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Déglaciation tardive par fonte sur place du nord-est de la péninsule d’Avalon, à Terre-Neuve : étude des données polliniques du début du Postglaciaire

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Joyce Brown MacPherson

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Article abstract

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DELAYED DEGLACIATION BY DOWNWASTING OF THE NORTHEAST AVALON PENINSULA, NEWFOUNDLAND: AN APPLICATION OF THE EARLY POSTGLACIAL POLLEN RECORD

Joyce Brown MACPHERSON*, Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3Z6.

ABSTRACT Basal radiocarbon dates from lake sites indicate that final deglaciation began at most a few centuries before 10 ka BP on the interior plateau and proceeded by down-wasting. Comparison of the pollen record with the sequence of vegetation from the Storbreen glacier foreland, Norway, studied by the Jotunheimen Research Expeditions, indicates that pioneer herb and dwarf shrub stages gave way within 200 years to shrub-birch heath into which spruce migrated at about 8.5 ka BP. It is shown that double maxima of dwarf shrubs result from the existence of terrains of different ages within each catchment at the time when lake sediment accumulation began. An independently dated pollen record from St. John's Harbour confirms the timing and mode of deglaciation and demonstrates that the Avalon Peninsula ice cap did not extend beyond the present coast at the beginning of the Holocene. The delays in both deglaciation and the immigration of spruce are attributed to cold ocean temperatures associated with eastward discharge of meltwater from the Laurentide Ice Sheet.

RÉSUMÉ *Déglaciation tardive par fonte sur place du nord-est de la péninsule d'Avalon, à Terre-Neuve : étude des données polliniques du début du Postglaciaire.* Les datations au radiocarbone à la base des sites lacustres laissent supposer que la déglaciation finale a commencé à peine quelques siècles avant 10 ka BP sur le plateau intérieur et s'est effectuée par fonte sur place. La comparaison entre le relevé pollinique et la séquence de la végétation enregistrée dans l'avant-pays du glacier Storbreen, en Norvège, indiquent que les premiers stades de végétation herbacée et de buissons nains ont laissé place en 200 ans à une lande de bouleaux nains où l'épinette blanche a migré vers 8,5 ka BP. Il est démontré que les deux pics de bouleaux nains enregistrés résultent de l'existence de terrains d'âges différents à l'intérieur d'un même bassin, au début de la sédimentation lacustre. Un relevé pollinique du St. John's Harbour daté de façon indépendante confirme la chronologie et le mode de déglaciation et démontre que la calotte glaciaire de la péninsule d'Avalon ne s'étendait pas au-delà de la côte actuelle, au début de l'Holocène. Les retards et de la déglaciation et de la migration de l'épinette sont attribués aux températures océaniques froides associées à l'écoulement vers l'est de l'eau de fonte de l'Inlandsis laurentidien.

ZUSAMMENFASSUNG *Verzögerte Enteisung durch Abzehrung des Nordostens der Avalon-Halbinsel, Neufundland: Auswertung der frühen postglazialen Pollen-Belege.* Radiokarbondaten an der Basis der untersuchten Seen zeigen, dass die endgültige Enteisung höchstens wenige Jahrhunderte vor 10 ka v.u.Z. auf dem inneren Plateau begann und sich durch Abzehrung vollzog. Der Vergleich des Pollen-Belegs mit der Vegetations Sequenz vom Vorland des Storbreen-Gletschers, Norwegen, welche von den Jotunheimen-Forschungsexpeditionen studiert wurde, zeigen, dass die ersten Kräuter- und Zwergsträucher-Stadien innerhalb von 200 Jahren einer Zwergbirken-Heide gewichen sind, in der sich um etwa 8.5 ka v.u.Z. Fichten ansiedelten. Es wird nachgewiesen, dass die zwei Höchstwerte von Zwergsträuchern auf Gelände verschiedenen Alters innerhalb desselben Einzuggebietes zurückgehen, zu der Zeit, als die Seesedimentakkumulation begann. Ein unabhängig davon datierter Pollen-Beleg vom St. John's Harbour bestätigt die Chronologie und die Art der Enteisung und zeigt, dass die Eiskappe der Avalon-Halbinsel sich zu Beginn des Holozäns nicht über die gegenwärtige Küste hinaus erstreckte. Die Verzögerungen sowohl bei der Enteisung wie bei der Ansiedlung von Fichten werden auf kalte Ozeantemperaturen in Verbindung mit dem ostwärts gerichteten Abfluss von Schmelzwasser von der laurentidischen Eisdecke zurückgeführt.

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* Adresse électronique / e-mail address : jmacpher@morgan.ucs.mun.ca

INTRODUCTION

Deglaciation on the island of Newfoundland has been dated principally by extrapolation from radiocarbon dates on shells from raised marine deposits; Grant (1989) provides a summary. By contrast, basal radiocarbon dates from lake and bog sediments have long been used to reconstruct the pattern and chronology of deglaciation in Labrador-Ungava, beginning with the pioneer work of Grayson (1956) and summarised by King (1985). As in Labrador-Ungava the present work applies evidence from lake sediment cores to the chronology of deglaciation of the northeast Avalon Peninsula of southeastern Newfoundland. The peninsula is the most easterly area of Canada (St. John's is more than 500 km distant from the nearest point on the mainland), and is in a critical position to monitor past oceanic influences upon climate.

Basal radiocarbon dates from eight small headwater ponds are evaluated according to criteria developed from Sutherland (1980) that do not depend exclusively on the basal pollen record. Sites meeting these criteria are further evaluated in terms of their basal pollen stratigraphies, by comparison with other early postglacial records and with the vegetation and pollen records from the recently-deglaciated Storbreen glacier foreland, Norway (Matthews, 1978a, 1978b; Caseldine, 1989). The pollen record from an independently-dated core segment from St. John's Harbour is compared with the lacustrine record to better resolve the regional sequence and timing of deglaciation.

REGIONAL SETTING

The northeast Avalon Peninsula (St. John's Peninsula; Henderson, 1972) is a roughly triangular area between Conception Bay and the Atlantic Ocean, measuring about 30 km from east to west and 50 km from south to north (Fig. 1). The St. John's Peninsula is underlain by Precambrian volcanics and derived metasediments (Harbour Main, Conception, St. John's and Signal Hill groups) forming an irregular plateau at 150-200 m asl; elevations above 300 m occur on the granite of the Holyrood Intrusive Suite in the extreme southwest. Bell Island, Conception Bay, is formed of upper units of a Cambrian-Ordovician clastic sequence which floors the bay and underlies a narrow coastal plain; elsewhere the plateau descends steeply to the coast (King, 1988).

Bedrock is overlain with thin (0-6 m) till of local derivation. During the Late Wisconsinan the Avalon Peninsula supported an independent ice cap, and the final ice movement on the St. John's Peninsula was from its spine toward the adjacent coastline (Henderson, 1972; N.R. Catto, Memorial University of Newfoundland, personal communication, 1995). Relative sea level has risen since deglaciation, submerging coastal basins such as St. John's Harbour (Lewis *et al.*, 1987).

The climate is oceanic, and the St. John's Peninsula forms part of the Northeastern Barrens subregion of Damman's (1983) Maritime Barrens ecoregion. At St. John's Airport (134 m) mean annual precipitation is 1481 mm, the mean growing season temperature (late May to late October) is 12°C and the mean July temperature is 15.4°C (Environment Canada, 1993). The interior upland is wetter, cloudier and more exposed to wind. Snow cover is varied, both temporally and spatially (Banfield, 1983). The thin soils, orthic and gleyed podzols and orthic gleysols (Heringa, 1981), support low-quality boreal forest at best. Less than 25% of the total area of the Avalon Peninsula is classified as productive forest; the dominant trees are *Abies balsamea* (77%), *Picea mariana* (13%) and *Betula*, mainly *B. cordifolia* (5%), with minor *Picea glauca* and *Larix laricina* (Newfoundland, Department of Forestry and Agriculture, 1990). On lower summits and headlands forest gives way to intermediate heath, with *Cladonia*, various Ericales, *Juniperus*, *Myrica gale* and dwarfed (krummholz) conifers. The present extent of these intermediate heaths may have been influenced by fire and other anthropogenic disturbance, but the alpine heath of exposed summits, where soils are subject to frost disturbance and support arctic species such as *Diapensia lapponica*, has persisted throughout the postglacial (Meades, 1983).

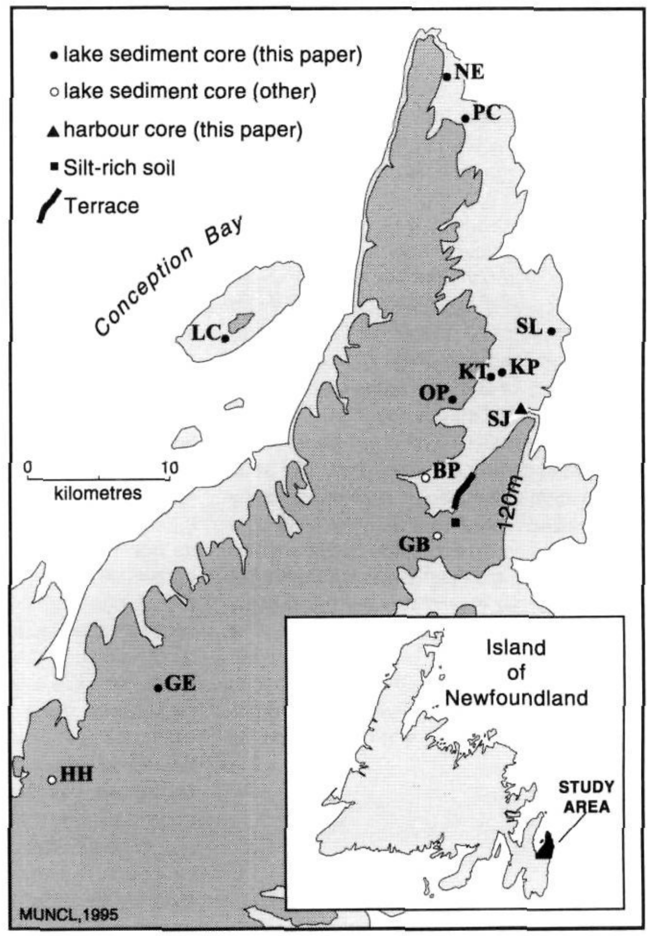


FIGURE 1. Northeast Avalon Peninsula, Newfoundland: locations of sites. BP: Branscombes P.; GB: Goulds Bog; GE: Golden Eye P.; HH: Hawke Hills; KP: Kennys P.; KT: Kents P.; LC: Lance Cove P.; NE: Pouch Cove Northeast P.; OP: Oxen P.; PC: Pouch Cove; SL: Sugarloaf P.; SJ: St John's Harbour.

Localisation des sites dans le nord-est de la péninsule d'Avalon, à Terre-Neuve : BP : Branscombes P. ; GB : Goulds Bog ; GE : Golden Eye P. ; HH : Hawke Hills ; KP : Kennys P. ; KT : Kents P. ; LC : Lance Cove P. ; NE : Pouch Cove Northeast P. ; OP : Oxen P. ; PC : Pouch Cove ; SL : Sugarloaf P. ; SJ : St John's Harbour.

THE SITES

The eight lake sites discussed here include all those with dated basal pollen assemblages indicating an early stage of vegetation development (Fig. 1; Table I). Sites from the St. John's Peninsula which fail to meet these criteria are listed but not discussed. Two of the eight sites to be discussed [Pouch Cove Northeast Pond (NE) and Pouch Cove (PC)] were examined by Mellars (1980) and one [Kents Pond (KP)] by Vardy (1988). Laboratory protocols have evolved over time and not all analyses were performed on every core.

The areas of the eight ponds range from 0.6 to 5.8 ha, and of the catchments from 5 to 44 ha. Most occupy rock basins; most of the major geological units of the region are represented. Where till occurs its composition reflects the local bedrock (King, 1990). The ponds lie at elevations between 208 m and 70 m, and are surrounded by vegetation ranging from sub-alpine and coastal heath to forest, some of which has been cleared.

Cores were normally obtained from the central or deepest parts of the basins. Bathymetric data for Oxen Pond (OP) and Sugarloaf Pond (SL) were made available by Dr. J. Evans, Department of Biology, Memorial University of Newfoundland, allowing the locations of springs in Oxen Pond to be avoided. Cores were obtained with a modified Livingstone corer of diameter 5 cm and barrel length 1 m from a raft or from ice depending on the season, to the limit of penetrability.

CHRONOLOGY

Most of the radiocarbon dates were provided by the Geological Survey of Canada (Table II). All are standard (decay) dates on bulk sediment, normally of a 5–cm core increment. No datable macrofossils were encountered. Basal dates range from 10 350 BP (10 100 ± 250) at Golden Eye Pond (GE) to 7220 BP (7350 ± 130) at Kents Pond (KT). Three of the oldest basal dates: 9440 ± 360 (OP); 9270 ± 150 (SL); and 9240 ± 190 (Lance Cove Pond, Bell Island, LC) are statistically indistinguishable. The basal date from GE may be indistinguishable from these with the increase in uncertainty resulting from the recognition of radiocarbon plateaux at 9.5 ka and 10.5 ka (Becker *et al.*, 1991; Lotter, 1991) (Fig. 2).

Even the oldest dates are younger than deglacial dates from coastal sites on the main part of the island, where shells in raised marine deposits have yielded dates as early as 14.1 ka BP on the southwest coast (Blake, 1988), 12.6 ka BP on the Northern Peninsula (Grant, 1986) and 12.5 ka BP on the northeast coast (Scott *et al.*, 1991). Since the northeastern Avalon Peninsula sites appear to contain no record of the 11-10 ka BP Younger Dryas oscillation, identified elsewhere

TABLE I

Site locations and characteristics: northeast Avalon Peninsula

Site and map reference	Location	Date cored	Elev. (m)	Water depth / Core length (cm)	Lake area / Catchment area (ha)	Catchment relief(m)	Basin type	Topography	Bedrock	Vegetation	References
Lake sites (this paper)											
Golden Eye P. GE	47°23.17' N 53°03.25' W	03.80	208	195 431	2.3 19	25	rock	plateau, rock knobs, till	Harbour Main Gp. basalt, siltst.	heath, woodland	
Kennys P. KP	47°35.42' N 52°40.50' W	07.82	70	223 308	3.0 13	10	kettle	kettled till	Conception Gp. siltst., sandst.	former forest	
Kents P. KT	47°35.27' N 52°43.10' W	10.87	71	164 541	7.5 50	30	rock	till–mantled lowland	Conception Gp. siltst., sandst.	former forest	Vardy, 1988
Lance Cove P. LC	47°36.67' N 52°58.75' W	10.78	116	150 477	3.3 17	20	rock	till–veneered plateau	Bell Island Gp. sandst., shale	poor forest, wetland	
Pouch Cove NE P. NE	47°47.00' N 52°46.75' W	07.79	105	335 530	5.8 44	123	rock	rock slopes, till veneer	Harbour Main Gp. basalt, sandst.	heath, woodland	Mellars, 1980
Oxen P. OP	47°34.43' N 52°45.83' W	11.78	136	170 410	3.6 36	50	rock	bedrock valley, till floor	Conception Gp. siltst., sandst.	forest	
Pouch Cove PC	47°44.82' N 52°45.52' W	03.79	115	173 438	0.6 5	10	rock	till veneer, bog	Conception Gp. siltst., sandst.	wetland, forest	Mellars, 1980
Sugarloaf P. SL	47°37.00' N 52°40.50' W	03.77	100	300 620	5.5 38	60	rock	bedrock valley	Signal Hill Gp. sandst., conglom.	forest	Macpherson, 1982
St. John's Harbour: core HU 81–045–75											
SJ	47°34.11' N 52°41.79' W	1981	0	2900 438							Lewis *et al.*, 1987
Other sites											
Branscombes P. BP	47°31.63' N 52°47.00' W	10.89	109	107 300	2.25 19	153	till depression	rock slope, till veneered terrace	Conception and St. John's Gps. shale, sandst.	former forest, wetland	Butler, 1990
Goulds Bog GB	47°29.00' N 52°46.00' W	1956	129	0 >518		<5	till depression	infilled lake	St. John's Gp. shale	wetland, former forest	Terasmae, 1963
Hawke Hills HH	47°19.33' N 53°08.00' W	11.77	220	0 250	0.05 2.5	20	kettle	hummocky till	Holyrood Suite granite	heath, wetland	Macpherson, 1982

TABLE II

Radiocarbon dates: northeast Avalon Peninsula

Site and map reference	Date (corrected)	Lab. no.	Sediment depth (cm)	$\delta^{13}C$ ‰	L-O-I %†	References
Lake sites (this paper)						
Golden Eye P.	8370±130	GSC-4015	310-315	−18.2	23	Blake, 1987
GE	10100±250	GSC-3136	419-424	−18.9	10	Lowdon and Blake, 1981; Macpherson, 1982
Kennys P.	3760±80	GSC-4016	192-197	−28.6	36	Blake, 1987
KP	•5830±100	Beta-32594	225-232	–	36	
	8570±90	GSC-3618	293-298	−23.5	25	Blake, 1983
Kents P.	7350±130	GSC-4605	500-505	−21.4	9	Vardy, 1988
KT						
Lance Cove P.	4900±110	GSC-4039	295-300	−30.7	–	Blake, 1987
LC	7680±100	GSC-4057	445-451	−23.9	44	Blake, 1987
	9240±190	GSC-3166	457-462	−20.9	5	Lowdon and Blake, 1981
Pouch Cove NE P.	8370±110	GSC-2961	521-526	−21.7	24‡	Mellars, 1980
NE						
Oxen P.	7650±200	GSC-4066	295-300	−26.2	24	Blake,
OP	9440±360	GSC-3182	385-390	−17.3	8	Lowdon and Blake, 1981
Pouch Cove	8480±90	GSC-2985	433-438	−28.8	38‡	Mellars, 1980
PC						
Sugarloaf P.	•7270±200	Dal-295	450-460	–	–	Macpherson, 1982
SL	*9270±150	GSC-2601	571-571	−25.3	9‡	Macpherson, 1982
St. John's Harbour: core HU 81-045-75						
SJ	♦8800±220	Beta-10156	369	–	–	Lewis *et al.*, 1987
	♦9900±250	Beta-10157	395	–	–	Lewis *et al.*, 1987
Other sites						
Branscombes P.	8010±90	GSC-5126	274-279	−24.9	–	
BP						
Goulds Bog	•7400±150	L-391 I	503-518	–	–	Terasmae, 1963;
GB						
Hawke Hills	•3160±85	Dal-289	118-128	–	–	Macpherson, 1982
HH	•4660±85	Dal-290	218-228	–	–	Macpherson, 1982
	•7290±150	Dal-323	235-245	–	–	Macpherson, 1982

Notes:† Loss-on-ignition at 550°C; ‡ estimated: – information unavailable; •uncorrected bulk sediment date; ♦AMS date on single marine mollusc shell; * correlates palynostratigraphically with 561-566 increment in core used for pollen analysis.

on the island in more than ten near-coastal sites (Anderson, 1983; Anderson and Macpherson, 1994; Macpherson and Anderson, 1985; Wolfe and Butler, 1994) it is probable that the Avalon lake basins were not open to receive sediment until after the Younger Dryas. Whether this was the result of regional cover by residual glacial ice, or was the result of persistent lake ice will be discussed below.

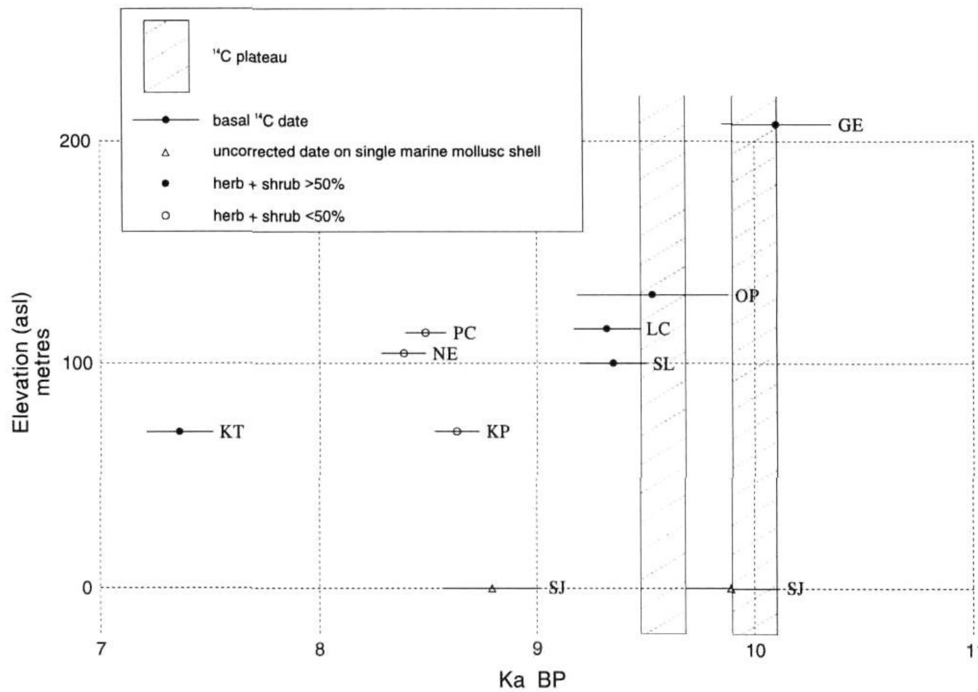
Internal consistency of the radiocarbon chronology is indicated by direct (GE, KP) or interpolated (LC, OP, SL) dates on the rise in *Picea* percentages (at LC, in *Picea* concentrations), most probably a regional event, at between 8.5 and 8.3 ka BP (Figs. 3A, 3B). At NE and PC the spruce rise is dated by interpolation at 8.2 (or 8.0) ka BP, but at these sites only the basal sediment was dated and interpolated dates are poorly constrained.

POTENTIAL ERRORS

The validity of the basal radiocarbon dates is crucial to the argument of this paper. Can there have been sampling or other errors leading to dates which are too young? In most cases coring was terminated in cohesive silty clay; experience indicated that deeper penetration could lead to difficulties of retrieval. Thus, except where a hard base was encountered (OP, PC) it is not known whether older organic sediments underlie the sampled material. However, the basal silty clay in the Avalon sites is sufficiently different from sediment attributed to the Younger Dryas in northeastern Newfoundland in its greater thickness and cohesiveness, in the occasional presence of clasts and in its paucity of pollen that it can be reasonably attributed to the initial phase of postglacial sedimentation.

FIGURE 2. Basal radiocarbon dates plotted against elevation (^{14}C plateaux after Becker *et al.*, 1991; Lotter, 1991).

Datations au radiocarbone basales par rapport à l'altitude (paliers de ^{14}C selon Becker et al., *1991 ; Lotter, 1991).*



Core segments for basal dating were selected from the greatest depths which would yield sufficient carbon in a five-cm increment. Unless sediment accumulation rates are very low, 5-cm increments are unlikely to lead to younging errors as described by Sutherland (1980); only at LC, where the rate of sediment accumulation is as low as 0.0074 cm/year between the dated levels of 445-451 cm and 457-462 cm, is this likely to be a problem.

The basal dated sediment contains pollen assemblages indicating early stages of vegetation development (Fig. 3). At four sites (GE, LC, OP and SL) the sum of herb and shrub (excluding shrub birch) exceeds 50%; the same is true for PC but here high proportions of Cyperaceae and *Myrica* reflect local fen vegetation. At the remaining sites the proportion of herb plus shrub pollen in the basal dated sediment exceeds 40%. In most cases it was possible to extend the pollen sequence to a greater depth than the dated increment, normally until the pollen concentration fell to less than 5000 grains per ml, but neither linear extrapolation of dates nor detailed consideration of pollen sequences, to be discussed below, suggests an interval of more than a few hundred years between the establishment of pioneer vegetation and the accumulation of the dated sediment.

Four of the basal dates, Kennys Pond (KP) (8570 ± 90), Pouch Cove (PC) (8480 ± 90); Pouch Cove Northeast Pond (NE) (8370 ± 110) and Kents Pond (KT) (7350 ± 130) are younger than 9.0 ka BP. The pollen sequences from KP, PC and NE are conformable with those from the sites with older basal dates. At KT the basal date of 7.4 ka BP is associated with shrub tundra pollen assemblages and the rise of *Picea* is dated 6.7 ka BP by interpolation (Fig. 3B) (*cf.* 8.5 - 8.0 ka BP at all other sites). There is no evidence of bioturbation, but the basal date from KT must be rejected as being too young, possibly as the result of percolation of younger humic material (Walker and Harkness, 1990); the site is not discussed further.

Kennys Pond (KP) is adjacent to KT. This site occupies a kettle and its young basal date is not unexpected. At PC the dated basal organic material rests on a hard base, and at the nearby NE site there is evidence of disturbance with the possibility of an incomplete record (Mellars, 1980); the diagram for NE (Fig. 3B) is a composite from two adjacent core segments. As the pollen assemblages in the dated material from these sites (Fig. 3B) do not indicate as early a stage of vegetation development as at the other sites, the basal dates must be regarded as being minimal for deglaciation, and NE and PC will not be discussed further.

A more common concern with basal dates on bulk sediment is aging. Old (inert) carbon released from bedrock by glacial erosion or from recycled organic matter can be incorporated in lake sediment. Further, if such old carbon is dissolved in lake water it can be incorporated in autochthonous organic material by aquatic photosynthesis, as may old CO_2 from glacial meltwater (reservoir effect). Such errors are particularly significant when the organic content of the dated material is low (Sutherland, 1980; MacDonald *et al.*, 1991).

However, the regional bedrock is poor in carbon and at most of the sites potential contamination of the organic carbon in the basal dated sediment by old mineral carbon is less than 2% and the potential aging error no more than 100 years (Olsson, 1986) (organic content of the dated sediment ≥8% and carbon content of the local and immediately up-ice bedrock ≤0.16%; P. Davenport, Newfoundland Geological Survey, personal communication, 1992; King, 1990; Papezik, 1970). At only one of the sites, Lance Cove Pond (LC), is there the potential for a significant aging error resulting from

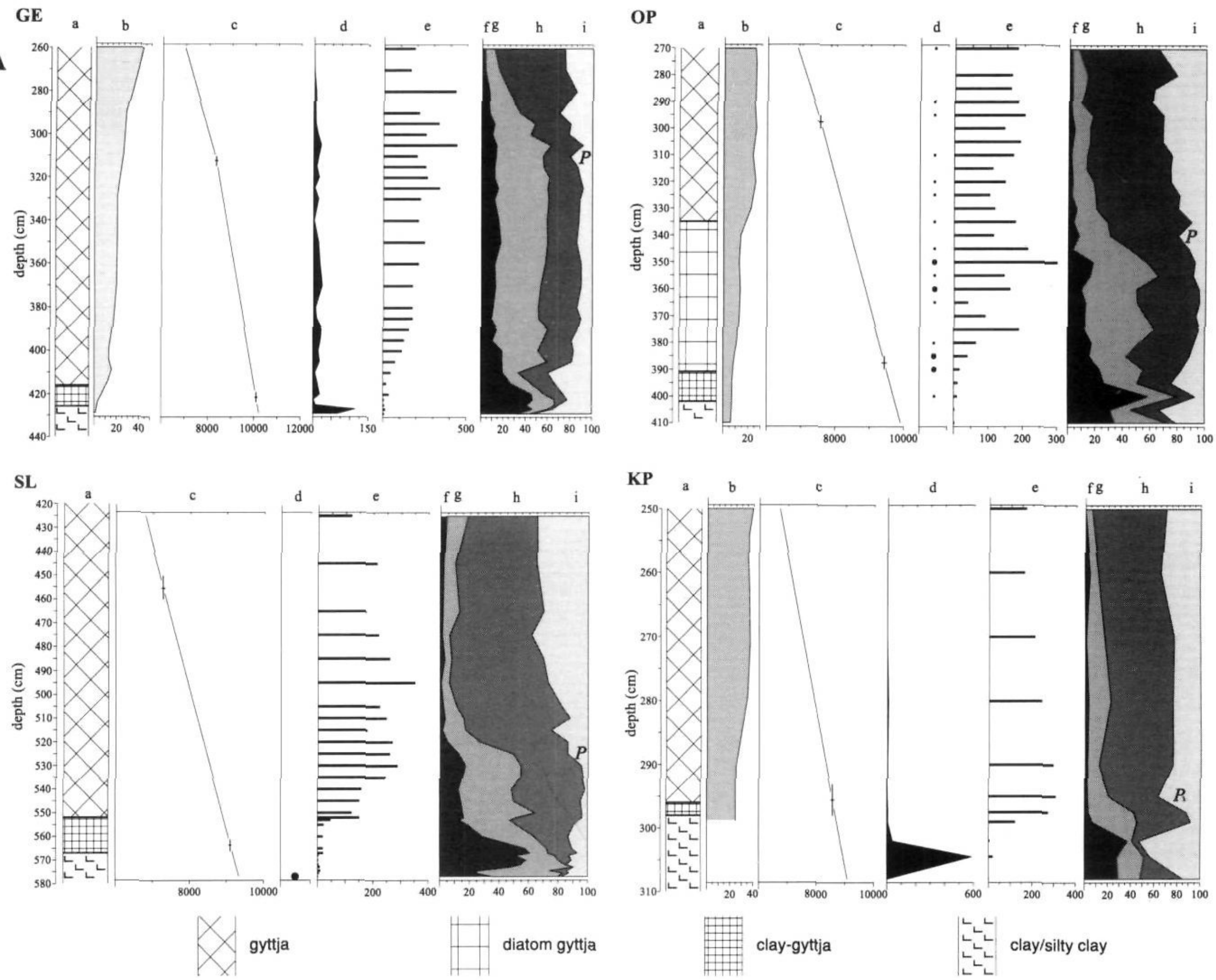


FIGURE 3. Summary diagrams: basal lithology, loss-on-ignition, age, *Pediastrum* concentrations, pollen concentrations and summary pollen percentages. A) Sites with a double basal peak of shrubs; B) Sites with a single basal peak of shrubs. Legend: a) lithology; b) loss-on-ignition at 550°C; c) age (radiocarbon years); d) *Pediastrum* concentrations (colonies.10^3/ml), or presence/abundance (symbol size); e) pollen concentrations (grains.10^3/ml; pollen percentages); f) herbs; g) shrubs; h) *Betula*; i) trees. P) *Picea* rise.

the presence of carbon derived from bedrock. Here the organic carbon content of the basal dated sediment is low (2.5%; loss-on-ignition 5%), and the mean carbon content of shale of the local Bell Island Group is 0.1%, suggesting potential contamination by old carbon of <4% and an aging error of <300 years (Olsson, 1986).

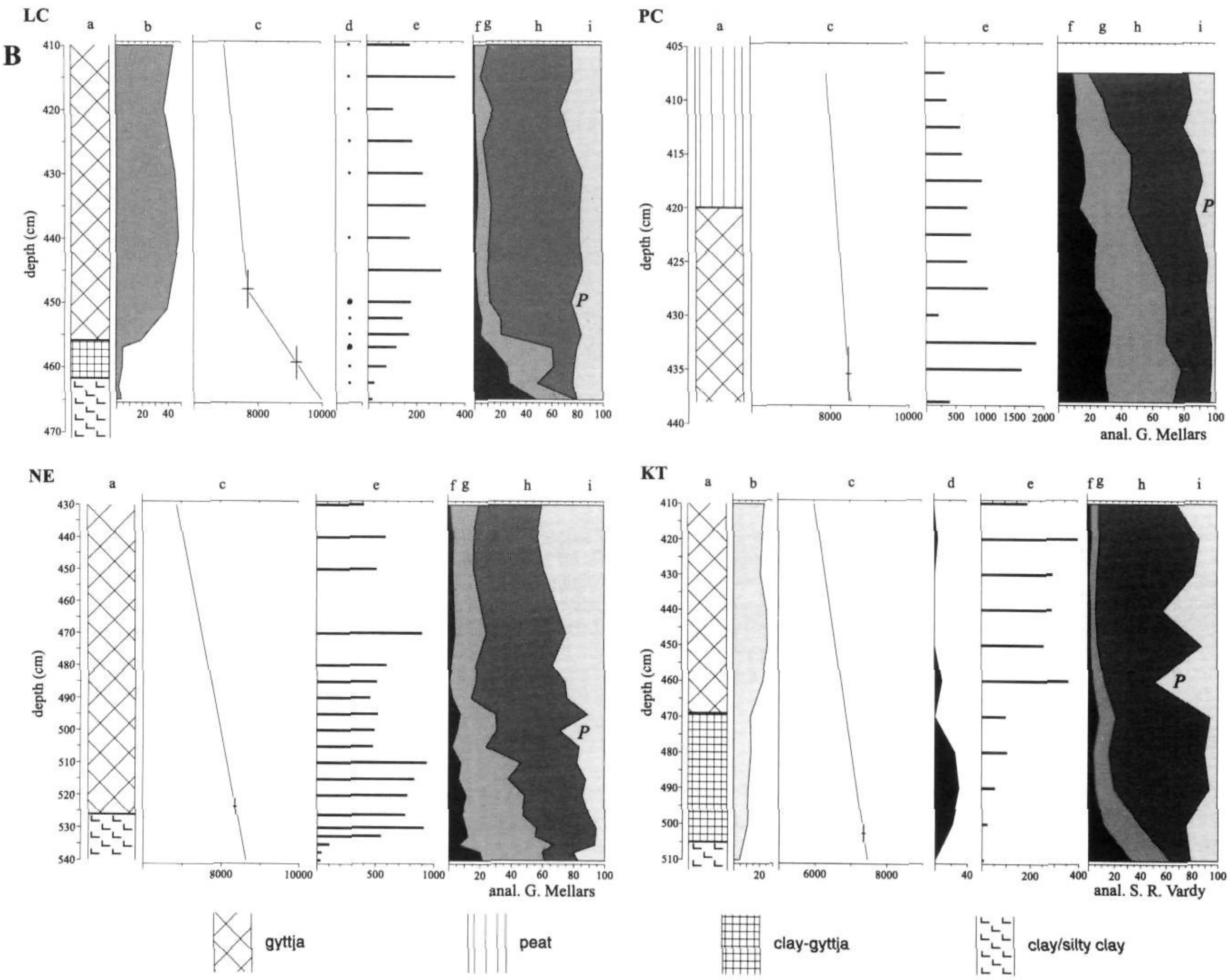
Contamination by older organic carbon can be ruled out in the absence of evidence of buried organic material of Late Pleistocene age, or of Lateglacial ice margin retreat and readvance such as occurred in Nova Scotia (Stea and Mott, 1989).

Where aquatic microfossils are abundant in the basal sediment an aging error due to the reservoir effect is possible (photosynthesis of ^{14}C-deficient carbon from glacial meltwater). Diatoms were not counted, but where evidence is available *Pediastrum* concentrations or presence/abundance are indicated in the summary diagrams (Fig. 3). Further evidence of an aquatic source for the organics in the dated sediment is provided by $\delta^{13}C$ enrichment (values less negative than −25‰). Thus the potential for aging errors from the reservoir effect is greatest at GE, LC and OP but is also present at KP and NE (Table II).

Sutherland (1980) proposed a method for testing for the combined effects of the presence of old carbon and the reservoir effect: if an age-depth curve indicates an apparently slower rate of sediment accumulation at the base, it may indicate that the basal date is too old. Applying this test to sites with more than one dated level supports a potential aging error for the basal date only at LC (Fig. 3B).

REGIONAL EVALUATION OF BASAL RADIOCARBON DATES

With the exclusion of KT, NE and PC basal dates from the remaining five sites fall into two groups: GE, OP, SL and LC, with early dates, wide statistical uncertainties, and the possibility that the dates are indistinguishable (range 9050-10 350 BP), and KP, a kettle site (8570 ± 90) (Fig. 2). The basal date at LC is almost certainly too old and limited aging



Diagrammes abrégés de la lithologie à la base, de la perte au feu, de l'âge, des concentrations de Pediastrum, *des concentrations polliniques et des pourcentages sommaires de pollen. A) Sites ayant un double pic d'arbrisseaux à la base ; B) Sites ayant un seul pic d'arbrisseaux. Légende : a) lithologie ; b) perte au feu à 550°C ; c) âge (années au radiocarbone) ; d) concentrations de* Pediastrum *(colonies.10^3/ml), ou présence et abondance (selon la dimension du symbole) ; e) concentrations polliniques (grains.10^3/ml) ; pourcentages polliniques f) des herbes ; g) des arbustes ; h) de* Betula *; i) des arbres ; P) augmentation de* Picea.

is also possible at GE and OP. Only at the two highest sites, GE (208 m) and OP (136 m), is it at all likely that the dated sediment was deposited before 10 ka BP. The basal date from the kettle site, KP, at the lowest elevation (70 m) lags by 700 years that from SL (100 m), the nearest rock-basin lake, 4 km distant.

Of the group of sites with early dates, LC stands out with its problematic basal date, its apparently very slow rate of basal sediment accumulation and the associated difficulty of discriminating early pollen sequences. Webb and Webb (1988) warn against the use of chronologies derived from sites with extremely slow sediment accumulation rates (<0.01 cm/year) and although evidence from the site is not in conflict with the regional reconstruction the pollen record will not be discussed further.

The early records at GE, OP and SL suggest that the basal dates from these sites may be, if not absolutely correct, at least in the correct order and therefore not identical. Certain measures for each site are plotted in Figure 4: (a) the site elevation, (b) the basal date, (c) the apparent duration of the period of organic sedimentation before the spruce rise (already shown to be an almost simultaneous event), and (d) the length of the organic core segment beneath the spruce rise as a fraction of the total organic core length. For these three sites the time span before the arrival of spruce, as well as the proportion of the total organic core length accumulating in this period, increases with elevation and with the radiocarbon age of the basal sediment. The most telling of these relationships is that of measure (d), which is independent of dating, with the basal dates; it supports the successively earlier deglaciation of higher ground suggested in Figure 2.

Two further measures are plotted in Figure 4, in order to assess the potential influence of sediment focusing on measure (d): (e) the mean rate of sediment accumulation between the basal date and the next date in the core and (f) a crude measure of lake basin slope ($2 \cdot depth \cdot \sqrt{area}^{-1} \cdot 100\%$, where

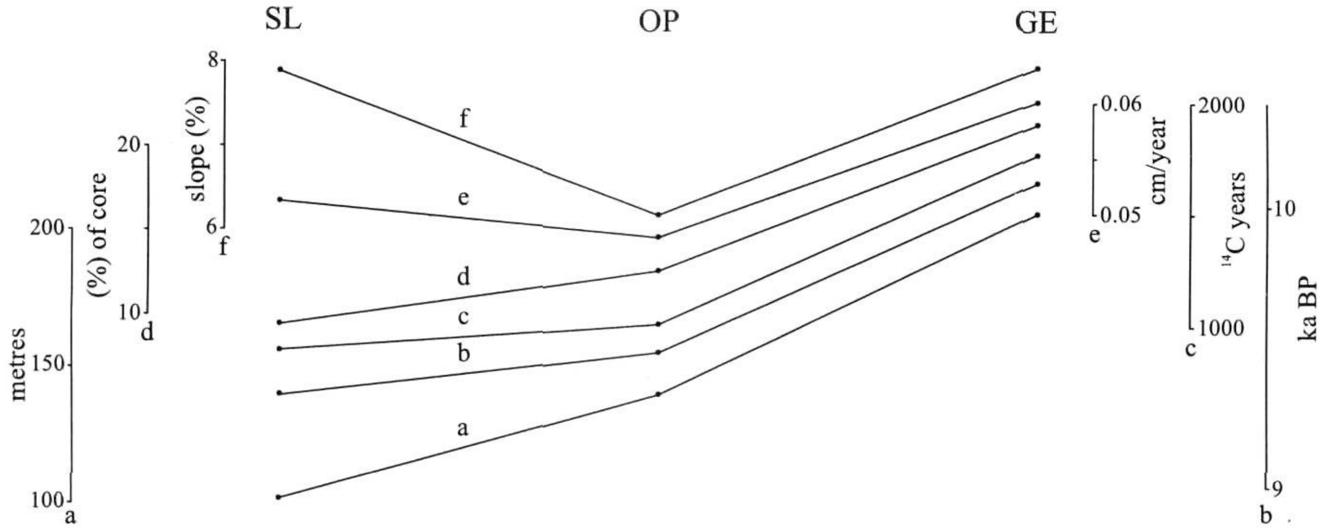


FIGURE 4. Evaluation of basal radiocarbon dates at Golden Eye (GE), Oxen (OP) and Sugarloaf (SL) Ponds.a) site elevation; b) basal date; c) duration in radiocarbon years of the period of organic sedimentation before the spruce rise; d) length of the organic core segment beneath the spruce rise as a fraction of the total organic core length; e) rate of sediment accumulation (cm/yr) between the basal date and the next date in the core; f) lake basin slope (2·depth·$\sqrt{\text{area}}^{-1}$·100%)

Évaluation des dates minimales aux Golden Eye Pond (GE), Oxen Pond (OP) et au Sugarloaf Pond (SL). a) Altitude du site ; b) date minimale ; c) durée (en années au radiocarbone) de la période de sédimentation organique avant l'accroissement de l'épinette ; d) longueur du segment de carotte avant l'acroissement de l'épinette en pourcentage de la longueur totale de la carotte ; e) taux d'accumulation sédimentaire (cm/année) pour une carotte, entre la date minimale et la date qui suit ; f) pente du bassin lacustre (2·profondeur·$\sqrt{\text{superficie}}^{-1}$·100%).

depth = water depth + core length at the coring site, taken to be the deepest point in the basin). Measures (e) and (f) appear to be related, but there is no clear relationship between these and measures (a)-(d), the inter-relationships of which thus are largely independent of lake morphology. Consequently, in the remainder of the paper the basal dates from GE, OP and SL will be treated as if correct.

Because of rapidly changing pollen assemblages and concentrations in the basal core segments, King's (1985) pollen influx correction was not applied. The age-depth curves in Figure 3 are simply extrapolated below the basal date to the depth of the lowest sample with a pollen count. The extrapolated dates give some indication of the time of development of vegetation, provided the intrinsic uncertainty of the dates as well as errors related to changing sediment accumulation rates are borne in mind. Based on these extrapolated dates postglacial revegetation of the St. John's Peninsula began at most a few centuries before 10 ka BP and was complete before 8.5 ka BP. In the following section the pollen record of the four lake sites (SL, OP, GE, KP) with the most reliable basal dates and the clearest basal pollen records will be examined to determine whether a significant delay could have occurred between deglaciation and the accumulation of datable sediment.

THE POLLEN RECORD

METHODS

Samples for pollen analysis were extracted at intervals of 5 cm or less where there was rapid change in the pollen profile, and at intervals of 10 or (rarely) 20 cm where the profiles were complacent. Samples were processed as follows: KOH, HF digestion, sodium pyrophosphate disaggregation and sieving where necessary (Cwynar *et al.*, 1979), acetolysis, staining and suspension in silicone oil. To permit determinations of pollen concentrations exotic pollen in the form of tablets or a suspension was added before processing. A land pollen sum of at least 300 was normally attained, but sums were lower in some basal mineral samples.

Pollen percentages were calculated using total land pollen (including Cyperaceae) = 100%. There is considerable overlap between the size ranges of species of *Betula* in Newfoundland (Macpherson, 1982), and where grains <20 μm in diameter are differentiated in the diagrams an additional and unknown proportion of shrub grains is included with grains >20 μm. Separate sums (total land pollen + total spores, etc.) were used to calculate percentages of spore taxa, aquatics, *Pediastrum* and indeterminable grains. The pollen diagrams are presented in Figures 5-8; Table III summarizes the pollen record from the four sites.

POLLEN DIAGRAMS: GENERAL CHARACTERISTICS

Pollen of *Oxyria/Rumex*, generally considered to be an indicator of early plant colonisation (Tipping, 1988), occurs near the base of the four cores. The *Oxyria/Rumex* maximum at GE, OP and SL is followed by higher values for Ericales. The single level at which *Oxyria/Rumex* is recorded at KP coincides with an Ericales peak, possibly because the sampling interval, although close, did not permit discrimination of individual peaks at this site with its relatively low rate of basal sediment accumulation. Thus these sites meet the principal criterion for postglacial primary succession used by Tipping

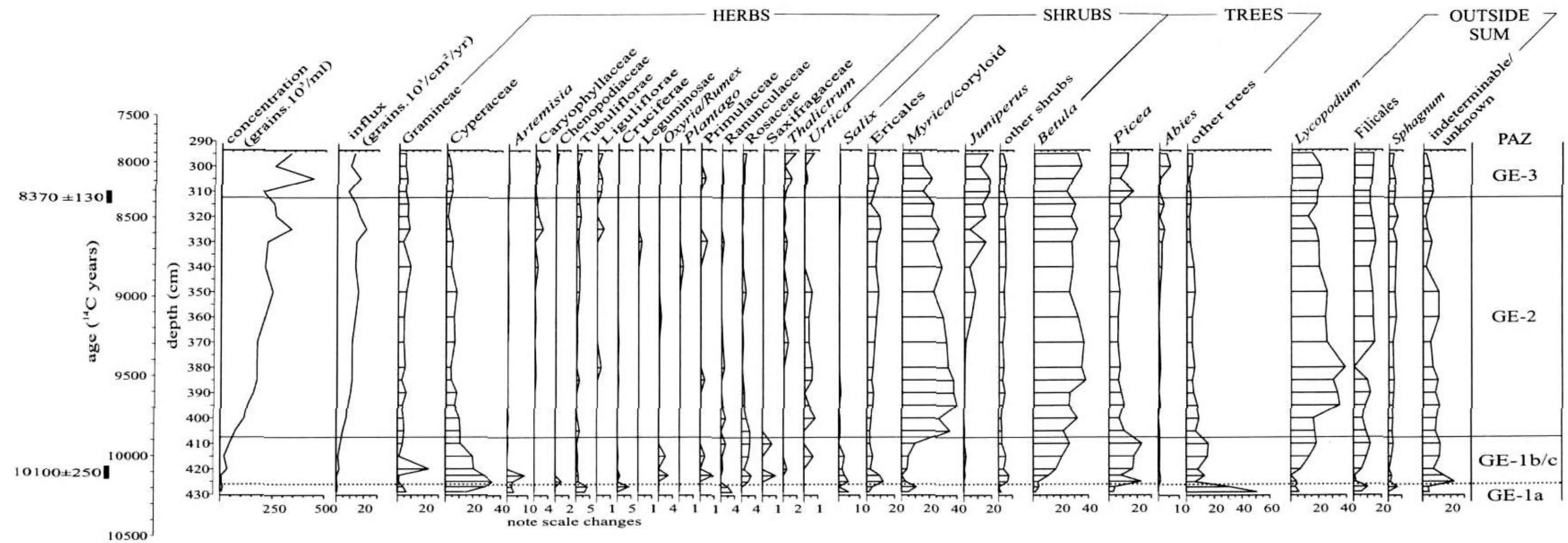


FIGURE 5. Abbreviated basal pollen percentage diagram: Golden Eye Pond. *Diagramme abrégé de pourcentages polliniques (Golden Eye Pond).*

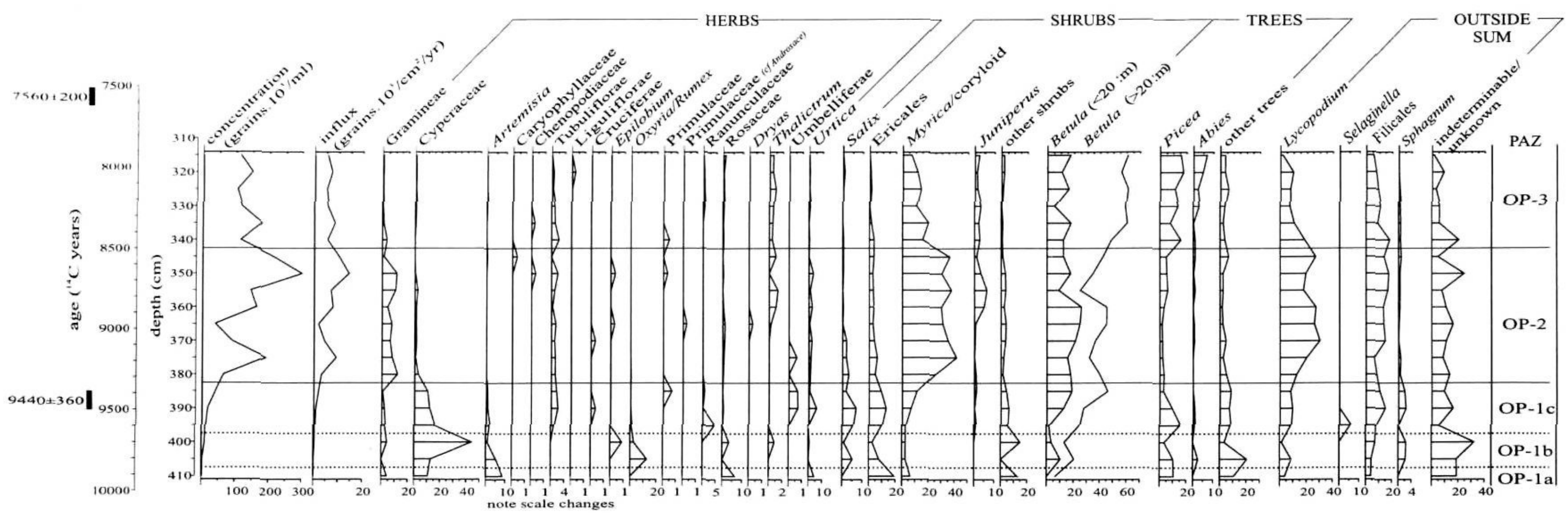


FIGURE 6. Abbreviated basal pollen percentage diagram: Oxen Pond. *Diagramme abrégé de pourcentages polliniques (Oxen Pond).*

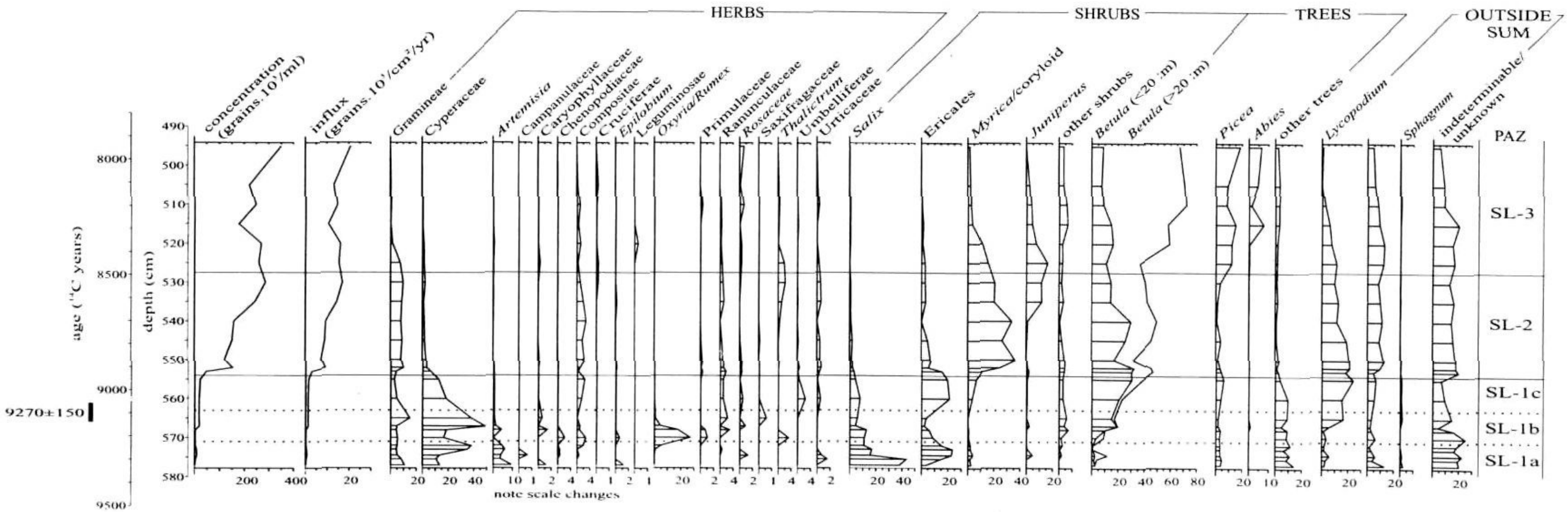


FIGURE 7. Abbreviated basal pollen percentage diagram: Sugarloaf Pond. *Diagramme abrégé de pourcentages polliniques (Sugarloaf Pond).*

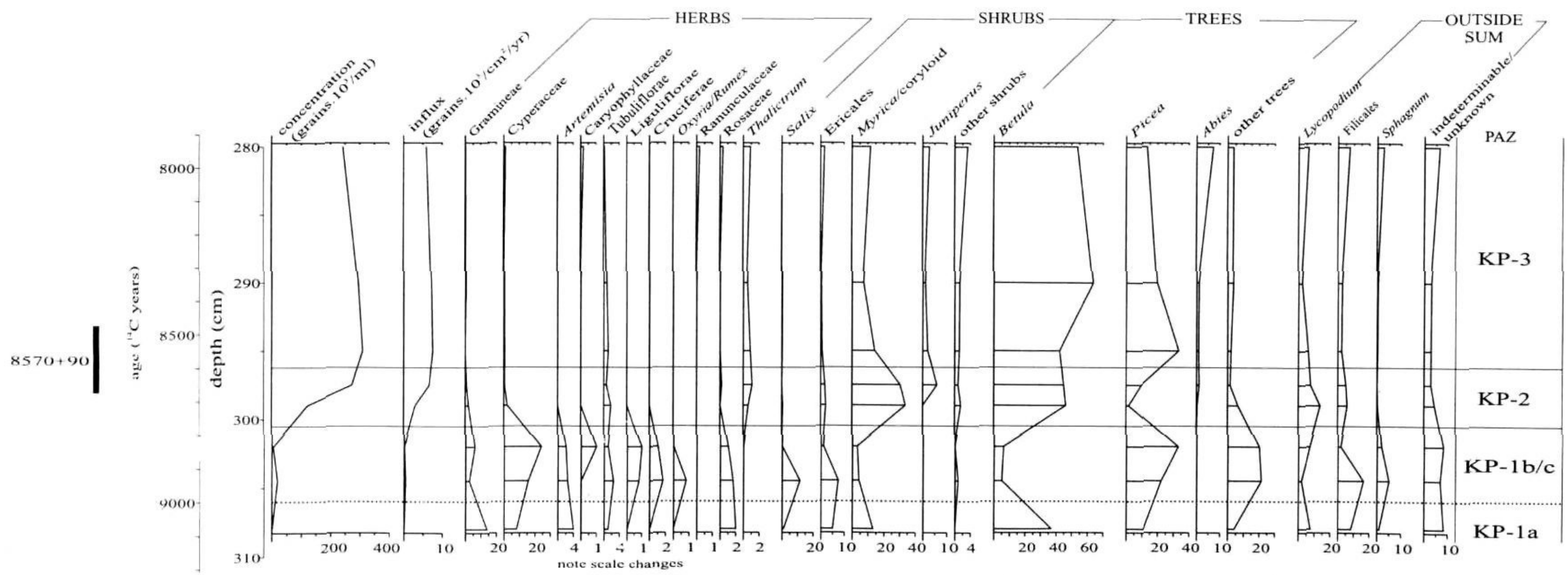


FIGURE 8. Abbreviated basal pollen percentage diagram: Kennys Pond. *Diagramme abrégé de pourcentages polliniques (Kennys Pond).*

in examining basal pollen sequences from a series of sites in the western Scottish Highlands, that a basal *Rumex* maximum should be followed by a maximum of *Empetrum* (Ericales). Discrimination of Ericales pollen to species level was not attempted for the Avalon Peninsula sites, but the widespread occurrence of *Empetrum* in upland and coastal heaths leaves little doubt that its pollen contributed to the early record of Ericales. Tipping cited studies of modern plant colonisation, such as those undertaken by Jotunheimen Research Expeditions (*e.g.* Matthews, 1978a) and numerous early postglacial pollen records from elsewhere in northwest Britain (*e.g.* Pennington, 1977; Walker and Lowe, 1985) all of which showed the *Oxyria/Rumex-Empetrum* (Ericales) sequence. The same sequence is found in basal pollen spectra from Labrador (Lamb, 1984; Engstrom and Hansen, 1985), northern Ungava (Richard, 1981), southern Greenland (Fredskild, 1973), and southwestern Norway (*e.g.* Paus, 1989).

In the Avalon Peninsula sites *Oxyria/Rumex* is associated with Gramineae, Cyperaceae, other herbs and shrubs, and defines pollen sub-zone 1b, rather than the basal sub-zone 1a, which will be discussed below. (The pollen assemblage zones for Sugarloaf Pond in this paper are slightly modified from those in Macpherson, 1982.) These herb-rich assemblages are followed by assemblages with increasing representation of a sequence of shrubs in addition to Ericales: *Salix* (the increase of which may be in terms of concentration only) in sub-zone 1c, and shrub *Betula*, *Myrica* and *Juniperus*, together with *Lycopodium*, in zone 2. (The category *Myrica*-coryloid includes *Myrica gale* and grains of similar gross morphology lacking clear pore structure.) In zone 3 *Picea* expands (8.5-8.4 ka BP), followed about two centuries later by *Abies*, and accompanied by *Betula* >20 μm; in zones 1 and 2 the similarity of the curves for small and large birch grains, where discriminated, suggests that all are from shrub birch. Indicators of heath vegetation persist after the expansion of boreal trees, most markedly at GE on the interior plateau.

The *Oxyria/Rumex* record is best expressed at OP and SL. At these sites the beginning of the *Oxyria/Rumex* record is followed by Ericales peaks in sub-zone 1c; subsequently this taxon declines rapidly to low values which persist into zone 3. At GE, on the interior plateau, the Ericales curve continues to show a slow increase for 1500 years, throughout zone 2. At all sites there is a percentage peak of *Betula* (undifferentiated at GE and KP, grains <20 μm at OP and SL) within 350 years of the beginning of the pioneer stage, as estimated from extrapolation of rates of sediment accumulation.

Below the herb-dominated zone at all sites, but more clearly defined at OP and SL, there is a problematic assemblage, in pollen sub-zone 1a, with herbs such as *Artemisia*, Cyperaceae and Gramineae, together with dwarf shrubs, *Betula*, *Picea* and "other trees" (mainly *Pinus*). Pollen concentrations are low (<2000-9600 grains/ml) in mineral sediment, and the arboreal pollen is considered to be of extra-regional origin or to be derived from glacier ice (McAndrews, 1984). Factors which may have contributed to high basal tree percentages are low pollen productivity within the lake catchment (GE) and a relatively small local pollen recruitment area (KP).

Artemisia attains significant percentages only at or near the base of pollen zone 1, but concentrations peak in zone 2 or higher. Maximum percentage values of *Artemisia* are widespread in early postglacial and lateglacial pollen diagrams from elsewhere in North America (*e.g.* Mott, 1975; Richard, 1977; Ritchie, 1984) and northwest Europe (*e.g.* Macpherson, 1980; Pennington, 1980). Alpine and low arctic species of *Artemisia* occur today on exposed sites with scanty snow cover, well drained disturbed mineral soil and discontinuous plant cover, in association with Gramineae and dwarf shrubs such as *Salix*, *Dryas*, and *Arctostaphylos* (Böcher, 1954; Birks, 1980a; Pennington, 1980; Eisner *et al.*, 1995). *Artemisia* is not recorded as a pioneer on recently deglaciated terrain even where it is locally present (*e.g.* Birks, 1980a, 1980b) and it would be unwise to regard it as a post-glacial pioneer. It is here considered an associate of the dwarf shrubs in the basal pollen record.

Potential explanations for the initial presence of shrub pollen in pollen sub-zone 1a and for its percentage decline in the overlying herb sub-zone 1b, are: a) climatic deterioration indicated by the herb sub-zone; b) long-distance dispersal of dwarf shrub pollen before the plants became established locally; c) transport by meltwater from previous deposition on the residual Avalon Peninsula ice cap or on snow; d) local presence of dwarf shrubs from the beginning of the record.

a) Potential climatic deterioration

Climatic deterioration as an explanation is not supported by other lines of evidence. Sediment organic content, indicated by LOI values at GE and OP, increases steadily upward through the herb sub-zone (Fig. 3A). Pollen concentration values, while decreasing in the herb zone at SL, show no consistent pattern and are probably related to rates of sediment influx. Acceptance of the argument for climatic deterioration would require the herb zone at all sites to be synchronous, even at the kettle site, KP, with consequent rejection of the radiocarbon chronology.

b) Long-distance dispersal

Although long-distance pollen dispersal cannot be ruled out for the early records of *Betula* (Marcoux and Richard, 1993) and *Myrica*, there is evidence for only local dispersal of dwarf *Betula* (Andrews *et al.*, 1980; Jacobs *et al.*, 1985) and more particularly of *Salix* and Ericales. At a local scale Caseldine (1989) found that *Salix* and Ericales pollen was almost exclusively confined to surface samples from quadrats where the plants were present on the 1 km^2 Storbreen foreland. Similar evidence is available on a regional scale from the Cumberland Sound and Pangnirtung areas of eastern Baffin Island, where moss polsters yield the following mean values: *Salix*, 8.3%, 10.0%; Ericales, 24.3%, 12.0%; exotic *Pinus*, 3.4%, 1.4%, while on the nearby Penny Ice Cap the proportions of *Salix* and Ericales decline to <5% and <1% while *Pinus* increases to 50% (Short *et al.*, 1985; Short and Holdsworth, 1985). Despite inherent difficulties with percentage data, and the problems of comparing surface and lake sediment pollen spectra, the high basal values for *Salix* (>40% at SL) and Ericales (>20% at SL, 20% at OP, >10% at GE) in

TABLE III

Summary of local basal pollen assemblage zones

ka BP	GOLDEN EYE POND	OXEN POND	SUGARLOAF POND	KENNYS POND	ST. JOHN'S HARBOUR
8.0	**GE-3**: *Picea* - *Betula* - *Juniperus*	**OP-3**: *Picea* - *Betula*	**SL-3**: *Picea* - *Betula*	**KP-3**: *Picea* - *Betula*	
8.5	**GE-2**: *Myrica* - *Betula* - *Lycopodium* - Ericales	**OP-2**: *Myrica* - *Betula* - *Lycopodium*	**SL-2**: *Myrica* - *Betula* - *Lycopodium*	**KP-2**: *Myrica* - *Betula*	**SJ-C**: *Betula* - *Salix* - *Myrica*
				KP-1b/c: AP - herbs - *Salix* - Ericales	
9.0			**SL-1c**: Ericales - *Betula* -	**KP-1a**: AP-herbs-*Artemisia*	**SJ-B**: AP - herbs - *Artemisia*
			SL-1b: herbs - *Betula*		
			SL-1a: *Salix* - Ericales - herbs - *Artemisia*		
9.5		**OP-1c**: Ericales - *Betula* - *Salix*			
		OP-1b: herbs - AP			
		OP-1a:AP-Ericales-*Artemisia*			
10.0	**GE-1b/c**: AP - herbs - *Betula* - Ericales				**SJ-A**: herbs - Ericales
	GE-1a: AP-herbs-*Artemisia*				

the Avalon Peninsula record seem incompatible with dispersal over any great distance.

c) Derivation from melting glacier ice or snow

Following a similar argument, if the dwarf shrub pollen were derived from melting glacier ice or snow, it would be expected that *Salix* and Ericales values would be lower, and *Pinus* values higher than the 15-20% at OP and SL. At GE a glacial source is more likely, for *Pinus* (included with "other trees") attains 50% and the sum of dwarf shrub pollen (>20%) is lower than at OP and SL.

d) Local presence of dwarf shrubs

If the dwarf shrub pollen originated in each catchment, then the record from the Storbreen glacier foreland strongly suggests that the shrubs must have been growing on older, higher terrain while pioneer herbs colonised the most recently deglaciated terrain adjacent to the lake. This explanation was favoured by Tipping (1988) to account for similar sequences in sites in western Scotland. It is significant that the resulting double peak in dwarf shrubs is more clearly expressed at OP and SL (basin relief respectively 50 m and 60 m) than at GE (basin relief 25 m) where the range of terrain age is likely to have been less. This preferred explanation for the basal record of the Avalon sites will be discussed in more detail in the following section.

COMPARISON WITH VEGETATION AND POLLEN SEQUENCES FROM THE STORBREEN GLACIER FORELAND, NORWAY

The Storbreen glacier foreland was selected as a modern analogue for the early Postglacial on the Avalon Peninsula for three reasons: high-resolution chronology extending back over more than two centuries; the occurrence on the foreland and adjacent climax heath of a suite of plants also present in Newfoundland-Labrador (in particular Ericales species which are common on Avalon Peninsula heaths) (Matthews, 1978a, 1978b; Meades, 1983; Rouleau, 1978; Whittaker, 1989); and similarities between modern pollen spectra from the foreland (Caseldine, 1989) and early pollen spectra from the Avalon Peninsula. Estimated summer temperatures for the Storbreen area are 10°C lower than summer temperatures on the eastern Avalon Peninsula, and precipitation is somewhat less (Matthews, 1978a).

Caseldine's records from moss polsters from 38 sites on the foreland include all but two of the taxa (*Myrica* and Primulaceae) recorded at the base of the Newfoundland profiles, and are dominated by the same taxa. He found local pollen to be poorly dispersed and spectra to be dominated by regional arboreal taxa.

Caseldine relates his statistically determined pollen groupings to Matthews's (1978a) sequence of vegetation types: grass-dominated pioneer herb assemblages → *Salix herbacea*-dominated snowbed assemblages → *Empetrum hermaphroditum* heath assemblages with increasing *Betula nana*. Comparison with Matthews's isochrone map reveals broad and overlapping ranges of terrain age for Caseldine's pollen groupings. Pioneer assemblages are not succeeded by snowbed assemblages where soil is unstable, and dwarf-shrub heath locally fails to replace snowbed assemblages. Whittaker (1989) addresses the influence of site environment, quantifying relationships between plant abundance, terrain age and environmental factors on the foreland. His ordination of eighty-five taxa from 108 sites along the gradient of terrain age is of limited palynological utility, since the species are not grouped into "pollen-equivalent taxa" (*sensu* Caseldine). For instance, in Whittaker's analysis all grass species are considered as separate taxa rather than as the "pollen-equivalent" taxon Gramineae.

For the purposes of this study a simple model of vegetation change over time on an "ideal" site with minimal soil instability and normal snow-lie was developed, with his permission, from an analysis of Matthews's original plant distribution maps (1978a; 1978b) in conjunction with his map of terrain age. Of his original 638 sites a sub-set of 352 from the valley floor and lower slopes was selected and ranked according to age; sites on the steep upper slopes most liable to soil instability or prolonged snow-cover were rejected. In all but two of the selected time-intervals the number of sites exceeded twenty. Sites in each time-interval were scored for presence/absence (not abundance) of 36 of Matthew's 49 mapped species; percentage presence is plotted in Figure 9A with percentages for the youngest terrain at the base. Of the remaining 13 taxa mapped by Matthews three (Juncaceae) do not contribute to pollen assemblages and ten are relatively rare on the foreland or are rare in Newfoundland pollen spectra. Figure 9B is a schematic summary of the data of Figure 9A showing "pollen equivalent" taxa with no percentage scale; its purpose is to indicate the timing of frequency peaks and hence expected peak pollen output of these composite taxa.

Pioneer species, Gramineae, Caryophyllaceae, Cruciferae, *Saxifraga* and *Salix*, as well as *Oxyria digyna*, are widespread within 20 years. Between 20 and 30 years Cyperaceae increases rapidly. Gramineae, the single genus of Caryophyllaceae, Cruciferae and *Saxifraga* peak in frequency after 30 years, with *Saxifraga* showing the most rapid subsequent decline. *Oxyria digyna* is most widespread after 40 years, maintaining a considerable presence for a further 80 years. While individual pioneer grass species decline in a similar way, Gramineae as a group maintains its presence by the later increase of other species. *Salix* declines somewhat after 150 years.

The Ericales expand later than *Salix*, led by *Empetrum hermaphroditum* and followed in sequence by other species, the last being *Vaccinium vitis-idaea*. Compositae, *Lycopodium selago* and *Betula nana* expand after 100 years, to be joined by *Juniperus communis* after 150 years. *Betula nana* peaks after 220 years (Matthews and Whittaker, 1987).

Similarities between the early pollen sequences of the Avalon Peninsula (sub-zones 1b, 1c; zone 2) and the vegetation sequence at Storbreen are striking, especially for *Oxyria/Rumex, Salix,* Cyperaceae, Ericales and *Betula* (Figs. 9A, 9B, 9C). *Juniperus* was a much later arrival on the Avalon Penisula than at Storbreen. Shrub-birch heath at Storbreen is well developed by 170 years. On the Avalon Peninsula this development required 350 years by extrapolation of basal rates of sediment accumulation; the Storbreen chronology suggests that the actual duration of the Avalon Peninsula sequence may have been closer to 200 years.

Using internal evidence, and by analogy with the Storbreen record, it is now possible to understand the pollen assemblages in the basal mixed zone of the Newfoundland diagrams. As each basin became open to accumulate sediment *Salix* and Ericales pollen could have been transported to the lake by surface flow resulting from snowmelt (Fredskild, 1983; Lamb, 1985) from terrain no older than 50 years and *Betula* from terrain about 200 years old. Gramineae and other herb grains could have originated from plants colonising the youngest terrain near the lake; the lake had not been open to record the pioneer vegetation from older terrain. The onset of the *Oxyria/Rumex* record could mark a further stage in succession on the youngest terrain. *Picea*, "other tree" (mainly *Pinus*), and "other shrub" (largely *Alnus*) grains were of extra-regional origin or had been released from melting snow or ice. Shrub percentages (and in some cases concentrations) could have decreased in PAZ 1b with increasing plant cover (and hence decreased surface flow) and herb pollen production near the lake.

This reconstruction requires that terrains of different ages existed within each of the catchments on the northeastern Avalon Peninsula at the beginning of the pollen records, and since the pollen records were initiated sequentially, it follows that after about 10 ka BP the area emerged from downwasting glacier ice, or, less likely, from long-lasting snowbanks. It was not a single pulse of climatic amelioration which melted lake ice and permitted sedimentation.

Pollen records with double peaks of dwarf shrubs have been recorded elsewhere in eastern Canada where there is no evidence of a climatic oscillation such as the Younger Dryas. In southeastern Québec, at Lac à l'Ange (Labelle et Richard, 1981) and Lac Ouellet (Richard *et al.*, 1992) peaks of *Salix* with smaller peaks of Ericaceae precede and follow a herb-dominated zone with *Oxyria digyna* in mineral sediment older than 10.7 ka and 10.6 ka respectively. Adjacent sites have a similar record but lack Ericaceae. The explanation developed for the northeastern Avalon Peninsula may also apply to these sites in Québec.

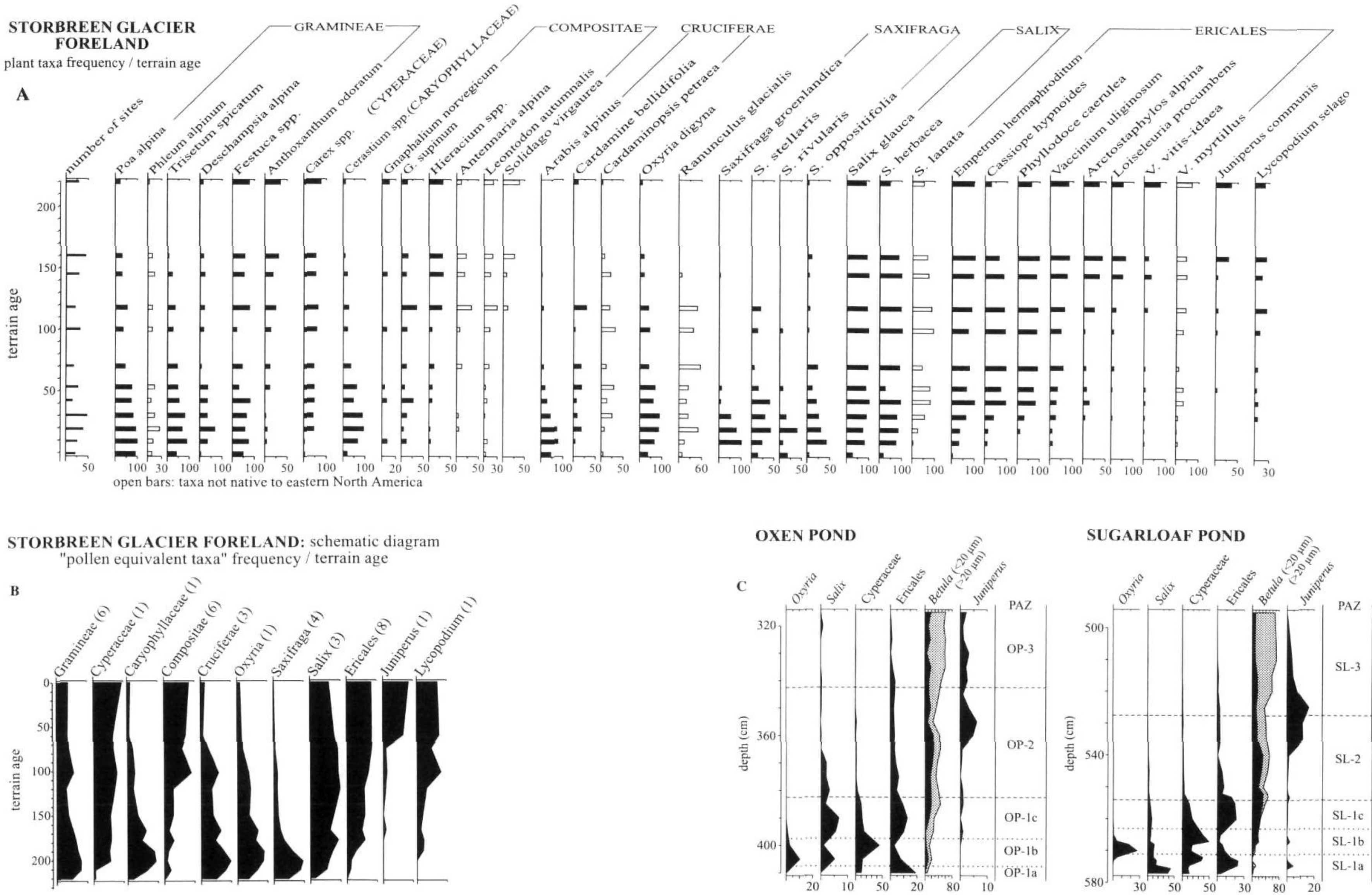


FIGURE 9. A) Storbeen glacier foreland: plant taxa presence/terrain age at a sub-set of sites on the valley floor and lower slopes (data from Matthews, 1978a, 1978b). B) Storbreen glacier foreland: schematic diagram of "pollen-equivalent taxa" presence/ terrain age (data from Matthews, 1978a, b; numerals indicate species / taxon). C) Selected pollen curves for Oxen Pond and Sugarloaf Pond.

A) Avant-pays du glacier Storbeen : fréquence des taxons de plantes par rapport à l'âge du terrain d'un sous-ensemble de sites dans le fond de la vallée et au bas des pentes (données de Matthews, 1978a, b). B) Avant-pays du glacier Storbeen : diagramme schématique des taxons à équivalence pollinique par rapport à l'âge du terrain (données de Matthews, 1978a, b ; le chiffre donne le nombre d'espèces par taxon). C) Courbes polliniques choisies au Oxen Pond et au Sugarloaf Pond.

ST. JOHN'S HARBOUR: BASAL SEDIMENTARY AND POLLEN RECORD

Evidence to support the chronology of deglaciation and vegetational development outlined above is provided by a core from St. John's Harbour (Figs. 10A, 10B). Eight samples were extracted for pollen analysis from the 350-431 cm increment of core HU81-045-075, 438 cm in length, taken in a water depth of 29 m. No sediment was available for pollen analysis from the bottom 7 cm of the core. The levels which were sampled included those (369 cm and 395 cm) of marine mollusc shells which yielded AMS dates of 8800 ± 220 (Beta 10156) and 9900 ± 250 (Beta 10157) (Lewis *et al.*, 1987).

The sediment in the analysed core segment consists of marine clayey silt with abundant pebble-cobble clasts and scattered shells (350-378 cm) overlying massive silty clay (378-420 cm) and laminated silty clay (420-431 m) which continues to the base (438 cm). Shell hash occurs at 348 cm, immediately above the analysed core segment. Within the massive silty clay unit a thecamoeban-foraminiferal transition at 410 cm marks a change from earlier brackish to later marine conditions (Lewis *et al.*, 1987). Microfossils at the base of the core, below 437 cm, indicate that the basal sediment was deposited in fresh water (D.B. Scott, Dalhousie University, personal communication). This sequence indicates inundation of a lake in the harbour basin as sea level rose above the level of the rock sill (-14 m; Lewis *et al.*, 1987). Stratigraphic comparison of Core HU81-045-075 with an adjacent core (HU81-045-074) taken in shallower water (*ca* 22 m) indicates that the basal unit in the basin is a massive silt diamicton which was probably deposited during ice retreat. The diamicton was not reached in core HU81-045-075 (C.F.M. Lewis, Bedford Institute of Oceanography, personal communication).

The samples for pollen analysis were processed as described above. Pollen totals of greater than 100 identifiable land pollen grains were achieved in all samples except those from 380 cm and 395 cm where pollen concentrations were very low. The results are presented as percentage and concentration diagrams in Figures 10A, 10B. The sum for percentage calculations was the total of all identifiable and indeterminable pollen.

Significant changes are apparent in both percentage and concentration diagrams. The highest pollen concentration of 15 000 grains/ml occurs at the base. Concentrations decrease to 1100 grains/ml at 380 cm in the silty clay unit, increasing again to 9000 grains/ml at 350 cm. The four lowest, relatively pollen-rich samples (pollen zone SJ-A) are dominated by herb taxa, notably Cyperaceae (up to 58%), Gramineae (up to 19%) and *Oxyria/Rumex* (up to 4%) and by Ericales (up to 27%); *Pinus* contributes up to 21%. Possible factors contributing to the upward decrease in pollen concentrations in this zone are increased flushing as the former lake became part of a marine embayment, inundation of part of the former pollen recruitment area as sea level rose, and an increase in the rate of sediment accumulation with the change from laminated to massive sediment. *Oxyria/Rumex* pollen identifies the pollen assemblages with the herb sub-zone (1b) of the lake sites. The presence of Ericales pollen suggests that older terrain was present on the slopes above the harbour basin. High proportions of Cyperaceae pollen may have been produced in moist sites close to the water level. The mixed basal sub-zone (1a) of the lake sites, with more shrub pollen, is absent from the base of the core, but may have been present in the unsampled sediment below 431 cm.

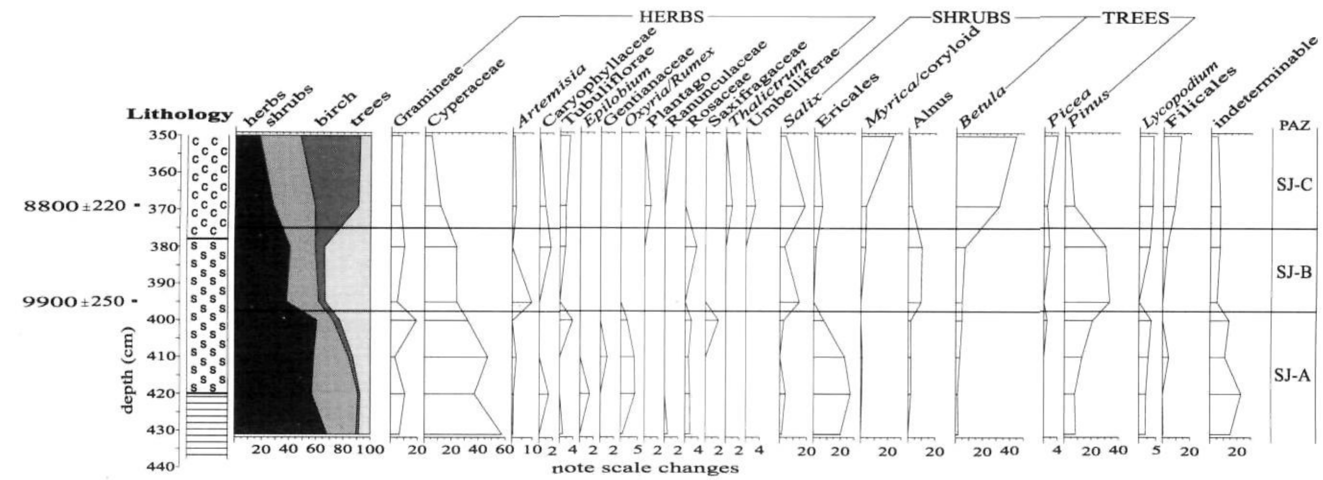
The taxa which dominate the four lowest samples are relatively insignificant in the pollen spectra of the two top samples (zone SJ-C) which are dominated by decreasing *Salix* (from 18%) and increasing *Betula* (to 44%) and *Myrica* (to 24%); *Picea* increases to 4% at 350 cm. Most of the birch grains are 20-25 μm in diameter and could be from either shrub or tree species (Macpherson, 1982). The high values for *Betula* and *Myrica* identify this zone as the equivalent of pollen zone 2 at GE, OP and SL, but *Salix* values are high. Ignoring for the moment the two middle samples, the pollen sequence in pollen zones SJ-A and SJ-C resembles the sequences in sub-zones 1b and 1c from the lacustrine records at GE, OP and SL, with earlier pioneer herb dominance and later shrub dominance with birch and *Myrica.*

The two middle samples (380 and 395 cm; zone SJ-B) appear out of place in the sequence (Fig. 10A). Values for pollen concentration demonstrate a decrease in all taxa excepting *Pinus*, *Alnus*, and *Artemisia* (present in only one sample); percentage values for these taxa increase accordingly. Pollen spectra are dominated by Cyperaceae (24%), Gramineae (up to 10%), *Pinus* (up to 33%) and *Alnus* (10%); *Salix* attains a secondary peak of 14%, and the *Artemisia* peak of 10% is registered. These pollen spectra resemble those from the basal sub-zone, 1a, of GE, OP and SL, with high values for Gramineae, Cyperaceae and *Artemisia*, and for exotic *Pinus* (other trees) and *Alnus* (other shrubs).

If the anomalously "early" pollen assemblage of pollen zone SJ-B had been intruded into the pollen sequence as the result of slumping within the harbour basin, the sediment would be expected to contain microfossils indicative of the fresh or brackish conditions which prevailed following deglaciation, but it does not. The presence of a marine foraminiferal assemblage, rather than the thecamoeban assemblage from lower in the core, precludes slumping as the process of emplacement of the sediment of zone SJ-B.

An explanation for the anomalous pollen sequence can be found in the extent of the catchment draining into the harbour (61 km^2; Batterson, 1984) given the probability of the co-existence of terrains of varying age. It is suggested that the massive silty clay containing the samples of zone SJ-B accumulated as underflow deposits during a period of rapid meltwater discharge into the harbour. If such discharges resulted from breaching of an ice dam or dams, it is possible that the sediment with its contained pollen could have been flushed from an ice-dammed lake (or sequence of lakes) which had received pollen only from recently-exposed terrain.

Support for this scenario is provided by further evidence. First, many of the *Pinus* grains in the silty unit are badly degraded, indicating that they were not deposited directly from the atmosphere. Second, terraces cut in till at elevations of



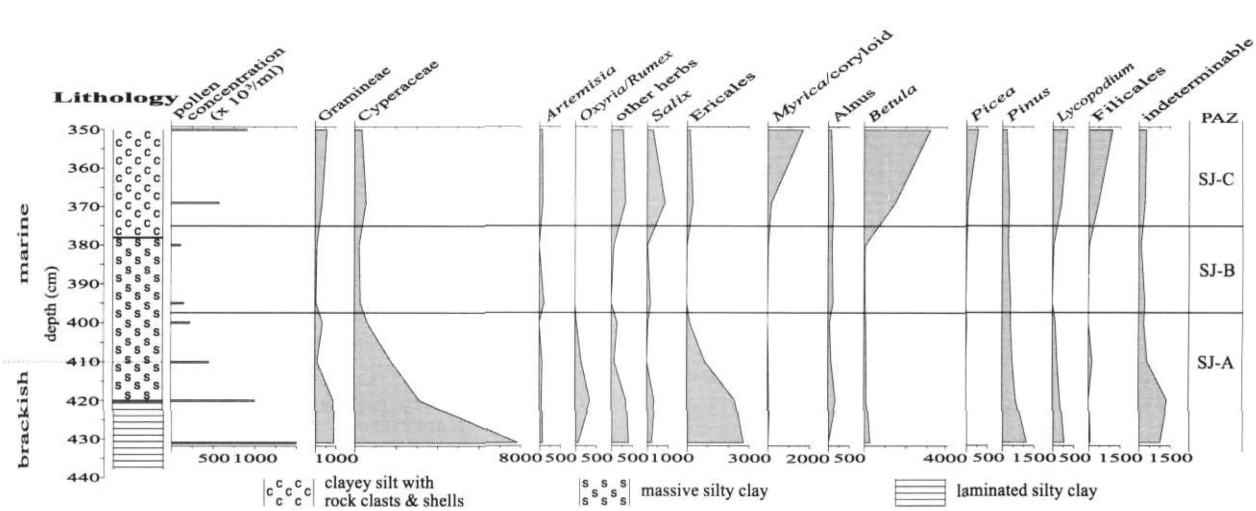


FIGURE 10. St. John's Harbour core: A) Basal lithology and pollen percentages. B) Basal pollen concentrations (selected taxa); brackish-marine boundary is based on microfossil indicators (Lewis *et al.*, 1987).

Sondage de St. John's Harbour. A) lithologie à la base et pourcentages polliniques. B) Concentrations polliniques à la base (taxons choisis) ; la llmite entre les eaux salées et saumâtres est fondée sur des indicateurs microfossiles (Lewis et al.*, 1987).*

100 to 125 m on the flank of the South Side Hills on the east side of the Waterford River valley, which drains into the harbour from the southwest, are attributed to erosion by ice-marginal streams (Fig. 1; Batterson, 1984). Bouzane (1993) discusses a soil with a high silt content occurring at an elevation of 132 m south of the South Side Hills terraces (Fig. 1); it is possible that the silt is the product of a short-lived ice-marginal lake, and that discharge from this lake, or a successor, eroded the terraces downstream and deposited the silty clay in the harbour basin. This reconstruction only adds to the widespread and abundant evidence of meltwater activity on the Avalon Peninsula (Henderson, 1972).

The radiocarbon dates are normalised to $\delta^{13}C = -25‰$ PDB; adjusting for a marine carbonate $\delta^{13}C = 0‰$ PDB increases the ages by about 400 years. Application of a further minimal 450-year North Atlantic reservoir correction (Mangerud and Gulliksen, 1975) to the date (9900 ± 250 BP) on the mollusc shell at 395 cm dates the upper part of the massive marine silty clay, and probably also the final disintegration of a residual ice mass in the Waterford river valley, at 9850 ± 250 BP; a greater and perhaps more realistic reservoir correction (Bard, 1988) would reduce the age of this horizon. The corrected age is applicable to the end of the pioneer herb zone in the immediate harbour catchment, and is close to the interpolated age of this horizon at GE.

Corresponding adjustment of the reported date (8800 ± 220 BP) gives a maximum corrected age of 8750 ± 220 BP for the mollusc shell at 369 cm. This is the level of the initial *Betula* rise, which precedes an increase in *Picea*, dated regionally at 8.5-8.3 ka BP. Thus the shell dates provide independent support for the bulk organic dates from lake sediment and help to date final disintegration of the ice cap on the northeast Avalon Peninsula.

DISCUSSION

Final disintegration of the ice cap over the St. John's Peninsula began with the end of the Younger Dryas cold episode. Earlier deglacial dates elsewhere in eastern Newfoundland imply only restricted coastal deglaciation, followed by glacial readvance during the Younger Dryas (Liverman *et al.*, 1991; Munro, 1994). Pre-Younger Dryas glacial retreat was more extensive in the southwest and western interior of the island (Anderson and Macpherson, 1994; Batterson *et al*, 1993; 1995), as it was in the Maritime Provinces (Mott *et al.*, 1986; Stea and Mott, 1989).

A likely explanation for persistence of glacial ice over the Avalon Peninsula during the Allerod warm episode preceding the Younger Dryas is suggested by the natural experiment of 1991-3, when cool summers coincided with low ocean temperatures. In 1991, the most extreme of these years, mean temperatures at St. John's airport in June and July were almost 2°C below normal, ocean temperatures and salinity were anomalously low off St. John's and the extent and duration of sea ice-cover were the greatest in 30 years (Narayanan and Prinsenberg, 1994). During the Allerod, despite the routing of runoff from western and central sectors of the Laurentide Ice Sheet through the Mississippi valley to the Gulf of Mexico, an annual volume of water calculated by Teller (1990) to be twice as great entered the Atlantic through the Gulf of St. Lawrence and Hudson Strait. Whether or not the flow through Hudson Strait were augmented by the iceberg flux postulated by Miller and Kaufman (1990), surface waters of the Labrador Current and in the Gulf of St. Lawrence would have remained cold, relatively fresh and prone to sea ice formation in winter, and summer onshore winds from any direction would have been cold. The situation would have been analogous to the "winterization of summer" today over the Hudson Bay Lowlands (Rouse, 1991). In addition, Maasch and Oglesby (1990) model a reduction in intensity of the North Atlantic storm track resulting from cooling of the Gulf of Mexico at 12 ka BP, one effect of which could have been to reduce further the advection of heat over a residual ice cap on the Avalon Peninsula.

A further potential consequence of continued eastward discharge of meltwater from the Laurentide Ice Sheet following the Younger Dryas may have been the prolonged period of *Betula* - dwarf-shrub heath recorded at several Avalon Peninsula sites, corresponding to evidence of cooling at many locations adjacent to the Great Lakes and Gulf of St. Lawrence (Anderson and Lewis, 1992). By analogy with the Storbreen glacier foreland (Matthews, 1978a) and with climate stations on southern Baffin Island where dwarf birch is present (Andrews *et al.*, 1980) it is suggested that the warmest month may initially have been as much as 10°C cooler than today's 15°C. Expansions of *Juniperus* at 9.0 and 8.7 ka associated with decreasing shrub *Betula* and *Myrica* suggest some summer warming. *Picea* migrated into the heath at 8.5 ka. Anderson and Lewis (1992) suggest that evidence of warming at this time coincides with the break-up of the Laurentide Ice Sheet and the re-routing of major meltwater discharge to Hudson Bay.

CONCLUSIONS

1. Acceptable basal radiocarbon dates from St. John's Peninsula lakes range from 10 100 ± 250 BP to 8570 ± 90 BP. The basin of St. John's Harbour was free of glacial ice before 10 000 BP.

2. Pioneer pollen assemblages with *Oxyria/Rumex* occur in sediment at or below the levels of the basal dates; the duration of the pioneer stage is estimated to have been no longer than two centuries at any site. It was replaced by a *Betula* - dwarf-shrub heath into which *Picea* migrated between 8.5 and 8.3 ka; the duration of the heath stage approached 2000 years at the interior upland site of Golden Eye Pond.

3. Pollen assemblages with dwarf-shrub heath taxa and very low pollen concentrations occur below (or in the case of Kennys Pond at the same level as) the pioneer assemblages. The source of these basal heath assemblages was terrain older than 200 years within each catchment; the pollen was transported by surface flow.

4. Co-existence of terrains of different ages points to deglaciation, rather than climatic change, as the starting point for the vegetational succession.

5. Positive correlation between site elevations and basal dates indicates down-wasting as the mode of deglaciation. Discharge of glacial meltwater into St. John's Harbour basin after a period of relatively slow sedimentation supports this conclusion.

6. Deglaciation of high ground on the St. John's Peninsula began within a few centuries of 10 000 BP. Deglaciation of St. John's Harbour basin was almost simultaneous, indicating the restricted size of the local ice cap at the beginning of the Holocene.

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Note added in proof

Incorrect adjustments were made to the reported dates on marine shells from St. John's Harbour Core HU 81-045-075. The reported dates are already normalized to –25‰ for $\partial^{13}C$ and only the marine reservoir adjustment is required. Thus the adjusted age of the shell at 369 cm (dated 8800 ± 220; Beta 10156) becomes 8350 ± 220 BP and of that at 395 cm (dated 9900 ± 250; Beta 10157) becomes 9450 ± 250 BP. The column relating to St. John's Harbour in Table III should be amended to show the base of pollen zone SJ-C at ~ 8600 BP and the base of pollen zone SJ-B at ~ 9550 BP. These corrections do not substantially affect the argument of the paper. I am greatly indebted to Dr. A.S. Dyke, Geological Survey of Canada, for drawing my attention to the error.

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