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Pre-Late Wisconsinan Paleoenvironments in Atlantic Canada
Paléoenvironnements des provinces atlantiques du Canada avant le Wisconsinien supérieur
Paläogeographische Umwelt in den Atlantischen Provinzen Kanadas vor dem späten Wisconsin

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Article abstract

Numerous Quaternary organic deposits of various lithologies beneath one or more till units of Wisconsinan age have been discovered in boreholes and exposures in coastal bluffs, quarries and river banks at widespread localities throughout Atlantic Canada. Ongoing palynological and macro-fossil studies, still in a preliminary stage at many sites, reveal a variety of environments from forests dominated by thermophilous hardwood genera and white pine, to mixed temperate hardwood and conifer forests, to boreal coniferous forests of spruce and balsam fir, and forest tundra and tundra communities characterized by spruce, shrubs and herbs. Lithologie and pollen stratigraphie relationships and radiocarbon, amino acid and Thorium/Uranium dating allow a tentative assignment to the Sangamonian Stage and possibly to Early and Middle Wisconsinan time. Three intervals of organic accumulation are apparent: an early interval, when climate became warmer than the present; a second interval, when climate was similar to the present; and a third interval, with cooler climate. The latter interval is characterized by at least three climatic cycles, each one cooler than the previous cycle. Tentative correlations with the deep-sea oxygen isotope record and continental palynological records are presented.

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PRE-LATE WISCONSINAN PALEOENVIRONMENTS IN ATLANTIC CANADA

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ABSTRACT Numerous Quaternary organic deposits of various lithologies beneath one or more till units of Wisconsinan age have been discovered in boreholes and exposures in coastal bluffs, quarries and river banks at widespread localities throughout Atlantic Canada. Ongoing palynological and macrofossil studies, still in a preliminary stage at many sites, reveal a variety of environments from forests dominated by thermophilous hardwood genera and white pine, to mixed temperate hardwood and conifer forests, to boreal coniferous forests of spruce and balsam fir, and forest tundra and tundra communities characterized by spruce, shrubs and herbs. Lithologic and pollen stratigraphic relationships and radiocarbon, amino acid and Thorium/Uranium dating allow a tentative assignment to the Sangamonian Stage and possibly to Early and Middle Wisconsinan time. Three intervals of organic accumulation are apparent: an early interval, when climate became warmer than the present; a second interval, when climate was similar to the present; and a third interval, with cooler climate. The latter interval is characterized by at least three climatic cycles, each one cooler than the previous cycle. Tentative correlations with the deep-sea oxygen isotope record and continental palynological records are presented.

RÉSUMÉ *Paléoenvironnements des provinces atlantiques du Canada avant le Wisconsinien supérieur*. Des dépôts organiques aux lithologies variées, surmontés d'au moins une unité de till wisconsinien, ont été découverts dans des trous de forage, dans des coupes le long des falaises littorales et de talus alluviaux, ainsi que dans des carrières en de nombreux endroits des provinces atlantiques. L'étude des macrofossiles et la palynologie de ces dépôts, encore à l'étape préliminaire dans de nombreux cas, révèlent l'existence de différents environnements : forêts dominées par des essences feuillues thermophiles et par le pin blanc; forêts mixtes à essences décidues tolérantes et de conifères; forêts boréales d'épinettes et de sapins baumiers; communautés de toundra forestière et de toundra caractérisée par les épinettes, les arbustes et les herbes. Les corrélations lithologiques et palynostratigraphiques, ainsi que les datations au radiocarbone, aux acides aminées et à l'uranium/thorium permettent d'attribuer ces dépôts au Sangamonien et probablement au Wisconsinien inférieur et moyen. On distingue trois périodes d'accumulation des sédiments organiques : la première se caractérisait par un climat plus chaud que maintenant; la deuxième, par un climat comparable à celui d'aujourd'hui, la troisième, par un climat plus frais. La dernière période d'accumulation a connu au moins trois cycles climatiques, chacun plus froid que le précédent. On présente également un essai de corrélation entre la courbe de l'oxygène isotopique océanique et les données palynologiques enregistrées sur le continent.

ZUSAMMENFASSUNG *Paläogeographische Umwelt in den Atlantischen Provinzen Kanadas vor dem späten Wisconsin*. Verschiedene organische Ablagerungen aus dem Quartär mit unterhalb einer oder mehrerer Till-Einheiten aus dem Wisconsin sind in Bohrlöchern und in Schnitten entlang der Steilküsten, in Steinbrüchen und an Flußböschungen an zahlreichen Plätzen quer durch die Atlantik-Provinzen entdeckt worden. Gegenwärtige palynologische und makrofossile Studien, die sich vielerorts noch in einem Anfangsstadium befinden, lassen eine Umweltvielfalt erkennen, angefangen bei Wäldern, die von thermophilen Hartholzarten und Weißtannen beherrscht sind, zu Mischwäldern von Hartholz und Nadelbäumen gemäßigten Klimas, zu nördlichen Nadelwäldern von Fichten und Balsamtannen, bis zu Wald-Tundra und Tundra-Einheiten, die durch Fichten, Sträucher und Pflanzen gekennzeichnet sind. Lithologische und pollenstratigraphische Beziehungen sowie Radiokarbondatierungen, Aminosäure und Thorium/Uranium-Datierungen erlauben eine vorläufige Zuordnung zum Sangamon-Interglazial und möglicherweise zur Zeit des frühen und mittleren Wisconsin. Drei Perioden organischer Akkumulation sind erkennbar: eine frühe, als das Klima wärmer als heute war; eine zweite, als das Klima dem gegenwärtigen ähnlich war; und eine dritte mit kälterem Klima. Diese letztere ist durch mindestens drei klimatische Zyklen gekennzeichnet, deren jeder kälter als der vorhergehende Zyklus war. Vorläufige Korrelationen mit dem Tiefsee Sauerstoff-Isotop Beleg und kontinentalen palynologischen Belegen werden vorgestellt.

INTRODUCTION

During recent years numerous sub-till organic deposits have been discovered in Atlantic Canada. All give nonfinite radiocarbon dates (>33 to >53 ka) and hence predate Late Wisconsinan time as defined by FULTON (1984, p. 3). Palynological results from twenty-five sites (Fig. 1), preliminary in some cases, comprise a bank of paleoenvironmental data for the period between the last two glacial stages.

Unlike some organic deposits in Europe that contain a continuous record for the Late Quaternary (WIJMSTRA, 1969; WOILLARD, 1978; BEAULIEU and REILLE, 1984), the organic deposits in Atlantic Canada represent a discontinuous, fragmented and scattered record. Included are deposits representing intervals that were as warm or warmer than the present as well as intervals that were cooler, or even glacial. The environmental history must be pieced together using stratigraphic considerations, palynostratigraphy and chronology. Unfortunately, the age of the deposits is beyond the range of radiocarbon dating, and the stratigraphic position is in many cases ambiguous, but the use of the Th/U disequilibrium method for dating wood has provided some chronometric control (CAUSSE *et al.*, 1984; de VERNAL *et al.*, in press).

The task of reconstructing the paleoenvironmental history has been greatly advanced through detailed study of sites along East Bay, Bras D'Or Lake, Cape Breton Island, where several organic beds record distinctive pollen sequences, and Th/U analyses of wood have produced apparently reliable ages (de VERNAL *et al.*, 1984, in press). The following account uses the results obtained from two sites along East Bay, the so-called East Bay Site and Castle Bay Site, as a framework, and enhances this framework with results from several other sites to outline the paleoenvironmental history of the last interglacial period for Atlantic Canada.

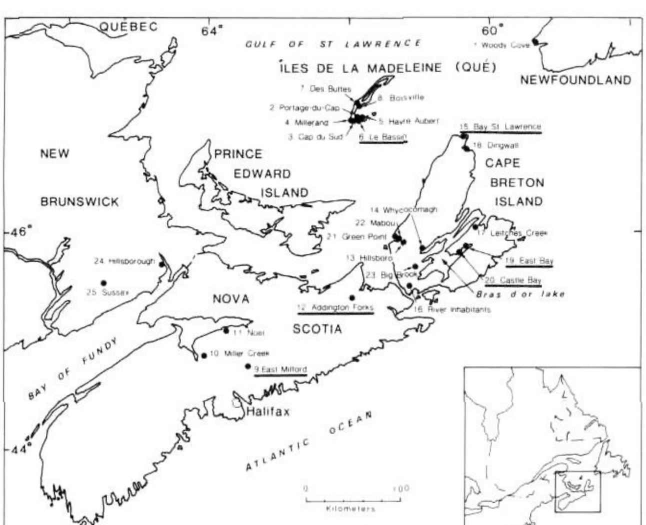

FIGURE 1. Location map for pre-Late Wisconsinan organic deposits in Atlantic Canada. Sites discussed in text are underlined.
Carte de localisation des dépôts organiques enfouis avant le Wisconsinien supérieur dans les provinces atlantiques. Les sites dont on parle dans le texte sont soulignés.

PREVIOUS PALYNOLOGICAL WORK

Buried organic deposits have been known from Atlantic Canada for more than a century since DAWSON (1855, p. 50) noted organic sediments beneath till in a river section near River Inhabitants, Cape Breton Island. Palynological studies of buried organic deposits in Atlantic Canada date to much more recent times. A report on radiocarbon dates (FLINT and RUBIN, 1955) included a preliminary palynological analysis by L. R. Wilson of a single sample from a site near Hillsboro (formerly Hillsborough) on Cape Breton Island, but it was MOTT and PREST (1967) who published the first palynological report on sites from Atlantic Canada. They reported results from four sites all in Cape Breton Island, Nova Scotia, including the Hillsboro site, and tentatively correlated these deposits with the St.Pierre interstade. An independent analysis of the Hillsboro site was reported by LIVINGSTONE (1968). Palynological study of the re-discovered River Inhabitants site (GRANT, 1971) revealed boreal spectra which were assigned to an early Wisconsinan interstade (MOTT, 1971).

PREST *et al.* (1976) concluded that a buried organic site on Îles de la Madeleine, Québec, recorded conditions warmer than the present and was of interglacial rank.

One buried organic site is known from Newfoundland, the Woody Cove site, which BROOKES *et al.* (1982) assigned to an interglacial interval, probably the Sangamonian, based on spectra dominated by conifers that indicate climate as warm or warmer than the present.

STEA and HEMSWORTH (1979) included a pollen analysis by Mott of a buried peaty clay from the Miller Creek site in mainland Nova Scotia and suggested deposition during the Sangamonian interglacial interval. MOTT *et al.* (1982) reported pollen and macrofossil results from the nearby East Milford site that indicate interglacial conditions and concluded the sediments were deposited during Sangamonian interglacial time.

De VERNAL *et al.* (1983) published a palynological study of the Quaternary sediments exposed in a sea cliff at Bay St. Lawrence on the northern tip of Cape Breton Island. An enclosed peat layer with tundra and boreal pollen spectra suggested a cool interstadial. A silty clay unit higher in the sequence contains tundra indicators.

Two new sites along East Bay, Bras D'Or Lake (de VERNAL *et al.*, 1984, in press; de VERNAL and MOTT, 1986) contain several organic units that are referred to both interglacial and interstadial intervals. Results from these sites form the basis for the framework of the paleoenvironmental reconstruction given below.

STRATIGRAPHIC FRAMEWORK

The deep-sea oxygen isotope record (EMILIANI, 1971; SHACKLETON, 1969) provides a world wide standard of climatostratigraphy and chronology. The oxygen isotope stratigraphy for the North Atlantic developed by RUDDIMAN and McINTYRE (1981, 1984) for core V30-97 probably provides the best deep-sea record for correlation with Atlantic Canada.

On that basis, GRANT and KING (1984) developed a stratigraphic framework for this region based on terrestrial and marine sedimentary sequences related to that deep-sea core. According to their scheme, deposits of the Illinoian Glaciation, the last interglaciation, and the last or Wisconsin Glaciation form three broad groups that are assigned to deep-sea oxygen isotope Stage 6, Stage 5 and Stages 4/3/2, respectively.

In keeping with a recommendation by FULTON (1984) and a practice followed in most Canadian regional summaries the last interglaciation, or Sangamonian Stage in Atlantic Canada, is thus considered to encompass all of oxygen isotope Stage 5, a lengthy period of about 50 000 years, with a variable climate, dating from about 128ka to 75ka in the deep-sea record. Included in this period are intervals that were as warm or warmer than the present, as well as cooler or even glacial intervals.

Nonglacial deposits which contain organic sediments are relatively abundant in this region. They usually underlie till or tills of the last glacial stage, the Wisconsinan, and are occasionally underlain by till of the previous, or Illinoian Glaciation. However, the nonglacial deposits may also rest on bedrock which in a few localities forms a wave cut platform at an elevation of 4-6 m that is attributed to the warmest part of the last interglacial when sea level was highest (GRANT, 1980, 1985). This platform probably correlates with Substage 5e of the deep-sea record. A second high sea level, higher than the present but not as high as the Substage 5e level, is recorded at a few sites but its significance is not understood at present.

Since no one organic deposit seems to encompass the whole of Stage 5, or probably even one substage, a continuous palynological profile is not available. However, one site (East Bay site) contains several organic layers within which three distinct pollen sequences can be discerned. Stratigraphic evidence at the site allowed a somewhat equivocal palynostratigraphy to be developed, but since the age of the organic deposits are all beyond the range of radiocarbon dating, the chronology of events could not be outlined. The advent of Th/U age determinations on wood has provided a means of at least determining relative ages and absolute chronology for some deposits.

CHRONOLOGY

Several wood samples from East Bay site, and from numerous other sites, were radiocarbon dated at high pressure and long counts to give the maximum nonfinite date possible to verify that the deposits were, in fact, beyond the limit of radiocarbon dating. Except for a few determinations, all the dates are nonfinite (Table I). Those that are finite are deemed spurious because, 1) they are directly associated with dates from the same deposit that are nonfinite, and/or 2) palynological results show the age to be untenable. Contamination of the sample by modern rootlets may have been a problem in some cases.

Amino-acid racemization ratios on wood (N. W. Rutter, unpublished data) do seem to show that all deposits belong to one lengthy interval, but they have not proven useful in determining stratigraphic position in this region. Wide ranges of ratios were obtained, often within the same deposit. In other instances, ratios from wood in deposits that had palynofloras indicative of warm interglacial conditions were similar to ratios from deposits related to very cool intervals. The species of wood used for analysis does not appear to be a factor in the results, but the state of preservation of the wood may be significant.

Th/U age determinations on wood have been helpful in developing a chronology, although this method is not without problems, and the ages should probably be considered minimum ages (CAUSSE *et al.*, 1984; de VERNAL *et al.*, in press). A relatively open radioactive system can lead to leaching and/or secondary influx of uranium isotopes (^{238}U, ^{234}U) and the incursion of thorium. Fortunately, the occurrence of detrital thorium can be detected by the presence of ^{232}Th. An arbitrary value of 3.0 for the $^{230}Th/^{232}Th$ ratio is a threshold below which the samples are considered too contaminated to produce valid ages (de VERNAL *et al.*, in press). However, high $^{230}Th/^{232}Th$ ratios do not necessarily indicate a closed radioactive system and valid dates.

Th/U dates for several sites are shown in Table II along with pertinent isotope values. None of the ages should be considered absolute although some may not be far from their true age. Considerably more work is required in evaluating Th/U ages before they can be accepted as reliable, but work is continuing in this direction. In the meantime, the ages at least provide some indication of relative stratigraphic position of various deposits, and a rough estimate of their age.

In summary, the radiometric measurements support the original age assignments based on stratigraphic position, namely that they belong to a long interval immediately preceeding the onset of Wisconsin Glaciation in the region.

THE EAST BAY RECORD

East Bay is a northeast arm of Bras D'Or Lake, a landlocked body of sea water. Two sites, the East Bay site and Castle Bay site occur along the northwest shore of East Bay and comprise what is referred to herein as the East Bay record. The East Bay site includes several organic beds with differing palynofloras. Wood from these beds provided a Th/U chronology that is unique for the Maritimes. Thick beds of organic silts at Castle Bay site record three climatic cycles involving a lengthy time interval.

EAST BAY SITE

East Bay site is a complex sea cliff section where exposures reveal several organic beds whose relative stratigraphic positions are not completely understood because of collapse due to sinkhole development in the underlying gypsum bedrock. Palynology and Th/U chronology have been reported by de VERNAL and MOTT (1985) and de VERNAL *et al.* (1984, in press). The irregular bedrock surface of the interbedded Mississippian gypsum and shale is overlain by unconsolidated Quaternary sediments comprising basal coarse to medium

TABLE I

Radiocarbon dates on buried organic deposits in Atlantic Canada

Site	Pollen Sequence	Lab. No.	Age (Years BP)	Material dated	Reference
Woody Cove (Site 1)	I?	I-10203	>40 000	wood	BROOKES *et al.*, 1982
Portage-du Cap (Site 2)	II	BGS-259	>35 000	plant detritus	PREST *et al.*, 1976
		GSC-2313	>38 000	wood	
Cap du Sud (Site 3)	III?	GSC-3413	>38 000	peat	
Millerand (Site 4)	?	GSC-3631	>46 000	wood	
Havre-Aubert (Site 5)	?	GSC-3633	>47 000	wood	
Le Bassin (Site 6)	I	GSC-3623	>46 000	wood	
East Milford (Site 9)	II	GSC-33	>33 800	wood	LOWDON and BLAKE, 1973; PREST, 1970
		GSC-1642	>50 000	wood	MOTT *et al.*, 1982
Miller Creek (Site 10)	III?	I-3237	33 000 ± 2000	wood	MacNEILL, 1969
		GSC-2694	>52 000	wood	STEA and HEMSWORTH, 1979
Addington Forks (Site 12)	I	I-3236	$33\ 700 \pm^{2300}_{1800}$	wood	MacNEILL, 1969
		GSC-1598	>42 000	wood	LOWDON and BLAKE, 1973
Hillsboro, N.S. (Site 13)	III?	W-157	>40 000	wood	FLINT and RUBIN, 1955
		GSC-370	>51 000	wood	MOTT and PREST, 1967
Whycocomagh (Site 14)	III?	GSC-290	>44 000	wood	MOTT and PREST, 1967
Bay St.Lawrence (Site 15)	III	GSC-283	>38 300	wood	MOTT and PREST, 1967
		GSC-3636	44 200 ± 820	wood	
		GSC-3864	>46 000	wood	
River Inhabitants (Site 16)	III?	GSC-1406-2	>49 000	wood	GRANT, 1971; MOTT, 1971
Leitches Creek (Site 17)	III?	GSC-2678	>52 000	peat	
Dingwall (Site 18)	III?	GSC-3381	32 700 ± 560	wood	
		GSC-3417	>39 000	wood	
		GSC-3541	>48 000	wood	
Eat Bay (Site 19)	I, II, III	GSC-3861	>50 000	wood	
		GSC-3871	>49 000	wood	
		GSC-3878	>50 000	wood	
Castle Bay (Site 20)	III	GSC-1577	>42 000	organic silt	
		GSC-1619	>52 000	wood	
Green Point (Site 21)	I	GSC-3220	>53 000	wood	GRANT and KING, 1984
Mabou (Site 22)	III?	GSC-3317	>53 000	wood	
Big Brook (Site 23)	III?	GSC-3289	>49 000	wood	
		GSC-3206	36 200 ± 1280	organic silt	
		GSC-3880	>52 000	wood	
Hillsborough, N.B. (Site 24)	?	GSC-1222	13 600 ± 200	bone	GRANT and KING, 1984
		GSC-1310	37 300 ± 1310	peat	
		GSC-1680	>43 000	coprolites	
Sussex (Site 25)	?	BGS-806	>35 000	wood	RAMPTON *et al.*, 1984

TABLE II

Thorium/Uranium disequilibrium method age determinations on wood

Site	Pollen Sequence	Lab. No.	^{238}U. ppm	^{234}U/^{238}U	^{230}Th/^{232}Th	^{232}Th dpmg	Age (Years) $\pm 1\sigma$	Reference
East Bay (Site 19)	I	UQT-175	0.041 ± .002	1.221 ± .048	3.561 ± .202	0.007 ± .000	126 400 ± 15 000 / 12 800	de VERNAL *et al.*, in press
		UQT-176	0.011 ± .001	1.235 ± .048	2.078 ± .112	0.003 ± .000	123 400 ± 30 000 / 23 400	"
		UQT-108	0.109 ± .004	1.110 ± .040	1.314 ± .026	0.037 ± .002	106 600 ± 9 600 / 8 600	"
		UQT-179	0.447 ± .010	1.190 ± .026	1.360 ± .048	0.121 ± .006	60 800 ± 5 100 / 5 000	"
	II	UQT-109	0.173 ± .006	2.096 ± .070	6.138 ± .190	0.025 ± .002	86 900 ± 6 000 / 5 700	"
	III-1	UQT-177	0.234 ± .008	1.202 ± .032	72.167 ± 12.588	0.001 ± .000	62 100 ± 5 000 / 4 600	"
	III-1	UQT-227	0.106 ± .002	1.024 ± .022	2.286 ± .074	0.021 ± .002	98 700 ± 10 500	C. Causse, pers. comm.
	III-2	UQT-188	0.519 ± .016	1.153 ± .032	0.959 ± .028	0.171 ± .008	50 200 ± 5 000	de VERNAL *et al.*, in press
Le Bassin (Site 6)	I	UQT-183	0.661 ± .016	1.399 ± .026	4.491 ± .132	0.096 ± .006	106 400 ± 8 400 / 8 000	"
		UQT-182	0.770 ± .024	1.386 ± .032	3.282 ± .158	0.147 ± .010	101 700 ± 17 000 / 14 200	"
		UQT-184	0.864 ± .030	1.453 ± .036	3.824 ± .110	0.137 ± .008	89 400 ± 8 000 / 7 100	"
East Milford (Site 9)	II	UQT-185	0.763 ± .018	1.229 ± .020	12.099 ± .702	0.031 ± .002	84 900 ± 6 500 / 6 100	"
		UQT-186	0.178 ± .006	1.317 ± .042	3.953 ± .152	0.024 ± .002	84 200 ± 11 300 / 10 100	"
Bay St.Lawrence (Site 15)	III	UQT-178	4.073 ± .096	1.539 ± .012	138.797 ± 28.026	0.011 ± .012	47 000 ± 4 700 / 4 300	"

unstratified gravels that grade upward into stratified gravels. The gravels are, in turn, overlain by till. Three distinct types of organic sediments underlie or are enveloped within the basal unstratified gravels. They are: 1) A compact woody peat, 4 m thick, which occurs in one exposure where it occupies a karst depression that extends below sea level and is highly disturbed by collapse. 2) Thinly stratified silty clays with interbedded sand and gravel that grade upward into alternating silty clay and peaty and woody organic layers. Large, well preserved logs occur in the thinly stratified silty clays in one exposure. These sediments overlie bedrock and, although deformed by collapse, retain coherent stratification. 3) Organic-rich silts that are found in several exposures where they are enclosed in the unstratified gravels or occur along the gradational contact with the overlying stratified gravels. These silts are often highly contorted by collapse.

The three types of organic deposits are distinctive palynologically in that each one shows a different sequence of characteristic pollen assemblage zones (termed Palynostratigraphic Units in de VERNAL and MOTT, 1985). The compact peat is distinguished by a pollen sequence with pollen assemblage zones dominated by *Quercus, Pinus strobus* and other thermophilous hardwood pollen (Fig. 2); the silty clays and interbedded organic layers by *Abies balsamea* pollen with some thermophilous hardwood and *Tsuga* pollen, followed by coniferous assemblages dominated by *Picea* (Fig. 3); and the organic silts by coniferous assemblages of *Picea, Pinus* and abundant NAP pollen (Fig. 4) (de VERNAL *et al.*, 1984; de VERNAL and MOTT, 1986).

Th/U age determinations on wood from East Bay section suggests that the three distinctive palynostratigraphic units may belong to separate time intervals of organic accumulation (de VERNAL *et al.*, in press). As discussed earlier, the Th/U dates must be used with discretion and should be considered minimum ages in many cases. However, the most reliable dates indicate that Unit I is about 120 000 years old, Unit II about 85 000 years old, and Unit III about 60 000 years old.

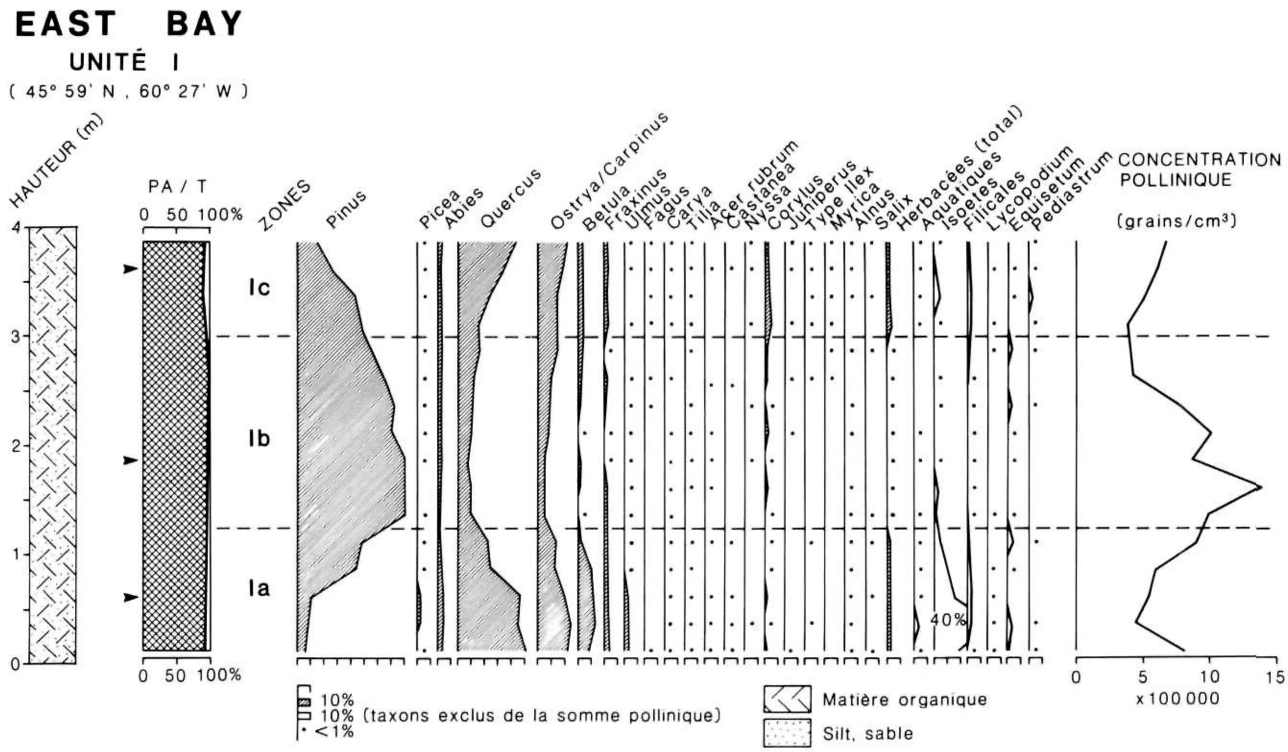

FIGURE 2. Pollen diagram for Unit I, East Bay site (de VERNAL and MOTT, 1986).

Diagramme pollinique d'East Bay, unité I (de VERNAL et MOTT, 1986).

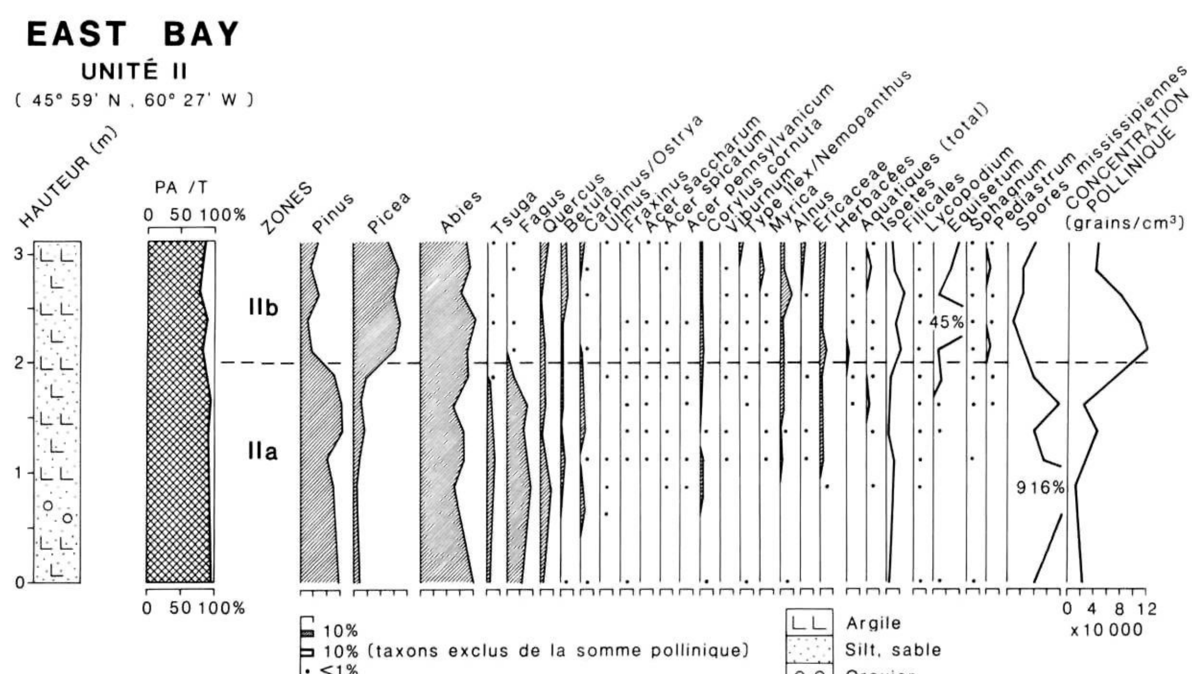

FIGURE 3. Pollen diagram for Unit II, East Bay site (de VERNAL and MOTT, 1986).

Diagramme pollinique d'East Bay, unité II (de VERNAL et MOTT, 1986).

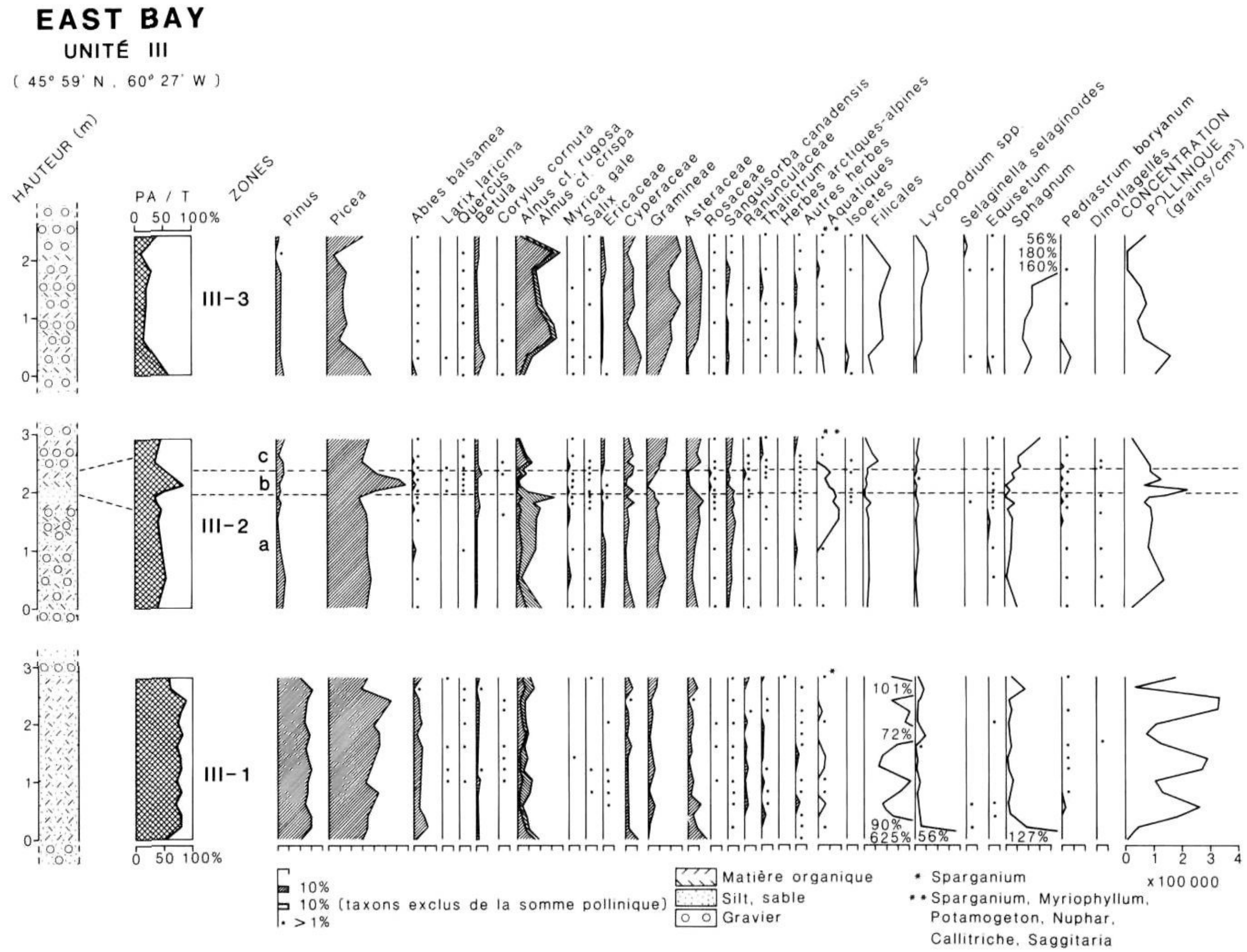

FIGURE 4. Pollen diagram for Unit III, East Bay site (de VERNAL and MOTT, 1986).

Diagramme pollinique d'East Bay, unité III (de VERNAL et MOTT, 1986).

CASTLE BAY SITE

At the Castle Bay section, till and coarse colluvium overlie a thick sequence of finely laminated organic silts and interstratified deltaic sands which rest on a planar bed of indurated gravels (GRANT, 1972; de VERNAL *et al.*, 1984; de VERNAL and MOTT, 1986).

The pollen sequence (Fig. 5) begins with assemblages in which *Pinus* and *Picea* dominate, followed by three intervals where nonarboreal pollen taxa are dominant, alternating with two intervals where coniferous assemblages dominate (de VERNAL *et al.*, 1984; de VERNAL and MOTT, 1986). Diatom analyses of the organic silts, indicates that input of marine and freshwater assemblages fluctuated during deposition. LORTIE *et al.* (1984) interpreted this in terms of isostatic adjustments in response to glacial fluctuations in the region. GRANT (in press) however believes that the silts are proglacial lake sediments partly constituted of marine mud reworked from the floor of East Bay by an advancing glacier; the microfossil variations thus have a dual meaning and their elevations have no isostatic implications.

CORRELATIVES OF THE EAST BAY RECORD

Preliminary palynology and chronometry of sites along East Bay thus suggest three periods of organic accumulation, each relating to an interval with distinctive palynofloras and hence distinctive vegetation and climate. However, the record is far from complete. The oldest bed at East Bay represents a relatively short part of what was probably the warmest part of the interval. Thermophilous hardwood and *Pinus strobus* pollen assemblages suggest relatively warm conditions; not represented are spectra related to cooler conditions of a waxing and waning climatic cycle. The record of the second interval at East Bay is somewhat longer and shows a cooling trend, but late and early cool phases are not represented. The third interval, represented by several organic beds, records alternating cool and cold conditions. Th/U ages, stratigraphy and palynology are not sufficient to arrange the units in a sequence, and hence it remains unknown to what degree this lengthy interval is represented. However, estimates based on pollen concentrations of the thick silty clay sediments at Castle Bay section suggest a duration of from 14 000 to 52 000 years.

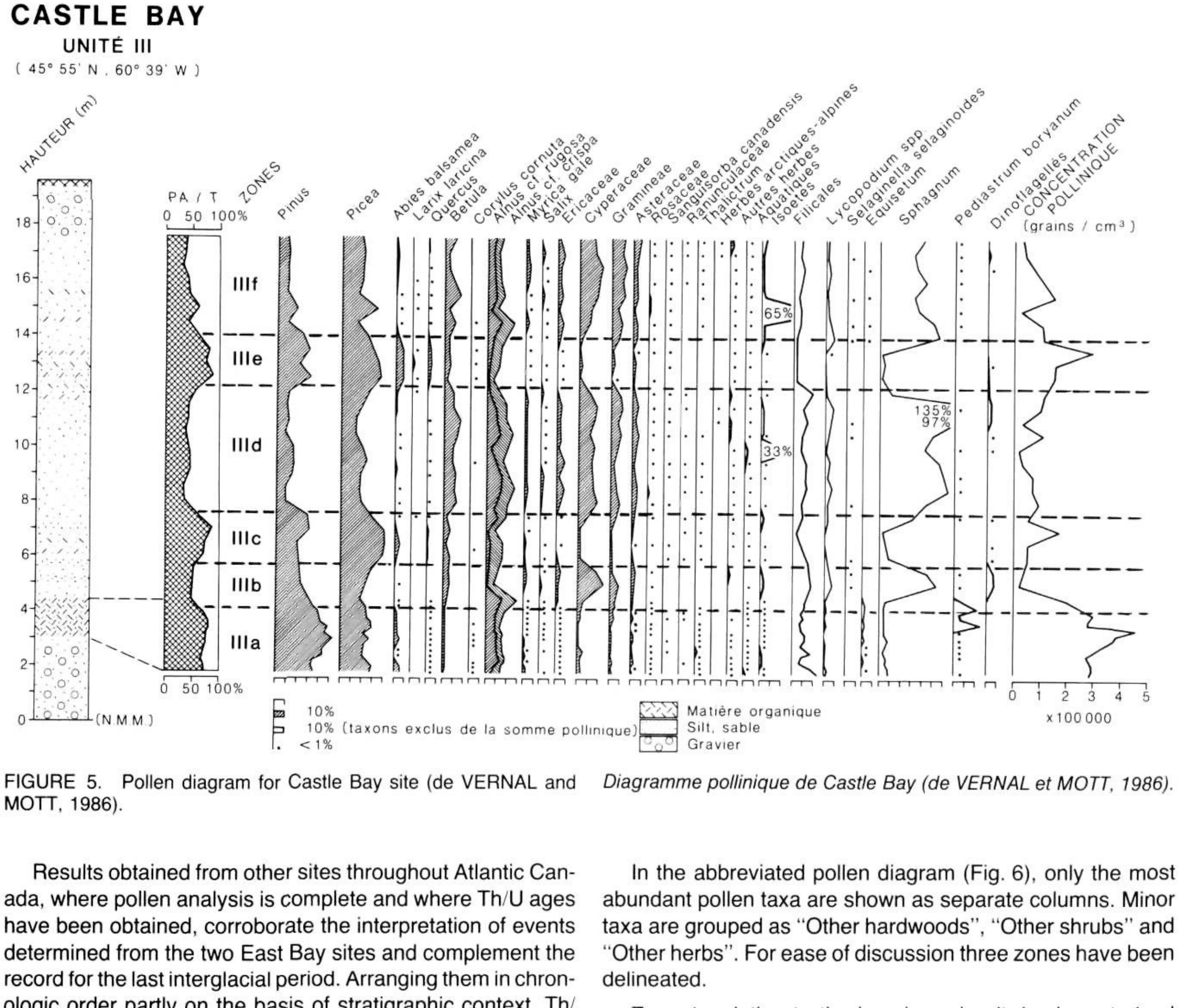

FIGURE 5. Pollen diagram for Castle Bay site (de VERNAL and MOTT, 1986).

Diagramme pollinique de Castle Bay (de VERNAL et MOTT, 1986).

Results obtained from other sites throughout Atlantic Canada, where pollen analysis is complete and where Th/U ages have been obtained, corroborate the interpretation of events determined from the two East Bay sites and complement the record for the last interglacial period. Arranging them in chronologic order partly on the basis of stratigraphic context, Th/U age, and pollen assemblage, the regional sequence is as follows.

FIRST INTERVAL — PALYNOSTRATIGRAPHIC UNIT I

Two sites can be related to the early interval by their palynofloras and Th/U ages. Le Bassin is a coastal site exposed on Îles de la Madeleine, Québec (Site 6, Fig. 1). Addington Forks is an inland site in northeastern mainland Nova Scotia (Site 12, Fig. 1).

Le Bassin Site

The site is located at the western end of Le Bassin lagoon, a salt to brackish water body along the southeastern coast of Île du Havre-Aubert, separated from the open sea by a tombolo connecting bedrock headlands. Laminated sand and silt a few decimetres above sea level grades into sand below sea level (Fig. 6). Overlying the sand is a 20 cm-thick compact woody peat unit that is overlain by about 20 cm of clay with organic stringers and 60 cm of somewhat laminated silty clay. The sequence is capped by 15 cm of sand and a thick (>1 m) till layer.

In the abbreviated pollen diagram (Fig. 6), only the most abundant pollen taxa are shown as separate columns. Minor taxa are grouped as "Other hardwoods", "Other shrubs" and "Other herbs". For ease of discussion three zones have been delineated.

Zone 1, relating to the basal sand unit, is characterized by Cyperaceae pollen and the shrubs *Betula, Salix* and *Alnus*; Gramineae and other herbs are present. *Pediastrum* remains attest to deposition in a freshwater environment. Zone 2 shows a succession of abrupt maxima in several taxa: shrub and herbaceous taxa near the base of the peat unit are followed by a maximum in *Betula*, then *Picea*, and then a small peak in *Quercus* pollen. Near the top of the peat unit, *Pinus strobus* pollen becomes abundant, then declines slightly as *Quercus, Betula* and other hardwoods (including *Carya, Fagus, Tilia*, etc) become more abundant in the overlying clay unit (Zone 3). Marine dinoflagellates and diatoms in the clay unit reflect deposition in a marine environment. *Pinus strobus* wood from the top of the peat unit gave Th/U ages of $106\,400\ ^{+\,8400}_{-\,8000}$ (UQT-183), $101\,700\ ^{+\,17\,000}_{-\,14\,200}$ (UQT-182) and $89\,400\ ^{+\,8000}_{-\,7100}$ (UQT-184) years (Table II).

Addington Forks Site

The exposure is in a road cut adjacent to the west bank of James River 0.5 km north of Addington Forks crossroad. About 80 cm of silt with organic seams, organic silt, and peat

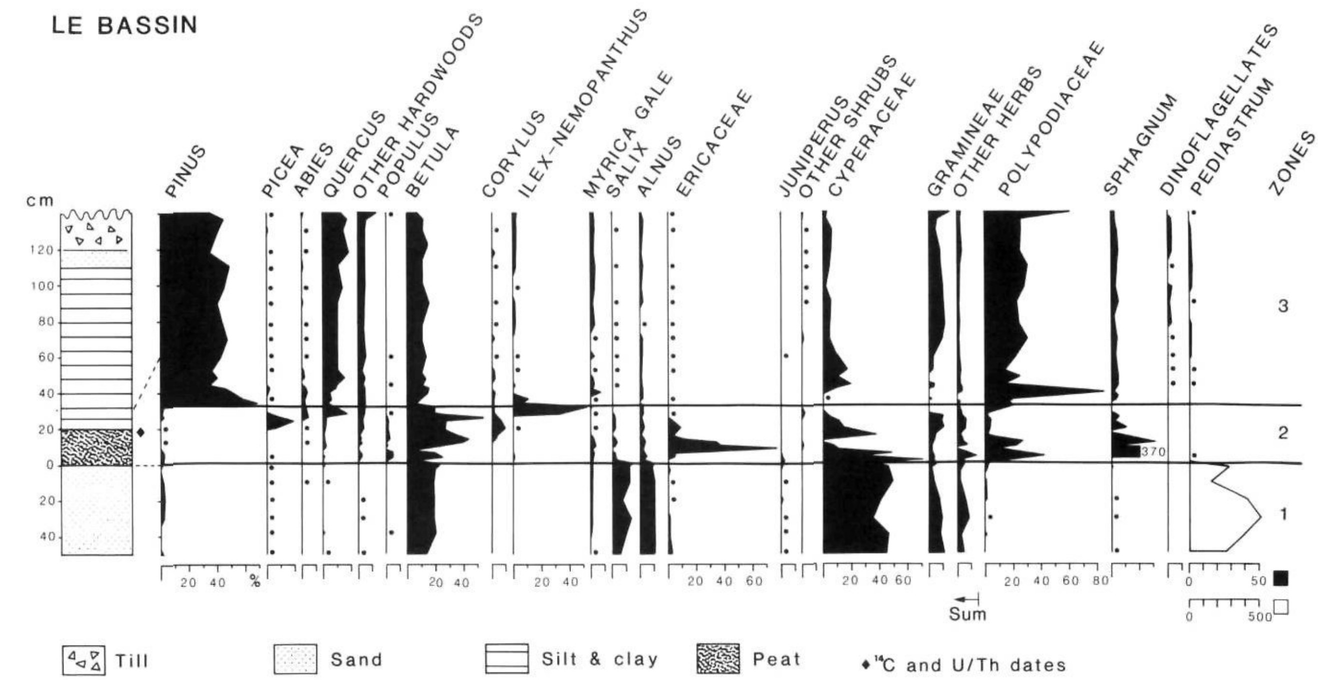

FIGURE 6. Pollen diagram for Le Bassin site showing selected taxa. Taxa not shown individually are grouped in columns designated "Other hardwoods", "Other shrubs" and "Other herbs". Note expanded scale in centre of diagram.

Diagramme pollinique de certains taxons du site Le Bassin. Les taxons non présentés individuellement ont été regroupés sous les colonnes suivantes: "Other hardwoods", "Other shrubs" *et* "Other Herbs". *L'échelle est agrandie au centre du diagramme.*

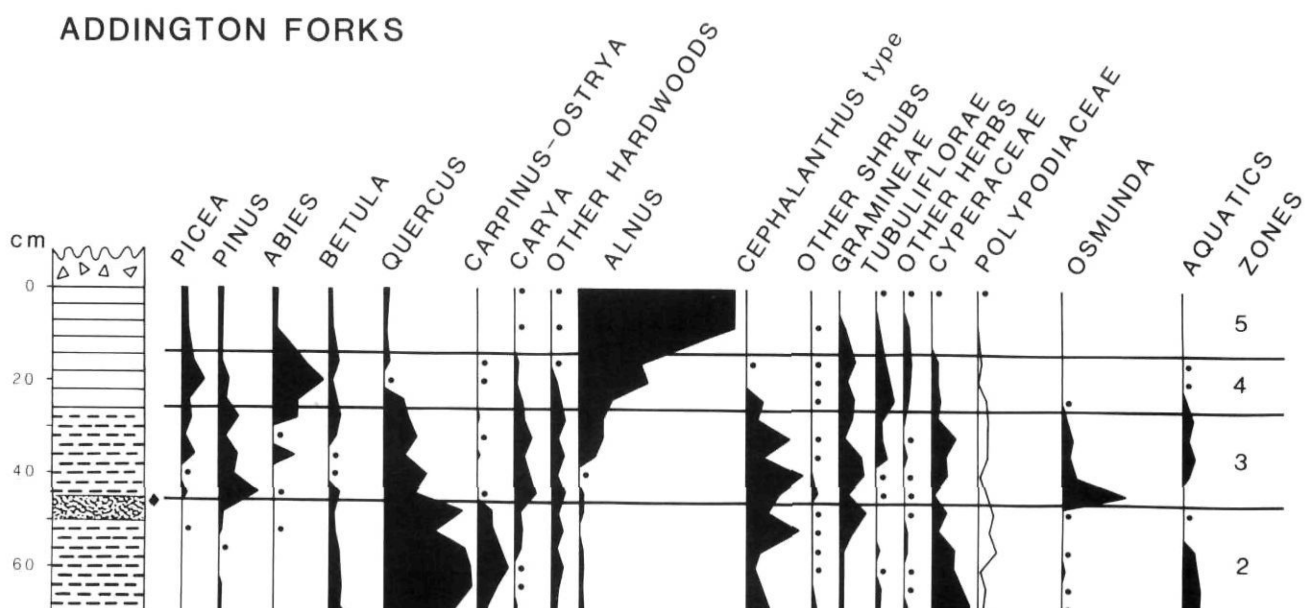

FIGURE 7. Pollen diagram for Addington Forks site showing selected taxa. Taxa not shown individually are grouped as noted for Figure 6.

Diagramme pollinique de certains taxons d'Addington Forks. Les taxons non présentés individuellement ont été regroupés de la même façon que pour la figure 6.

make up a nonglacial package of sediments sandwiched between a basal red-brown till and an overlying red till. The peat layer, less than 10 cm thick, is very compact.

The abbreviated pollen diagram (Fig. 7) has been divided into 5 zones. The basal Zone 1 is dominated by Polypodiaceae and *Osmunda* spores and tree pollen of *Quercus* and *Betula*. *Quercus* dominates in Zone 2 along with significant amounts of *Carnipus/Ostrya*. *Quercus* decreases and *Pinus, Carya* and other thermophilous hardwoods (such as *Fagus, Tilia* and *Ulmus*) increase in Zone 3. *Cephalanthus* type and Gramineae are local flora indicators in this part of the diagram. *Osmunda* spores attain a second maximum in this zone as well. Decline of *Pinus* pollen and thermophilous hardwoods in Zone 4 accompanies increases in *Abies, Picea* and *Alnus*. In Zone 5, extremely large *Alnus* values supplant most other taxa.

The Le Bassin and Addington Forks sequences are correlated with the East Bay Palynostritigraphic Unit I because of the high *Pinus* and *Quercus* in the former and the high *Quercus* and thermophilous genera values in the latter.

SECOND INTERVAL — PALYNOSTRATIGRAPHIC UNIT II

The second interval, as seen in the Palynostratigraphic Unit II at East Bay site, is represented at two other sites, one of which is on Îles de la Madeleine and the other in mainland Nova Scotia. Correlations are made on the basis of palynology alone for Portage-du-Cap site, and by palynology and Th/U dating for East Milford site.

Portage-du-Cap Site

PREST *et al*. (1976) described a thin (up to 25 cm thick) sand and silt lens with abundant organic remains in a gravel pit on Île du Havre-Aubert at an elevation of 13 m. The organic unit is underlain by gravels over bedrock and overlain by diamicton.

The pollen diagram (Fig. 8) shows abundant *Picea, Pinus* and *Betula* pollen with lesser amounts of *Quercus* and *Fagus* and small percentages of *Abies* and *Tsuga*. Deposition in a marine environment and conditions warmer than the present are indicated by diatom and coleoptera analyses (PREST *et al*., 1976). The peat lies between two beach gravels, the lower much more weathered; both are assigned to the two sea-level peaks of Stage 5 (GRANT *et al*., 1985).

East Milford Site

Overburden removal during quarrying operations at East Milford gypsum quarry of the National Gypsum Company has repeatedly uncovered organic sediments over the last 30 years. One exposure (MOTT *et al*., 1982) showed grey and red clay and black organic clay overlying rubbly gravel and gypsum bedrock. A compressed peat layer over the clays was covered by thick (≈20 m) till layers which STEA (1982) refers to the three main Wisconsin glacial episodes recognized throughout Nova Scotia.

Pollen analysis of the black clay and peat revealed a pollen sequence beginning in the basal clays with spectra dominated by Polypodiaceae spores as seen in Zone 1 of the abbreviated diagram (Fig. 9). Pollen is very poorly preserved at the base of the sequence, but farther up Polypodiaceae spores are associated with abundant hardwood pollen, especially *Fagus* and some *Betula* and *Abies* (Zone 1). In Zone 2, thermophilous genera are less abundant, but *Betula* is more abundant. *Abies, Pinus* and *Picea* show slight increases. *Abies balsamea* and then *Picea* pollen increase greatly in Zone 3, and *Betula* and other hardwood genera decline. Polypodiaceae spores are much less abundant, and Cyperaceae pollen is more plentiful. Zone 4 shows high values of *Alnus* pollen, abundant *Abies balsamea* and less *Picea*. In an adjacent pit (Sect. C), the exposed organic sediment contains abundant *Picea* pollen, less *Alnus* and other coniferous genera, some Cyperaceae and abundant *Sphagnum*.

Th/U analyses of well preserved wood from the peat layer gave ages of $84\,900 \pm ^{6500}_{6100}$ (UQT-185) and $84\,200 \pm ^{11\,300}_{10\,100}$ (UQT-186) years (Table II).

THIRD INTERVAL — PALYNOSTRATIGRAPHIC UNIT III

The third interval, typified by Unit III as described from East Bay and Castle Bay sites, probably records a succession of climatic cycles, each somewhat cooler than the previous, whereas the two older intervals probably involve only single climatic cycles.

A number of sites are distinguished by palynofloras similar to those included in Palynostratigraphic Unit III. However, only Bay St. Lawrence site has a Th/U date at present, and it will be the only one described here.

Bay St. Lawrence Site

The site is located on the northern tip of Cape Breton Island (MOTT and PREST, 1967). The site was later studied

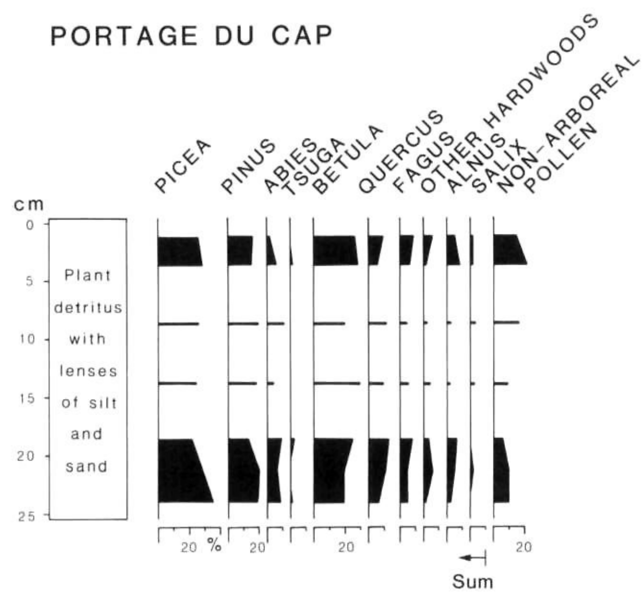

FIGURE 8. Pollen diagram for Portage-du-Cap site (after PREST *et al*., 1976). Taxa not shown individually are grouped in columns designated "Other hardwoods" and "Non-arboreal pollen".
Diagramme pollinique du Portage-du-Cap (d'après PREST et al., *1976). Les taxons non présentés individuellement ont été regroupés sous les colonnes* "Other hardwoods" et "Non-arboreal pollen".

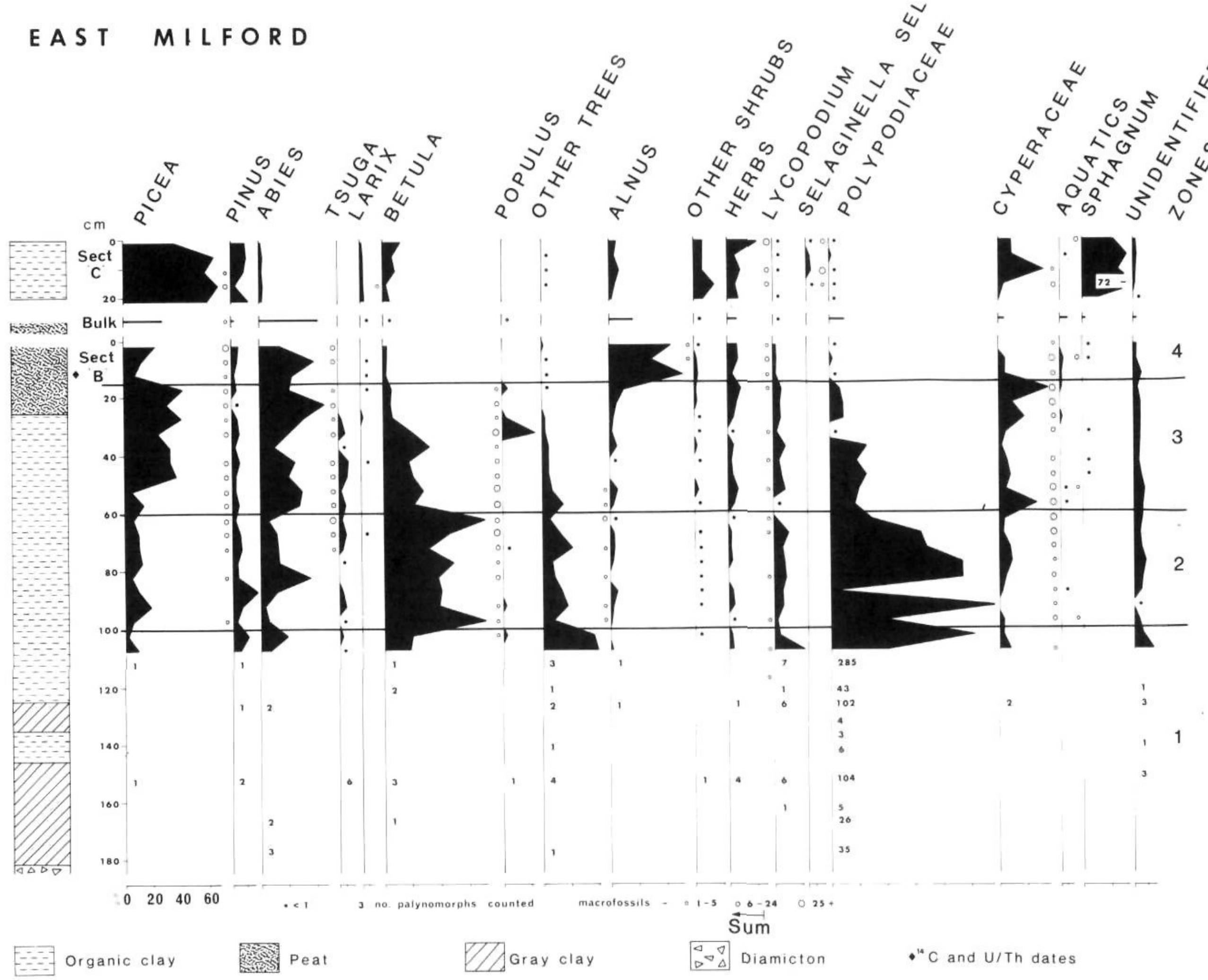

FIGURE 9. Pollen diagram for East Milford site (after MOTT *et al.*, 1982). Taxa not shown individually are grouped in columns designated "Other trees", "Other shrubs" and "Herbs".

Diagramme pollinique d'East Milford (d'après MOTT et al., *1982). Les taxons non présentés individuellement ont été regroupés sous les colonnes* "Other trees", "Other shrubs" et "Herbs".

by NEWMAN (1971) and in more detail by de VERNAL (1983) and de VERNAL *et al.* (1983). The sea cliff at the site has a thick (≈30 m) sequence of Quaternary sediments resting on an elevated wave-cut bedrock bench 4-6 m above tide level. A compact pebbly and sandy organic unit and a lenticular clay and silty clay unit separated by gravels, sands and silts, are overlain by a thick sequence of bouldery gravels and underlain by a bouldery diamicton. The overlying gravels and basal diamicton were originally interpreted as tills (MOTT and PREST, 1967; NEWMAN, 1971) and later as colluvium (de VERNAL, 1983; de VERNAL *et al.*, 1983).

A complete vegetation cycle is apparent from pollen analysis of the peat unit and adjacent sediment (de VERNAL, 1983; de VERNAL *et al.*, 1983). Three pollen zones have been outlined in Figure 10. Early herbaceous tundra spectra of Cyperaceae, Gramineae, *Sphagnum, Lycopodium*, etc., in Zone 1, are followed in Zone 2 by high *Alnus crispa* and *Betula* with small amounts of *Picea* and *Pinus* and fewer herbaceous pollen taxa. These are in turn succeeded by herbaceous spectra in Zone 3 that resemble the lower herbaceous Zone 1.

The upper silty clay unit containing marine organisms characteristic of deep water environments (GUILBAULT, 1982) showed pollen assemblages representing tundra with admixed pollen of a warmer interval (de VERNAL, 1983). The unit is interpreted as being derived from an offshore marine deposit dating from an older, warmer interval that was reworked by glaciers and redeposited in a tundra environment (de VERNAL, 1982).

One Th/U determination on wood from the peat unit gave an age of 47 000 $^{+4700}_{-4300}$ (UQT-178) years (Table II) that appears to be reliable.

PALEOENVIRONMENTAL RECONSTRUCTION

FIRST INTERVAL

If the correlations based on similar palynofloras outlined above are valid, East Bay I, Le Bassin and Addington Forks

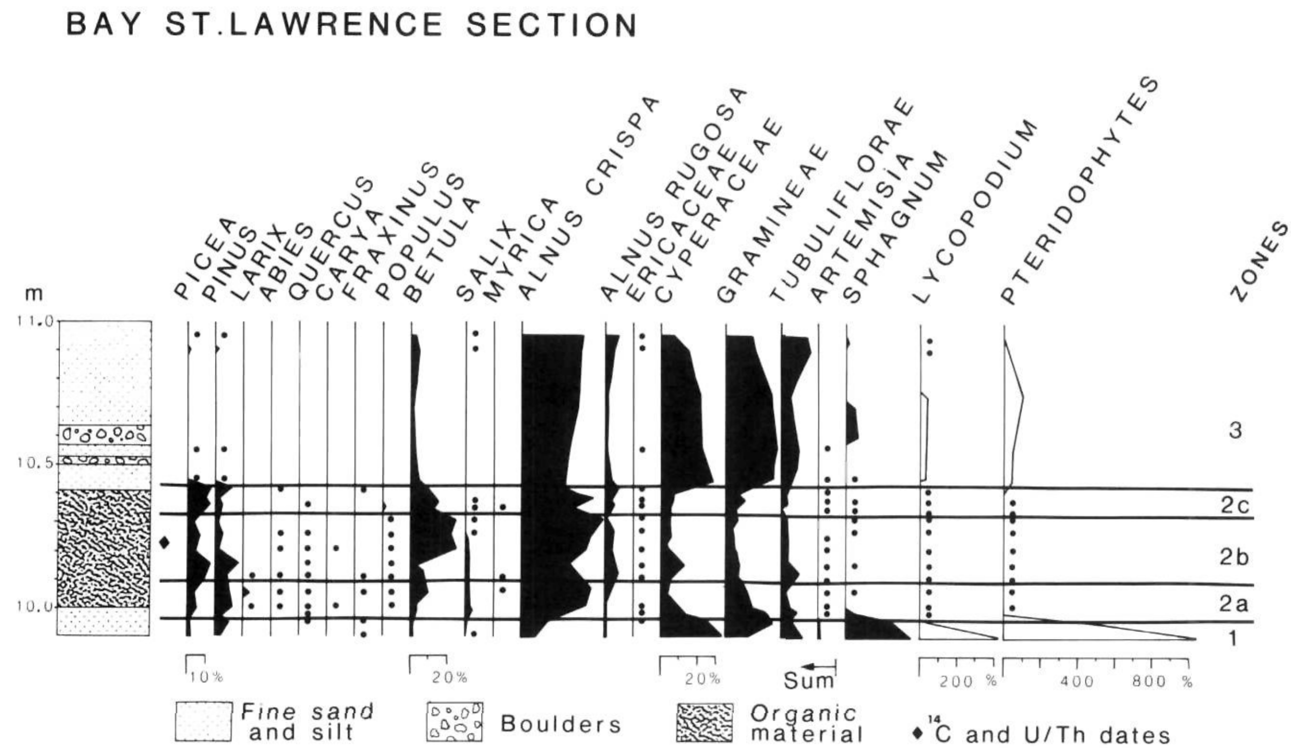

FIGURE 10. Pollen diagram for Bay St. Lawrence site (after de VERNAL, 1983). Herbaceous taxa with very low values are not included.

Diagramme pollinique de la baie Saint-Laurent (d'après de VERNAL et al., 1983). Les taxons herbacés rares ne sont pas inclus.

sites all relate to the same interval probably dating from early in the Sangamonian interglaciation. Warming following retreat of late Illinoian glaciers led to incursion of tundra plants as seen in the Le Bassin profile. Vegetation proliferated and diversified until birch and spruce trees invaded the area, and during the altithermal, white pine and probably even oak grew on Îles de la Madeleine.

In mainland Nova Scotia and Cape Breton Island, oak and white pine and thermophilous trees such as hickory and basswood, formed a mosaic of mixed hardwood and white pine associations over much of the area. The climate must have been considerably warmer and drier than the present to support these associations.

Deteriorating climate with cooler temperatures and possibly greater rainfall followed, and boreal conifers such as balsam fir and spruce displaced the hardwood taxa. Further deterioration of the climate led to proliferation of alder as seen in the Addington Forks diagram. No evidence is yet available to indicate whether the climate deteriorated further and induced return to tundra conditions, or whether climatic conditions suitable for boreal forest vegetation was the ultimate cooling experienced by the region.

SECOND INTERVAL

Correlations between East Bay palynostratigraphic Unit II and the Portage-du-Cap and East Milford sites depend partly on pollen results and partly on similar Th/U ages. Segments of pollen diagrams from all three sites have *Abies balsamea* pollen associated with some *Tsuga* and such hardwood genera as *Fagus* and *Quercus*.

The pollen stratigraphy outlined above beginning with hardwood dominated assemblages suggests deposition when the climate had already warmed considerably. The early warming phase does not appear to be represented at any other sites. During this altithermal period, hardwoods, particularly beech, were prominent along with birch, some oak and other minor thermophilous genera. Ferns were locally abundant. This association was widespread throughout the Maritimes, with pine and balsam fir more abundant in some areas of Cape Breton Island and on Îles de la Madeleine. Although not exactly analogous to the present vegetation, the genera and associations are similar and suggest climatic conditions similar to the present.

Birch and balsam fir increased, and hardwoods declined on the mainland when the climate cooled. Balsam fir and spruce, and then alder became abundant as the climate deteriorated further resembling the end of the previous warm interval. Again, evidence has not been found to indicate whether or not the region experienced further climatic cooling.

THIRD INTERVAL

All deposits at East Bay, Castle Bay and Bay St. Lawrence sites, assigned by their palynofloras to palynostratigraphic Unit III, have spectra dominated by conifer or tundra elements. Some spectra have high values of *Picea* and *Pinus* pollen with minor *Abies* pollen and indicate boreal forest; other spectra suggest tundra. However, climate during the interval never approached the warmth of the two older intervals.

Rather than showing one period of climatic amelioration, Unit III shows at least three climatic cycles, as seen at Castle Bay site, and possibly even more. The early cycle at Castle Bay was likely the warmest with forests of spruce, pine (jack pine type) and some balsam fir dominating the entire region. Climate did not become as mild as at present in the region. Later periods, including the one represented at Bay St. Lawrence site were even cooler. Spruce was dominant with only minor pine and balsam fir present. Shrubs and herbs were more abundant and widespread. Other periods were even colder and supported only tundra vegetation.

The continually cooling climate may reflect the onset of continental glaciation, which like glacial retreat was probably not a simple process, but included a series of oscillations that culminated in complete glaciation of the region.

DISCUSSION

REGIONAL SEQUENCE

Despite the accumulation of considerable data concerning the sequence of events during the last, or Sangamonian, interglaciation in Atlantic Canada, the record is far from complete. Palynological data suggest that deposits belong to three main intervals.

Deposits dating from the first interval produced pollen spectra that indicate a rapid warming of the climate that culminated in temperatures warmer than the present followed by a cooling trend. Early tundra and boreal forest vegetation was supplanted during the altithermal by mixed forests of thermophilous hardwoods and white pine throughout the region encompassing mainland Nova Scotia, Cape Breton Island and Îles de la Madeleine. These mixed hardwood forests were supplanted in turn by coniferous forests, and eventually by cold temperate vegetation dominated by spruce and alder.

During a second interval, climate apparently warmed again, but did not duplicate climatic conditions that had occurred previously, although it may have been as warm as the present for part of the interval. An early vegetation succession at the beginning of the interval is unknown. The record begins abruptly with a climate warm enough to support mixed hardwood and balsam fir, and some pine and spruce. A change to forests dominated by conifers such as balsam fir and spruce, and eventually spruce and alder reflect deteriorating climate once again.

A third interval followed when the climate warmed again to the extent that pine and spruce with minor balsam fir and birch formed climax coniferous forests. Evidently, the warming was insufficient to promote the extensive spread of hardwood forests as in earlier intervals. Evidence, particularly from sites along East Bay, indicate that this interval may have encompassed more than one climatic cycle with successive climatic maxima being cooler than the previous one. The latter cycles could support only forest tundra or tundra.

Obvious gaps occur in the record, particularly for periods between the three main intervals of organic accumulation. The pollen sequence that distinguishes the first interval ends with spectra dominated by *Alnus* and *Picea* that indicate boreal forest, at least in the Addington Forks site area. Did boreal forests persist for some time until the climate warmed once again to promote the second interval of organic accumulation? Or did even cooler, and possibly glacial, conditions evolve that are not represented at any of the sites?

Similar boreal forests mark the end of the record for the second interval of organic deposition, and similar questions can be raised as the third interval begins with a pollen record of boreal forests of spruce and pine.

The chronology provided by the Th/U age determinations on wood corroborates the pollen evidence of three distinct intervals of organic accumulation, although a wide range of values is apparent for each interval. The most reliable ages for Unit I, that is those $^{230}Th/^{232}Th$ ratios greater than 3.0, range from 126 400 to 89 400 years (Table II). Possibly, East Bay Unit I and Le Bassin represent different time intervals, one dating about 120 ka and the other about 100 ka. However, the sites are palynologically similar, and when the large statistical errors ($\pm 1\sigma$) are considered for UQT-175 and UQT-183, the age ranges overlap and indicate that the dates may belong to the same interval. The obviously anomalous 60 800 $^{+5100}_{-5000}$ years (UQT-179) for Unit I is a strong indication that a large amount of contamination may be involved.

Ages for Unit II are closely grouped between 84 200 $^{+11\,300}_{-10\,100}$ and 86 900 $^{+6000}_{-5700}$ years suggesting that the dates may be reliable. It should be remembered, however, that samples from East Milford are from the peat layer at the top of the section that records boreal forest to forest tundra conditions, whereas, East Bay wood is from the base of the section where mixed thermophilous forests are recorded. Therefore, East Milford ages should be younger, possibly several thousand years younger, than those for East Bay, but they are not. Again, discretion should be observed when using the dates.

Unit III dates are also quite variable, especially those from East Bay site. UQT-227 and -188 exhibit abundant contamination and are disparate. The more reliable date of 62 100 $^{+5000}_{-4600}$ (UQT-177) years (judging by the high $^{230}Th/^{232}Th$ values) differs considerably from the Bay St. Lawrence site age of 47 000 $^{+4700}_{-4300}$ (UQT-178) years, however, Unit III probably encompassed a considerable time interval as shown in the Castle Bay section, so the approximately 15 000 year difference is realistic. This does not negate the possibility that the dates are anomalous.

UQT-178 from Bay St. Lawrence is within the limit of radiocarbon dating, and one ^{14}C date from the site is finite (GSC-3636, 44 200 ± 820, Table I). Nevertheless, a nonfinite date of >46 000 years BP (GSC-3864) was also obtained on another piece of wood from the same unit. Credence should not be placed on the finite date of 44 200 because it is close to the >46 000 year figure. The true age of the deposit may be just slightly beyond 46 000 years, but a sample more than

100 000 years old could produce a >46 000 BP ^{14}C date (as for Le Bassin; GSC-3623; Table I).

CORRELATION WITH DEEP-SEA OXYGEN ISOTOPE RECORD

The vegetation and climatic events, deduced from the palynologic and chronostratigraphic record can be correlated, at least tentatively, with the deep-sea oxygen isotope record for the North Atlantic (RUDDIMAN and McINTYRE, 1984), as was first attempted by GRANT and KING (1984). They too correlated all organic deposits with Stage 5 of the oxygen isotope record, but suggested two intervals of organic accumulation related to Substages 5e and 5a. However, data obtained since their interpretation was made suggest that organic accumulation occurred during three main intervals, and thus the assignment of individual organic beds to specific intervals of Stage 5 by Grant and King requires revision.

The time of maximum warmth shown by the pollen profiles from East Bay I, Le Bassin and Addington Forks (assigned to the oldest interval) probably correlates with Substage 5e, the time of maximum warmth and minimal ice volume in the oxygen isotope deep-sea record. The cooling trend at the end of the interval may possibly be the record of Substage 5d. Alternatively, this interval could encompass Substages 5e-5c if the Th/U chronology is valid (de VERNAL and MOTT, 1986).

The second interval of organic accumulation seen at East Bay II, East Milford and Portage-du-Cap, may relate to the latter part of Substage 5c; the early part of the interval is not apparent from the known record. Substage 5b may be represented, at least in part, by the cooling trend evident at the end of the record for the second interval. Another possibility, based on the Th/U dates in the range of 80 000 years, is that Unit II relates to Substage 5a, which would also be a consequence of assigning Unit I to Substages 5e-5c.

Assignment of the third interval of organic accumulation to a particular substage is difficult on pollen and stratigraphic evidence alone. Some of the organic deposits at East Bay site and the basal part of Castle Bay site may correlate with Substage 5a, but the remainder of the record at Castle Bay, the Bay St. Lawrence site, and some organic beds at East Bay site may have been deposited during Stage 4, or even Stage 3. If the Th/U dates of 62 ka and 47 ka are valid, Unit III would have to be assigned to the latter part of Stage 4 and the early part of Stage 3. The problem is that the area was probably ice-covered because Stage 4 was a time of dramatic cooling and extensive ice build-up in Atlantic Provinces region according to the deep-sea record (RUDDIMAN and McINTYRE, 1979) and the Atlantic continental shelf record (GRANT and KING, 1984, Table I; KING and FADER, 1985). But, the fact remains that the inception of glaciers on land in this area has not been dated. Therefore, at least the part of the record at Castle Bay, East Bay III and Bay St. Lawrence sites, which suggests progressive cooling and advancing glaciation, probably correlates with Stage 4 and possibly Stage 3.

LONG DISTANCE CORRELATIONS

Long distance correlation with deposits in Europe may be premature, but there are many similarities with the long pollen sequences and chronologies developed in France for Grande Pile (WOILLARD, 1978; WOILLARD and MOOK, 1982) and Les Échets (BEAULIEU and REILLE, 1984). These deposits show three warm and two cool periods following the penultimate glaciation that are correlated with Substage 5e to 5a, respectively. Other climatic cycles extending into Stages 4 and 3 follow. It is also apparent in Atlantic Canada, that there were three warm periods separated by cooler times, followed by at least three other climatic cycles of lesser magnitude. While it is tempting to correlate the two sequences, this may not be warranted because the Th/U dates are grouped into only two periods during Stage 5 rather than three (de VERNAL and MOTT, 1986).

Correlation with the Canadian continental record farther west in Ontario and Québec is even more speculative. A recent summary of Quaternary stratigraphy (FULTON *et al.*, 1984) places the Don Formation in the classical "Sangamonian" or Substage 5e. The overlying Scarborough and Pottery Road Formations may relate to Substage 5a or to Substages 5a-5d combined. The Saint-Pierre Sediments possibly represent cool interglacial conditions correlated with the end of Stage 5. This arrangement conforms to the sequence of events noted above for Atlantic Canada of two warm intervals within Stage 5 followed by progressively cooler intervals in Stages 4 and/or 3. (de VERNAL and MOTT, 1986). More work will be required before such long distance correlations can be made with any certainty.

CONCLUSIONS

The evidence accumulated thus far from detailed study of sites along East Bay, enhanced by results from several other sites, leads to the following tentative conclusions:

1) A long period that postdates the penultimate glaciation and predates Wisconsinan glaciation is recorded by nonglacial deposits in Atlantic Canada.

2) During this period, organic sediments accumulated at many sites when climatic and physiographic conditions favoured vegetation growth and residue accumulation.

3) Three main intervals of organic accumulation occurred; a) an early interval when climate became warmer than the present, and thermophilous hardwood and white pine forests attained prominence throughout much of the region; b) a second interval when the climate was similar to the present, and mixed hardwood and coniferous forests prevailed; and c) a third lengthy interval when climate fluctuated in cycles at least three times but never became as warm as the present, with each cycle being cooler than its predecessor. Coniferous forests existed early in the interval and forest tundra or tundra characterized the later cycles.

4) These intervals of organic accumulation relate to deep-sea oxygen isotope Stage 5, and possibly extend into Stages 4 and 3 as well.

Two correlation schemes are possible: Units I, II and the lower part of III may relate to Substages 5e, 5c and 5a, respectively, with two cooler intervals between the three correlating with Substages 5d and 5b. The upper part of Unit III would relate to Stage 4 or possibly Stage 3. Validity of the Th/U ages would support an assignment of Unit I to Substage 5e or to 5e-5d combined, Unit II to Substage 5a, and Unit III to Stage 4 and/or Stage 3. Some similarities exist with the continuous palynostratigraphic records at Grande Pile and Les Échets in France, and to some extent with the continental record in Eastern Canada.

Continuing palynological work on numerous other sites, augmented by additional Th/U ages and macrofossil studies, will complement the tentative scenarios depicted above, and ultimately elucidate the paleoenvironmental history of the last interglacial period, the Sangamonian.

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