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Sangamonian Forest History and Climate in Atlantic Canada
L'évolution de la forêt et du climat au Sangamonien dans l'est du Canada
Entwicklung des Waldes und des Klimas im Sangamonium, atlantisches Kanada

Robert J. Mott

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The Last? Interglaciation in Canada
Le dernier (?) interglaciaire au Canada

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Résumé de l'article

Des quelque vingt-cinq dépôts organiques enfouis datant d'intervalles non glaciaires pré-wisconsiniens, sept d'entre eux pourraient être attribués à l'optimum climatique de l'Interglaciaire du Sangamonien. c'est-à-dire le stade isotopique 5e. Ces sites sont les suivants: East Bay et Green Point, à l'île du Cap-Breton, Addington Forks et East Milford. en Nouvelle-Ecosse. Le Bassin et Portage-du-Cap, aux îles de la Madeleine, et Woody Cove, à Terre-Neuve. Aucun des sites, sauf celui de Woody Cove, n'a enregistré un cycle climatique complet, et la séquence des événements doit être reconstituée à partir d'inventaires disparates. Les spectres, caractérisés par des quantités importantes de taxons thermophiles qui ne sont plus aussi abondants ou même présents dans la région aujourd'hui, sont semblables de façon générale aux spectres holocènes de sites localisés immédiatement au sud des Grands Lacs inférieurs. La comparaison entre les spectres fossiles de cinq sites et des spectres de surface actuels de l'est de l'Amérique du Nord fait ressortir des sites analogues actuels qui démontreraient que le climat des Maritimes au cours de l'optimum climatique du dernier interglaciaire était plus continental et passablement plus chaud que maintenant.

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SANGAMONIAN FOREST HISTORY AND CLIMATE IN ATLANTIC CANADA*

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ABSTRACT Seven of the more than twenty five buried organic deposits in Atlantic Canada assigned to pre-Wisconsinan non-glacial intervals possibly relate to the climatic optimum of the Sangamon Interglaciation, that is substage 5e of the deep-sea oxygen isotope record. These sites are East Bay and Green Point on Cape Breton Island, Addington Forks and East Milford in mainland Nova Scotia, Le Bassin and Portage-du-Cap on the Iles de la Madeleine, Québec, and Woody Cove, Newfoundland. Except for Woody Cove, none of the sites records a complete climatic cycle, and the sequence of events must be pieced together from their disparate records. The spectra, characterized by significant amounts of thermophilous taxa that are not as abundant or present in the region today, are similar in general to Holocene spectra at sites immediately south of the lower Great Lakes. Comparison of the fossil spectra from five sites with modern surface spectra from eastern North America yields modern analogs which, if valid, indicate that the climate in Atlantic Canada during the climatic optimum of the last interglacial interval was more continental in character and considerably warmer than present.

RÉSUMÉ *L'évolution de la forêt et du climat au Sangamonien dans l'est du Canada.* Des quelque vingt-cinq dépôts organiques enfouis datant d'intervalles non glaciaires pré-wisconsiniens, sept d'entre eux pourraient être attribués à l'optimum climatique de l'Interglaciaire du Sangamonien, c'est-à-dire le stade isotopique 5e. Ces sites sont les suivants: East Bay et Green Point, à l'île du Cap-Breton, Addington Forks et East Milford, en Nouvelle-Écosse, Le Bassin et Portage-du-Cap, aux îles de la Madeleine, et Woody Cove, à Terre-Neuve. Aucun des sites, sauf celui de Woody Cove, n'a enregistré un cycle climatique complet, et la séquence des événements doit être reconstituée à partir d'inventaires disparates. Les spectres, caractérisés par des quantités importantes de taxons thermophiles qui ne sont plus aussi abondants ou même présents dans la région aujourd'hui, sont semblables de façon générale aux spectres holocènes de sites localisés immédiatement au sud des Grands Lacs inférieurs. La comparaison entre les spectres fossiles de cinq sites et des spectres de surface actuels de l'est de l'Amérique du Nord fait ressortir des sites analogues actuels qui démontreraient que le climat des Maritimes au cours de l'optimum climatique du dernier interglaciaire était plus continental et passablement plus chaud que maintenant.

ZUSAMMENFASSUNG *Entwicklung des Waldes und des Klimas im Sangamonium, atlantisches Kanada.* Von den mehr als 25 vergrabenen organischen Ablagerungen im atlantischen Kanada, die prä-wisconsinischen nichtglazialen Intervallen zugeschrieben werden, gehören sieben möglicherweise dem klimatischen Optimum des sangamonischen Interglazial an, das heisst Unterphase 5e des Tiefsee-Sauerstoff-Isotop-Belegs. Die sieben Vorkommen sind East Bay und Green Point auf Cape Breton Island, Addington Forks und East Milford auf dem Festland von Nova Scotia, Le Bassin und Portage-du-Cap auf den îles de la Madeleine, Québec, und Woody Cove, Newfoundland. Ausser Woody Cove belegt keiner dieser Plätze einen ganzen klimatischen Zyklus und die Abfolge der Ereignisse muss aus ihren disparaten Belegen zusammengesetzt werden. Die Spectra, die durch signifikante Mengen von thermophilen Taxa gekennzeichnet sind, welche heute in der Gegend nicht so reichlich vorhanden oder nicht so zugegen sind, ähneln im allgemeinen den Holozän-Spectra an Plätzen unmitellbar südlich der unteren grossen Seen. Ein Vergleich der Fossil-Sprectra von fünf Plätzen mit modernen Oberflächen-Spectra von Ost Nordamerika liefert moderne Analoge, welche, wenn sie gültig sind, darauf hinweisen, dass das Klima im atlantischen Kanada während des klimatischen Optimums des letzten Interglazial einen kontinentalen Charakter hatte und bedeutend wärmer war als gegenwärtig.

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INTRODUCTION

Southeastern New Brunswick, northeastern mainland Nova Scotia, Cape Breton Island, the Iles de la Madeleine, Québec and southwestern Newfoundland comprise the region of Atlantic Canada that has yielded numerous buried organic-bearing non-glacial deposits that pre-date the Late Wisconsinan glaciation (Fig. 1). More than a century ago, J. W. Dawson (1855) described a section with organic sediments beneath till in a river bank exposure near River Inhabitants, Cape Breton Island. However, it was not until more recent times that palynological and macrofossil studies were conducted on buried organic sites in Atlantic Canada. L. R. Wilson included a preliminary pollen analysis of a single sample from a site near Hillsboro on Cape Breton Island in a report on radiocarbon dates (Flint and Rubin, 1955). Mott and Prest (1967) reported palynological results from four sites on Cape Breton Island, including the Hillsboro site, and suggested a possible correlation with the St. Pierre interstade of the St. Lawrence Valley. The Hillsboro site was also studied by Livingstone (1968) who referred to it as interglacial. Palynological spectra from Dawson's re-discovered River Inhabitants site (Grant, 1971) indicated cool boreal conditions, and the deposit was assigned to an Early Wisconsinan interstade (Mott, 1971).

Pollen and micro-/macrofossil analyses of a buried organic site on the Iles de la Madeleine, Québec, led Prest *et al.* (1976) to conclude that the site recorded conditions warmer than present and was therefore of interglacial rank. Similarly, the buried organic site from Woody Cove, Newfoundland, was also assigned to an interglacial interval, probably the Sangamonian, based on spectra indicative of climate warmer than present (Brookes *et al.*, 1982).

In mainland Nova Scotia, stratigraphy and pollen analysis of a buried peaty clay from the Miller Creek site suggested deposition during the Sangamonian interglacial interval (Stea and Hemsworth, 1979). Mott *et al.* (1982) concluded from pollen and macrofossil results that non-glacial sediments beneath till at the East Milford site were probably deposited during Sangamonian interglacial time.

Cape Breton Island has recently yielded many more interesting finds. Vernal *et al.* (1983) analysed Quaternary sediments exposed in a sea cliff at Bay St. Lawrence near the northern tip of Cape Breton Island. Results indicate that cool boreal and tundra conditions prevailed suggesting cool interstadial conditions. Several organic units at sites along East Bay of Bras D'Or Lake contain pollen and macrofossils that suggest both interstadial and interglacial intervals are represented (Mott and Grant, 1985; de Vernal and Mott, 1986).

All of these deposits in Atlantic Canada are stratigraphically beneath deposits of the Wisconsin Glaciation. They are underlain by deposits of the penultimate glaciation, or by bedrock. In many cases the bedrock has been truncated by erosion related to formation of a bench presumably cut by a high stand of the sea during the Sangamon Interglaciation (Grant and King, 1984). Therefore, these deposits can be assigned to the Sangamonian interglacial interval (*sensu lato*), stage 5 of the deep-sea oxygen isotope record (Fulton *et al.*, 1984), or possibly at some sites to the Early of even, Middle Wisconsinan intervals (stages 4 and 3) if Th/U dates on wood from the deposits are valid (de Vernal and Mott, 1986; Causse and Hillaire-Marcel, 1986, Hillaire-Marcel and Causse, 1989). Several of the deposits have floral and faunal assemblages indicative of climatic conditions as warm as or warmer than

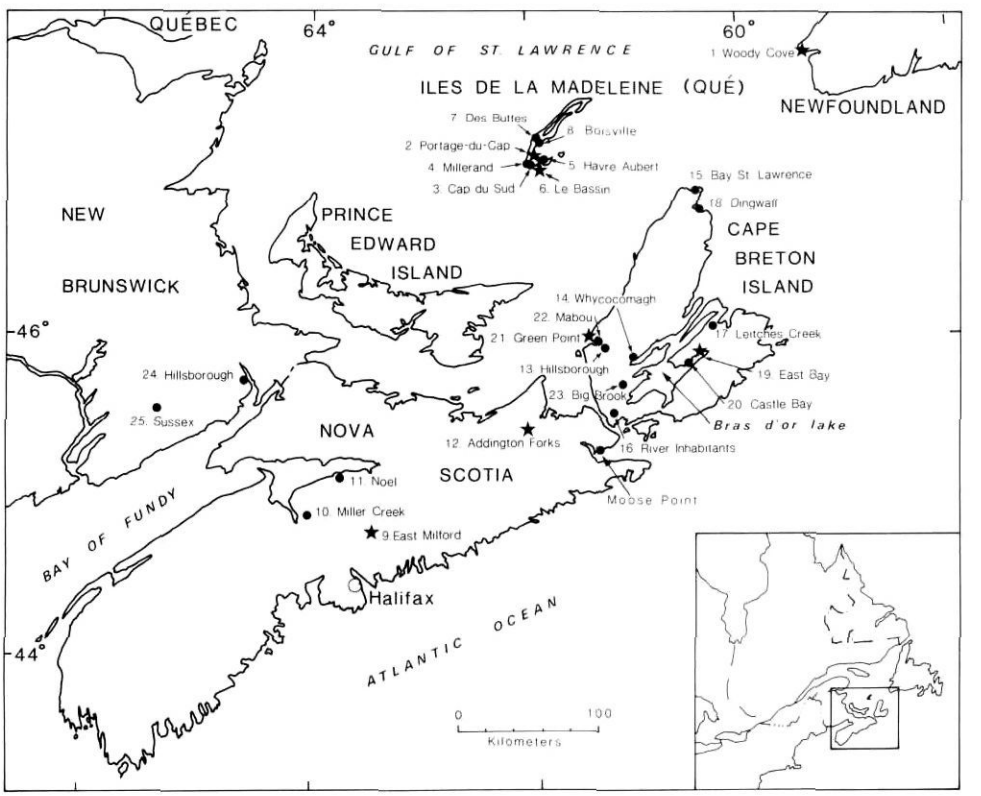


FIGURE 1. Location map for pre-Wisconsinan buried organic sites in Atlantic Canada with sites discussed herein marked with stars.

Localisation dans les Maritimes des sites de dépôts organiques enfouis pré-wisconsiniens. L'étoile identifie les sites dont on traite ici.

present in their respective areas. These can be correlated with the warmest part of the last interglaciation, or Sangamonian (*sensu stricto*), that is substage 5e of the deep-sea oxygen isotope record, or to a younger interval, substage 5a, when climatic conditions may have been similar to the present (Mott and Grant, 1985).

Those sites with pollen spectra indicative of conditions as warm as or warmer than present will be examined herein with the objective of outlining the environmental and climatic conditions that prevailed in Atlantic Canada at the time of deposition of these deposits. The fossil pollen spectra for selected sites are compared with modern pollen spectra in an eastern North America data base. The January and July mean temperatures and annual precipitation values for the modern sites provide possible analog conditions for the time of deposition of the interglacial sediments.

SITES

Of at least twenty-five known sites where organic deposits associated with pre-Wisconsinan non-glacial intervals occur in Atlantic Canada, seven have evidence indicating that the climate became at least as warm as the present, if not warmer (Fig. 1). These sites include: Le Bassin and Portage-du-Cap on the Iles de la Madeleine, Québec; East Bay and Green Point on Cape Breton Island; East Milford and Addington Forks in mainland Nova Scotia; and Woody Cove in Newfoundland. Many other sites may relate to the same interval or intervals, but because the evidence indicates boreal forest conditions, it is difficult to ascertain whether they record a waxing or waning phase of a warm interval or some other cooler interval. Therefore, only the seven sites listed above are pertinent to characterizing the climate of the last interglacial when conditions were warmest.

Le Bassin

Le Bassin site is a wave-cut section located at the western end of Le Bassin lagoon, a brackish water body cut off from the sea by a tombolo connecting bedrock headlands along the south shore of Ile du Havre-Aubert, one of the islands of Iles de la Madeleine archipelago. A compact woody peat bed, the sand beneath and the overlying marine silty clay and sands and gravels form a non-glacial sediment package between the sandstone bedrock and the glacial deposits that cap the sequence (Mott and Grant, 1985).

In the pollen record from the sands, peat and silty clay (Fig. 2), shrub and herb taxa dominate Zone 1 from the basal sand unit. Abundant algal remains (*Pediastrum*) indicate deposition in fresh water. Zone 2 in the lower half of the peat bed is a transition zone where taxa reflecting local habitats are successively replaced as these habitats changed. The regional changes are seen in the sprectra for *Betula* (birch), *Picea* (spruce), *Abies balsamea* (balsam fir) and *Quercus* (oak) which form successive peaks. In the upper half of the peat and in the overlying silty clay (Zone 3), *Pinus* (in this case *P. strobus* — white pine) pollen becomes dominant along with Polypodiaceae (fern) spores. Other tree taxa are also represented. Wood of white pine in the peat attests to the local presence of this species.

The sequence of events inferred from the pollen data begins with cool tundra-like conditions with shrubs and herbs occupying the landscape around shallow ponds (Zone 1). Peat invaded the shallow wet areas, and various plant communities, such as sphagnum/heath bog, grass/sedge fen and shrubby fen, dominated as conditions changed locally (Zone 2). Warming of the climate led to invasion of the uplands by poplar/aspen (*Populus*), birch, spruce and balsam fir (Zone 2).

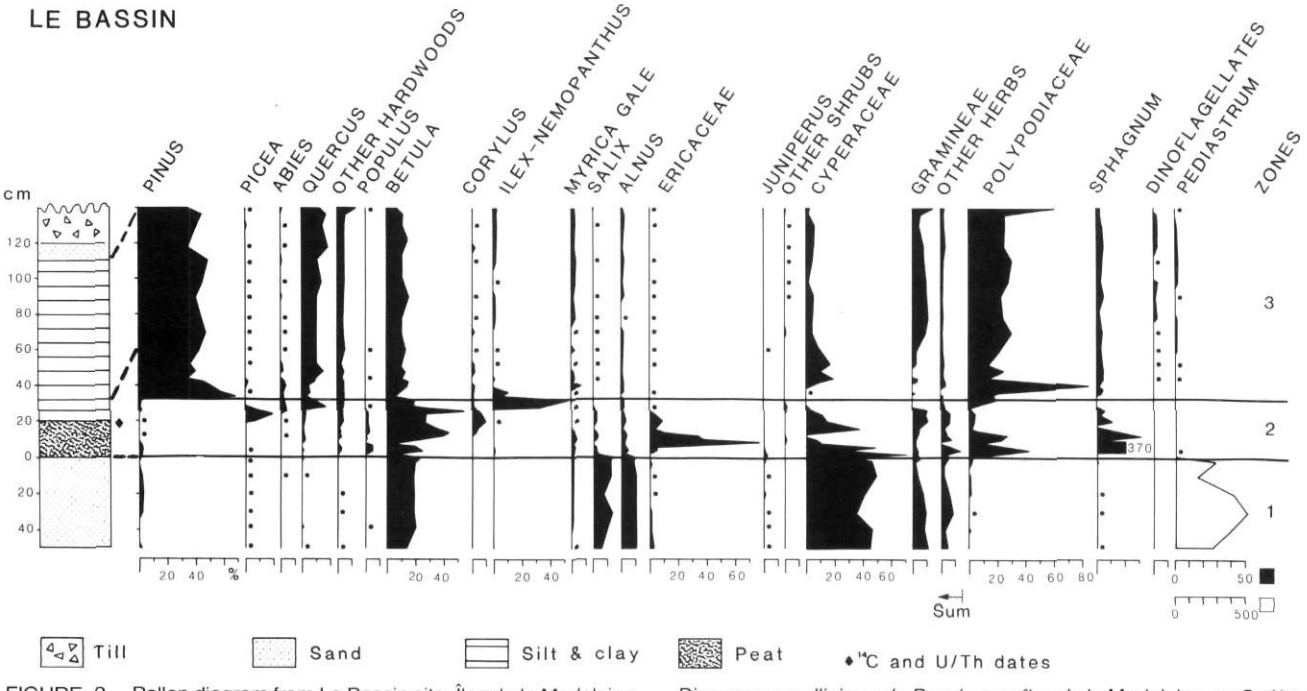


FIGURE 2. Pollen diagram from Le Bassin site, Îles de la Madeleine, Québec (from Mott and Grant, 1985).

Diagramme pollinique du Bassin, aux îles de la Madeleine, au Québec (de Mott et Grant, 1985).

Eventually white pine and possibly some oak (Zone 3) invaded the islands. The bog was then inundated as the sea rose to its interglacial high stand (Grant, 1980), and marine silts and clays were deposited. Beach and nearshore gravels and sands were deposited as sea level rose and fell prior to glaciation of the area.

A radiocarbon age determination on wood from the peat gave an age of >46,000 yrs BP (GSC-3623), whereas, age determinations by the Thorium/Uranium disequilibrium method gave ages of 106,400 ± 8400/8000 (UQT-183), 101, 700 ± 17,000/14,200 (UQT-182) and 89,400 ± 8000/7100 (UQT-184) years (Mott and Grant, 1985).

Portage-du-Cap

The Portage-du-Cap site is located in a gravel pit on Ile du Havre-Aubert approximately 1.5 km northwest of Le Bassin site. Studied in detail by Prest *et al.* (1976), this site shows a gravel sequence covering sandstone, the surface of which contains borings of a rock-boring pelecypod. A sand unit with layers of peaty organic sediment overlies the gravel and is in turn overlain by a red diamicton which caps the sequence.

The pollen diagram for the organic interval (Fig. 3) shows little variation throughout, and the spectra are characterized by abundant arboreal pollen. In addition to relatively abundant *Picea, Pinus, Abies* and *Betula* pollen, there are significant amounts of *Quercus* and *Fagus* (beech). Diatom and coleoptera analyses in addition to the pollen results led to the conclusion that the organic sediments were deposited in a marine environment and the climate was warmer than the present (Prest *et al.*, 1976).

These results confirm the conclusion drawn from the Le Bassin data that spruce, balsam fir, birch and probably white pine were growing on the islands. It is postulated here that sea level continued to rise after inundating the Le Bassin site and deposited the gravels and the sand containing the organic sediments before reaching its maximum elevation. Two radiocarbon dates, one on plant detritus at >35,000 yrs BP (BGS-259), and one on wood at >38,000 yrs BP (GSC-2313), provide only minimum ages for the deposit.

East Bay

The north shore of East Bay, Bras D'Or Lake, on Cape Breton Island is the location of several pre-Wisconsinan organic deposits. The East Bay site near the head of the Bay is a complex of non-glacial sediments, including organic beds, capped by till, overlying and infilling karst depressions in the interbedded Mississippian shale and gypsum bedrock (de Vernal and Mott, 1986).

One exposure showed a 3 m thick mass of highly disturbed compact organic silt with woody peat layers occupying a karst depression. The pollen diagram for the deposit is dominated by *Quercus* and *Carpinus/Ostrya* type (ironwood/blue beech) pollen along with minor representations of several other thermophilous hardwood taxa (Other trees) near the base (Fig. 4A). Among the thermophilous taxa are such genera as *Tilia (basswood), Carya (hickory)* and *Nyssa (gum tree). Pinus* (predominantly *P. strobus*) becomes extremely abundant in the central

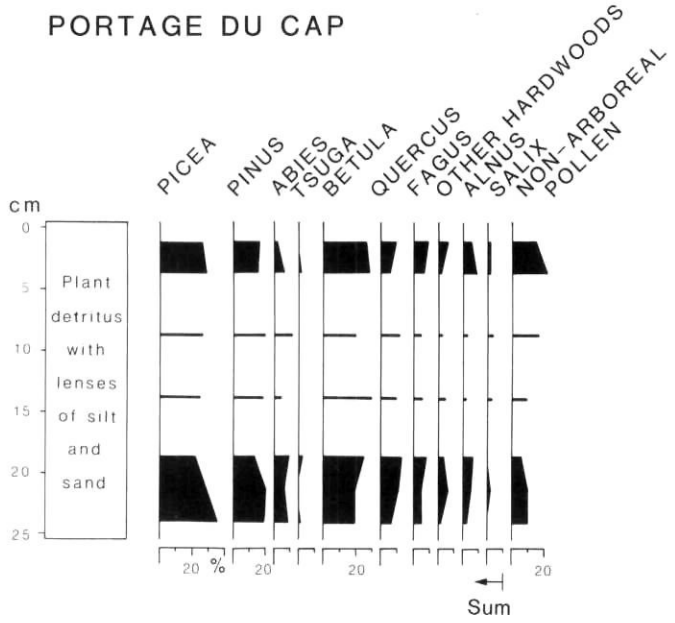


FIGURE 3. Pollen diagram for Portage-du-Cap site, Îles de la Madeleine, Québec (after Prest *et al.*, 1976).

Diagramme pollinique de Portage-du-Cap, aux îles de la Madeleine, au Québec (d'après Prest et al.,*1976).*

part of the profile. *Quercus* and *Carpinus/Ostrya* regain dominance in the upper part as *Pinus* declines. Wood of white pine and juniper (*Juniperus*) was recovered from the peat.

Wood from the peat produced a radiocarbon date of >50,000 yrs BP (GSC-3861), and Th/U ages of 126,400 ± 15,000/12,800 (UQT-175), 123,400 ± 30,000/23,400 (UQT-176), 106,600 ± 9600/8600 (UQT-108) and 60,000 ± 6000/5700 (UQT-179) years (Mott and Grant, 1985). Only one of the Th/U dates (UQT-175) is considered valid as relatively high detrital Thorium content in the other samples suggest contamination and spurious dates (de Vernal *et al.*, 1986).

In an adjacent exposure, silty clay containing large logs and overlying stratified silty clays and peaty silts cover the bedrock. These deposits are stratigraphically above the compact organic silt unit, and the pollen spectra derived from this exposure are distinctly different (Fig. 4B) (de Vernal and Mott, 1986). The lower part of the diagram contains abundant *Abies balsamea* pollen, *Pinus* (in this profile the pollen is predominantly *P. banksiana/resinosa*, jack/red pine type), and significant representations of *Fagus* and *Tsuga canadensis* (hemlock). In the upper part, *Pinus* and most of the hardwood taxa give way to *Picea*, but *Abies* remains abundant. The large logs near the base of the section were identified as hemlock; wood higher in the section included balsam fir and spruce.

A radiocarbon date of >49,000 yrs BP (GSC-3871) was obtained on wood from this exposure. A Th/U date of 86,900 ± 6000/5700 years (UQT-109) was also obtained (Mott and Grant, 1985; de Vernal and Mott, 1986).

Two interpretations of the stratigraphic sequence at the East Bay site are possible. If the Th/U ages are accepted as valid, then the two exposures relate to completely separate intervals. However, if the single age (UQT-109) is considered a minimum

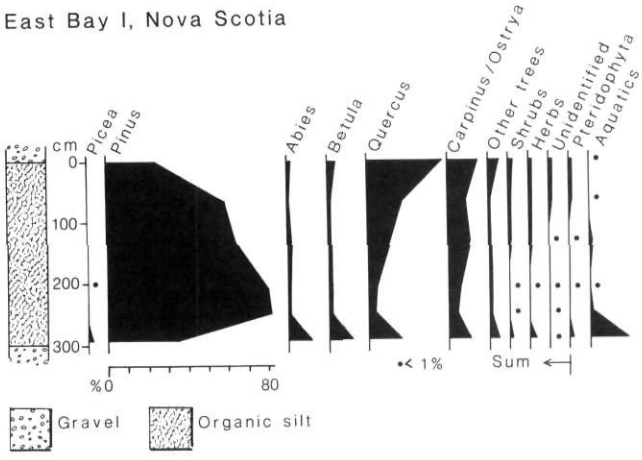
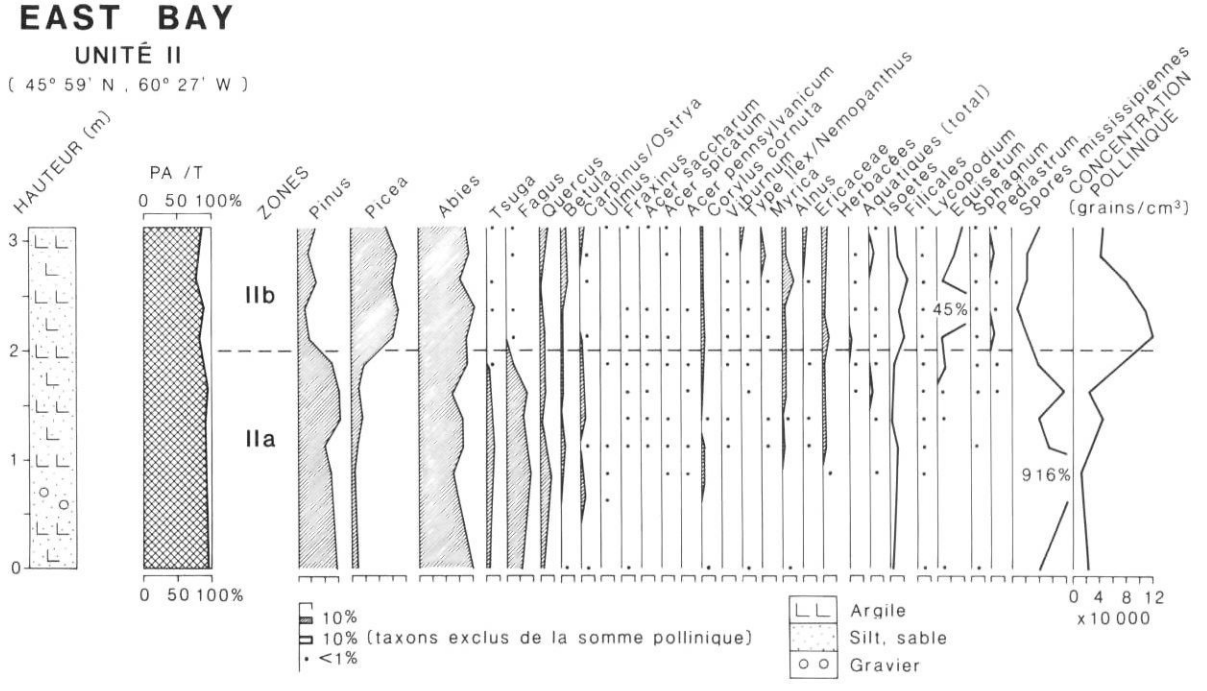


FIGURE 4. Pollen diagrams for East Bay I and East Bay II sites, Cape Breton Island, Nova Scotia (East Bay II after de Vernal and Mott, 1986).

Diagrammes polliniques de East Bay I et East Bay II, à l'île du Cap-Breton, en Nouvelle-Écosse (East Bay II d'après de Vernal et Mott, 1986).



age for that exposure, then different parts of only one interval may be represented. In the latter interpretation, the compact organic silt would have been deposited during the warmest part of the interval, and the adjacent section would have accumulated as the climate cooled somewhat. The mixed white pine, oak and thermophilous hardwood forests of the climatic optimum were replaced first by balsam fir, beech, hemlock and other hardwoods and minor amounts of jack/red pine, and then by spruce and fir forests with few hardwoods.

Green Point

On the western coast of Cape Breton Island near the town of Mabou, organic sediments are exposed in a sea cliff at the mouth of Mabou Harbour (Fig. 1). Flanking the bedrock point is a thick sequence of non-glacial gravels, sands and silts that are truncated by a thick till unit. Just below the till contact are thin beds of peat and organic silts with abundant wood fragments that were deformed by the ice emplacing the overlying till (Grant, 1987).

Pollen analysis shows spectra dominated by thermophilous hardwood taxa (Fig. 5). *Quercus, Carya, Tilia* and *Carpinus/Ostrya* are prominent along with *Pinus strobus* and *Abies*. Gramineae pollen and Polypodiaceae (fern) spores are plentiful. Some variation is seen in profiles from the different exposures. *Pinus strobus* dominates in the lower profile relative to hardwood taxa, particularly *Quercus*, whereas, the reverse is apparent in the upper profile. However, since the true stratigraphic relationship of the separate exposures could not be determined, the significance of these differences will not be elaborated on here. Wood of hickory, ash (*Fraxinus*) and juniper have been identified.

A radiocarbon age of >53,000 yrs BP (GSC-3220) (Mott and Grant, 1985) and a Th/U date of 117,400 ± 10,000/8800 yrs (UQT-181) (de Vernal *et al.*, 1986) were obtained from a large juniper log.

A closed mixed forest of thermophilous hardwoods, white pine and balsam fir covered the surrounding uplands with the

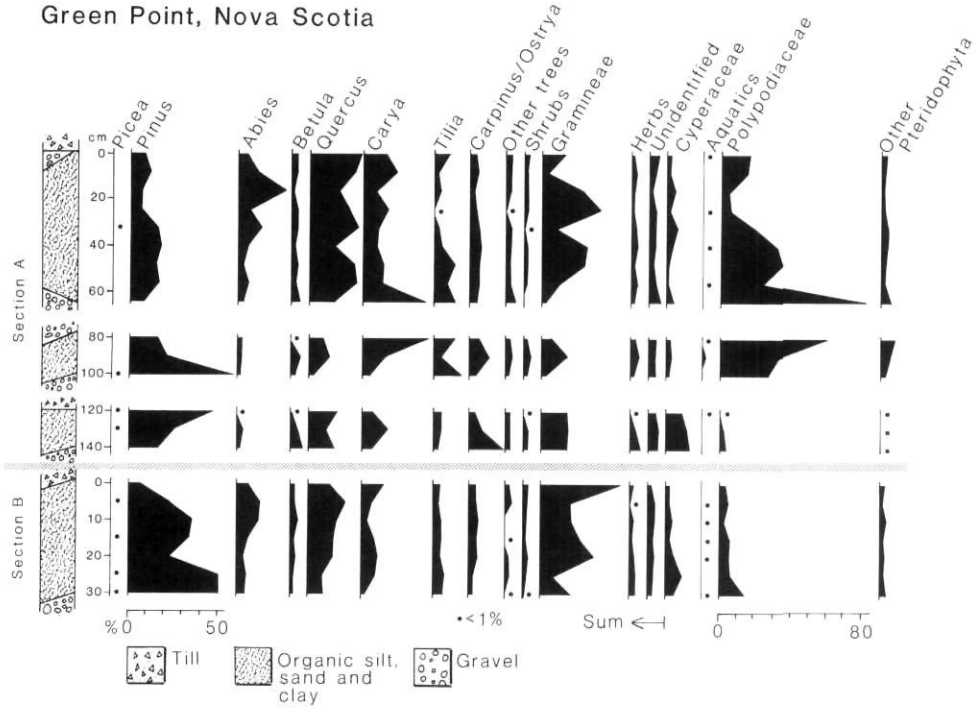


FIGURE 5. Pollen diagrams for Green Point, Cape Breton Island, Nova Scotia. Two separate sections are shown. In section A, three exposures revealed organic sediments in the same stratigraphic context. However, they may not record exactly the same time interval.

Diagramme pollinique de Green Point, à l'île du Cap-Breton, en Nouvelle-Écosse. On montre deux coupes. La coupe A montre trois affleurements dans lesquels les sédiments organiques appartiennent au même contexte stratigraphique, mais ne représentent peut-être pas exactement le même intervalle.

amount of white pine relative to hardwoods varying with time. Grasses and ferns dominated the sandy coastal areas. The relatively short time represented, judging by the lithology and thickness of the organic units and the lack of gross variation in the regional component of the pollen spectra, relates to the thermal maximum when the climate was considerably warmer than present.

Addington Forks

The Addington Forks site was exposed in a road cut along the west bank of the James River about 0.5 km north of the Addington Forks crossroad approximately 10 km southwest of Antigonish. A 10 cm thick layer of highly compacted peat within an 80 cm thick unit of silt and organic silt comprises a non-glacial sediment package between an underlying red-brown till and an overlying red till.

Detailed pollen analysis of the inter-till sediments revealed pollen spectra that can be divided into five pollen zones (Fig. 6) (Mott and Grant, 1985). The basal zone 1 contains abundant spores of Polypodiaceae and *Osmunda* ferns. Also well-represented are *Betula, Quercus* and Cyperaceae pollen. *Quercus* pollen becomes dominant in zone 2, and *Carpinus/Ostrya* type pollen forms a small peak. Cyperaceae and Polypodiaceae are still fairly well represented. A decline in *Quercus* pollen abundance and increased abundances of *Pinus, Carya* and other thermophilous hardwood taxa such as *Fagus, Tilia* and *Ulmus* characterize zone 3. Fern spores are also more abundant. An *Abies* peak and rising *Alnus* values occur in zone 4. *Picea* and herbaceous taxa percentages increase, but the more thermophilous taxa decline. Zone 5 at the top of the profile is dominated by *Alnus* pollen. Spruce/Tamarack wood was identified from a woody horizon near the top of the zone 4 level.

Wood from the site was originally dated at 33,700 ± 2300 yrs BP (I-3236) (MacNeill, 1969). Subsequently, a date of >42,000 yrs BP (GSC-1598) was obtained (Mott and Grant, 1985). A third dating attempt produced a finite age of 36,100 ± 520 yrs BP (GSC-3848). Contamination by modern rootlets is suspected as the cause of the spurious finite dates, as the stratigraphy and pollen spectra suggest correlation with the much older sites.

Birch, oak and other hardwoods formed a mixed hardwood forest during the time of deposition of the early part of the sequence. Hickory and several thermophilous taxa then became more abundant as oak declined before this mixed forest gave way to a conifer forest dominated by balsam fir. Alder then became extremely plentiful, at least locally. These changes reflect deterioration of the climate from conditions at least comparable to the present if not warmer, through cooler boreal to possibly subarctic type climate.

East Milford

Organic sediments have been uncovered on several occasions in the East Milford gypsum quarry of the National Gypsum Company located near the village of East Milford about 8 km south of Shubenacadie. In one exposure uncovered beneath a 20 m thick till sequence, the gypsum bedrock was overlain by rubbly gravel, grey and red clay, black organic clay and a compressed peat layer (Mott *et al.*, 1982).

Palynological results are shown in Figure 7 (Mott *et al.*, 1982). Pollen grains in the basal clays are very poorly preserved, but Polypodiaceae (fern) spores are very abundant. Where preservation is better in the black clay, hardwood genera (mainly *Fagus* in the "Other Trees" column) are associated with the fern spores. Upward in the profile through successive zones, dominance varies. In zone 2 the fern spores remain

abundant, pollen of thermophilous hardwood genera decline and *Betula* becomes abundant. Pollen of hardwood taxa in general decline in zone 3 and is replaced by *Abies* and *Picea*. *Alnus* is very abundant along with *Abies* in zone 4.

Abundant plant and arthropod macrofossils were recovered from the sediments. The plant macrofossils are shown adjacent to the pollen profiles for respective taxa. Arthropod remains could only be identified to species in a few cases, but they add to the overall detailed interpretation (Mott *et al.*, 1982). Wood was abundant in the peat horizon and was identified as spruce and balsam fir.

Radiocarbon dates of >38,800 (GSC-33) and >50,000 (GSC-1642) were obtained on wood from the peat unit at the top of the exposure (Mott *et al.*, 1982). Ages of 84,900 ± 6500/6100 (UQT-185) and 84,200 ± 11,300/10,100 (UQT-186) years were obtained on wood by the Th/U disequilibrium method (Mott and Grant, 1985).

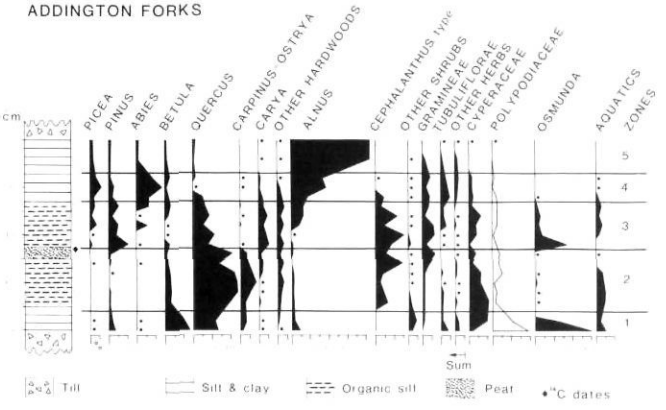


FIGURE 6. Pollen diagram for Addington Forks site, Nova Scotia (from Mott and Grant, 1985).

Diagramme pollinique d'Addington Forks, en Nouvelle-Écosse (de Mott et Grant, 1985).

Hardwoods, particularly beech and birch, characterized the mixed forests that occurred in the region at the time of deposition of the basal organic sediments. Ferns were abundant locally. Spruce and balsam fir gradually replaced the hardwood taxa until coniferous forests characterized the area. Alder then became abundant and boggy conditions resulted in peat deposition at the site. A clear cooling trend similar to that seen at Addington Forks is recorded at this site as well.

Woody Cove

The one possible last interglacial site discovered to date in Newfoundland is located in the extreme southwest corner of the province at Woody Cove near the village of Codroy (Fig. 1). An eroding sea cliff has truncated a karst depression in shale and gypsum bedrock and shows highly deformed nonglacial sediments capped by till (Brookes *et al.*, 1982). A thick rubble, colluvium and gravel complex overlies the bedrock and in turn is overlain by a pebbly clay-silt sequence of freshwater and marine origin containing abundant organic remains and is covered by till and outwash.

The pollen diagram for the site (Fig. 8) is divided into three zones (Brookes *et al.*, 1982). The basal zone A is characterized by high percentages of Cyperaceae pollen, abundant Gramineae, Ericaceae, *Betula* and *Alnus* pollen. In zone B, *Picea, Abies* and *Betula* pollen are prominent, and *Dryopteris* (fern), *Lycopodium* (clubmoss) and *Sphagnum* spores are abundant. A thin zone C has less pollen from tree taxa and more abundant pollen from Cyperaceae and other herbaceous

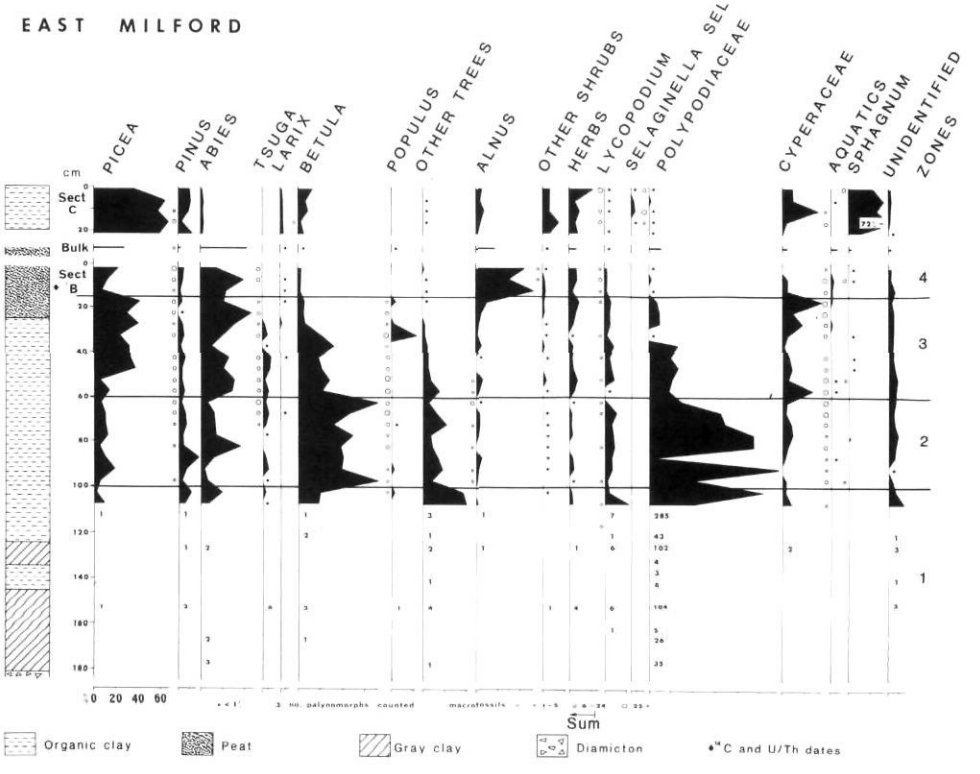


FIGURE 7. Pollen diagram for East Milford site, Nova Scotia (after Mott *et al.*, 1982). Note that in the "Other Trees" column *Fagus* is the most abundant taxon.

Diagramme pollinique du site de East Milford, en Nouvelle-Écosse (d'après Mott et al.,*1982). À noter que dans la colonne «Other Trees»,* Fagus *est le taxon le plus abondant.*

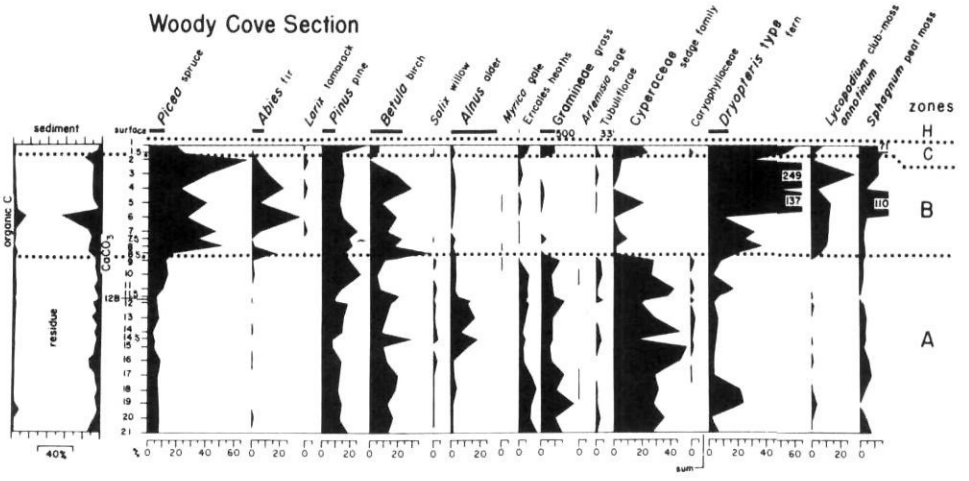


FIGURE 8. Pollen diagram for Woody Cove site, Newfoundland (after Brookes *et al.*, 1982).

Diagramme pollinique du site de Woody Cove, à Terre-Neuve (d'après Brookes et al.,*1982).*

taxa. Ostracodes and foraminifera were recovered from the silt-clay unit. Balsam fir wood was radiocarbon dated at >40,000 yrs BP (I-10203).

Sinkhole formation caused slumping of the local bedrock and glacial deposits into a depression that became a pond as subsidence continued. Freshwater deposition of organic-rich silty clay was followed by brackish water deposition as the sinkhole wall was breached by coastal erosion. Tundra-like vegetation of herbs and shrubs covered the surrounding landscape at first, but as the climate warmed boreal forests of spruce, fir, pine and birch invaded the area. Falling sea-level and continued collapse of the depression created freshwater conditions once again, but the climate cooled and vegetation became tundra-like. Glaciers eventually advanced over the area depositing till in the depression. Inferred climatic conditions as warm as, if not warmer than the present prompted Brookes *et al.* (1982) to tentatively assign the interval to the Sangamonian Interglaciation.

RECONSTRUCTION OF CLIMATE CHANGES

All of the sites described above have pollen spectra and macrofossil evidence that indicate that, for at least part of the interval represented, the climate became as warm as, if not warmer than the present in their respective areas. Only one site, Woody Cove, seems to record a complete climatic cycle: tundra to boreal forest and back to tundra again. Other sites show either the early warming trend to a peak (Le Bassin); the relatively short warm interval itself (Portage-du-Cap, East Bay I and Green Point); or the cooling trend following the climatic optimun (East Bay II, Addington Forks and East Milford).

A number of scenarios regarding the stratigraphic succession of the deposits and the general time interval to which they belong can be envisaged. Since the deposits all underlie what have been interpreted as deposits of the Wisconsin Glaciation, and overlie a till or bedrock, often into which the Sangamonian high sea-level terrace has been eroded, they have all been assigned to the last interglaciation, presumably the Sangamonian (*sensu lato*), that is oxygen isotope stage 5 (Fulton *et al.*, 1884). This is the simplest interpretation, but it may not necessarily be correct in all cases. It is possible that an interglacial interval other than the Sangamonian is represented, although the evidence does not support this possibility. If all the deposits are related to stage 5, then more than one climatic oscillation that attained conditions equal to or warmer than present may be represented. This possibility has been suggested by Grant and King (1984), Mott and Grant (1985) and de Vernal *et al.* (1986), and is valid if the Th/U ages are reliable. Causse and Hillaire-Marcel (1986) and Hillaire-Marcel and de Vernal (1989) have demonstrated that results generated by the Th/U disequilibrium method for East Bay I, Le Bassin and Green Point all fit into one single isochron that yields an age of about 120,000 years (substage 5e). On the other hand, results for the East Bay II and East Milford sites plot on an isochron suggesting a substage 5a age of about 85,000 years.

However, if the Th/U ages are considered to be minimum ages, the sites could all relate to the same interval. This scenario is in accord with the deep-sea record, particularly for the North Atlantic, which shows that conditions as warm, or warmer than present probably prevailed only during substage 5e, the Sangamonian (*sensu stricto*) (Ruddiman and McIntyre, 1984).

If only one warm interval is involved, a generalized sequence of events for the region encompassed by northeastern Nova Scotia, Cape Breton Island and the Iles de la Madeleine can be envisaged. The Woody Cove site in Newfoundland is not included in the sequence because it may record a complete interglacial cycle that is too far removed from the other sites and has a different climatic regime.

Le Bassin is the only site that records the warming trend for the region. The early shrub and herb tundra-like vegetation that invaded the region following deglaciation was soon replaced by forests that included such taxa as poplar/aspen, spruce, birch and balsam fir. These boreal type forests then gave way to mixed forests of white pine and oak as seen in the profiles not only from the the upper part of Le Bassin site, but from East Bay I, Green Point sites as well. Addington Forks area had abundant oak but not as much pine. Several other relatively thermophilous taxa also reached the region in response to the warming climate. These included hickory, basswood, and possibly gum tree, none of which occur in the region today. Maple and beech were also abundant. Somewhat cooler conditions then favoured a return to temperate hardwoods and conifers, with spruce, birch, balsam fir and jack pine

becoming dominant as shown by the profiles from Addington Forks, East Bay II, Portage-du-Cap and East Milford.

Compared with the present interglacial interval, the climate attained during the Sangamon Interglaciation in Atlantic Canada was considerably warmer. This is readily apparent when Sangamonian profiles are compared with those of the present interglacial interval. For example, a representative pollen profile from Basswood Road Lake, New Brunswick (Mott, 1975) (Fig. 9) shows that, even during the early Holocene, the forests of Atlantic Canada never produced spectra with as much *Pinus strobus* and/or thermophilous hardwood pollen as occurred at East Bay I, Le Bassin, Green Point and Addington Forks.

Perusal of the palynological literature (particularly Bryant and Holloway, 1985) reveals that the area south of the Great Lakes has the closest analogous postglacial pollen profiles. Crystal Lake, Pennsylvania (Walker and Hartman, 1960), serves as an example (Fig. 10). Although different in some details and in some of the taxa involved, the diagram does show early boreal coniferous spectra. The central and upper parts of the profile are characterized by *Pinus* dominated assemblages, then *Tsuga*/*Quercus*/hardwood pollen domination succeeded by a return to abundant *Pinus*. The present interglaciation, of course, has not yet reverted to boreal coniferous and tundra conditions in the Crystal Lake region as happened during the last interglaciation in Atlantic Canada.

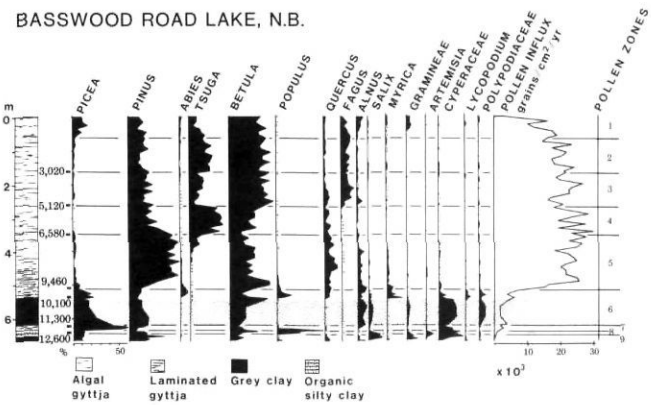


FIGURE 9. Basswood Road Lake pollen diagram (after Mott, 1975).

Diagramme pollinique de Basswood Road Lake (d'après Mott, 1975).

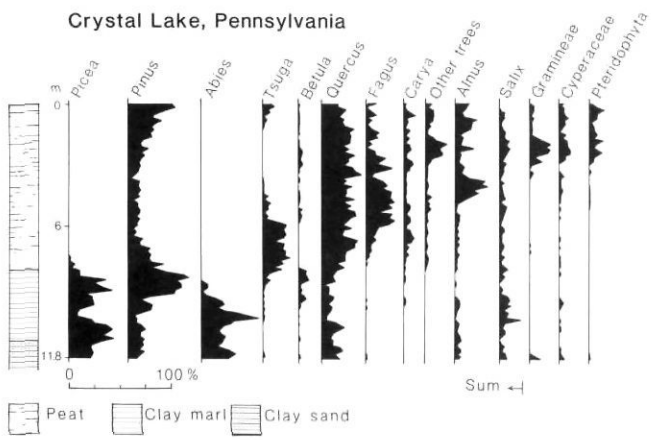


FIGURE 10. Crystal Lake, Pennsylvania, pollen diagram (after Walker and Hartman, 1960).

Diagramme polinique de Crystal Lake, en Pennsylvanie (d'après Walker et Hartman, 1960).

Quantitative estimates of possible climatic conditions that prevailed during the last interglacial interval can be gained by comparing selected pollen spectra from five of the interglacial sites containing thermophilous taxa with modern pollen spectra from eastern North America. Analog spectra were obtained using the Brown University modern pollen data base and dissimilarity coefficients that matched the fossil to the modern spectra (Overpeck *et al.*, 1985). The climatic data associated with the modern sites were then used to estimate the past climates (T. Webb III and K. Anderson, personal communication, 1988). Thirty taxa or groups of taxa were used in the analysis (Table I). Square chord distance dissimilarity coefficients of < 0.15 are considered to be possible valid analogs, and the modern spectra can be used to reproduce the fossil spectra. Sites matched with values > 0.15 relate to only the most similar spectra available and may not match the fossil spectra in all aspects.

Results of comparison of modern and fossil spectra are shown in Figures 11-15. Location of possible modern valid or closest analog sites are shown on a map of eastern North America for the five fossil sites. An adjacent column, or Table II in the case of Le Bassin site (Fig. 11), lists the dissimilarity coefficient for each level. The accompanying graphs give the mean January and July temperature and annual precipitation values determined from the modern sites for each level of the fossil pollen profile.

The sequence of changes in the fossil spectra from Le Bassin are reflected in the regions to which the spectra correlate (Fig. 11). The early spectra (Zone 1) have the best match with modern sites in northern Québec, Labrador and Baffin Island. Zone 2 spectra compare with sites in southern Québec and west of the Great Lakes. The most thermophilous spectra (Zone 3) correlate with sites west of the Great Lakes and with sites along the United States eastern seaboard. Mean January and July temperatures generated from Zone 1 analogs are well

TABLE I

Pollen types used in the calculation of the dissililarity coefficients

Pinus	*Tilia*
Betula	*Fraxinus*
Picea	*Carya*
Quercus	*Carpinus/Ostrya*
Gramineae	*Celtis*
Prairie forbs	*Populus*
Alnus	*Corylus*
Cyperaceae	Rosaceae
Tsuga	*Juglans*
Ulmus	Umbelliferae
Abies	*Liguidambar*
Salix	*Castanea*
Fagus	*Larix*
Cupressaceae	*Morus*
Acer	*Platanus*

below the modern means for Le Bassin site as would be expected from the northern locations of the possible analogs. Zone 2 means are variable, probably reflecting the fact that many of the spectra do not have valid analogs. Mean temperatures do rise toward the top of the zone, with the July mean close to the modern mean. Zone 3 January means, although higher, remain well below the present, whereas, the July means exceed the present value. Early precipitation values are very low and increase later, but except for a few instances in Zone 2 and 3, they remain well below the modern value.

TABLE II

Squared chord distance dissimilarity coefficients for Le Bassin site (refer to Fig. II for map and climatic data)

Depth (cm)	Coefficient	Depth (cm)	Coefficient
0	0.1269	97	0.1179
4	0.0670	98	0.2631
10	0.0992	100	0.2820
22	0.0849	102	0.2397
30	0.0808	103	0.2871
42	0.0761	104	0.2105
50	0.1052	105	0.2370
62	0.0765	106	0.1692
70	0.0716	107	0.2250
80	0.0766	108	0.2036
84	0.1151	109	0.0970
86	0.1265	110	0.1204
88	0.1067	112	0.0631
89	0.0669	120	0.0557
90	0.0744	130	0.0669
92	0.0757	140	0.0547
93	0.0860	150	0.0762
94	0.1993	160	0.0762
96	0.2073		

The spectra for East Bay I site are duplicated by spectra at sites southwest of the upper Great Lakes and in the mid-southeastern United States (Fig. 12). Both January and July mean temperatures exceed modern values for the base of the profile, and precipitation values are close to present. Modern sites with spectra comparable to those from the upper part of the profile have January means below, but July means above present values. Annual precipitation values are considerably less.

At Green Point, possible analog or nearest analog sites, like those for East Bay I, are located in two general regions, southwest of the Great Lakes and in the mid-southeastern United States (Fig. 13). As such, the mean July temperatures are higher than present for almost all the possible analogs, whereas, January values are much higher where the analog site is to the south, and lower where the possible analogs are to the west. Generally, the annual precipitation values are less, sometimes considerably less, and in only three instances are slightly more.

No valid analogs were generated for Addington Forks spectra, but the closest possible analogs show an eventual cooling trend from sites in the mid-southeastern states and the area southwest of the Great Lakes, to sites in northeastern North

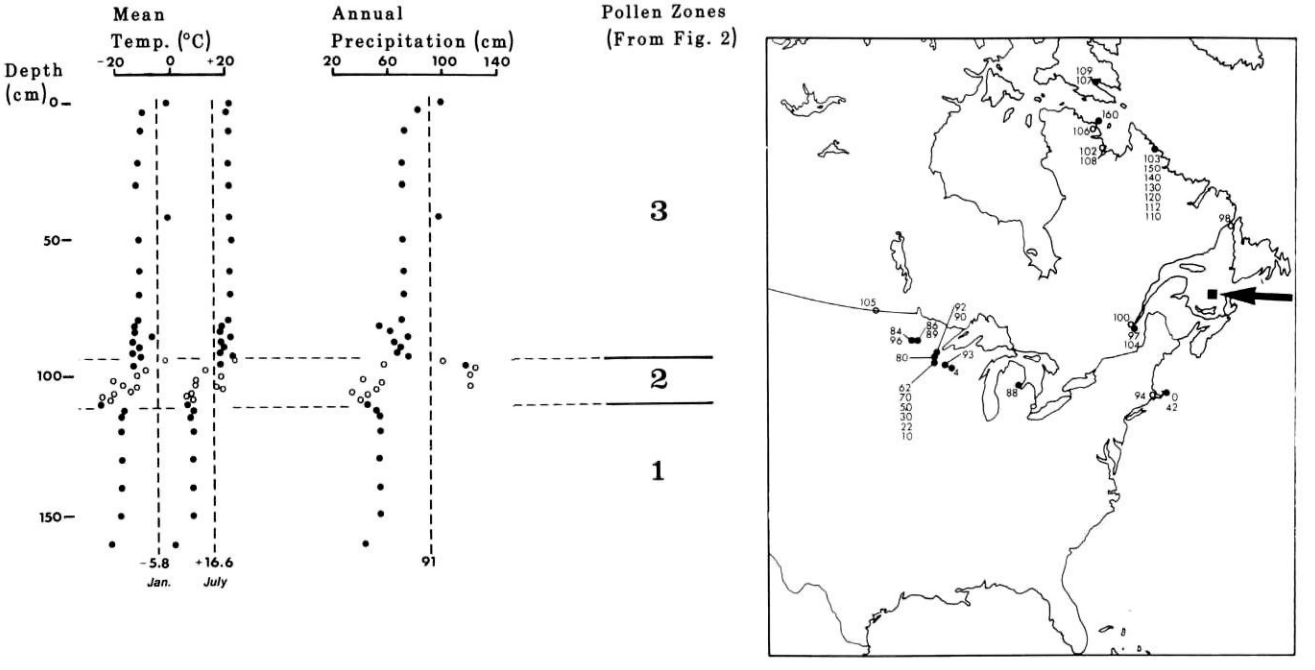


FIGURE 11. Location of modern analog and closest analog sites and climatic parameters for Le Bassin. Closed circles are valid modern analog sites with spectra dissimilarity coefficients < 0.15; open circles are closest analog sites with coefficients > 0.15. Symbols are the same in subsequent diagrams.

Localisation des sites analogues actuels ou presque analogues et paramètres climatiques au Bassin (îles de la Madeleine). Les points noirs sont des sites analogues valables dont le coefficient de dissimilitude du spectre est < 0,15; les points blancs sont des sites presque analogues dont le coefficient est > 0,15. Les symboles sont les mêmes dans les diagrammes qui suivent.

America (Fig. 14). Higher than present mean July temperatures, lower mean January temperatures and considerably less annual precipitation characterize zones 1 and 2 of the profile. For zone 3, mean January and July temperatures are above the present value, and precipitation values are significantly higher. Zone 4 has July means below the present, January means near the present value and precipitation at or below the present. Zone 5 January means are below, July means considerably below and precipitation substantially higher than the modern value.

Possible modern analog and closest analog sites for East Milford spectra are concentrated in the northeastern states and eastern Canada (Fig. 15). Mean July temperature values are close to the modern value in zones 1 and 2, are slightly less in zones 3 and 4, and are significantly less for section C spectra. Mean January values are near of slightly less than modern

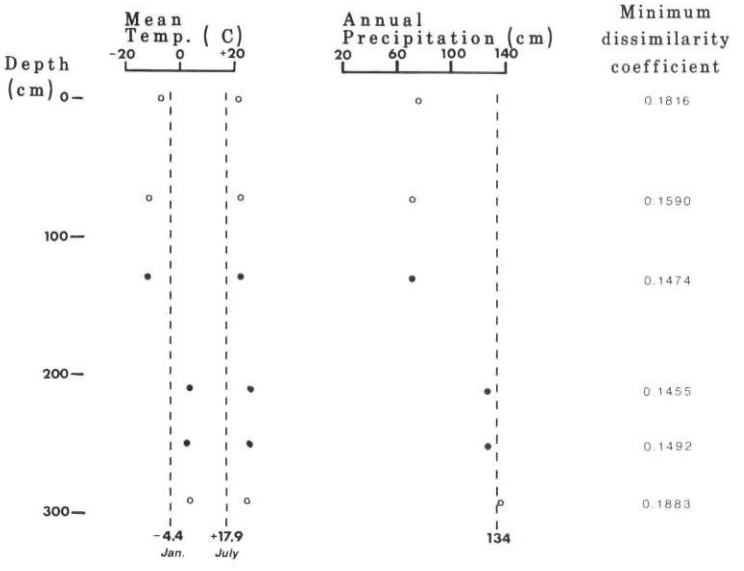


FIGURE 12. Location of modern analog sites and climatic parameters for East Bay I site.

Localisation des sites analogues actuels et paramètres climatiques au site de East Bay I.

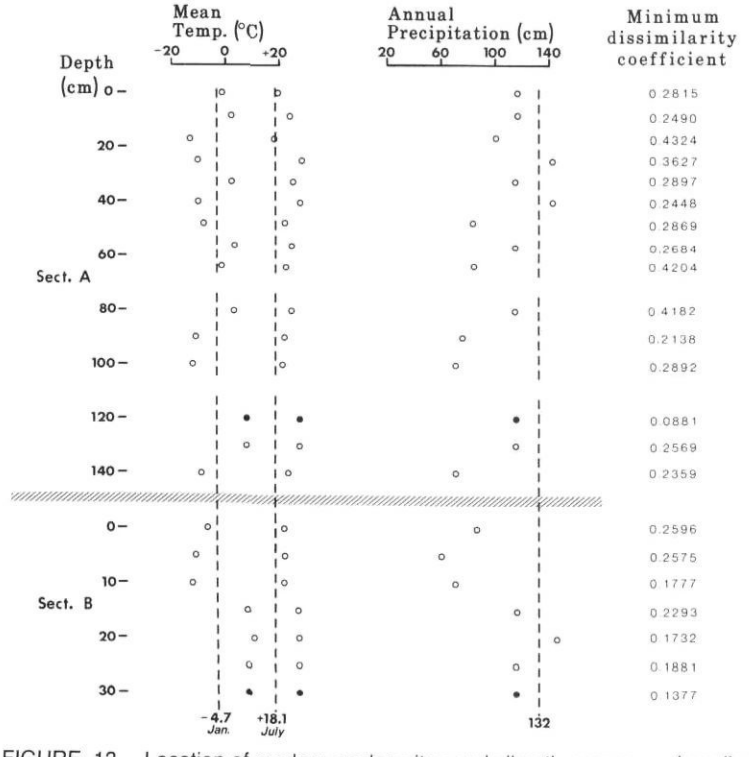
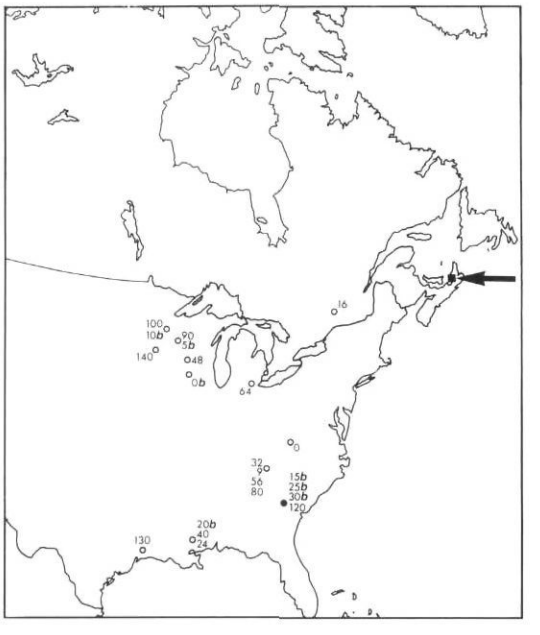


FIGURE 13. Location of modern analog sites and climatic parameters for Green Point site.



Localisation des sites analogues actuels et paramètres climatiques au site de Green Point.

in zones 1 and 2, are somewhat less in zone 3, and considerably less in zone 4 and Section C. Precipitation values are variable for the lower part of the sequence; most are at or slightly below the modern value, although a few exceed it. Zone 4 and Section C values are consistently less, with values for the latter considerably less.

Not all of the possible analogs are realistic because some of the species involved cannot be differentiated palynologically. This is probably true particularly for modern analog candidate sites from the southeastern United States pine-oak forests where the species of pine and oak that dominate are different from the fossil species. This caveat also applies to a somewhat lesser degree to modern sites from the United States Midwest. Nevertheless, it is obvious that at the time of greatest climatic warming during the Sangamon Interglaciation in Atlantic Canada, the forests more closely resembled more southerly forests than those of the same area today.

The actual climatic differences are much more difficult to discern. Not only is there some variation between climatic conditions at the locations of the interglacial sites today, but there is a wide variation between the possible analog sites as well. Except for East Milford, where one of the best potential analogs has climate values similar to the general Nova Scotia values, the values for the other sites are distinctly different from those of the Maritimes today. Mean July temperatures are from 4 to 10°C warmer. Mean January temperatures in some cases are much warmer, but in others they are much colder. In the latter cases, the potential analogs are in the Midwest and reflect the

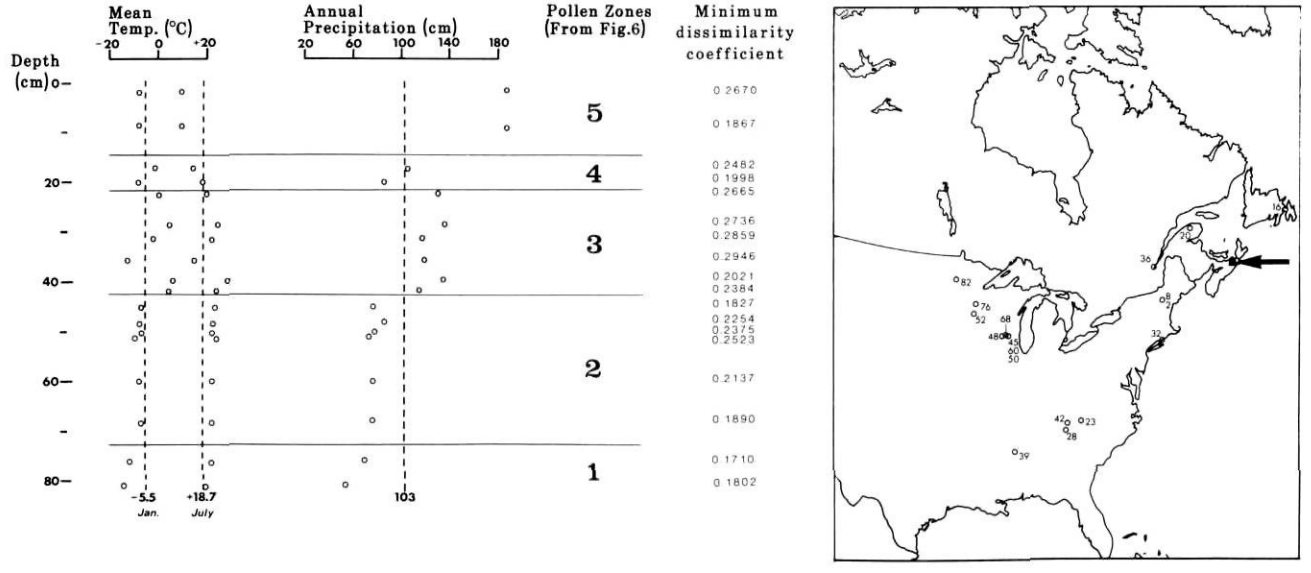


FIGURE 14. Location of modern analog sites and climatic parameters for Addington Forks site.

Localisation des sites analogues actuels et paramètres climatiques au site de Addington Forks.

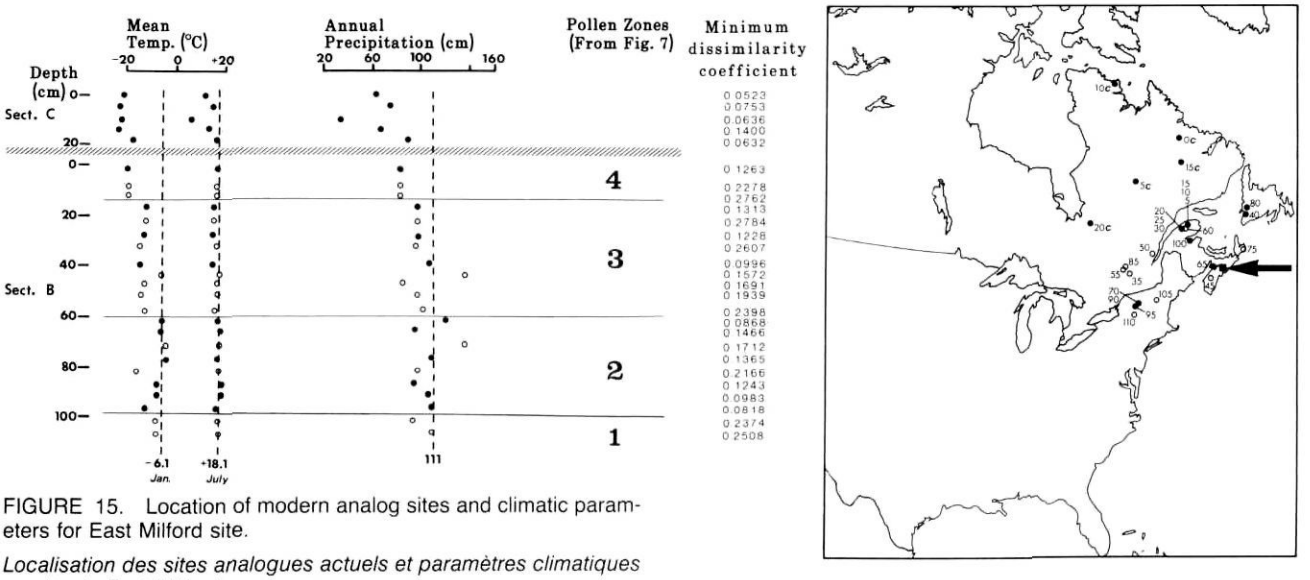


FIGURE 15. Location of modern analog sites and climatic parameters for East Milford site.

Localisation des sites analogues actuels et paramètres climatiques au site de East Milford.

greater continentality of that region. Precipitation values also reflect the potential analog site locations. Southeastern modern sites are wetter than the fossil site localities, and the Midwest analogs are drier. Values for the most southerly analog site are probably not reasonable for reasons discussed above, and they can be excluded. Since the fossil sites are in a maritime region, the climate may have been slightly drier but not as dry as the Midwest, and warmer, but not as warm as the southern potential analogs would suggest.

CONCLUSIONS

The results obtained from palynological studies of buried organic deposits in Atlantic Canada suggest that the Sangamon Interglaciation, whether considered in the narrow or broad sense, seems to have begun abruptly and reached a climatic optimum early in the interval. Climate probably became significantly warmer than the present particularly during the summer. Modern analogs suggest warmer conditions by 4°C, and possibly as much as 10°C, may have been involved. As far as winter was concerned, the results are equivocal. The potential analogs indicate two possibilities for winter climate; more continental and, therefore, colder and drier than today, or warmer with more precipitation. The maritime localities of the interglacial sites may favour the latter interpretation. The climate then changed through cool temperate to boreal and eventually to subarctic conditions. Evidence from other sites (Mott and Grant, 1985; de Vernal and Mott, 1986) indicate that non-glacial conditions prevailed not only during the warmest interval (substage 5e) described above, but continued, with other climatic cycles, throughout stage 5 and possibly even into stages 4 and 3.

Response of the vegetation to the climatic warming saw tundra shrub and herb communities replaced by boreal coniferous forests, and then by mixed forests that ultimately supported abundant oak and white pine or oak and a variety of thermophilous hardwoods. Thermophilous taxa such as, hickory, basswood and possibly even gum-tree were present in the region. White pine, and possibly oak, even reached the Iles de la Madeleine. Boreal forests of spruce and balsam fir dominated southwestern Newfoundland. The climatic cooling that followed forced a return to mixed temperate forests, boreal forests and eventually to forest/tundra and tundra conditions. Climatic warming once again possibly made conditions more favourable for mixed temperate forests, or at least for coniferous boreal forests.

The interpretations discussed above are a first attempt to characterize the climate of Atlantic Canada during substage 5e, the warmest period of the Sangamon Interglaciation. Or, if two intervals are involved, then the climate may have warmed to near present conditions again during substage 5a as well. These results are promising, but more work is required, not only by comparison with better analogs, but also by study of plant and animal macrofossils that may better characterize the local climate at various sites, and by improved chronological control. Knowledge of the last interglacial interval may provide useful insight into what may be in store for humanity in the not too distant future due to natural and human influences on climate.

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REFERENCES

Brookes, I. A., McAndrews, J. H. and von Bitter, P. H., 1982. Quaternary interglacial and associated deposits in southwest Newfoundland. Canadian Journal of Earth Sciences, 19: 410-423.

Dawson, J. W., 1855. Acadian Geology. Oliver and Boyd, Edinburgh, 388 p.

Causse, C. and Hillaire-Marcel, C., 1986. Géochimie des familles U et Th dans la matière organique fossile des dépôts interglaciaires et interstadiaires de l'est et du nord du Canada: potentiel radiochronologique, p. 11-18. *In* Recherches en cours, Partie B, Commission géologique du Canada, Étude 86-1B.

Flint, R. F. and Rubin, M., 1955. Radiocarbon dates of pre-Mankato events in eastern and central North America. Science, 121: 649-658.

Fulton, R. J., Karrow, P. F., LaSalle, P. and Grant, D. R., 1984. Summary of Quaternary stratigraphy and history, Eastern Canada, p. 193-210. *In* R. J. Fulton (ed.), Quaternary Stratigraphy of Canada — A Canadian Contribution to IGCP Project 24, Geological Survey of Canada Paper, 84-10.

Grant, D. R., 1971. Surficial geology of southern Cape Breton Island, Nova Scotia. Geological Survey of Canada Report of Activities, Paper 72-1A, Part A:160-163.

——— 1980. Quaternary sea-level change in Atlantic Canada as an indication of crustal deleveling, p. 201-214. *In* N. A. Mörner (ed.), Earth Rheology, Isostacy and Eustacy, John Wiley.

——— 1987. Glacial advances and sea-level changes, southwestern Nova Scotia, Canada, p. 427-432. *In* D. C. Roy (ed.), Geological Society of America Centennial Field Guide.

Grant, D. R. and King, L. H., 1984. A stratigraphic framework for the Quaternary history of the Atlantic Provinces, Canada, p. 173-191. *In* R. J. Fulton (ed.), Quaternary Stratigraphy of Canada — A Canadian Contribution to IGCP Project 24, Geological Survey of Canada Paper, 84-10.

Hillaire-Marcel, C. and de Vernal, A. 1989. Isotopic and palynological records of the late Pleistocene in eastern Canada and adjacent ocean basins. Géographie physique et Quaternaire, 43: 263-290.

Livingstone, D. A., 1968. Some interstadial and postglacial pollen diagrams from Eastern Canada. Ecological Monographs, 38: 87-125.

Mott, R. J., 1971. Palynology of a buried organic deposit, River Inhabitants, Cape Breton Island, Nova Scotia. Report of Activities, Part B, Geological Survey of Canada, Paper 71-1: 123-125.

——— 1975. Palynological Studies of lake sediment profiles from southwestern New Brunswick. Canadian Journal of Earth Sciences, 12: 273-288.

Mott, R. J. and Prest, V. K., 1967. Stratigraphy and palynology of buried organic deposits from Cape Breton Island, Nova Scotia. Canadian Journal of Earth Sciences, 4: 709-723.

Mott, R. J., Anderson, T. W. and Matthews, J. V., Jr., 1982. Pollen and macrofossil study of an interglacial deposit in Nova Scotia. Géographie physique et Quaternaire, 36: 197-208.

Mott, R. J. and Grant, D. R., 1985. Pre-Late Wisconsinan paleoenvironments in Atlantic Canada. Géographie physique et Quaternaire, 39: 239-254.

Overpeck, J. T., Webb, T., III and Prentice, I. C., 1985. Quantative interpretation of fossil pollen spectra: Dissimilarity coefficients and the method of modern analogs. Quaternary Research, 23: 87-108.

Prest, V.K., Terasmae, J., Matthews, J. V., Jr. and Lichti-Federovich, S., 1976. Late-Quaternary history of Magdalen Island, Québec. Maritime Sediments, 12: 39-59.

Ruddiman, W. F. and McIntyre, A., 1984. Ice-age thermal response and climatic role of the surface Atlantic Ocean, 40° N to 63° N. Geological Society of America Bulletin, 95: 381-396.

Stea, R. and Hemsworth, D., 1979. Pleistocene stratigraphy of the Miller Creek section, Hants County, Nova Scotia. Nova Scotia Department of Mines and Energy, Paper 79-5, 16 p.

Vernal, A. de, Richard, P. J. H. and Occhietti, S., 1983. Palynologie et paléoenvironnements du Wisconsinien de la région de la baie Saint-Laurent, île du Cap-Breton. Géographie physique et Quaternaire, 37: 307-322.

Vernal, A. de and Mott, R. J., 1986. Palynostratigraphie et paléoenvironnements du Pléistocène supérieur dans la région du lac Bras d'Or, île du Cap-Breton, Nouvelle-Écosse. Canadian Journal of Earth Sciences, 23: 491-503.

Vernal, A. de, Causse, C., Hillaire-Marcel, C., Mott, R. J. and Occhietti, S., 1986. Palynostratigraphy and Th/U ages of upper Pleistocene interglacial and interstadial deposits on Cape Breton Island, eastern Canada. Geology, 14: 554-557.

Walker, P. C. and R. T. Hartman, 1960. The forest sequence of the Hartstown bog area in western Pennsylvania. Ecology, 413: 461-474.