major contradictions or inconsistencies.

Scotian Shelf

The continental shelf around Nova Scotia, including Gulfs of Maine and St. Lawrence, like that around Newfoundland, is essentially an extension of the adjacent onshore glacial landscapes and bears all the marks of intense glacial erosion. Both hard and soft shelf strata are truncated by longitudinal and transverse glacial depressions and by broad glacial troughs, some of which have hanging tributaries. Closure on the largest depressions is more than 200 m. Clearly a system of pre-Quaternary fluvial lowlands and trunk valleys has been deeply modified by selective linear erosion and areal scouring (Loring and Nota, 1973; King and MacLean, 1976; King, 1980). The major troughs reach far inland as evidence of powerful outlet glaciers from a Shield-based ice sheet, while the effect of a separate Newfoundland ice cap can be seen in the radial system of fiords reaching the shelf. The extent of shelf basins and troughs indicates the minimum average limit of successive glacial expansions. The flat outer banks beyond these features evidently have largely escaped modification. There is thus essentially no argument about whether the shelf was glaciated – only when, by what ice, and for how long.

Stratigraphic studies on the Scotian Shelf over the last 20 years by L.H. King, G.B. Fader, and B. MacLean provide the best documented Quaternary history and serve as a link between terrestrial and deep oceanic sequences. King (1980) provided the most recent summary interpretation. From seismic profiling, an "acoustic" stratigraphy has been developed which consists of four lithostratigraphic units. All are thought to date from the Wisconsinan (Table 1). Presumably, older Quaternary deposits were removed before and during the last glaciation. The oldest unit is the Scotian Shelf Drift which extends virtually to the edge of the shelf and which may have been deposited by an advancing grounded Early Wisconsinan glacier after the St. Pierre Interstade. Radiocarbon dating shows that the wastage was well underway by 50 ka, by which time the grounded ice sheet had become an ice shelf that floated over the basinal areas and that was anchored to the seafloor where it impinged on the surrounding banks.

This condition lasted until about 30 ka as recorded by the distribution and chronology of the resulting subglacial meltout deposit – a glaciomarine drift termed the Emerald Silt. Thus the Early Wisconsinan advance is represented by an extensive drift sheet. The following prolonged interval of thinning and retreat correlates with the lengthy period of climatic improvement during the early part of the Middle Wisconsinan. The onlap of dated Emerald Silt onto Scotian Shelf Drift shows that the grounding line had retreated to the inner part of the shelf basins by 38-30 ka. At that time a pause in the retreat is inferred from the bulky subglacial moraine that formed along the zone of liftoff from ice sheet to ice shelf. The belt of basal drift, which intertongues with the proglacial Emerald Silt beyond, is termed the Scotian Shelf End Moraine Complex (Fig. 1) and is currently dated to the later part of Middle Wisconsinan time ca. 28-30 ka. The moraine extends from Laurentian Channel to the Gulf of Maine. Its connections with the margins of land-based ice masses in Newfoundland and New England remains obscure.

Subsequent retreat of grounded ice on the shelf, as recorded by transgressive overlap of Emerald Silt onto Scotian Shelf Drift, continued landward until a secondary morainal position was established just offshore, presumably during the Late Wisconsinan maximum (D.J.W. Piper, personal communication, 1982). This second grounding line moraine is traced westward into Gulf of Maine, north of Truxton Swell, beyond which it is difficult to find the link with the presumed stadial limit on Long Island. Depending on how dates on problematical glaciomarine facies in Stellwagen Basin are interpreted (Tucholke and Hollister, 1973), the Late Wisconsinan ice margin could have been situated near Boston as Flint (1963) proposed on the basis of weathering differences. Alternatively, it may have turned abruptly southward along Howell Swell as the Great South Channel ice lobe, and hence via Nantucket Island to the Long Island moraines. In any case final disappearance of whatever glaciers existed offshore in the gulfs of Maine and St. Lawrence took place before 13 ± 1 ka as proved by numerous dates on postglacial marine sediment along the coast.

The relatively simple monolithic model of glaciation of the offshore regions – one major advance in Early Wisconsinan time and a generally continuous linear retreat towards the land-based centres – conflicts somewhat with the terrestrial ice-dispersal history and therefore poses a problem for the correlation of certain lithostratigraphic units. It is difficult to reconcile the simple advance and retreat of glaciers from terrestrial sources onto the shelf, with the divergent sequence of ice movements in southwestern Nova Scotia, in southern Cape Breton and in Newfoundland. The latter two areas give evidence of strong intermediate-age onshore movements as if from ice caps or domes centred offshore in Chedabucto Trough and Placentia Bay, respectively (Grant, 1977b). Since the Scotian Shelf Moraine trends through the centre of the inferred ice dispersal area, the offshore ice-dispersal centre on the eastern Scotian Shelf must have functioned at an earlier date. The northward trajectory of this onshore flow over Cape Breton, however, implies drawdown in Gulf of St. Lawrence (and, with respect to Newfoundland, onshore flow into Fortune Bay) – areas that should have been even more deeply filled with glacial ice at earlier stages of King's (1980) model. In order to accommodate both models, one alternative is to suppose that the offshore ice domes date from pre-Wisconsinan time; another is that they were ice rises which grew as ice shelves grounded on the outer banks during the initial ice flood. They persisted while Laurentian Channel caused drawdown and transition to an ice shelf in Gulf of St. Lawrence, and finally migrated onshore to become terrestrial ice sheets while offshore ice shrank to produce the onlap sequence of glaciomarine drift and moraines.

Newfoundland Shelf

Relatively little is known of the Quaternary stratigraphy of this area because few cores have been taken and little seismic profiling done. Preliminary studies by Dale and Haworth (1979) and by Piper et al. (1978) revealed a record of continuous marine sedimentation exhibiting substantial variations in microfossil type and abundance, none of which duplicate present interglacial conditions. They interpret the sequence to represent a series of stades and interstades, with no glaciers or shelf ice across the area since Illinoian time. This supports the view that the Wisconsinan ice sheet on Newfoundland reached only a short distance offshore, mainly in lowland areas (Grant, 1977b).

Labrador Shelf

Considerably more mapping and coring, spurred by hydrocarbon development, has been carried out in this area, and inferences about the age and extent of ice sheets based on the interpretation and dating of bottom sediments have ranged over a broad spectrum of hypotheses. There is now growing concensus that much of the shelf remained beyond the limit of (Late?) Wisconsinan glaciers. Vilks and Mudie (1978) cited evidence that the ice margin must have lain far inland of a coastal tundra belt in southeastern Labrador, as Coleman (1926) and Fulton and Hodgson (1979) inferred from geomorphic differences. Similarly for the northern part of the shelf, Fillon and Harmes (1982) depicted an ice shelf, fed by valley glaciers deploying between nunataks, that created ice rises over the outer banks. This model accommodates the Torngat weathering zones (Ives, 1958; Loken, 1962; Andrews, 1963) as extraglacial areas and makes the point that sedimentary facies can reveal differences between ice regimes: glacier, shelf, rise. This documentation of a multi-phase situation resolves some of the major arguments and contradictions that have confounded the reconstruction of ice limits in this area. Simply put, the weathering zone hypothesis, which calls for steeply declining ice surfaces to sea level at the present coast, is now largely reconciled by placing the grounding line just offshore and an extensive ice shelf over the inner basins, with ice rises beyond where it impinged on shallow banks and produced till. Thus there are Late Wisconsinan drifts far offshore, whereas pre-Wisconsinan or even unglaciated tracts exist far inland at higher elevations. Recent oral communications (Clark, 1983; Josenhans, 1983) indicate that a reconciliation of onshore and offshore glacial-geological histories is now in progress. Good stratigraphic documentation coupled with modern glaciology theory has brought shelf glacial chronology in line with the classical onshore models of limited ice. Geomorphology and stratigraphy have now converged on an internally consistent interpretation of ice extent along the Labrador margin, as summarized by Rogerson (1981, 1982).

Continental Slope and Seamounts

The longest and most continuous Quaternary record exists, of course, in deep ocean areas where sedimentation is slow and rarely interrupted, and where local influences are minimized so that major regional events are clearly recorded. Several cores from the continental slope and rise around the Grand Banks contain a record back to Middle Wisconsinan time (Alam and Piper, 1981; Alam et al., 1983), and others from the nearby Fogo Seamounts reach the Middle Pleistocene (Alam and Piper, 1977). Four sedimentary facies are distinguished on the basis of colour and biogenic content; differences in grain size and abundance of ice-rafted detritus (IRD) are also significant. The variations are interpreted in terms of the provenance and extent of continental glaciers that are assumed to be the main determinant of offshore sediment type. Other interrelated factors are eustatic variations of sea level, extent of emergent shelf areas, and temperature and position of major ocean currents. Correlations are based on lithological attributes, while temporal control back to 40 ka is provided by ^{14}C dating of total carbonate of pure foram-nanno ooze. Microfaunal markers, such as the extinction of **Globorotalia menardii flexuosa** during the last interglaciation and the restriction of **Emiliania Huxleyi** to the period since 15 ka, serve as reliable means of identifying the Wisconsinan part of the sequence. Oxygen isotope variations provide a proxy time scale for the last 500 ka and a means of correlation with the standard deep-sea temperature history.

Within what Alam and Piper (1977) termed the Wisconsinan part of the sequence, five biostratigraphic units (Units 1 to 5) are distinguished. These retain their original lithostratigraphic meaning (Table 1) though they are now referred to by other terms (Alam et al., 1983). Each gives evidence of oceanic temperature conditions, as well as of IRD influx and provenance of suspended sediment; each is therefore associated with a stade or interstade. Above Unit B6, which marks the last interglaciation because it resembles the Holocene, are five glacial units. Unit B5 reflects arctic water conditions and signifies extensive glacierization. Unit B4, dated to 50-45 ka ago, marks a distinct mild period at all sites. It corresponds well with the Middle Wisconsinan period of large-scale ice retreat which occurred in the mid-continent region, and to a lesser extent in the Atlantic Provinces. Unit B3 marks a frigid interval ca. 40-30 ka when conditions were more severe than during the Late Wisconsinan and when presumably glaciers covered a larger area. Unit B2 marks a second interstadial warming about 25-20 ka ago. Unit B1 corresponds to the Late Wisconsinan glacial maximum which Alam et al. (1983) date ca. 15 ka. It contains seams of red clay and sandstone IRD which may correlate with the brick-red horizons on the Scotian Slope dated ca. 18 ka (Stow, 1977). The glacial sequence is capped by interglacial-degree sediments of Holocene age.

Inferring the extent of land-based glaciers from biological indicators of water conditions, from the abundance of ice-rafted detritus, and from the amount of sea level lowering or shelf exposure as reflected in the abundance of turbidite layers, the sediments indicate that temperatures were cooler, glaciers more extensive, and sea level lower in the earlier part of Wisconsinan time than in the later. According to Alam et al. (1983), Newfoundland ice did not cross Avalon Channel at any time during the Wisconsinan. Moreover, the work of Dale (1979) and Whitehouse (1980) suggests that little or no IRD was derived from the present land area of Newfoundland during the Late Wisconsinan. This harmonizes with interpretations by Grant (1977b), Brookes (1977), Tucker and McCann (1980), and Rogerson (1982) of limited ice extent based on moraines and weathering trimlines. Thus there is general agreement between the onshore and offshore sequences for the Wisconsinan, both as to the pattern of temperature changes and the general extent of glacier cover.

DEEP-OCEAN 'STANDARD' OXYGEN ISOTOPE TEMPERATURE RECORD

It is useful and instructive to relate the lithostratigraphy of onshore and offshore sedimentary records to the sequence of sea-surface temperature variations as recorded in the sediments on the northwestern Atlantic Ocean abyssal plain. Ruddiman and McIntyre (1981) analyzed the cyclicity of temperature changes of the last 250 ka and found a good correlation with the 23 000-year precessional cycle that determines summer insolation and ablation of ice sheets. The resulting meltwater and calving, in turn, modulate ocean temperatures and sea-ice cover, thereby setting up a feedback relationship with winter moisture influx. This means that ice-cover fluctuations in eastern North America should closely approximate the 23 000-year cycle. Conversely, the temperature record for the deep sea should give the best representation of glacier extent.

For this reason the record from Core V30-97 is used to help substantiate the correlation of glacial and nonglacial events, based on their inferred temperature severity, and to help rank events of uncertain magnitude. There appears to be a striking similarity between the temperature record (Table 1) and the climatic events that can be inferred from the sedimentary sequences in various parts of the region. The close correspondence between semi-independent results substantiates the individual correlations and suggests that the various bases of correlation used in this analysis are generally sound.

A CLIMATOSTRATIGRAPHIC SCHEME FOR THE REGION

Assuming that the correlations are valid and that the deposits represent a series of major glacial and nonglacial events, certain climatostratigraphic terms may be designated for each as initially partly outlined by Grant (1980). The pre-last interglacial period of maximal ice cover, as represented by the strong erosion of the continental shelf, by the upper (or middle) weathered zone, and by deeply altered tills in Newfoundland, might be termed the "Vinlandian Glaciation", after the early Norse name for Newfoundland where most of the evidence has been found. For the last interglaciation, "Magdalen" is proposed as an appropriate term because the elevated shorelevel and warm climate are well documented there by littoral formations and organic beds. For the last glacial stage in Atlantic Canada a separate term might be justified in view of the fact that the largely independent Maritime Provinces and Newfoundland ice caps were distinct from the Laurentide (Labradorean) Ice Sheet, and hence the deposits may not be strictly coeval because of differing regimen. "Acadian Glaciation" is thus proposed for the last glacial stage in the Maritimes because the type sections are found in the thick-drift Acadian districts. For Newfoundland, where a separate ice-cap complex operated, "Terra Nova Glaciation" may be appropriate. By way of further subdivision, the major initial ice advance of the last glacial stage could be termed the "Fundy Stade" from the Yarmouth district stratigraphy to signify the ice flood that crossed Bay of Fundy and brought red material and marine sediment from the seafloor. Alternatively, on the basis of Cape Breton Island sequences, the Early Wisconsinan advance could be termed the "Cabot Stade" in recognition of the fact that Cabot Strait must have held a major grounded glacier. Similarly, a correlative "Fortune Stade" might be proposed for southeast Newfoundland to mark the glacial advance that crossed Fortune Bay.

The subsequent ice retreat is at present best represented by intertill soils and deglacial gravels in District of Clare, southwestern Nova Scotia, so this event might be termed the "Clare Interstade". The next readvance is best documented in Nova Scotia, in Digby County and so is provisionally labelled the "Digby Stade". For Newfoundland, the corresponding event was the "Burin Stade" when the peninsula of the same name was overrun by ice advancing from a centre on the shelf.

Final reactivation of upland ice caps in Nova Scotia gives rise to the term "Scotian Stade" for the Late Wisconsinan culmination.

SUMMARY AND CONCLUSIONS

Using various lines of evidence, numerous exposed terrestrial sedimentary sequences in Nova Scotia, New Brunswick, and Newfoundland are correlated. This reveals a broadly parallel series of events in the three areas. When this is linked to the offshore record obtained from cores on the shelf, slope, rise, and abyssal plain seamounts, a regionally consistent history emerges. Both compare well with the deep-sea temperature history which provides corroborative chronometric control.

On land, Nova Scotia provides the best documented record to which other areas are related. Apart from scattered outcrops of deeply weathered tills and other sediments, some of which may be pre-Quaternary, the sequence begins with deposits related to the last interglacial period. The prime marker is an emerged littoral horizon with associated organic beds which indicate climates as warm or warmer than that during the Holocene. As yet unpublished amino acid ratios on wood suggest that they belong to a lengthy interglacial complex which is considered to span the duration of oxygen isotope stage 5. With reference to this datum, deposits of the last glaciation are recognized to consist mainly of three till sheets: the oldest, a distinctive red till of northern provenance, was generated by a regional southeastward-flowing ice sheet of presumed Early Wisconsinan age which covered the entire province; the younger two are grey drifts of more local derivations that are attributed to upland ice caps which are inferred to have operated in Middle and Late Wisconsinan time. These failed to cover all areas judging by drift limits against more mature terrains, notably in Cape Breton Island. There, weathering and a Middle Wisconsinan mastodon dating 31.9 ka help to differentiate the stades.

In New Brunswick a similar threefold sequence is recognized on the basis of weathering contrasts delimiting ice-flow phases of differing pattern (Caledonia, Chignecto, Kent). Here also an organic deposit of Middle Wisconsinan age (37 ka) divides the latter two at Hillsborough. Magdalen Islands feature a 2-cycle last-interglacial littoral organic and beach formation (rich in Shield erratics from pre-Wisconsinan glaciation) overlain by a single Laurentide drift, of presumed Early Wisconsinan age, which grades to a supposed ice-shelf mantle. Only one later moraine-building readvance onto the northern extremity is recognized; it is probably pre-Late Wisconsinan.

In Newfoundland, lithostratigraphic subdivision is in its infancy. All deposits are referred to an independent ice cap complex; Laurentide ice covered only the northernmost extremity. Most studied deposits are on Burin Peninsula where they include pre-Wisconsinan tills, a last interglacial shoreline, and three younger till sheets - one deposited by a large Newfoundland ice cap, one by an ice dome on the shelf, and one by a lesser upland readvance. For the western highlands a parallel subdivision of glacial/nonglacial intervals is based on morphostratigraphic units known as "weathered zones". Three are recognized: the youngest is dated to 13 ka and is considered to mark the Late Wisconsinan stadial maximum; the oldest is assuredly pre-Wisconsinan. Unglaciated tracts on high pre-Quaternary peneplains are known.

In summary, land areas provide sparse and indirect evidence of: major pre-Wisconsinan glaciation; abundant organic remains from cool and warm intervals of higher sea level referred to a lengthy last interglacial complex; and three Wisconsinan till-forming events of declining vigour.

Offshore sequences corroborate and extend the terrestrial record. Scotian Shelf deposits trace the retreat of an Early Wisconsinan ice sheet via inner-shelf grounding line moraines dated ca. 35 ka to a Late Wisconsinan position just offshore at 15-20 ka. Seamount sediments, dated by microfaunal and magnetic markers, show a pronounced red-mud interval attributed to major glacial erosion of Gulf of St. Lawrence in oxygen isotope stage 6 (Illinoian) time; a long interglacial interval (stage 5); and three much weaker glacial pulses in the Wisconsinan.

Hence both onshore and offshore sediments represent a similar series of glacial variations. Their inferred age and individual vigour match the temperature fluctuations recorded by deep-sea oxygen isotope values: stage 6 was the most severe of the Late Quaternary; stage 5, the last interglacial period, was long and had two warm periods separated by a cool phase (when sea level dropped); the last glacial stage began after 73 ka with a greater advance than it culminated with.

ACKNOWLEDGMENTS

V.K. Prest, R.J. Mott, and L.A. Dredge kindly allowed unpublished observations from the Magdalen Islands to be used in the interpretation. R.R. Stea (Nova Scotia Department of Mines and Energy) and D.J.W. Piper and P. Mudie provided reviews of early versions of the report. R.J. Fulton and A. Dreimanis were critical readers and this version reflects their suggestions.

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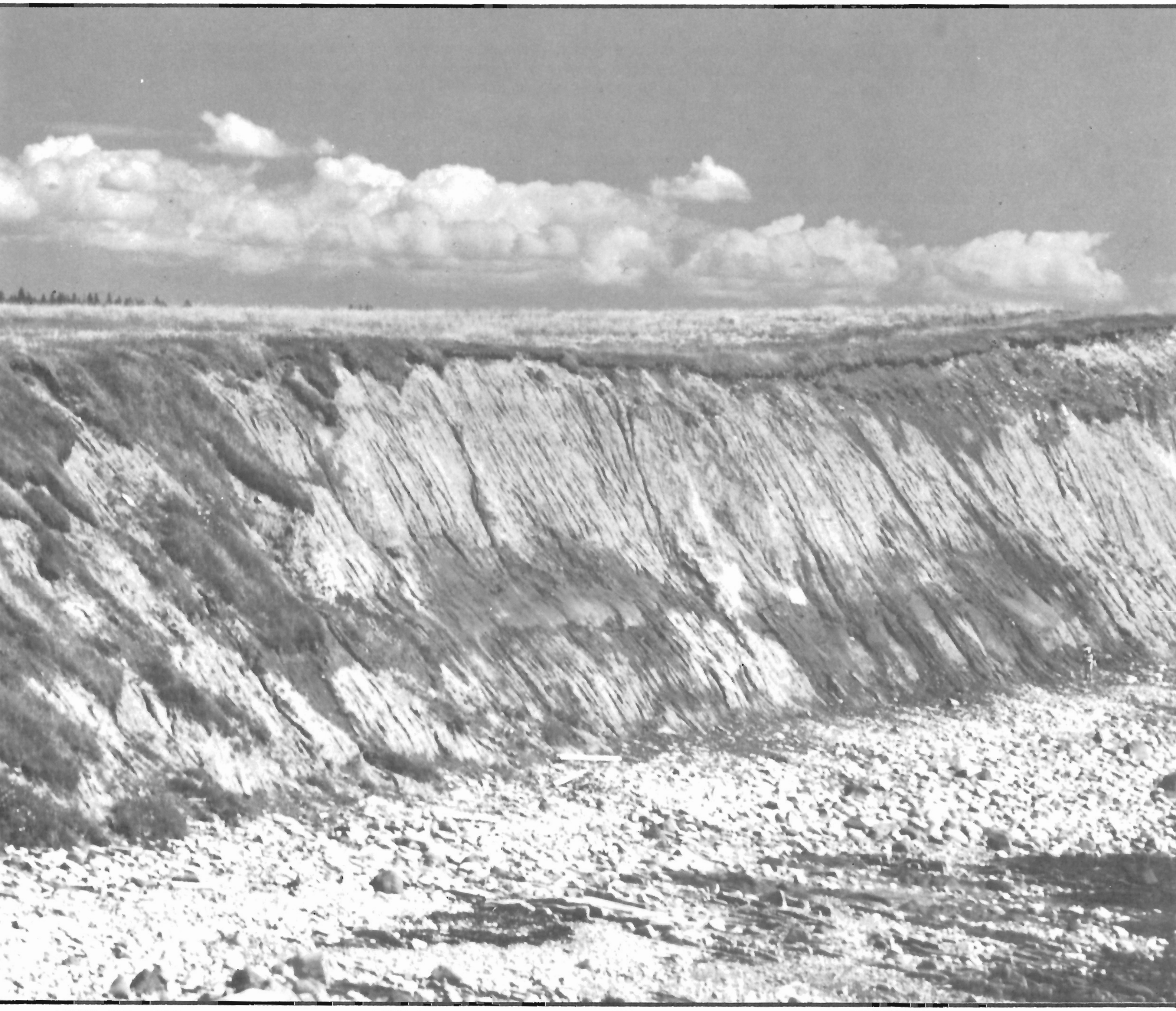
SUMMARY OF QUATERNARY STRATIGRAPHY AND HISTORY, EASTERN CANADA



Salmon River, western Nova Scotia: Red-brown till of Early Wisconsinan age at the base of the exposure is overlain by a unit of dark grey fossiliferous sand (wet layer in exposure) which, because of contact relations and presence of interglacial fossils, is thought to have been glacially emplaced. The main part of the section consists of grey till which becomes brown upwards and is thought to be Middle Wisconsinan. The gravelly unit at the right end of the section is a rubbly till end moraine which lies at the Late Wisconsinan glacial limit. Photo and stratigraphy by D.R. Grant, GSC 203193-U.

SUMMARY OF QUATERNARY STRATIGRAPHY AND HISTORY, EASTERN CANADA

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Fulton, R.J., Karrow, P.F., LaSalle, P., and Grant, D.R., Summary of Quaternary stratigraphy and history, Eastern Canada; in Quaternary Stratigraphy of Canada – A Canadian Contribution to IGCP Project 24, ed. R.J. Fulton; Geological Survey of Canada, Paper 84-10, p. 193-210, 1984.

Abstract

Deposits of three Wisconsinan substages, Sangamonian Stage, and older Quaternary stratigraphic units are recognized in Eastern Canada. The age assignment of these units is based on radiocarbon dating and correlation of events.

Quaternary deposits older than Sangamonian are recognized locally in Eastern Canada. In southern Ontario glacial deposits directly underlie Sangamonian sediments and are referred to as Illinoian in age. In other areas the ages of older sediments are largely unknown. Offshore core stratigraphy suggests that a major glaciation took place about 436 ka and that the Illinoian (oxygen isotope stage 6) was also a time of extensive glaciation.

In this report Sangamonian is used as the name for the chronostratigraphic stage that includes all of deep sea oxygen isotope stage 5 and consequently, on a regional basis, it includes warm interglacial deposits, glacial deposits, and cool interglacial deposits. In southern Ontario the warm interglacial deposits are represented by the Don Formation, the stadial deposits by the Scarborough Formation, and the cool interglacial deposits by the Pottery Road Formation. Warm interglacial deposits have not been recognized in Quebec (unless they are part of the pre-Johnville Sediments); the Bécancour Till is included as glacial Sangamonian sediments, and the St. Pierre Sediments are recognized as cool interglacial sediments.

The Early Wisconsinan appears to have been the time of maximum Wisconsinan glaciation in Eastern Canada with ice moving south of the International Boundary and well out onto the continental shelf.

The Middle Wisconsinan was primarily a nonglacial period in southern Ontario and a glacial stade elsewhere in Eastern Canada. In southern Ontario the Middle Wisconsinan record has been subdivided into two interstades (Port Talbot and Plum Point), separated by a stade (Cherrytree). The Port Talbot Interstade began before the limit of radiocarbon dating (before 48 ka) and ended about 40 ka; glacial or near glacial conditions of the Cherrytree Stage lasted from about 40 to 35 ka ago, and the Plum Point Interstade was from about 35 to 23 ka ago. Central St. Lawrence Lowland was occupied by ice throughout the Middle Wisconsinan, but southeastern Quebec and the Montreal area were briefly deglaciated. Scattered evidence in Atlantic Canada suggests local deglaciation of coastal areas during the Middle Wisconsinan but extensive ice remained on the continental shelf and ice from centres located on the shelf flowed onto land in at least two areas.

Glacial conditions predominated throughout Eastern Canada during the Late Wisconsinan. At the Late Wisconsinan maximum, through-moving ice deposited the Catfish Creek Drift in southern Ontario but ice lobes, which developed in the basins of the Great Lakes after 15.5 ka, controlled ice flow during a period of ice margin oscillation and retreat. A calving bay developed in lower St. Lawrence valley, after the Late Wisconsinan maximum, causing a reversal of flow on the south shore of the St. Lawrence and replacing ice in the valley with the Champlain Sea about 12 ka. Late Wisconsinan glaciers were largely limited to land areas in Atlantic Canada. Local ice caps dominated with complicated patterns of flow and retreat developing as centres of accumulation shifted and competing ice centres achieved dominance. The period of Late Wisconsinan retreat in Atlantic Canada appears to have lasted from about 14 to 10 ka ago.

Résumé

Des dépôts de trois sous-étages du Wisconsinien, de l'étage sangamonien et d'autres unités stratigraphiques quaternaires plus anciennes ont été identifiés dans l'Est du Canada. L'âge donné à ces unités est fondé sur la datation au carbone radioactif et sur la corrélation des événements.

Quelques dépôts pré-sangamoniens ont été identifiés par endroits dans l'Est du Canada. Dans le sud de l'Ontario, les sédiments sangamoniens reposent directement sur des dépôts glaciaires datant vraisemblablement de l'Illinoien. Ailleurs, l'âge des sédiments plus anciens demeure, pour la plupart, inconnu. La stratigraphie des carottes océaniques semble indiquer qu'une importante glaciation s'est produite il y a environ 436 ka et que l'Illinoien (étage 6 des isotopes d'oxygène) a également été marqué par une glaciation de grande étendue.

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Manuscript received: 1983-08-05
Final version approved for publication: 1984-02-10

Dans le présent rapport, les auteurs utilisent le nom Sangamonien pour désigner l'étage chronostratigraphique qui comprend tout l'étage 5 des isotopes d'oxygène déterminé à partir de sédiments océaniques; du point de vue régional, le Sangamonien comprend donc des dépôts d'interglaciaire chaud, des dépôts glaciaires et des dépôts d'interglaciaire froid. Dans le Sud de l'Ontario, la formation de Don représente les dépôts d'interglaciaire chaud, la formation de Scarborough, les dépôts stadiaires et la formation de Pottery Road, les dépôts d'interglaciaire froid. On n'a pas identifié de dépôts d'interglaciaire chaud au Québec (à moins qu'ils ne fassent partie des sédiments pré-Johnville); le till de Bécancour fait partie des sédiments glaciaires du Sangamonien et les sédiments de St-Pierre, des sédiments d'interglaciaire froid.

Dans l'Est du Canada, la glaciation du Wisconsin semble avoir atteint son maximum durant le Wisconsinien inférieur, la glace se déplaçant au sud de la frontière internationale et s'avançant loin sur la plate-forme continentale.

Le Wisconsinien moyen a été principalement une période non glaciaire dans le sud de l'Ontario et un stade glaciaire ailleurs dans l'Est du Canada. Le Wisconsinien moyen du sud de l'Ontario a été divisé en deux interstades (celui de Port Talbot et celui de Plum Point), qui sont séparés par le stade de Cherrytree. L'interstade de Port Talbot a commencé avant la limite de la datation au carbone radioactif (il y a plus de 48 ka) et a pris fin il y a environ 40 ka; les conditions glaciaires ou presque glaciaires de cet étage ont persisté pendant 5 ka, à partir de 40 ka, et l'interstade de Plum Point a duré 12 ka, à partir d'environ 35 ka. La partie centrale des basses-terres du Saint-Laurent a été englacée durant tout le Wisconsinien moyen, mais le sud-est du Québec et la région de Montréal ont été brièvement déglacés. Des dépôts épars dans la région atlantique portent à croire qu'il y a eu déglaciation locale des régions côtières au cours du Wisconsinien moyen, mais une vaste nappe glaciaire a persisté sur la plate-forme continentale et, à au moins deux endroits, de la glace provenant de deux centres situés sur la plate-forme continentale a recouvert des régions terrestres.

Les conditions glaciaires ont dominé dans l'Est du Canada au cours du Wisconsinien supérieur. Lors de son avancée maximale, la glace en mouvement a déposé les sédiments de Catfish Creek dans le sud de l'Ontario, mais ce sont les lobes glaciaires, formés dans les bassins des Grands lacs il y a environ 15,5 ka qui ont contrôlé l'écoulement de la glace au cours d'une période d'oscillation et de retraite du front glaciaire. Une baie aux rives vêlantes, formée dans la vallée du bas Saint-Laurent après le maximum du Wisconsinien supérieur, a fait inverser la direction d'écoulement de la glace sur la rive sud du fleuve et a permis aux eaux de la mer Champlain de remplacer la glace dans la vallée il y a environ 12 ka. En général, les glaciers du Wisconsinien supérieur étaient limités aux zones terrestres dans la région atlantique du Canada. Des calottes glaciaires ont dominé par endroits et des configurations complexes d'écoulement et de retraite se sont formées à mesure que les centres d'accumulation se sont déplacés et que les divers centres glaciaires ont pris le dessus. Dans la région atlantique, la période de retraite du Wisconsinien supérieur a vraisemblablement duré d'il y a environ 14 à 10 ka.

INTRODUCTION

This summary synthesizes in broad terms the Quaternary stratigraphy of Eastern Canada. Eastern Canada in the context of this report is southern Ontario, southern Quebec, Atlantic Provinces and adjacent shelf. This summary is based largely on the Great Lakes, Quebec, and Atlantic Provinces regional reports (Karrow, this volume; LaSalle, this volume; Grant and King, this volume).

Southern Ontario, as used in this report, consists of the Great Lakes basins and that part of the province lying south of Lake Nipissing and Ottawa River valley (Fig. 1). The area is underlain predominantly by Paleozoic sedimentary rock with Precambrian igneous, sedimentary, and metamorphic rocks occupying the basin of Lake Superior and the area east of Georgian Bay. The area of Paleozoic sedimentary rock exhibits flat to gently rolling topography, locally marked by escarpments tracing the outcrop of resistant beds. The area underlain by Precambrian rock consists of rolling to hilly country broken by structurally controlled escarpments and valleys. The Great Lakes basins developed through differential erosion of a Paleozoic-age carbonate-shale sequence, with the exception of Lake Superior which occupies a Precambrian-age sedimentary trough. Glacial erosion has deepened and accentuated these basins. Most areas of Precambrian rock are overlain by a thin veneer of glacial drift or have been swept bare of unconsolidated sediments by late glacial and postglacial processes. Local basins, structurally controlled valleys, and present drainage channels in many places contain glaciofluvial and glaciolacustrine deposits. The areas of Paleozoic sedimentary rock are in most places overlain by a significant thickness of Quaternary sediments (as much as 200 m in buried valleys and interlobate moraine areas) which consist dominantly of till, glaciofluvial, glaciolacustrine, and marine sediments of the last period of glaciation and of earlier glacial and nonglacial periods. The Quaternary sediment cover is generally thin in the basins of the Great Lakes with bedrock overlain by till, glaciolacustrine, and lacustrine sediments. Most Quaternary stratigraphic information has come from the north shore of lakes Erie and Ontario, where shoreline cliffs and local gullies have provided natural exposures, and from roadcuts, gravel pits, and other man-made exposures which are abundant in this heavily developed area.

The area of southern Quebec discussed in this report is St. Lawrence River valley, which developed mainly in Paleozoic sedimentary rock; the immediately adjacent area of the Canadian Shield to the north, consisting of Precambrian igneous and metamorphic rocks; and the Appalachian region to the south, which is composed of Paleozoic metamorphic, sedimentary, and igneous rocks. The Canadian Shield and St. Lawrence valley are contiguous with the parts of southern Ontario underlain by Precambrian and Paleozoic rocks, respectively, and are similar in topography and distribution of Quaternary sediments. The Appalachian area consists of mountainous, hilly, and ridged uplands consisting of strongly folded, variably metamorphosed, and locally intruded Paleozoic geosynclinal rocks (shales, sandstones, volcanics, and minor carbonates). Summit areas consist of flat to gently rolling remnants of a probable Upper Cretaceous peneplain, and lower areas are largely valley and ridge topography developed by differential erosion of the folded sedimentary and metamorphic rocks. Bedrock is at or

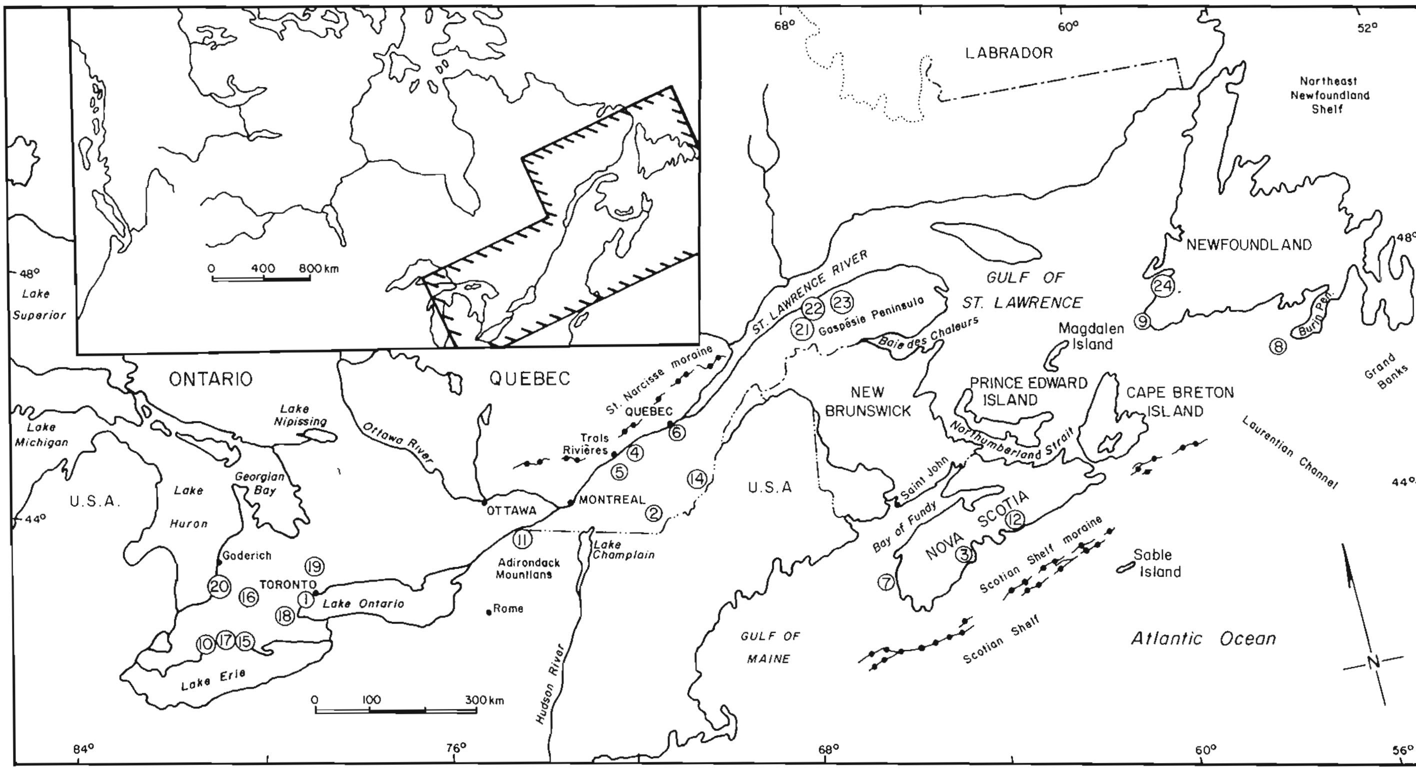

Figure 1. *Eastern Canada; numbers indicate the locations of type sections for units listed in Tables 1 to 5.*

near the surface in positive relief areas whereas till, glaciofluvial, glaciolacustrine, and fluvial deposits occupy many of the valleys and basins. The Quaternary sediments are mainly related to the last glacial substage but locally older deposits are exposed.

The Atlantic Provinces area of this report includes the Maritime Provinces (New Brunswick, Prince Edward Island, Nova Scotia), insular Newfoundland, and the Magdalen Islands. Prince Edward Island, and parts of Nova Scotia and New Brunswick adjacent to the Gulf of St. Lawrence, is underlain by upper Paleozoic sandstone and shale (dominantly redbeds). The terrain is flat to gently rolling and rock is near surface in most of the area, being covered only by a thin drift or marine veneer. The rest of the area is dominated by hilly uplands, consisting largely of blocks of pre-Carboniferous crystalline rocks raised along faults, and small irregular lowlands developed in areas of soft shale, sandstone, and locally gypsum and anhydrite. Summit areas are flat to gently rolling, reflecting the occurrence of the Cretaceous peneplain. Quaternary deposits are generally thin in upland areas, except in local buried valleys, and are somewhat thicker in the lowlands particularly in shale and gypsum areas and where preglacial valleys were oriented perpendicular to the direction of ice flow.

The shelf area adjacent to the Atlantic Provinces consists of the Scotian Shelf, Grand Banks, and Northeast Newfoundland Shelf, which are broadly rolling areas underlain by crystalline rocks nearshore and by sandstone and shales of upper Paleozoic to Tertiary age offshore, and the Gulf of St. Lawrence which is underlain largely by Carboniferous sandstones and shales. Laurentian Channel is a steep-sided trough which heads a short distance downstream from Quebec City and extends to Atlantic Ocean. The presence of aligned swells and hollows attests to former cover of at least part of the shelf by grounded, eroding glaciers; local subaerially carved valleys indicate that shallow parts of the shelf were at times emergent. Quaternary sediments are thin and discontinuous on the inner fringe where the shelves consist of resistant crystalline rock. In softer rock areas, Quaternary sediments may be more than 60 m thick (Ploessel et al., 1982) and consist of till, glaciomarine sediment, and marine sand and clay. The Grand Banks and parts of the Scotian Shelf near the continental slope, however, are bare rock or are covered only by a thin lag of gravel and sand. One major end moraine system – the Scotian Shelf Moraine – traverses the Scotian Shelf reaching from the Laurentian Channel to the Gulf of Maine (King, 1980, p. 48).

Stages and substages are the chronostratigraphic units used in this summary. Event units used are glaciation, interglaciation, and nonglacial. Both interglaciations and nonglacials are periods when the climate may locally have been as warm as or warmer than that of present, but the term interglaciation is reserved for periods that appear to correlate with world-wide reduction in ice cover to near present levels; nonglacial is used for periods of significant ice retreat when the global extent of ice is either unknown or is known to have been greater than that at present.

This report correlates events of the Wisconsinan and Sangamonian stages and combines older events as Illinoian and earlier. The Wisconsinan Stage is considered as equivalent to oxygen isotope stages 2 through 4 of Shackleton and Opdyke (1973). The early, middle, and late subdivisions of the Wisconsinan (75-65, 64-23, and 23-10 ka, respectively) are approximately those used by Dreimanis and Karrow (1972) and Dreimanis et al. (1981). The Sangamonian Stage, as used in this report, is the chronostratigraphic unit that corresponds to oxygen isotope stage 5. It is considered to have begun about 128 ka (oxygen isotope stage 5/6 boundary) and to have ended about 75 ka (oxygen isotope stage 4/5 boundary; Shackleton and Opdyke, 1973, p. 49). The Sangamonian may in the future be subdivided into substages corresponding to the oxygen isotope substages 5a to 5e, but at present too little is known about the deposits and the paleogeography of that time to make this feasible.

For those parts of the geological record falling within the limit of radiocarbon dating (Middle and Late Wisconsinan), correlations are based on this dating method. For earlier parts of the record, correlations are based largely on stratigraphic relationships.

This report considers the Quaternary stratigraphy of Eastern Canada in terms of the following time spans: Illinoian and earlier, Sangamonian, Early Wisconsinan, Middle Wisconsinan, and Late Wisconsinan. Stratigraphic units used in defining these are listed in the tables; the event units, correlation, and general paleogeography are discussed in the text. A general correlation chart shows the relationship of the major event units and proposed correlations with adjacent areas.

Acknowledgments

This paper has been greatly improved through critical review by A. Dreimanis, J.T. Andrews, and V.K. Prest.

ILLINOIAN AND EARLIER

Individual exposures of unconsolidated deposits known to be pre-Sangamonian are present at widely scattered localities. In some areas these deposits are thought to be of Illinoian age but in others they may be pre-Quaternary. Too little is known about these units and about the timing of their deposition to merit more than passing mention.

The only Quaternary unit found in southern Ontario that has been referred to pre-Sangamonian is the York Till at Toronto (Table 1; Terasmae, 1960, p. 26). It is considered to be of Illinoian age because it immediately underlies materials of Sangamonian age.

Pre-Sangamonian deposits are virtually unknown in southern Quebec. The pre-Johnville sediments (pebble gravel) of McDonald and Shilts (1971; Table 1) may fall in this category, but they could also be related to the warm part (oxygen isotope stage 5e) of the Sangamonian. The O'Malley Pond saprolite, Charlesbourg saprolite, and Château-Richer kaolinite are all the products of extensive weathering and might have developed during an early interglacial(s) but could also be remnants of pre-Quaternary weathering (LaSalle, this volume).

The Bridgewater Conglomerate (Table 1; Prest, 1898) of Nova Scotia consists of iron-cemented glacial drift and outwash and definitely is pre-Sangamonian, but possibly is pre-Quaternary (Prest et al., 1972). On the Burin Peninsula of Newfoundland, Tucker and McCann (1980) reported weathered and partly indurated till which they felt is much older than the other tills in the area and hence represents Early Wisconsinan or Illinoian Glaciation.

Deposits older than Early Wisconsinan have not been reported from the Atlantic shelf areas. A succession of older units is, however, reported from the adjacent continental slope and nearby seamounts and abyssal hills (Alam et al., 1983). These contain thick red mud units (Gulf of St. Lawrence provenance), suggesting extensive glaciation during oxygen isotope stages 6 (Illinoian) and 12 (436 ka, according to Johnson, 1982, p. 142). Grant and King (this volume), use these as an indication that glacier ice extended well out onto the shelf at least twice during pre-Sangamonian time.

SANGAMONIAN

The Sangamonian is the oldest time period to which workers in Eastern Canada extend their stratigraphies with any confidence. The Sangamonian Stage is defined by the Sangamon Soil and the Berry Clay Member of the Glasford Formation (Frye and Leonard, 1952, p. 119; Willman and Frye, 1970, p. 120). The Sangamonian Stage is a chronostratigraphic unit and hence includes all rocks deposited during the time defined by the Sangamon Soil and the Berry Clay Member in their type sections (North American Commission on Stratigraphic Nomenclature, 1983, p. 868). The Sangamon Soil is also used to define the Sangamon Interglaciation. Hence the name has become synonymous with interglacial conditions in many people's minds and in general it has been assumed that the Sangamon Soil developed during a single warm period; however, this is not necessarily true and the chronostratigraphic Sangamonian unit could contain deposits formed under both warm and cold climatic conditions.

In the type area in Illinois, the Sangamon Soil is developed in Illinoian Stage tills and the end of the Sangamonian Stage is represented by a thin sheet of colluvium that overlies the Sangamon Soil (Frye et al., 1974, p. 3). The time of the beginning of soil development cannot be dated and Frye et al. suggested that the event ending the Sangamonian occurred at about 75 ka. In the deep-sea record, however, the position, character, and length of this period can be relatively clearly seen. The prime interval, as defined by oxygen isotope ratios, which differs markedly from the bounding "glacial" records, is oxygen isotope stage 5 (Emiliani, 1971) which extends from about 128 to 75 ka ago (Shackleton and Opdyke, 1973). Five substages (5a-5e) have been defined within stage 5, based on variation of oxygen isotope values. Substage 5e (128-115 ka, Ruddiman et al., 1980, p. 34) – the oldest and warmest – a time when temperatures and sea levels were both higher than present, is what many workers consider to be equivalent to the Sangamon Interglaciation. Grant and King (this volume) have followed the lead of Woillard (1978) in defining the last interglacial as not only the time when temperatures were continuously as warm as or warmer than those at present, but included the entire complex period of oxygen isotope stage 5 during which conditions varied from warm to cool and even glacial. Karrow (this volume), on the other hand, used the more restricted definition of the Sangamonian and placed the Pottery Road and Scarborough formations of the Toronto

Table 1. Pre-Sangamonian Units

Region	Locality (Fig. 1)	Unit	Reference
Southern Ontario	1	York Till	Terasmae, 1960
Southern Quebec	2	Pre-Johnville Sediments	McDonald and Shilts, 1971
Atlantic Canada	3	Bridgewater Conglomerate	Prest, 1898

area (which probably represent oxygen isotope substage 5a-5d) in the Wisconsinan Stage. This summary report includes all deposits that formed during isotope stage 5 (128-75 ka, as defined by Shackleton and Opdyke, 1973) in the chronostratigraphic unit Sangamonian Stage, but does not necessarily accept the premise that these are all interglacial.

Southern Ontario

The Don Formation (Table 2; Karrow, 1969) has long been noted for its warm climate fossils (Coleman, 1933). Terasmae (1960, p. 37) stated that temperatures during deposition of the Don Formation were as much as 2°C warmer than at present and consequently he followed earlier workers in ascribing the deposits to an interglacial. Don Formation deposits at the type section are fluvial to estuarine and were deposited in a lake as much as 20 m higher than the present level of Lake Ontario. Following and during late stages of deposition of the Don Formation, climate cooled and lake level fell (Terasmae, 1960, p. 30).

In the Toronto area, the Don Formation is overlain by the Scarborough Formation (Table 2; Karrow, 1969) which consists of deltaic sands and clays deposited by a large river flowing from the north (Karrow, this volume); pollen content indicates that climate during deposition was as much as 5°C cooler than present (Terasmae, 1960, p. 38). The Scarborough delta was built into a lake whose level was some 45 m above present Lake Ontario (Karrow, this volume). A lake could only have existed at this level in the Ontario basin if St. Lawrence valley was blocked by ice. The cool climate during deposition and the necessity of an ice dammed St. Lawrence suggest that the Scarborough Formation formed during a glacial interval. This glacial interval is assumed to have resulted in deposition of Bécancour Till in St. Lawrence River valley (Karrow, this volume). Dreimanis and Karrow (1972) and Karrow (this volume) included these units in the Nicolet Stade which they assigned to the Early Wisconsinan Substage. Following the definition of the Sangamonian Stage used here, however, this stade falls within the Sangamonian rather than the Wisconsinan Stage.

Channels cut in the Scarborough Formation and containing a partial fill, referred to as the Pottery Road Formation (Table 2; Karrow, 1974), indicate lowered water levels in the Ontario basin following deposition of the Scarborough Formation. This lowering of water levels is correlated with removal of ice from St. Lawrence valley, an event that was followed by deposition of the St. Pierre Sediments. Little paleoenvironmental information is available for the Pottery Road Formation, which is very limited in known extent, but considerable data are available for the extensive St. Pierre Sediments (see below).

Southern Quebec

Warm climate interglacial deposits have not been identified in southern Quebec. The nonglacial St. Pierre Sediments, consisting of fluvial and organic sediment, were deposited on an alluvial plain which occupied central St. Lawrence valley for at least 6 to 7 ka previous to 75 ka (Table 2; Terasmae, 1958; Gadd, 1971; Occhietti, 1980, 1982; LaSalle, this volume). This unit has generally been referred to as an Early Wisconsinan interstadial deposit (Dreimanis and Karrow, 1972) because it was deposited under cooler conditions than present (2°C cooler according to Terasmae, 1958). The 75 ka age, based on a finite radiocarbon date of $74\,700 \pm {}^{2700}_{2000}$ BP (QL-198, Stuiver et al., 1978), however, indicates that the unit was deposited near the end of the Sangamonian (oxygen isotope stage 5, as defined here) rather than during the Wisconsinan Stage. The St. Pierre Sediments overlie Bécancour Till (Table 2; Gadd, 1971) with the Pierreville Varves (Table 2; Occhietti, 1980) separating the two. There is a paleoenvironmental transition from subarctic conditions during deposition of the underlying varves to a climate approaching that at present during deposition of the St. Pierre Sediments (Terasmae, 1958). Because this transition seems to rule out a hiatus between the two and because the St. Pierre does not overlie an interglacial soil or warm interglacial deposit, it appears that the underlying glacial deposit (Bécancour Till) was also deposited during the Sangamonian Stage (possibly during oxygen isotope stage 5b or 5d as suggested by Occhietti, 1982, p. 27). This being the case, Bécancour Till would appear to be the deposit formed by the glacier that blocked St. Lawrence valley and led to deposition of the Scarborough Formation in the Lake Ontario basin. The St. Pierre Sediments of the St. Lawrence probably correlate with the period of erosion following deposition of the Scarborough Formation and the subsequent gully fill, Pottery Road Formation, of the Lake Ontario basin.

Table 2. Sangamonian Units

Region	Locality (Fig. 1)	Unit	Reference
Southern Ontario	1	Don Formation	Karrow, 1969
	1	Scarborough Formation	Karrow, 1969
	1	Pottery Road Formation	Karrow, 1974
Southern Quebec	4	St. Pierre Formation	Gadd, 1971
	5	Pierreville Varves	Occhietti, 1980
	4	Bécancour Till	Gadd, 1971
	2	Massawippi Formation	McDonald and Shilts, 1971
	2	Johnville Till	McDonald and Shilts, 1971
	6	Anse-aux-Hirondelles sediments	LaSalle, this volume
	6	Pointe St-Nicolas till	LaSalle, this volume
Atlantic Provinces	7	Salmon River Sand	Grant, 1980a
	8	Langlade silt	Tucker and McCann, 1980
	9	Codroy Beds	Brookes et al., 1982

McDonald and Shilts (1971) correlated the Massawippi Formation of the Eastern Townships of Quebec with the St. Pierre Sediments and correlated the Johnville Till of the same area with the Bécancour Till (Table 2). LaSalle (this volume) correlated the Pointe St-Nicolas till and the Anse-aux-Hirondelles sediments (Table 2) of the Quebec City area with the Bécancour Till and the St. Pierre Sediments respectively.

Atlantic Provinces

In numerous coastal areas of the Atlantic Provinces, littoral rock platforms, elevated 2-6 m above present sea level, mark positions of sea level during the last interglacial (Grant, 1980b). Grant and King (this volume) have suggested that two levels of littoral platform are present and have assigned the higher one to oxygen isotope substage 5e and the lower one to substage 5a. Unnamed beach deposits and lagoonal silts associated with these benches are considered to be Sangamonian in age (Grant and King, this volume).

Numerous occurrences of organic deposits, all beyond radiocarbon dating range (>55 ka), are present in Nova Scotia. As these either overlie the littoral rock platform or underlie the oldest Wisconsinan tills, they are considered to be Sangamonian in age. The majority of the deposits have cool climate affinities and have been interpreted as Early Wisconsinan interstadial deposits (Mott and Prest, 1967), but evidence from one or two suggests conditions as warm as or warmer than present. At one site on southwestern Cape Breton Island an upper cool climate affinity bed is separated from a lower warm one by a deposit interpreted as a till of local origin (Grant and King, this volume). The warm affinity deposit is considered to have been laid down during "classical" (oxygen isotope stage 5e) Sangamonian, the local till during a Sangamonian stage cool period which resulted in local ice caps, and the cool climate organic beds on top during the latter part of the Sangamonian (oxygen isotope substage 5a).

The Salmon River Sand (Table 2) near Yarmouth is one of the few units exposed in the Atlantic Provinces which contains a warm affinity molluscan assemblage (Clarke et al., 1972). Largely because of this assemblage and the presence of an extinct gastropod (**Atractodon stonei**), this bed was assigned a Sangamonian age. Grant (1980a), influenced largely by a radiocarbon date of 38 600 ± 1300 BP (GSC-1440) corroborated by uranium-thorium and amino acid analyses, assigned this unit to a Middle Wisconsinan interstade. Grant and King (this volume), after reappraisal of the data, with particular emphasis on contact relationships, concluded that despite the dates, the Salmon River Sand was indeed deposited during the Sangamonian Stage but that it was later emplaced as an erratic block between two Wisconsinan till sheets.

Tucker and McCann (1980) described a marine silt exposed on Langlade Island (off the south coast of Newfoundland, 8 of Fig. 1), which has a similar foraminiferal assemblage to that of the Salmon River Sand. They accepted the Salmon River Sand as being a Wisconsinan interstade deposit and hence assigned the silt at Langlade to this time. With reassignment of the Salmon River Sand, the Langlade silt should also be considered as Sangamonian in age.

Brookes et al. (1982) reported on deposits (Codroy Beds) in a sinkhole in southwestern Newfoundland, which contained a faunal assemblage indicating transition from tundra to boreal forest to tundra conditions. Wood from this unit was beyond the range of radiocarbon dating (>40 000 BP, I-10203) and as there was not evidence for more than one overlying glacial cycle, they tentatively referred the Codroy Beds to the Sangamon Interglaciation.

There is no record of Sangamonian sediments from the Scotian Shelf or the Grand Banks. Cores from the Fogo Seamounts and Newfoundland basin contain a buried biostratigraphic interval comparable to Holocene, in terms of foraminiferal assemblages. This lies between two periods with cold affinities and is correlated with oxygen isotope stage 5 (Alam et al., 1983). These show evidence of climatic fluctuation, which could correspond with the warm-cold-warm cycle suggested to have occurred in Atlantic Provinces land areas, but the present data do not contain sufficient detail to permit correlation with oxygen isotope stage 5 substages.

EARLY WISCONSINAN

The Early Wisconsinan Substage in this report corresponds to oxygen isotope stage 4 of Shackleton and Opdyke (1973) and hence extends from ca. 75 to 64 ka ago.

Southern Ontario

Sunnybrook Till (Table 3; Terasmae, 1960, p. 27), which overlies an erosional unconformity on top of the Scarborough Formation, was deposited during the Early Wisconsinan in the Toronto area (Karrow, 1969, p. 12). Using composition of the till as the main criterion, Dreimanis and Terasmae (1958, p. 124) concluded that this unit was deposited by ice moving out of the Lake Ontario basin towards the west. Most investigators comment on the presence of waterlaid material within the Sunnybrook Till (Karrow, this volume, says it consists in large part of sand reworked from the underlying Scarborough Formation and sediments derived from proglacial lakes) but emphasize the glacial rather than the nonglacial aspects of this unit (Karrow, 1969, p. 12). Eyles and Eyles (1983), however, discounted the role of grounded ice in depositing the Sunnybrook Till and concluded that the diamicton was deposited by a variety of lake bottom processes. It must, however, be remembered that during each advance and retreat of glaciers in St. Lawrence valley, northeastward drainage of Lake Ontario basin was blocked so that lake levels were high. Consequently the ice margin in the Ontario basin advanced and retreated in proglacial lakes and a mixture of glacial and lacustrine sediments resulted.

The Bradtville Till, which is known only from borings on the north shore of Lake Erie, has been assigned an Early Wisconsinan age (Dreimanis et al., 1966).

Southern Quebec

Following the Quaternary stage and substage definitions used in this report, the glacial deposits immediately overlying the St. Pierre Sediments in central St. Lawrence valley are Early Wisconsinan in age. These include the Deschaillons Formation and probably the Gentilly Till (Table 3; Gadd, 1971). There is little problem in referring the Deschaillons varves to the Early Wisconsinan because they conformably overlie and apparently immediately postdate the St. Pierre Sediments. The Gentilly, however, is the only till overlying the St. Pierre Sediments. During the Late Wisconsinan, this part of the valley was occupied by ice until ca. 12 ka (Gadd et al., 1972, p. 13) when the Champlain Sea invaded the area. This means that at least the upper part of the surface till (the Gentilly) must be Late Wisconsinan in age. The question that has not been satisfactorily answered is whether Gentilly Till represents a glacial event which caused central St. Lawrence valley to be occupied by ice continuously from the end of deposition of the St. Pierre Sediments until invasion of the Champlain Sea, whether deposition of the Deschaillons Formation occupied Early and much of Middle Wisconsinan time, or whether there are unidentified hiatuses or unconformities within the succession.

Gadd (1971) and LaSalle (this volume) favoured the first interpretation. Occhietti (1982, p. 29) felt that the Deschaillons Formation was possibly deposited over a period as long as 5 ka. Lamothe et al. (1983, p. 503), using radiocarbon dates on carbonate concretions, suggested that Gentilly Till was not deposited until after 35 ka or, in other words, that central St. Lawrence valley was not occupied by ice during Early and most of Middle Wisconsinan time. This latter interpretation does not fit with the history of events developed for the Lake Ontario basin. At Toronto, Early Wisconsinan Sunnybrook Till was deposited by ice moving towards the southwest (Dreimanis and Terasmae, 1958, p. 126). This ice would have had to pass through central St. Lawrence valley before reaching the Ontario basin.

In the Appalachian area of southeast Quebec, two tills are recognized overlying deposits correlated with the St. Pierre Sediments. The oldest of these – Chaudière Till (Table 3; McDonald and Shilts, 1971) – is overlain by glaciolacustrine sediments dated at older than 20 ka and would therefore be Early Wisconsinan in age and correlative with the lower part of the Gentilly Till. Lower parts of the Chaudière Till were deposited by ice flowing from the northeast (out of the Appalachian Mountains), but upper parts were deposited by ice flowing from the northwest (across St. Lawrence River valley).

Prest and Hode-Keyser (1977) divided Wisconsinan-age drift of the Montreal area into three units. They correlated the oldest of these with the Malone Till of MacClintock and Stewart (1965; Table 3). This till was deposited by ice flowing towards the southwest, up St. Lawrence River valley. Through comparison of this stratigraphy with that of McDonald and Shilts (1971), they arrived at an Early Wisconsinan age for the Malone Till, in contrast to MacClintock and Stewart (1965) who referred to it as early Late Wisconsinan.

Atlantic Canada

The Wisconsinan record in Atlantic Canada consists almost entirely of glacial deposits. Because of the lack of nonglacial sediments, it is difficult to assign the various glacial units to specific Wisconsinan substages. The tills have, however, been subdivided into units based on lithology, provenance, and direction of ice flow, and a sequence of ice flow events has been tied to the Wisconsinan substages (Grant and King, this volume). The oldest tills and ice flow patterns are referred to the Wisconsinan because they overlie the Sangamonian littoral bench. They are referred to the Early rather than later stages of the Wisconsinan largely because Early Wisconsinan has been shown to have been a time of major glacial expansion in other areas and if this oldest Wisconsinan was not Early Wisconsinan, it would be difficult to fit all the later events into the Wisconsinan.

According to Grant and King (this volume), all parts of the Maritime Provinces appear to have been covered by a through-moving Early Wisconsinan ice sheet which in general flowed from northwest to southeast. The thickness and gradient of this ice sheet were sufficient to produce a uniform trajectory irrespective of relief, and consequently the terminus was probably far out on the Continental Shelf.

In New Brunswick, stratigraphic units have not been identified that can be related to this substage. Striae with a northwest-southeast orientation, however, are present on the Sangamonian littoral terrace in the southeastern part of the province and this same flow pattern is present in the Caledonian Highlands a short distance to the west, an area considered to have remained ice free during the Late Wisconsinan (Rampton et al., 1984).

In Nova Scotia, the till associated with the Early Wisconsinan flow pattern is generally thick, compact, has a reddish brown matrix derived from bottom muds in the Bay of Fundy and Northumberland Strait and a characteristic suite of foreign clasts (Grant and King, this volume). Table 3 lists three stratigraphic units related to this Early Wisconsinan event which Grant and King (this volume) have referred to as the Fundy and Cabot Stade.

According to Grant and King (this volume), Newfoundland was primarily glaciated by local ice with ice from the mainland (Laurentide ice) locally impinging on the island. During the Early Wisconsinan, Newfoundland-centred ice covered virtually the entire island, the main exception being several nunatak areas in the western highlands, and moved outward onto the adjacent shelf. Tucker and McCann (1980) associated drumlins and ice flow features on the Burin Peninsula with this Early Wisconsinan glaciation which they called Fortune Bay Event, and ascribed tills in several sections to this substage.

Early Wisconsinan ice moved southeastward across the Scotian Shelf and probably terminated near the shelf margin (Prest, this volume). King (1970, 1980) subdivided the Quaternary sediments of the Scotian Shelf into five formations; three of these – Scotian Shelf Drift, Emerald Silt, and Sambro Sand – are related to glaciation and the others – LaHave Clay and Sable Island Sand and Gravel –

Table 3. Early Wisconsinan Units

Region	Locality (Fig. 1)	Unit	Reference
Southern Ontario	1	Sunnybrook Till	Terasmae, 1960
	10	Bradtville Till	Dreimanis et al., 1966
Southern Quebec	4	Deschaillons Formation	Gadd, 1971
	4	Gentilly Till	Gadd, 1971
	2	Chaudière Till	McDonald and Shilts, 1971
	11	Malone Till	Prest and Hode-Keyser, 1977
Atlantic Provinces	12	East Milford Till	Stea, 1982
	13	Richmond Till	Grant, 1980a
	7	Red Head Till	Grant, 1980a
Offshore		Scotian Shelf Drift	King, 1970, 1980
		Emerald Silt	King, 1970, 1980
		Sambro Sand	King, 1970, 1980

were deposited under nonglacial conditions. The Scotian Shelf Drift and the proglacial Emerald Silt and Sambro Sand have not been closely dated and probably include elements deposited during all three Wisconsinan substages. Glacial deposits south of the Scotian Shelf Moraine (Fig. 1) are older than 26 ka (King, 1980, p. 44) and so probably relate at least in part to the Early Wisconsinan. According to Grant and King (this volume), grounded Early Wisconsinan ice extended virtually to the shelf edge and at 50 ka had receded to become an ice shelf anchored on higher parts of submarine banks. Little is known about Early Wisconsinan events in other parts of the Atlantic shelf although Piper et al. (1978) suggested that the Northeast Newfoundland Shelf has not been glaciated since Illinoian time.

MIDDLE WISCONSINAN

As defined in this report, the Middle Wisconsinan Substage includes oxygen isotope stage 3 and about half of stage 2 (Shackleton and Opdyke, 1973) and lasted from ca. 64 to 23 ka ago. This appears to have been a time of fluctuating ice margins and varying environmental conditions in Eastern Canada. In southern Ontario the geological record is largely nonglacial with local glacial incursions. In southern Quebec and the Atlantic Provinces the record is primarily glacial with local evidence of the existence of nonglacial conditions.

Southern Ontario

The Erie basin has the best record of Middle Wisconsinan nonglacial events in Eastern Canada. These have been used in constructing three Middle Wisconsinan units which, in chronological order are: Port Talbot Interstade, Cherrytree Stade, and Plum Point Interstade (Dreimanis and Karrow, 1972). The lithological units related to these are Tyrconnell Formation, Dunwich Drift, and Wallacetown Formation (Table 4).

The Tyrconnell Formation has been used to define the Port Talbot Interstade. It consists of a lower greenish clay overlain by varved clayey silt which is in turn overlain by lacustrine silt and sand containing peat and gyttja (Dreimanis et al., 1966, p. 311; Karrow et al., 1978, p. 22). The lower unit is interpreted as an accretion gley (Quigley and Dreimanis, 1972, p. 997) developed under open woodland conditions during a relatively long, mild interstade. The varved sediments were deposited in a proglacial lake which developed as ice advanced to the Lake Erie basin. The organic-rich lacustrine deposits, which form the upper part of the Tyrconnell Formation, were deposited 47.7 to 42.7 ka ago when the area supported a forest tundra. The Dunwich Drift was possibly formed when ice of the Cherrytree Stade overrode the area but it may instead be part of the drift complex related to the Nissouri Stade of Late Wisconsinan age (Dreimanis, 1982a, p. 25). The Wallacetown Formation, which consists of lacustrine sand and silt, has been assigned to the Plum Point Interstade (Karrow et al., 1978). The Plum Point Interstade is based on wood, dated 28.2 to 24.6 ka, collected from the Catfish Creek Till in the vicinity of Plum Point, Lake Erie (Dreimanis, 1958). Because the Wallacetown Formation does not contain autochthonous organic deposits, this correlation with Plum Point Interstade cannot be confirmed and it may relate instead to the advance of Nissouri Stage ice (Karrow et al., 1978, p. 22).

In the Toronto area, the Middle Wisconsinan is represented mainly by the Thorncliffe Formation which consists of upper, middle, and lower members (Table 4; Karrow, 1967). These members consist of sand, silt, and clay and include deltaic sequences which record lacustrine deposition in high-level lakes which suggests that drainage through St. Lawrence River valley was blocked at this time. The upper and lower members of the Thorncliffe Formation are separated by two till units with associated varved clays (Seminary and Meadowcliffe, Table 4; Karrow, 1967) which enclose the middle member. These glacial units are correlated with the Cherrytree Stade and are evidence that ice advanced, at least locally, into the Ontario basin during the Middle Wisconsinan. Karrow (this volume) placed the age of the Cherrytree Stade in the Toronto area as 40 to 35 ka.

Southern Quebec

The only finite Middle Wisconsinan radiocarbon dates from southern Quebec are on carbonate concretions (Lamothe et al., 1983), are suspected of being erroneous, or were obtained from material contaminated with modern rootlets (LaSalle, this volume). As noted under the discussion of Early Wisconsinan deposits, the Gentilly Till is thought to have been deposited by ice that occupied central St. Lawrence River valley continuously from the Early through Late Wisconsinan. To the south and adjacent to central St. Lawrence River valley, however, Middle Wisconsinan deposits have tentatively been identified. In the

Table 4. Middle Wisconsinan Units

Region	Locality (Fig. 1)	Unit	Reference
Southern Ontario	10	Tyrconnell Formation	Karrow et al., 1978
	10	Dunwich Drift	Dreimanis, 1980
	10	Wallacetown Formation	Karrow et al., 1978
	1	Thorncliffe Formation	Karrow, 1967
	1	Seminary Till	Karrow, 1967
	1	Meadowcliffe Formation	Karrow, 1967
Southern Quebec	4	Gentilly Till	Gadd, 1971
	14	Gayhurst Formation	McDonald and Shilts, 1971
Atlantic Provinces	7	Saulnierville Till	Grant, 1980a
Offshore		Scotian Shelf Drift	King, 1970, 1980
		Emerald Silt	King, 1970, 1980
		Sambro Sand	King, 1970, 1980

Eastern Townships varved lake sediments of the Gayhurst Formation (Table 4; McDonald and Shilts, 1971) are referred to the Middle Wisconsinan because they lie between two tills which postdate the St. Pierre Sediments and contain organic materials dated at older than >20 000 BP (GSC-1137). At Montreal, Prest and Hode-Keyser (1977) recognized a complex of stratified sediments and tills, which might be of Middle Wisconsinan age, lying between their two main till units. These two Middle Wisconsinan (?) units suggest that even though ice may have occupied central St. Lawrence Lowlands throughout most of the Wisconsinan, parts of the upper valley and areas of adjacent uplands were temporarily ice free. Glacial lake sediments, reported by LaSalle (this volume) as underlying the surface till south of Montreal, could also be of Middle Wisconsinan age.

Atlantic Provinces

Little is known about the paleogeography or paleoenvironment of the Atlantic Provinces during the Middle Wisconsinan and nonglacial deposits of proven Middle Wisconsinan age have not been found. As noted earlier, Salmon River Sand and Langlade silt, once considered to be Middle Wisconsinan, are now thought to be Sangamonian. A date of 31 000 ± 630 BP (GSC-1220) on a mastodon bone from Cape Breton Island and a date of 37 300 ± 1310 BP (GSC-2469) on mastodon coprolites from New Brunswick (Grant and King, this volume) suggest, however, that nonglacial conditions may have locally prevailed. Weathered horizons, possibly truncated soil profiles, at the top of tills in several coastal exposures are also suggestions of at least partial Middle Wisconsinan deglaciation (Grant and King, this volume).

Because of the lack of verified Middle Wisconsinan nonglacial sediments, it is difficult to identify Middle Wisconsinan glacial deposits. In Nova Scotia, Grant (1980a) described a till of "mixed lithology" (Saulnierville Till, Table 4) and Grant and King (this volume) referred to an intermediate till of hybrid lithology which might be Middle Wisconsinan. Grant and King (this volume) interpreted these deposits as the result of either an interplay between local glaciers and external ice or more likely to a change from dominance by foreign glaciers to a regime controlled by local ice caps.

Tucker and McCann (1980, p. 1476) suggested that till and northwest trending striae of the Burin Peninsula of Newfoundland were formed by Middle Wisconsinan flow from an offshore source. Grant and King (this volume) placed the centre responsible for this onshore flow on the Placentia Bay seafloor. Grant (in Prest et al., 1972, p. 46) had earlier recognized onshore flow on Cape Breton Island where he defined an ice cap centred on the continental shelf between the Laurentian Channel and Sable Island. This too was considered to be of Middle Wisconsinan age.

The history of glacier fluctuation on the shelf itself is poorly known and the concepts of onshore movement from ice centres on the shelf and for local deglaciation of coastal areas have not been integrated into the offshore picture. Middle Wisconsinan stratigraphic units are not recognized as separate entities in the Wisconsinan shelf sequence (King, 1970, 1980). Grant and King (this volume) envisaged the grounded Early Wisconsinan ice sheet, which reached almost to the shelf margin, as thinning to become largely a floating ice shelf about 50 ka and apparently retreating so that the Scotian Shelf Moraine was built at the zone of transition from ice sheet to ice shelf conditions about 30 to 28 ka.

At this moment, the continental shelf record cannot be correlated with the record from farther offshore where, in their summary of the late Quaternary of the Grand Banks continental margin, Alam et al. (1983) noted seven biostratigraphic units in the Wisconsinan. Three of these units, one representing cold conditions separating two representing warmer, possibly correspond to the Port Talbot Interstade, Cherrytree Stade, and Plum Point Interstade of the southern Ontario record.

To sum up, during the Middle Wisconsinan the glacier regime of the Atlantic Provinces area appears to have been controlled mainly by maritime factors with an interplay of locally centred, land-based ice caps and glacier movements onto land from centres located on the continental shelf. There is scattered evidence that ice recession may have been great enough for local coastal areas to have been deglaciated and highlands, such as the Caledonian (southeast New Brunswick) and those of Cape Breton, and western Newfoundland, to have been at least partly deglaciated during the Middle Wisconsinan. Grant and King (this volume) have assigned Middle Wisconsinan events in Nova Scotia to the Clare Interstade and Digby Stade and events in Newfoundland to the Burin Stade.

LATE WISCONSINAN

The Late Wisconsinan, as defined in this report, consists of the period from 23 to 10 ka. This period in Eastern Canada was a time of dominantly glacial conditions.

Southern Ontario

Dreimanis and Karrow (1972) named the time of the maximum Late Wisconsinan ice advance the Nissouri Stade. The main lithological unit assigned to this stade is the Catfish Creek Drift (Table 5; deVries and Dreimanis, 1960). It generally consists of a stony, sandy silt till, which is remarkably homogeneous, deposited by ice which flowed in a southwesterly direction (Cowan, 1978, p. 1026); it is interpreted as the till sheet deposited when Late Wisconsinan ice was thickest and flowed southward with little evidence of lobation (Karrow, this volume). The youngest date from below Late Wisconsinan till in Ontario is 22 800 ± 450 BP (GSC-816; Hobson and Terasmae, 1969, p. 5) on wood in the buried St. David's Gorge. Deposition of this wood must have shortly predated overriding by the ice that deposited the Catfish Creek Drift because this ice was advancing southward across Ohio as early as 22 ka. After reaching its maximum, the ice fluctuated near its limit for ca. 4 ka (Dreimanis, 1982b, p. 75; Karrow, this volume).

The youngest Nissouri Stade ice advance occurred ca. 17.2 to 16.5 ka (Dreimanis and Goldthwait, 1973). Following this, the ice retreated from the Lake Erie basin, north at least as far as Goderich in the Lake Huron basin and into the Lake Ontario basin (Mörner and Dreimanis, 1973). Proglacial lakes, in which extensive fine grained sediments were deposited, occupied the deglaciated parts of the lake basins and when continued ice retreat opened lower outlets to the east, water levels in the Erie basin fell below the level of the present lake. This period of ice retreat was named the Erie Interstade by Dreimanis (1958). No datable Erie Interstade organic deposits have been found but the retreat during the Erie Interstade is estimated to have ended about 15.6 ka (Mörner and Dreimanis, 1973, p. 120). Following the Erie Interstade, ice readvanced to reoccupy the Huron and Erie basins and moved southward into Ohio and Michigan, reaching a maximum position about 15 ka (Dreimanis and Goldthwait, 1973, p. 94). This period has been referred to as the Port Bruce Stade. Because the ice was advancing over lake sediments, the till produced was fine grained and nearly stone free. The ice cover in southern Ontario was relatively thin at this time and the topography, dominated by the major lake basins, played a major role in controlling the configuration of ice lobes. Proglacial lakes were present

Table 5. Late Wisconsinan Units

Region	Locality (Fig. 1)	Unit	Reference
Southern Ontario	15	Catfish Creek Drift	deVries and Dreimanis, 1960
	16	Tavistock Till	Karrow, 1974
	16	Stratford Till	Karrow, 1974
	16	Stirton Till	Karrow, 1974
	16	Mornington Till	Karrow, 1974
	16	Elma Till	Karrow, 1974
	16	Maryhill Till	Karrow, 1974
	16	Rannoch Till	Karrow, 1977
	16	Wartburg Till	Karrow, 1977
	17	Port Stanley Drift	deVries and Dreimanis, 1960
	16	Wentworth Till	Karrow, 1959
	18	Halton Till	Karrow, 1959
	19	Newmarket Till	Gwyn, 1972
	20	St. Joseph Till	Cooper and Clue, 1974
	19	Kettleby Till	Gwyn, 1972
Southern Quebec	4	Gentilly Till	Gadd, 1971
	2	Lennoxville Till	McDonald and Shilts, 1971
	11	Malone Till	MacClintock and Stewart, 1965
	11	Fort Covington Till	MacClintock and Stewart, 1965
	6	Quebec City Till	LaSalle, this volume
	6	St-Nicolas drift	LaSalle, this volume
Gaspésie	21	Tamagodi Till	Lebuis and David, 1977
	21	Langis Till	Lebuis and David, 1977
	22	Petite Matane Till	Lebuis and David, 1977
	23	Grand Volume Till	Lebuis and David, 1977
Atlantic Provinces	12	Rawdon Till	Stea, 1982
	7	Beaver River Till	Grant, 1980a
	12	Bennet Bay Till	Stea, 1982
	24	St. George's River Drift	MacClintock and Twenhofel, 1940
	24	Robinsons Head Drift	MacClintock and Twenhofel, 1940
Offshore		Scotian Shelf Drift	King, 1970, 1980
		Emerald Silt	King, 1970, 1980
		Sambro Sand	King, 1970, 1980

adjacent to the lobes and not only did these supply an abundance of fine grained sediments, which became incorporated in later tills, but they provided a dynamic environment in which ice lobes could advance or retreat rapidly and in which interfingering glacial and glaciolacustrine materials were deposited. The ice lobes in the Huron, Erie, and Ontario basins acted largely independently and the many oscillations of each resulted in the formation of many moraines and till sheets (Port Stanley, Wentworth, Tavistock, Stirton, Stratford, Mornington, Wartburg, Elma, Newmarket, Rannoch, and Maryhill of Table 5; Karrow, this volume). During the Port Bruce Stade an area of southern Ontario midway between lakes Ontario, Erie, and Huron became permanently deglaciated and Lake Maumee, the earliest ancestor of the Ontario Great Lakes, came into existence.

Ice retreat, following the Port Bruce stadial maximum, probably began ca. 14 ka and by 13.3 ka the ice front was as far north as the north end of Lake Michigan (Evenson and Dreimanis, 1976, p. 219); this period is referred to as the Mackinaw Interstade (Dreimanis and Karrow, 1972). During this interstade, ice withdrew completely from the Lake Erie basin, from a major part of the main Lake Huron basin, and from a large part of the Lake Ontario basin. Drainage was once again established to the east and the lake level in the Erie basin fell.

The last major readvance in southern Ontario occurred ca. 13 ka during the Port Huron Stade (Dreimanis and Goldthwait, 1973). During this advance the ice refilled the Huron and Ontario basins and occupied the eastern part of the Erie basin (Barnett, 1979). Prominent moraines and several till sheets were deposited around these basins during this advance (St. Joseph, Halton, and Kettleby tills of Table 5; Karrow, this volume). Glacial lakes Whittlesey and Saginaw are contemporaneous with the building of the moraine system (Port Huron) that marks the maximum of this advance (Dreimanis and Goldthwait, 1973, p. 95).

Recession following the Port Huron Stade opened the Huron, Erie, and Ontario lake basins and the later Wisconsinan history is largely one of changing lake levels. During early stages of retreat, lake levels fell as ice recession opened lower, more northerly outlets. Later, lake levels rose as isostatic tilting raised the northern outlets. At the time of deglaciation, single water bodies – Lake Warren which drained across Michigan, and lakes Grassmere and Lundy, which drained either directly into Lake Michigan or eastward to the Ontario basin – occupied the Huron and Erie basins (Prest, 1970, Fig. XII-16 d, e). When retreat in the Ontario basin permitted drainage at lower levels, Lake Algonquin developed in the Huron basin with a low level lake in the Erie basin (Prest, 1970, Fig. XII-16 f). Lake Algonquin expanded northward as ice retreated from the Huron basin and the area to the north and finally drained when low outlets were opened to Ottawa valley about 10.4 ka (Karrow et al., 1975, p. 53). The Lake Ontario basin was occupied by glacial Lake Iroquois which drained eastward to Hudson River through an outlet near Rome, New York, about 12 ka (Karrow, this volume); lower level lakes occupied the basin as ice retreat from the north side of Adirondack Mountains opened lower outlets into Lake Champlain and St. Lawrence River valleys (Prest, 1970, Fig. XII-16 f-h). Deglaciation of the isostatically depressed St. Lawrence River valley permitted invasion by marine waters which may have temporarily been confluent with waters in the Ontario basin.

The western end of the Lake Superior basin was first deglaciated during retreat from the Port Huron Stade maximum and was occupied by glacial Lake Keweenaw which drained westward to Mississippi River. Further retreat opened lower outlets to the Lake Michigan basin which was experiencing a period of low water levels during which the Two Creeks Forest Bed (11.9 ka) was deposited (Two Creeks Interstade, Dreimanis and Karrow, 1972). Rapid readvance, possibly a surge, about 11.8 ka, led to deposition of Two Rivers Till over the Two Creeks Forest Bed in the Lake Michigan basin. During this, the Greatlakean Substage (formerly the Valderan Substage, Evenson et al., 1976), ice again completely occupied the Superior basin (Prest, 1970, Fig. XII-16 i). Lake Duluth, draining to the west, occupied the western end of the Superior basin during retreat from the Greatlakean maximum. As ice continued to recede from the basin, lower outlets were opened, first to the Lake Michigan basin and later to the Huron basin. Final deglaciation of the Superior basin was probably complete by 9.5 ka (Karrow, this volume).

At the time ice recession exposed the lowest outlet for each lake basin, water levels fell below modern lake levels. Isostatic recovery raised these low outlets and after about 8 ka of tilting and shifting of outlets, the Great Lakes attained their current drainage configuration, (Karrow, this volume; for changes in lake configurations see Prest, 1970, Fig. XII-16 i-x).

Southern Quebec

As mentioned earlier, the entire Wisconsinan glacial record of the central St. Lawrence Lowlands is considered to be represented by the Gentilly Till (Table 5; Gadd, 1971) and consequently the upper part of the Gentilly would be considered Late Wisconsinan.

In the Eastern Townships, where partial Middle Wisconsinan deglaciation occurred, Lennoxville Till (Table 5; McDonald and Shilts, 1971) is referred to the Late Wisconsinan. At the Late Wisconsinan maximum, the ice that deposited this till moved from the northwest. During recession, there was locally a reversal of flow that has been linked with the development of a calving bay in the St. Lawrence Lowlands (LaSalle, this volume).

In the vicinity of Montreal and in St. Lawrence valley to the south and west, two Wisconsinan-age tills are recognized – the Malone and Fort Covington (Table 5; LaSalle, this volume). Dreimanis and Karrow (1972) accepted the age assignment made by MacClintock and Stewart (1965) and referred the Malone to the early Late Wisconsinan Nissouri Stade and the Fort Covington to the Port Huron Stade. Dreimanis (1977) interpreted Late Wisconsinan events as follows: Nissouri Stade in upper St. Lawrence was a time characterized by vigorous southwestward ice flow (deposition of Lower Malone Till); partial deglaciation occurred during the Mackinaw Interstade (deposition of Upper Malone Drift); during the Port Huron Stade, ice advanced from the northwest (depositing Fort Covington Till) and a later readvance or a shifting to more northerly flow directions locally remoulded some drumlins. Prest and Hode-Keyser (1977), largely by correlating the stratigraphy of McDonald and Shilts (1971) with their own and that outlined by MacClintock and Stewart (1965), interpreted the Malone as Early Wisconsinan and the Fort Covington as Late Wisconsinan. In their interpretation the Middle Till Complex underlying the Fort Covington Till was deposited during partial Middle Wisconsinan deglaciation, the Fort Covington Till was deposited during the Late Wisconsinan (Nissouri Stade?), and the later readvance could have occurred during the Port Huron.

Following the Late Wisconsinan maximum, proglacial lakes draining to the south (Lake Albany and Lake Vermont) developed in Lake Champlain and Hudson River valleys and expanded northward as the ice retreated (see Prest, 1970, Fig. XII-16 b-g). In lower St. Lawrence valley, Late Wisconsinan ice flowed northeastward into the Gulf of St. Lawrence and during recession a calving bay developed with marine waters rapidly invading the isostatically depressed lowlands to form the Champlain Sea (Gadd, 1980, p. 1451). Dates on marine shells indicate that marine waters had reached the Gaspésie coast of the Gulf of St. Lawrence by 13.5 ka, Quebec City before 12.4 ka, and Ottawa by 12.8 ka (LaSalle, this volume). Hence the retreating Late Wisconsinan ice in St. Lawrence Lowlands was fronted on three sides by large water bodies: Lake Iroquois in the Ontario basin, Lake Vermont in the Lake Champlain basin, and the sea in the Gulf of St. Lawrence. Prest (1970, Fig. XII-16 f-i) indicated that the lakes in the Ontario and Champlain basins extended into the upper St. Lawrence Lowlands to form a single water body before marine waters had made their way farther up valley than Quebec City. Gadd (1980; personal communication, 1983), primarily using ice flow features and radiocarbon dates on shells, suggested rapid opening of a channel by calving between Quebec City and Ottawa while remnant ice continued to restrict Lake Iroquois to the Ontario basin and Lake Vermont to the Lake Champlain area. Karrow (1981), mainly on the basis of radiocarbon dates on wood related to Lake Iroquois and thickness and ice profile estimates, opposed this interpretation explaining conflicts in ages between Lake Iroquois and the Champlain Sea in the Ottawa area as being due to the problem of comparing radiocarbon dates on wood (basis of Lake Iroquois chronology) with those on shells (basis of Champlain Sea chronology).

Limited ice readvance into the Champlain Sea occurred at several places. Near Quebec City, till overlies marine sediments dated 12.4 ka; the glaciomarine St-Nicolas drift (Table 5; LaSalle, this volume) has been dated at 11.2 ka. Glaciomarine sediments dated 11-11.3 ka in the Trois-Rivières area are overlain by glacial sediments which were deposited before 10.6 ka (Occhietti, 1980, p. 115). In upper Ottawa River valley, Catto et al. (1981) described till overlying Champlain Sea sediments but found no information that would permit direct dating of the ice advance. The early readvance at Quebec City may have been a minor oscillation related to deglaciation; the glacial deposits at St-Nicolas and Trois-Rivières are part of the St. Narcisse Moraine which extends from north of Quebec City to Ottawa (LaSalle, this volume) and has been interpreted as being climatically induced (Occhietti and Hillaire-Marcel, 1977, p. 127) or being related to a change in characteristics of the ice sheet at the point where the glacier was retreating in water to where the margin was on land (Andrews, 1973, p. 196; Hillaire-Marcel et al., 1981, p. 213).

The Champlain Sea continued to occupy St. Lawrence Lowlands until isostatic rebound lifted the area above sea level. This appears to have occurred shortly after 10 ka as indicated by radiocarbon dates of ca. 9.7 ka on freshwater shells from deposits on top of Champlain Sea sediments (Richard, 1978; LaSalle, this volume).

Gaspésie Peninsula

The Quaternary history of Gaspésie Peninsula is not well understood. Lebuis and David (1977) recognized four different tills in central and northern Gaspésie (21-23 of Fig. 1), but little is known about the absolute ages or extent of these deposits. Prest (1977, p. 11), in a correlation table, showed the four tills as Wisconsinan in age. The oldest till -- Tamagodi (Table 5) -- was probably deposited by a local ice cap. The overlying Langis Till (Table 5) possibly correlates with Lennoxville Till (Late Wisconsinan) and may be related to an invasion by the Laurentide Ice Sheet; however, the high summits of Gaspésie probably remained as nunataks (Lafrenière and Gray, 1981). Glaciomarine deposits indicate that part of the Petite Matane Till (Table 5), deposited by a large Appalachian glacier, dates from ca. 13.5 ka. The youngest till -- Grand Volume (Table 5) -- was deposited by small ice caps and valley glaciers which had disappeared from the high areas before 9.8 ka.

Atlantic Canada

In contrast to the rest of Eastern Canada, which in general lay well north of the Late Wisconsinan limits, Atlantic Canada lay near the margin so that higher areas and certain coastal regions probably remained ice free throughout the Late Wisconsinan. Prest (this volume) discussed two possible configurations of the Late Wisconsinan margin. His minimum portrayal limit is nearly coincident with the limit proposed by Grant (1977) and is accepted in this report as the most likely of the two possibilities. As noted earlier, only scant evidence exists that parts of Atlantic Canada remained ice free during the Middle Wisconsinan. It is possible that the area remained ice covered throughout the Wisconsinan and that the till units and glacial flow patterns assigned to Early, Middle, and Late Wisconsinan substages are due purely to evolutionary changes in ice thickness and patterns of flow.

Nova Scotia

The upper drift of Nova Scotia (Rawdon and Beaver River tills, Table 5; Grant, 1980a; Stea, 1982) is typically thin, loose, sandy, and locally derived and evidently was deposited by glaciers flowing coastward from ice caps centred on the uplands. This drift is presumed to be of Late Wisconsinan age because it is associated with marine and fluvial beds dated directly and indirectly to the period 14 to 12 ka (Grant and King, this volume). As indicated by Grant (1977, p. 252), the ice did not reach the coast along much of the Bay of Fundy and the highland plateaus of northwestern Cape Breton were not covered.

Stea (1982) recognized a younger drift unit – Bennet Bay Till (Table 5) – which he ascribed to late westward flow into Bay of Fundy. Grant (1975) also recognized a late event, dated ca. 10 ka, which resulted in deposition of colluvium and possibly till over peat. He ascribed this event to a climatic deterioration which might correlate with the younger Dryas of Fennoscandia.

New Brunswick

No formally named Late Wisconsinan units have been designated in New Brunswick. Rampton et al. (1984), however, outlined a series of flow patterns and presented a general picture of ice retreat. Early retreat was controlled by flow from centres located in southern New Brunswick, in the Gulf of St. Lawrence north of Prince Edward Island, and in northern New Brunswick. The offshore ice centre soon disappeared and as deglaciation proceeded, more northerly and westerly centres became dominant. Late Wisconsinan ice in New Brunswick appears to have been contiguous with ice in Maine and possibly with the Laurentide Ice Sheet in upper Saint John River valley. There is, however, no evidence of strong ice movement from these areas into New Brunswick, rather these regional ice masses appear to have confined the local ice so that it could not flow towards the west and northwest. After lowering of the surface of the Laurentide Ice Sheet in St. Lawrence River valley north of New Brunswick, ice flow in northern New Brunswick reversed and flowed towards the northwest.

There are few dates closely related to Late Wisconsinan glacial events but in general the Fundy coast of New Brunswick was undergoing deglaciation about 14 ka; there was a period of major moraine building at Saint John about 13.2 ka; a readvance occurred in Baie des Chaleurs about 12.4 ka; and the last ice disappeared from northwestern New Brunswick about 11 ka.

The Magdalen Islands

The Magdalen Islands lack clear glacial features and exposures of extensive glacial till and consequently there has been considerable controversy about the role of glaciation in the Quaternary history of the area (see discussion in Prest et al., 1976). Prest (1969) showed the islands as ice free at the maximum of the last glaciation and Prest (1970, p. 711) reported that there was no evidence of Wisconsinan glaciation above the limit of marine submergence and that till-like material at low elevations was deposited under water. Grant and King (this volume) reported evidence that Early Wisconsinan ice reached the Magdalen Islands but reported that there is no evidence that Late Wisconsinan glaciers reached the islands.

Newfoundland

As reported by Grant and King (this volume), there is general agreement that local ice was responsible for essentially all glacial deposits in Newfoundland. Grant (1977) showed somewhat limited ice cover in Newfoundland during the Late Wisconsinan. This left Burin Peninsula and several other peninsulas beyond the ice margin, several highlands in the interior of the province as nunataks, unglaciated areas in the highlands along the west coast of the island, and piedmont glaciers at the mouths of fiords.

Brookes (1974, 1977) considered the St. George's River Drift of southwestern Newfoundland (Table 5; MacClintock and Twenhofel, 1940) to be Late Wisconsinan. He dated the retreat of the ice that deposited this unit from coastal areas, at ca. 13.8 ka. A readvance brought ice back to near the coast (deposited Robinsons Head Drift, Table 5; MacClintock and Twenhofel, 1940) about 12.6 ka.

Near the northern tip of Newfoundland, Grant (1969) noted that northeastward retreat of ice which occupied the strait between Newfoundland and Labrador was followed by a readvance (Ten Mile Lake) of ice from the Newfoundland Highlands which incorporated shells dated 10.9 ka.

Offshore Atlantic

According to Grant and King (this volume) the Scotian Shelf Moraine Complex was built as a "grounding line moraine" during the Middle Wisconsinan and subsequently the grounded ice on the shelf continued to retreat landward with a secondary morainal position established just offshore, presumably at the Late Wisconsinan maximum. It is difficult however to reconcile this Late Wisconsinan limit with the more southerly position proposed for the Late Wisconsinan maximum by workers in eastern United States (see discussion in Prest, this volume; and Grant and King, this volume).

Little information is available for the Northeast Newfoundland Shelf but what data are available suggest that Late Wisconsinan ice reached only a short distance offshore, mainly off lowland areas (Grant and King, this volume).

To sum up the Late Wisconsinan story of Atlantic Canada: ice cover was limited, with nunataks and local uncovered coastal areas; retreat from the terminal position was underway by 14 ka; and local readvance occurred about 12.6 ka in southwestern Newfoundland, 10.9 ka in northern Newfoundland, and 10 ka on Cape Breton Island.

REGIONAL CORRELATIONS

The time-stratigraphic subdivision devised by Dreimanis and Karrow (1972) for the Great Lakes-St. Lawrence region has for the past decade been used as a standard with which other Canadian Quaternary chronologies have been correlated. The term Wisconsinan has, however, been applied in this report only to events reaching back to the beginning of oxygen isotope stage 4 (about 75 ka) and a glacial stade (the Nicolet) is included in the Sangamonian Stage (cf. Fig. 2 with Fig. 2 of Dreimanis, 1975). This considerably shortens the Early Wisconsinan and moves both the St. Pierre Interstade and the Nicolet Stade into the Sangamonian Stage. There is general agreement that these two units probably correlate with substages of the deep-sea oxygen isotope stage 5. There has, however, been no agreement on whether the chronostratigraphic stage containing the last interglacial should include all of oxygen isotope stage 5 or be restricted to the warmest substage, 5e.

The Fawn River gravel of the Hudson Bay Lowland has been tentatively dated at 76 ka (Andrews et al., 1983, p. 21) and hence it would appear to correlate with the St. Pierre Sediments of the St. Lawrence Lowlands which have yielded a finite age of 75 ka (Stuiver et al., 1978). Andrews et al. (this volume) correlated the Quajon Interstade with the Fawn River gravel. Hence, if the St. Pierre Interstade is included as a Sangamonian Stage unit, the Fawn River gravel and Quajon Interstade must equally be referred to as late Sangamonian.

SUMMARY

The Quaternary stratigraphy of Eastern Canada has been subdivided into four defined and one older chronostratigraphic units. These units, the deposits representing them, and the events are:

1. Illinoian and older: York Till at Toronto has been referred to as Illinoian; nonglacial deposits in southeastern Quebec have been referred to as pre-Wisconsinan and could be pre-Sangamonian; scattered deposits, possibly older than Sangamonian, are present in the Atlantic Provinces.
2. Sangamonian Stage: Sangamonian deposits in southern Ontario consist of the Don Formation, deposited under conditions warmer than at present, overlain by the Scarborough Formation which was deposited at a time of high lake levels under cooler conditions, overlain in turn by the Pottery Road Formation which was deposited when lake levels were lower. In southern Quebec, warm climate Sangamonian deposits are not known, but Bécancour Till is correlated with the Scarborough

		① OXYGEN ISOTOPE STAGES	② AGES	SOUTHERN ONTARIO Karrow, 1984	SOUTHERN QUEBEC LaSalle, 1984	ATLANTIC CANADA Grant, 1984	PRAIRIES Fenton, 1984	HUDSON BAY LOWLAND Shilts, 1984	BAFFIN ISLAND/ LABRADOR Andrews et al, 1984
WISCONSINAN STAGE	LATE	1		GREATLAKEAN STADE	CHAMPLAIN SEA EPISODE	ACADIAN GLACIATION			FOXE GLACIATION: BAFFINLAND STADE
			11.9	TWO CREEKS I/S					
		—13 ka—		PORT HURON STADE		SCOTIAN STADE	LOSTWOOD GLACIATION	TILL (Kipling Till)	
				MACKINAW I/S					
		2		PORT BRUCE STADE	GENTILLY STADE				
			15.5	ERIE INTERSTADE					
			16 5	NISSOURI STADE					
			23						
	MIDDLE	—32 ka—		PLUM POINT I/S					
		3	35	CHERRYTREE STADE		DIGBY STADE	WATINO NONGLACIAL	VARVES (Friday Creek sediments)	IRON STRAND SEDIMENTS
			40	PORT TALBOT I/S		CLARE INTERSTADE			
	EARLY	—64 ka— 4		GUILDWOOD STADE		FUNDY STADE	BURKE LAKE GLACIATION	TILL (?)	
SANGAMONIAN	STAGE	—75 ka— 5	80	ST PIERRE I/S	ST PIERRE INTERSTADE	MAGDALEN ISLAND INTERGLACIATION: BRAS D'OR INTERSTADE	OSLER NONGLACIAL	FLUVIAL GRAVEL (Fawn River gravel)	QUAJON I/S
				NICOLET STADE	NICOLET STADE			TILL (Adam Till)	AYR LAKE STADE
		—128 ka—		SANGAMONIAN		ILSE ROYALE INTERSTADE		MISSINAIBI FORMATION	Betula-rich buried soils

① from Shackleton and Opdyke, 1973 ② ages in ka for contact or midpoint of substages as given in Karrow (this volume)

Figure 2. Correlation chart for the Quaternary of Eastern Canada.

Formation of Ontario; the St. Pierre Sediments, were deposited, under conditions slightly cooler than at present, after retreat of the Bécancour ice and are correlated with the Pottery Road Formation of the Toronto area. The Salmon River Sand and Langlade silt of Nova Scotia and Newfoundland might be of Sangamonian age and unnamed warm and cool climate organic deposits have been correlated with this stage. The dominant features related to the last (Sangamon) interglacial in the Atlantic Provinces are wave-cut platforms several metres above present sea level; the highest, most prominent one, has been correlated with oxygen isotope stage 5e, and lower, more poorly developed benches, with oxygen isotope stage 5a.

3. Early Wisconsinan Substage: This was a time of glaciation in all parts of Eastern Canada with glaciers reaching Wisconsinan maximum, particularly in Atlantic Canada where ice moved well out onto the continental shelf. The Bradtville and Sunnybrook tills in southern Ontario; Chaudière, and possibly Malone, and lower part of Gentilly tills in Quebec; East Milford, Richmond, and Red Head tills in Atlantic Canada are assigned to this substage.

4. Middle Wisconsinan Substage: Southern Ontario was largely deglaciated at this time with cool climate Port Tablot interstadial deposits laid down early (prior to 40 ka), cooler climate Plum Point interstadial deposits later (35-23 ka), and glacial or near glacial conditions returning during the Cherrytree Stade (40-35 ka). Central St. Lawrence valley of Quebec appears to have remained ice coverd at this time but southeastern Quebec and the Montreal area may have been briefly deglaciated. There is scattered evidence that coastal areas in the Atlantic Provinces were locally deglaciated but also evidence that large parts of the continental shelf remained under ice cover and that ice flowed onshore from shelf-based ice sheets.

5. Late Wisconsinan: In southern Ontario, an approximately 4 ka period of vigorous glaciation, during which Catfish Creek Till was deposited, was followed by about 6 ka of oscillating retreat of ice margins, which resulted in deposition of many local till units. In Quebec, deposition of upper Gentilly, Fort Covington, and Lennoxville tills was followed by development of a calving bay in St. Lawrence River valley which caused local reversal of ice flow and led to development of the Champlain Sea without an intervening period of fluctuating ice margins. The ice readvanced to or remained near the St. Narcisse Moraine on the north side of St. Lawrence River valley until about 10.6 ka. Late Wisconsinan glaciation in Atlantic Canada was largely related to the development of local ice caps and deposition of tills composed mainly of locally derived materials. Few details of ice retreat are known other than that it appears to have been underway by 14 ka and that local readvances occurred.

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