Géographie physique et Quaternaire

Postglacial Vegetational History of the Eastern Avalon Peninsula, Newfoundland, and Holocene Climatic Change Along the Eastern Canadian Seaboard

Histoire postglaciaire de la végétation de l'est de la péninsule d'Avalon, Terre-Neuve, et changement climatique à l'Holocène le long de la côte est du Canada

Растительносиь восточной части полуострова Авалон на Ньюфаундленде в послеледниковый период и изменение климата в период голоцена на восточном подережье Канады

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Volume 36, numéro 1-2, 1982

URI : https://id.erudit.org/iderudit/032476ar
DOI : https://doi.org/10.7202/032476ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Brown Macpherson, J. (1982). Postglacial Vegetational History of the Eastern Avalon Peninsula, Newfoundland, and Holocene Climatic Change Along the Eastern Canadian Seaboard. *Géographie physique et Quaternaire*, *36*(1-2), 175–196. https://doi.org/10.7202/032476ar

Résumé de l'article

Deux profils polliniques dressés à partir de données recueillis dans la péninsule d'Avalon orientale, et datés au ^{14}C, nous portent à supposer qu'il y eut là une déglaciation tardive (probablement après 9700 BP sur le littoral) suivie d'une courte période marquée par la croissance d'une végétation de toundra. Après 9300 BP, la riche toundra arbustive fut colonisée, dans les endroits peu élevés, par l'épinette, le sapin baumier et le bouleau arborescent jusqu'à former, vers 8400 BP, une forêt clairsemée. La forêt conserva ce caractère au cours des 3000 ans qui suivirent. Des traces d'incendies et la constance de la présence de Populus font penser que le climat était alors plus sec et plus chaud qu'aujourd'hui. Au maximun climatique, environ entre 5400 et 3200 BP, correspondit une densification du couvert forestier, une remontée de la limite de la forêt jusque sur les hautes terres et une augmentation des précipitations. Après 3200 BP, le refroidissement du climat entraîna une régression de la limite de la forêt. L'interprétation des changements climatiques qui ont affecté la péninsule d'Avalon est comparée aux interprétations fondées sur les études paléoenvironnementales faites le long de la côte est de l'Amérique du Nord, depuis l'île de Baffin jusqu'à la Nouvelle-Angleterre. On peut supposer qu'une série de régulateurs variables influencèrent la circulation atmosphérique de la région à l'Holocène.

Géographie physique et Quaternaire, 1982, vol. XXXVI, n^{os} 1-2, p. 175-196, 9 fig., 3 tabl.

POSTGLACIAL VEGETATIONAL HISTORY OF THE EASTERN AVALON PENINSULA, NEWFOUNDLAND, AND HOLOCENE CLIMATIC CHANGE ALONG THE EASTERN CANADIAN SEABOARD

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ABSTRACT Two radiocarbon-dated pollen profiles from the eastern Avalon Peninsula suggest late deglaciation (probably no earlier than 9700 BP at the coast), followed by a brief period of tundra vegetation. After 9300 BP a rich shrub tundra at lower elevations was invaded by spruce, balsam fir and tree birch until at *ca* 8400 BP the vegetation was an open woodland. The forest remained open for the next 3000 years; evidence of fire and the continuous presence of *Populus* suggest drier and warmer conditions than at present. The period of maximum warmth, *ca* 5400-3200 BP, saw the closing of the forest cover, a rise in the level of the tree limit in the interior upland and an increase in precipitation. After 3200 BP decreasing temperatures resulted in a lowering of the tree limit. The climatic changes inferred for the Avalon Peninsula are compared with those inferred from palaeo-environmental studies along the eastern North American seaboard from Baffin Island to New England. A sequence of changing controls on the regional atmospheric circulation during the Holocene is suggested.

RÉSUMÉ *Histoire postglaciaire de la végétation de l'est de la péninsule d'Avalon, Terre-Neuve, et changement climatique à l'Holocène le long de la côte est du Canada.* Deux profils polliniques dressés à partir de données recueillis dans la péninsule d'Avalon orientale, et datés au ^{14}C, nous portent à supposer qu'il y eut là une déglaciation tardive (probablement après 9700 BP sur le littoral) suivie d'une courte période marquée par la croissance d'une végétation de toundra. Après 9300 BP, la riche toundra arbustive fut colonisée, dans les endroits peu élevés, par l'épinette, le sapin baumier et le bouleau arborescent jusqu'à former, vers 8400 BP, une forêt clairsemée. La forêt conserva ce caractère au cours des 3000 ans qui suivirent. Des traces d'incendies et la constance de la présence de *Populus* font penser que le climat était alors plus sec et plus chaud qu'aujourd'hui. Au maximun climatique, environ entre 5400 et 3200 BP, correspondit une densification du couvert forestier, une remontée de la limite de la forêt jusque sur les hautes terres et une augmentation des précipitations. Après 3200 BP, le refroidissement du climat entraîna une régression de la limite de la forêt. L'interprétation des changements climatiques qui ont affecté la péninsule d'Avalon est comparée aux interprétations fondées sur les études paléoenvironnementales faites le long de la côte est de l'Amérique du Nord, depuis l'île de Baffin jusqu'à la Nouvelle-Angleterre. On peut supposer qu'une série de régulateurs variables influencèrent la circulation atmosphérique de la région à l'Holocène.

РЕЗЮМЕ *Растительность восточной части полуострова Авалон на Ньюфаундленде в послеледниковый период и изменение климата в период голоцена на восточном побережье Канады.* Определение возраста пыльцы с восточной части полуострова Авалон с помощью радиоактивного углерода позволило установить позднее отступление ледников (вероятно не ранее 9700 года до настоящего времени /до 1950 года нашей эры/ на побережье), за которым последовал короткий период тундровой растительности. После 9300 года до настоящего времени богатая кустарниковая растительность тундры стала вытесняться на небольших возвышенностях елью, пихтой бальзамической и березой до 8400 года до настоящего времени, когда растительность представляла собой редкий лес. Лес сохранял открытый характер в течение следующих 3000 лет. Следы пожаров и постоянного присутствия Populus указывают на более сухие и теплые климатические условия, чем в настоящее время. В период максимального потепления в 5400-3200 годы до настоящего времени произошло смыкание лесного покрова, увеличение площади лесного покрова на возвышенностях, удаленных от побережья, и увеличение количества выпадания осадков. После 3200 года до настоящего времени понижение температур привело к снижению площади лесного покрова. Предполагается, что климатические изменения на полуострове Авалон аналогичны изменениям, установленным палеонтологическими исследованиями окружающей среды на восточной части северо-американского побережья от острова Баффин до Новой Англии.

INTRODUCTION

The postglacial vegetational history of much of the eastern Canadian seaboard has been outlined in recent studies. ANDREWS *et al.* (1980) and SHORT and ANDREWS (1980) have reported on vegetation changes in Baffin Island since the middle Holocene. SHORT and NICHOLS (1977, also SHORT, 1978), JORDAN (1975) and LAMB (1980) have worked respectively in northern, central and southern Labrador, while sites in the Maritime Provinces have been examined by LIVINGSTONE (1968), RAILTON (1973), HADDEN (1975), MOTT (1975a), GREEN (1976) and ANDERSON (1980). However, the central section of the eastern seaboard, formed by the island of Newfoundland (Fig. 1), has received relatively little attention from Quaternary palynologists, hindering the development of a regional synthesis. Much of the information available for Newfoundland relates to the northernmost tip of the island, where data have been gathered in connection with archaeological investigations of the mediaeval Norse site at l'Anse aux Meadows on the Strait of Belle Isle (KUC, 1975; MOTT, 1975b; HENNINGSMOEN, 1977; McANDREWS and DAVIS, 1978; DAVIS, 1980; DAVIS and McANDREWS, in progress). Three pollen profiles from the Avalon Peninsula in the southeast of the island were published by TERASMAE (1963). Basal radiocarbon dates were included, the oldest (8420 ± 300 BP; I (GSC)-4) dating the migration of spruce into a shrub tundra. More recent work by MELLARS (1981) confirms this finding, but neither work provides firm evidence of the dates of deglaciation and plant recolonisation. Minimum dates for deglaciation obtained from marine shells in northeastern Newfoundland are as early as 12,000 BP (TUCKER, 1974), while terrestrial material from southeastern Labrador has been dated at 10,500 ± 290 BP (SI-3139; LAMB, 1980).

The present work was undertaken in an attempt to establish more precisely the time of deglaciation of the eastern Avalon Peninsula, to use pollen influx to examine and date postglacial vegetational and climatic changes, and to place the inferred Holocene climatic history within the regional framework of the eastern Canadian seaboard.

Coring sites were selected in two locations (Fig. 2). Sugarloaf Pond (47°37′N, 52°40′W) lies little more than 1 km from the eastern coast of the peninsula at an elevation of *ca* 100 m. It was selected because the bathymetry had been surveyed (EVANS, 1972), and its catchment has experienced relatively little human interference and remains largely forested. Sites in the Hawke Hills (47°20′N, 53°08′W), the central upland of the eastern Avalon Peninsula, were selected because the area had been proposed as the location of the final stagnating ice mass on the peninsula (ROGERSON and TUCKER, 1972). It was expected also that the sites might yield evidence of Holocene climatic change, because they lie close to the present altitudinal tree limit.

REGIONAL SETTING

The Avalon Peninsula, a fragment of the Appalachian mountain system, has been reduced to a low plateau which for the most part terminates in a steep coastal slope. Much of the plateau surface lies at 150-200 m, but occasional summits on more resistant rock, such as the Hawke Hills, rise to 300 m. The mainly acidic Precambrian rocks have an irregular cover of locally derived till, on which have developed soils classified mainly as orthic and gleyed podzols and orthic gleysols (PAGE, 1971).

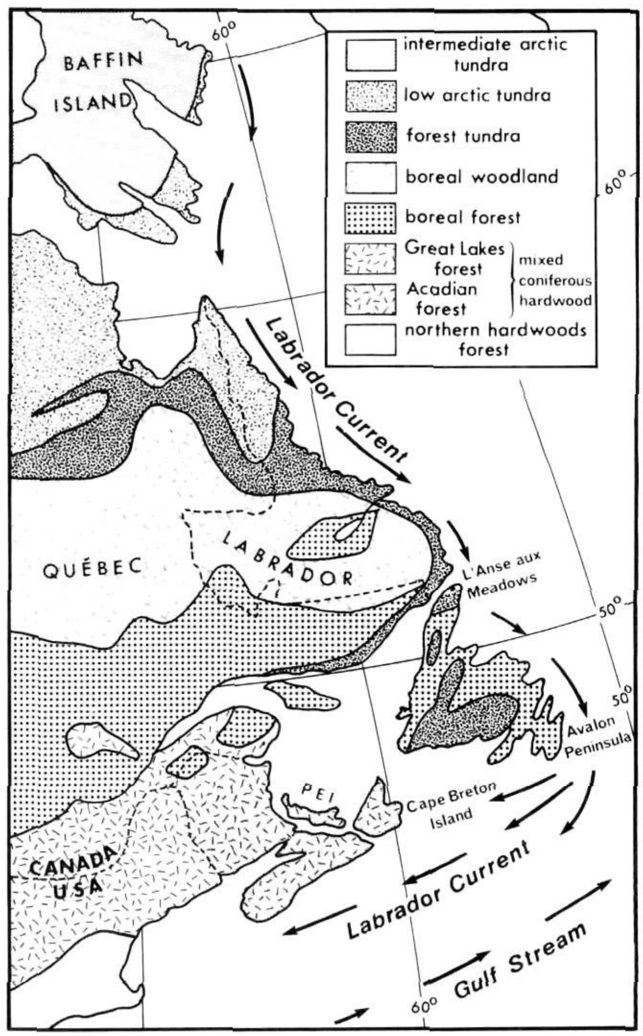


FIGURE 1. Eastern Canada: generalized vegetation regions (after RICHARD, 1980a; ROWE, 1972; YOUNG, 1971)

L'est du Canada: les régions végétales (d'après RICHARD, 1980a; ROWE, 1972; YOUNG, 1971).

The climate is oceanic, with abundant precipitation and cool summer temperatures. The mean annual precipitation at St. John's airport (Torbay) is 1516 mm; the mean annual snowfall is 366 cm, but snowfall amounts and snowcover depth and duration are very variable (ENVIRONMENT CANADA, 1975a). The mean temperature during the growing season (late May to late October) is 12°C (ENVIRONMENT CANADA, 1975b), and during this period only 39% of the total possible bright sunshine is received (CANADA, DEPARTMENT OF TRANSPORT, 1968), while fog is frequent, exceeding the total hours of bright sunshine in duration (MANNING, 1969). DAMMAN (1976) has demonstrated the increase in mean growing season temperatures with distance from the open Atlantic Ocean and the cold Labrador Current, but this effect is counteracted in the interior upland by increased elevation, cloudiness and exposure to wind (BANFIELD, 1981). In winter, wind scours snow from the upland summits where exposure of the surface to repeated freeze-thaw cycles results in the formation of active soil polygons (DAY, 1978).

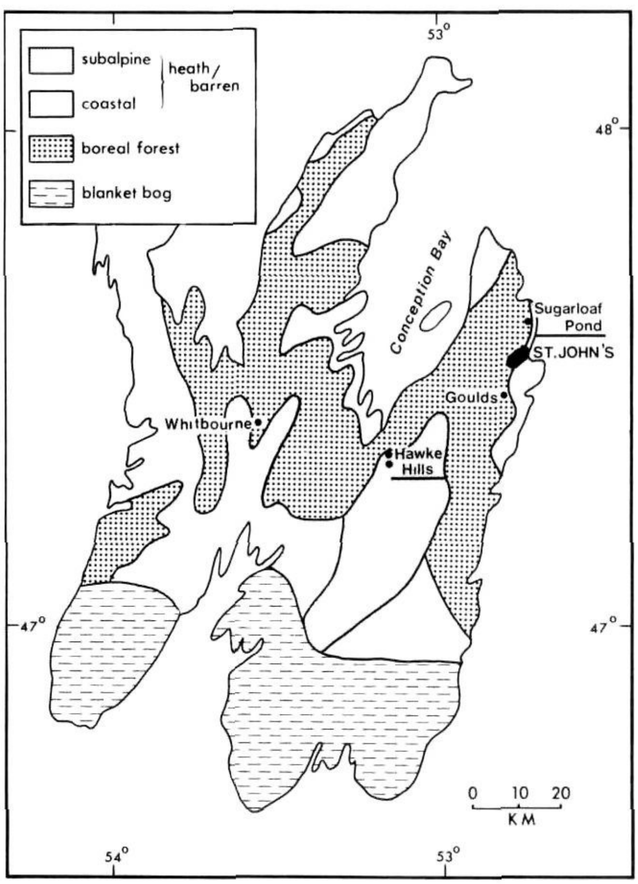


FIGURE 2. Avalon Peninsula, Newfoundland: generalized vegetation regions and locations of sites. Vegetation after ROBERTSON and WOOD (1981); Sugarloaf Pond and Hawke Hills sites, this paper; Goulds and Whitbourne sites from TERASMAE (1963).

La péninsule d'Avalon, Terre-Neuve: les régions végétales et localisation des sites. Végétation selon ROBERTSON et WOOD (1981); sites du Sugarloaf Pond et des Hawke Hills, présent article; sites de Goulds et de Whitbourne d'après TERASMAE (1963).

The greater part of the Avalon Peninsula lies in Forest Region 7 (NEWFOUNDLAND, MINISTRY OF FORESTRY AND AGRICULTURE, 1974) in which only 33% of the area is classified as productive forest. The percentages of gross merchantable volume indicate the composition of the productive forest which is dominated by three taxa: balsam fir *(Abies balsamea)* 55%, black spruce *(Picea mariana)* 32% and birch (mainly mountain white birch *(Betula cordifolia)* 7%, with small amounts of white spruce *(P. glauca)* and larch *(Larix laricina)*. In the poorer forest of the eastern part of the peninsula birch is less common, while larch occurs frequently on poorer soils. Above the treeline a heath vegetation (Fig. 2) classified by AHTI (1959) as subalpine lichen barren, includes *Cladonia* and low-growing shrubs such as members of the Ericaceae, *Empetrum eamsii*, *Juniperus communis* and *Myrica gale*. This gives way on exposed summits with frost-disturbed soil to a discontinuous vegetation classified as alpine heath (MEADES, 1973), in which the presence of arctic species such as *Diapensia lapponica* testifies to the absence of forest throughout the post-glacial (MEADES, 1973; DAY, 1978). However, conifers can survive in cushion or krummholz (tuckamore) form above the treeline where protection by snow is adequate.

THE SITES

Sugarloaf Pond (5.5 ha) occupies a rock basin on the seaward side of the coastal range of hills north of St. John's (Fig. 3). Its catchment (38 ha) is underlain by reddish arkosic sandstone and conglomerate of the Precambrian Signal Hill formation (ROSE, 1952) which is irregularly veneered with till. Summits at 170 m and 150 m lie to west and south of the lake, but a windgap below 115 m leaves the catchment open to the southwest.

The lake supports little aquatic vegetation and the shoreline is rocky (EVANS, 1972). The only channelled inflow is provided by a small ditch, usually dry, draining from the windgap to the southwest; most of the inflow is therefore in the form of soil through-flow and surface run-off, with a possible contribution from springs. A small perennial stream carries the outflow northeastward. The maximum recorded water depth is 3.7 m, and the bottom sediment exceeds 2 m in depth over about half the area. At the coring site the depth of ice plus water was 3.0 m and the sediment was cored to the limit of penetrability at 6.2 m below the mud-water interface. Duplicate cores were obtained in 1 m increments with a modified Livingstone-type sampler with an internal diameter of 5 cm. One core was used for radiocarbon dating, the other for pollen analysis.

The Hawke Hills sites (Fig. 4) lie at the western margin of the granitic central upland where it descends from rounded summits at over 300 m a.s.l. in a west- and northwest-facing escarpment overlooking lower terrain developed on folded and faulted volcanic and sedimentary rocks of the Precambrian Harbour Main Group (McCARTNEY, 1954, 1967). The headwaters of two unnamed streams, both tributaries of South River which drains northward to Conception Bay, rise on the granite escarpment. At its foot their valleys are almost linked by a col into which a glacial meltwater gully is incised. The floor and north side of the col support forest with balsam fir, spruce and larch.

The gully is partially filled with peat, its surface at about 195 m, underlain in places with gyttja, indicating the persistence of pools in the channel floor after glacial meltwater had ceased to flow. The peat is fibrous and woody and it was only with difficulty that a core through the lowest 110 cm of the sediment at the deepest point was extracted with a small Hiller sampler, and it was not possible to obtain sufficient sediment for radiocarbon dating.

The triangular lake immediately west of the col has accumulated less than 2 m of sediment, of which the lowest 50 cm or so is granular and incohesive, and thus was considered unsuitable for sampling.

Hummocky till, thought to be the product of stagnating ice (HENDERSON, 1972), mantles the foot of the west-facing escarpment. A pond, 25 m in diameter, occupies the centre of a partially peat-filled kettle at the treeline, *ca* 220 m a.s.l. The pond is fed by a small stream and drains into the western tributary of South River. Although operational difficulties prevented sampling of sediment from the deepest part of the kettle, a modified Livingstone sampler was used through and from the edge of the marginal bog to obtain a composite core of gyttja 245 cm long. The composition of the pollen assemblage from the surface moss was so different from that of the surface mud in the pond that it would have been confusing to have included the gyttja-

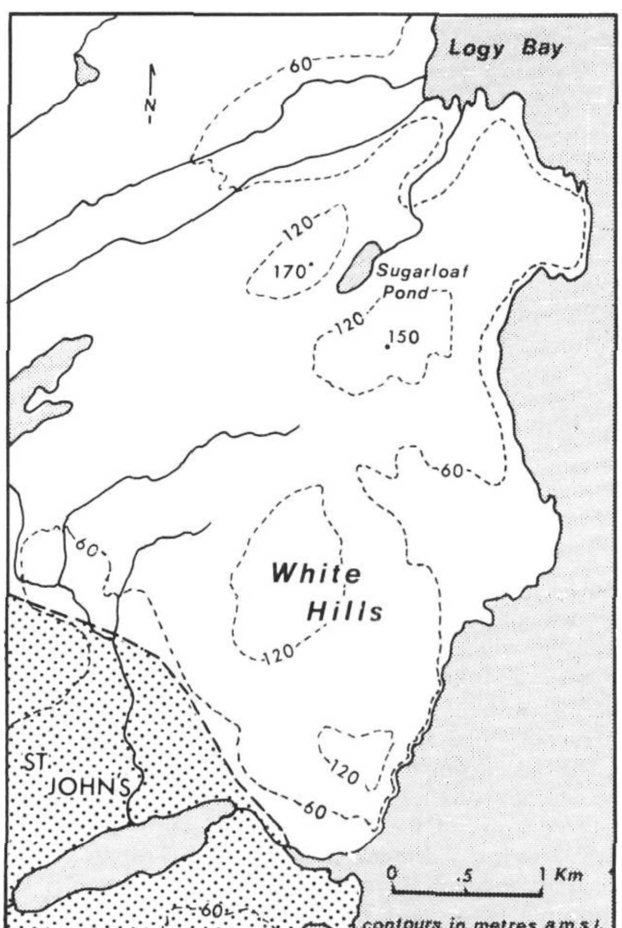


FIGURE 3. Location of Sugarloaf Pond.

Localisation du Sugarloaf Pond.

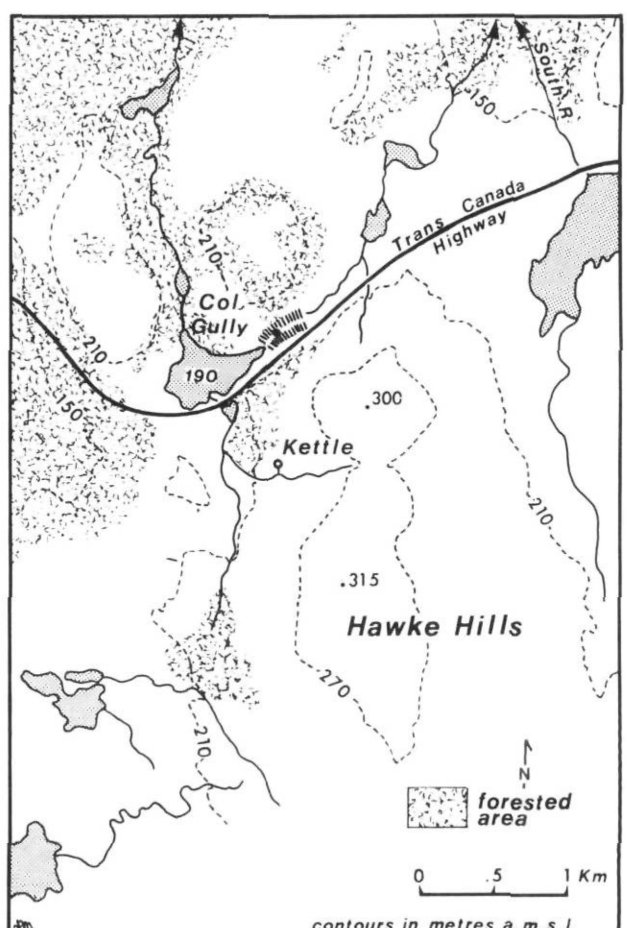


FIGURE 4. Locations of Hawke Hills sites.

Localisation des sites dans les Hawke Hills.

peat transition in the material to be analysed. The composite core is the best available material for pollen analysis from this area, despite the uncertainty of a site with restricted water depth (35 cm at the pond margin).

STRATIGRAPHY AND RADIOCARBON DATES

The stratigraphy of the three cores is indicated in Table I, radiocarbon dates and sedimentation rates from Sugarloaf Pond and the Hawke Hills kettle site in Table II, while time-depth curves are plotted in Figure 5.

SUGARLOAF POND

The Sugarloaf Pond core shows the expected postglacial transition from mineral to organic sediment. Laminated thixotropic silty clay below 581 cm was probably deposited directly from glacial meltwater. Only 14 cm of mineral sediment lies between this and the basal organic sediment, dated at 9270 ± 150 BP (GSC-2601). Extrapolating the mean rate of sediment accumulation, 0.059 cm a^{-1}, for the core segment between the two lowest radiocarbon dated samples, this 14 cm of mineral sediment accumulated in about 250 years, but this is probably an over-estimate. It is suggested, therefore, that deglaciation of this site occurred no earlier than

TABLE I

Stratigraphy

A. Sugar Loaf Pond (core used for pollen analysis)	
0 – 552 cm	gyttja, dark greenish brown to 495 cm, brown below
552 – 567 cm	clay-gyttja
567 – 573 cm	grey clay with pinkish bands
573 – 576 cm	laminated grey silty clay
576 – 580 cm	grey silty clay
580 – 581 cm	grey clay
581 – 620 cm	laminated grey thixotropic silty clay, becoming dense and impenetrable
B. Hawke Hills kettle site	
0 – 110 cm	light brown fibrous gyttja
110 – 220 cm	brown gyttja
220 – 245 cm	pale fibrous gyttja
	sand
C. Hawke Hills col gully site	
0 – 350 cm	woody peat, with fibrous gyttja or very well decomposed *Sphagnum* peat below 300 cm
350 – 417 cm	pale gyttja, fibrous in part
417 – 425 cm	clay-gyttja (found in auger section of borer; not sampled)
	rock

TABLE II

Radiocarbon dates and sedimentation rates

Sample depth (cm)	Years BP	^{13}C ‰	Laboratory No.	Sedimentation rate (cm a^{-1})	
Sugarloaf Pond					
				0.524	
50 – 60	105 ± 80*	—	Dal-291		
				0.078	
150 – 160	1385 ± 90*	—	Dal-292		
				0.588	0.063 (see Fig. 5)
250 – 260	1555 ± 90*	—	Dal-293		
				0.417	
350 – 360	1795 ± 90*	—	Dal-294		
				0.018	
450 – 460	7270 ± 200	—	Dal-295		
				0.059	
571 – 576 +	9270 ± 150	−25.3	GSC-2601		
			Mean	0.062	
Hawke Hills kettle site					
				0.023	
68 – 78	3160 ± 85		Dal-289		
				0.067	
168 – 178	4660 ± 85		Dal-290		
				0.025	
235 – 245	7290 ± 150		Dal-323		
			Mean	0.033	

* date rejected

\+ equivalent of 561-566 cm in core used for pollen analysis

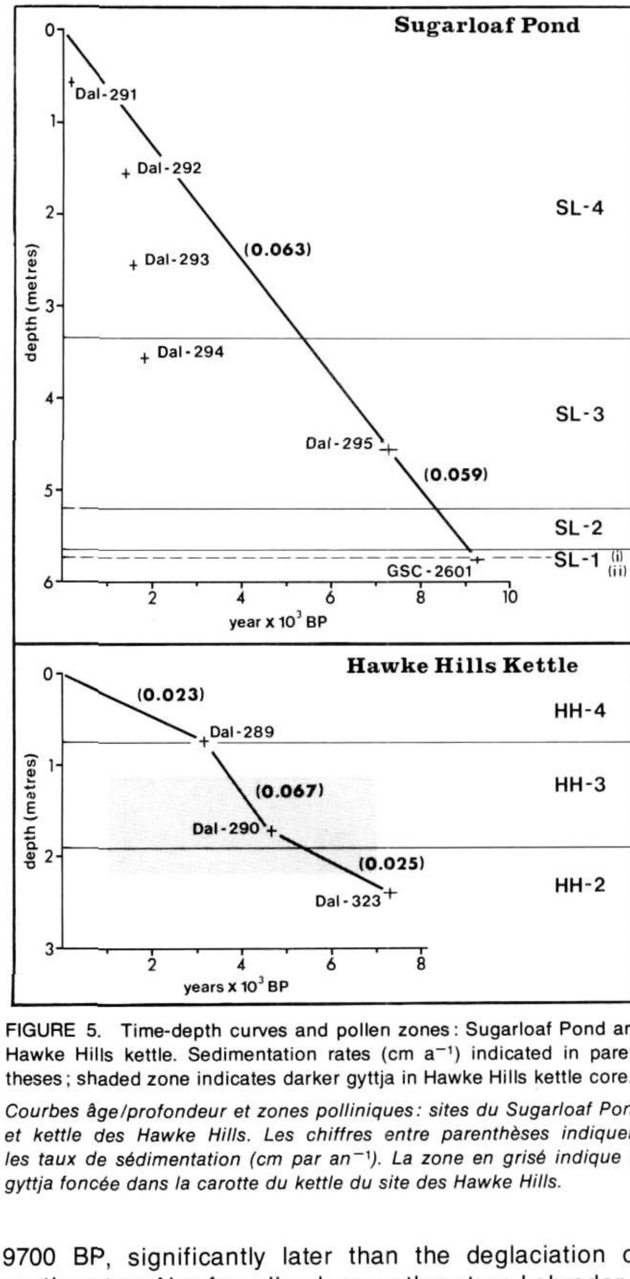


FIGURE 5. Time-depth curves and pollen zones: Sugarloaf Pond and Hawke Hills kettle. Sedimentation rates (cm a^{-1}) indicated in parentheses; shaded zone indicates darker gyttja in Hawke Hills kettle core.

Courbes âge/profondeur et zones polliniques: sites du Sugarloaf Pond et kettle des Hawke Hills. Les chiffres entre parenthèses indiquent les taux de sédimentation (cm par an^{-1}). La zone en grisé indique la gyttja foncée dans la carotte du kettle du site des Hawke Hills.

9700 BP, significantly later than the deglaciation of northeastern Newfoundland or southeastern Labrador.

The mineral sediment between 567 and 581 cm lacks the distinct laminations of the basal material, except in a narrow band between 574 and 576 cm. It is likely that this sediment was derived by surface wash from sparsely vegetated till slopes within the catchment, and from the margins of the lake. The preservation of pinkish banding and laminations in some of this sediment, together with black streaks (iron sulphide?) apparent when the material was first extruded, point to restricted circulation within a cold meromictic lake. Temperatures may have been kept low by local residual ice. Pinkish bands or laminae in early post-glacial sediments have been noted elsewhere (PENNINGTON, *et al.*, 1972; LOWE, and WALKER, 1977). Pennington attributes such sediment to the input of unoxidised particles from the catchment, and the occurrence of pink unweathered sediment in this area of reddish bedrock is thus not surprising.

It was only during the period of accumulation of the mineral sediment, before the establishment of a complete cover of vegetation, that any periglacial modification of the land surface could have occurred. Neither the limited thickness of the deposit nor the inferred brevity of the period of its accumulation support the profound periglacial modification of the landscape proposed by BRÜCKNER (1969). Sugarloaf Pond lies within the limit of late-Wisconsin ice proposed by GRANT (1977); evidence of strong periglacial activity is more likely to be found outside such an ice limit. Thus at the Sugarloaf Pond site there was a rapid amelioration of environmental conditions following deglaciation. This conclusion will be supported by evidence from pollen analysis.

The mean rate of accumulation for the whole organic section of the core is 0.062 cm a^{-1}. The calculated rates for the core segments above 360 cm differ so widely from the mean, with no corresponding variation in pollen concentrations (Fig. 6), that the four upper dates are rejected. The mean rate of accumulation for the segment above 460 cm is 0.063 cm a^{-1}, but it would be of little value to use this mean rate to determine pollen influx.

HAWKE HILLS

Pollen evidence to be presented below indicates that the earliest date from the Hawke Hills (7290 ± 150 BP; Dal -323) is considerably younger than the date of deglaciation. Indeed, basal organic material containing a sedge-tundra pollen assemblage from a site at a similar elevation 10 km to the northeast has yielded a date of 10,100 ± 250 BP (GSC-3136). It is therefore not to be expected that the Hawke Hills cores would yield stratigraphic evidence of early postglacial conditions. The col gully site demonstrates a normal hydroseral sequence from clay-gyttja, to gyttja or *Sphagnum* peat, to woody peat. The core from the kettle site contained only gyttja, the lower and upper parts more fibrous and lighter in colour than the segment between 110 and 220 cm which accumulated *ca* 6500-3700 BP. Table II and Fig. 5B indicate a mean rate of sediment accumulation here of about half that in Sugarloaf Pond, but the segment between 73 and 173 cm, corresponding in part with the darker gyttja, accumulated at a rate closer to the mean rate for Sugarloaf Pond. Thus it is possible that during this period the soil and vegetation surrounding the pond were similar to those found today at lower elevations. Although it is not possible to determine whether the rate of sedimentation in Sugarloaf Pond increased during a similar time interval, reduced pollen concentrations between 245 cm and 325 cm suggest more rapid sedimentation between about 5000 and 4000 BP (Figs. 5A and 6).

POLLEN ANALYSIS

METHODS

The lower parts of all cores were sampled at invervals of 5 cm or less, as was the upper part of the core from the Hawke Hills kettle site. Intervals of 10 or 20 cm were used when considerable similarity was found between the pollen spectra of adjacent samples. The samples were processed by the standard method described by FAEGRI and IVERSEN (1975) and mounted in silicone oil. Exotic *Eucalyptus* pollen was added in tablet form before processing to permit the calculation of pollen concentrations. Pollen grains were identified and counted at magnifications of 500 and 1250.

For the Sugarloaf Pond core it was intended to count to a minimum of 200 land pollen grains, including the equivalent in whole grains of fragmented conifer pollen. When it was realised that the inclusion of these "reassembled" grains added little information they were removed from the pollen sum, which was thus reduced to less than 200 but not less than 179 grains, in 8 of 19 topmost samples. The pollen sum is less than 200 in samples from the minerogenic sediment at the base of the core where pollen concentrations are very low (Fig. 6). The sum includes the pollen of all land taxa including Ericales and Cyperaceae; this seems justified in the absence of bog from the lake margin. The pollen sum for each group of taxa is indicated on the pollen diagram.

Fragmented conifer grains were ignored in samples from the Hawke Hills sites. In counting, a minimum of 250 land pollen grains was achieved. However, it became apparent that the inclusion of pollen of taxa common on the surface of the adjacent bog in the pollen sum obscured significant changes in the representation of dry land taxa. Accordingly, four wetland taxa (*Myrica gale*, Ericales, Cyperaceae and *Thalictrum*) were treated as a separate group, reducing the basic pollen sum (dry land taxa only) to below 250 in a few cases. Percentages were calculated as for the Sugarloaf Pond core.

POLLEN IDENTIFICATION

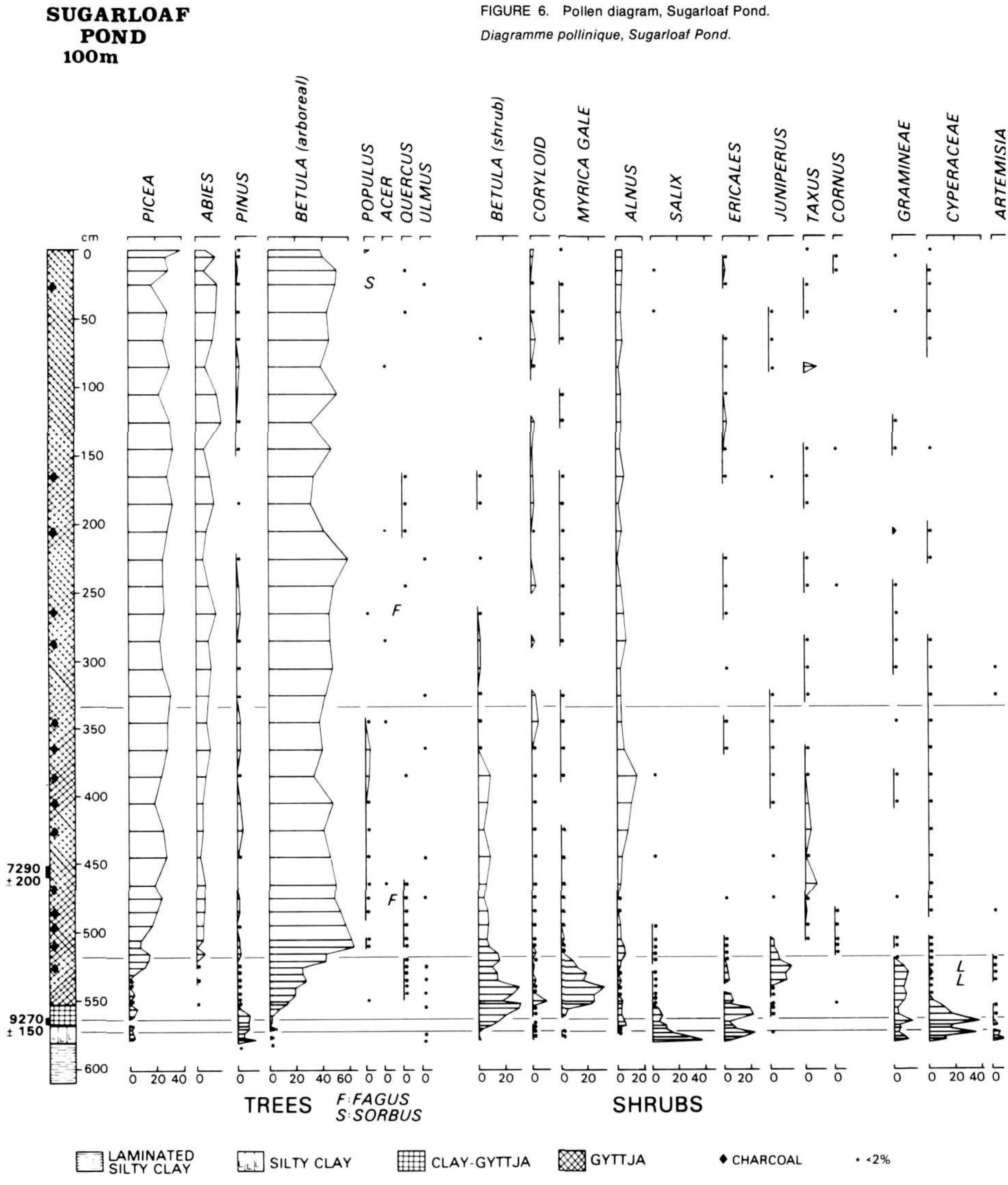
During the initial counting attempts were made to distinguish between *Picea mariana* and *Picea glauca* by visual inspection, but consistent results could not be achieved. *Picea* has therefore been treated as one taxon in the diagrams. However, application of the method of BIRKS and PEGLAR (1980) to modern pollen from the Avalon Peninsula demonstrates its practicability in the differentiation of local pollens of the two spruces. Accordingly, twenty spruce grains from each of four levels in the Sugarloaf Pond core (surface, 445 cm, 475 cm and 520 cm) and from two levels in the core from the Hawke Hills kettle pond (surface and 275 cm) were measured after the pollen diagrams were drawn. In each case, except the lowest sample from the Sugarloaf Pond core, all the spruce grains could be assigned with some certainty to *P. mariana*. The sample from 520 cm in the Sugarloaf Pond core appeared to contain a mixture of both *P. mariana* and *P. glauca*. Thus, although *P. glauca* appears to have experienced a relative or absolute decline since its early arrival, as it did in southeastern Labrador (LAMB, 1980), it appears to have been accompanied on the Avalon Peninsula by *P. mariana* from the outset. No attempt was made to distinguish between the pollens of the pines or of the poplars.

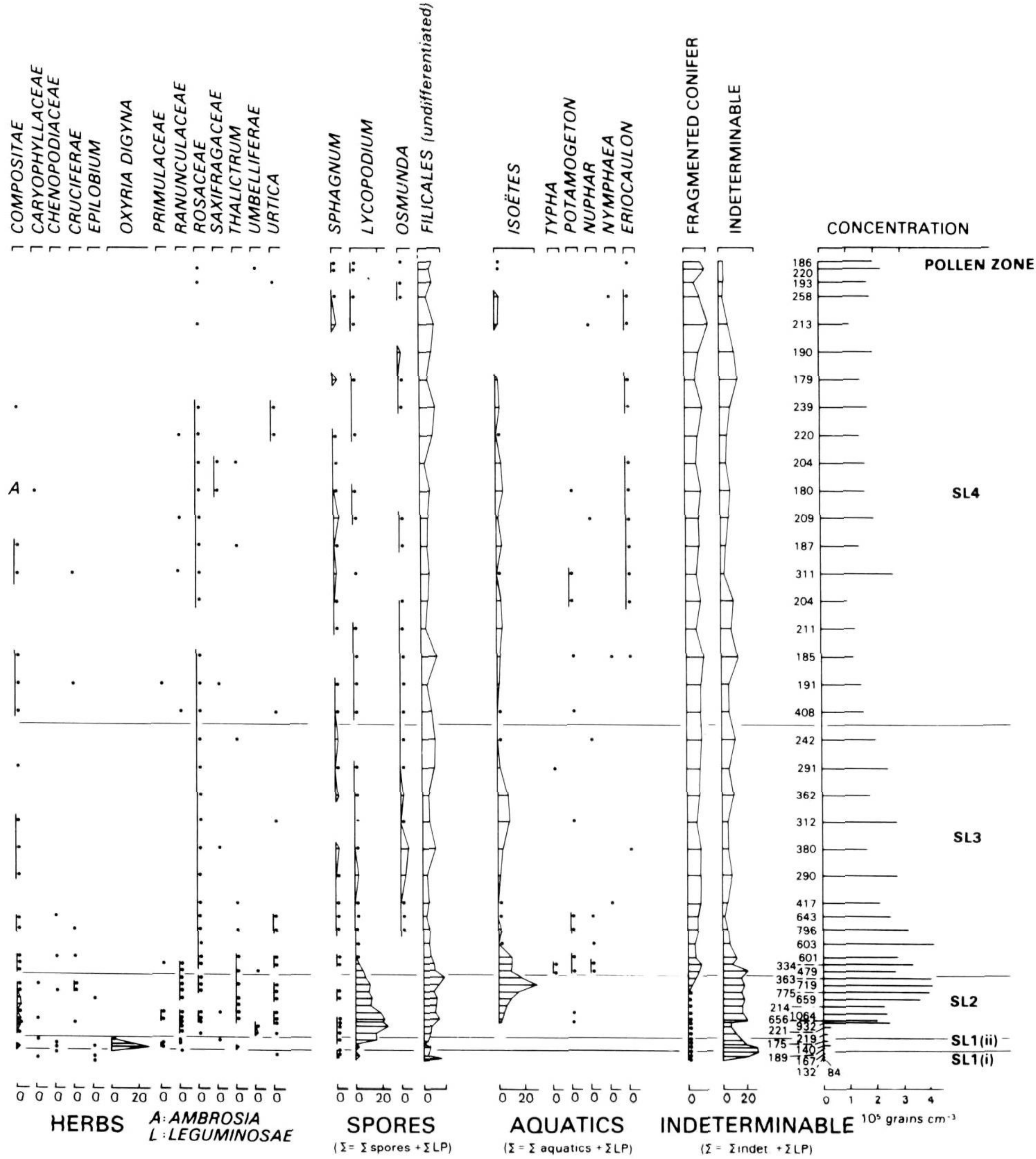
Following the work of LEOPOLD (1956) and IVES (1977), *Betula* pollen was classified according to size; grains greater in diameter than 20 μm were considered to represent arboreal sources, while smaller grains were considered to represent shrub birch. Subsequent measurements of modern birch pollen grains from the Avalon Peninsula indicate that the size ranges of pollen of *B. cordifolia*, *B. pumila* and *B. michauxii* all extend below 20 μm, as do those of *B. glandulosa* and *B. nana* (IVES, 1977), whereas the diameters of grains of *B. papyrifera* and *B. lutea* exceed 23 μm and 28μm respectively. Thus the criterion adopted is likely to ensure that all but a small proportion of the grains classified as being of shrub origin are correctly assigned, the exception being a few small grains of *B. cordifolia*. However, a larger proportion of the grains classified as being of arboreal origin will, in fact, be of shrub origin, since there is considerable overlap between the size ranges of modern tree and shrub birch grains.

Of the shrubs, *Alnus crispa* and *A. rugosa* were not differentiated. Grains of both types were present, although *A. rugosa* does not now occur on the Avalon Peninsula. Pollen classified as "coryloid" includes all triporate grains with no clear pore structure; this group almost certainly includes *Corylus* at the base, but the majority of such grains are probably somewhat deteriorated *Myrica gale* pollen. *Empetrum* pollen is grouped with the Ericaceae, as Ericales.

Reference slides were used for identification wherever possible. In particular, attempts were made to obtain or prepare reference slides of pollen types which had not previously been encountered and which had

FIGURE 6. Pollen diagram, Sugarloaf Pond.
Diagramme pollinique, Sugarloaf Pond.




COMPOSITAE
CARYOPHYLLACEAE
CHENOPODIACEAE
CRUCIFERAE
EPILOBIUM
OXYRIA DIGYNA
PRIMULACEAE
RANUNCULACEAE
ROSACEAE
SAXIFRAGACEAE
THALICTRUM
UMBELLIFERAE
URTICA
SPHAGNUM
LYCOPODIUM
OSMUNDA
FILICALES (undifferentiated)
ISOËTES
TYPHA
POTAMOGETON
NUPHAR
NYMPHAEA
ERIOCAULON
FRAGMENTED CONIFER
INDETERMINABLE
CONCENTRATION
POLLEN ZONE
SL4
SL3
SL2
SL1(ii)
SL1(i)
A
HERBS
A: AMBROSIA
L: LEGUMINOSAE
SPORES
(Σ = Σ spores + Σ LP)
AQUATICS
(Σ = Σ aquatics + Σ LP)
INDETERMINABLE
(Σ = Σ indet + Σ LP)
10⁵ grains cm⁻³

been provisionally identified through the use of pollen keys. Such types include *Taxus canadensis, Oxyria digyna* and *Androsace septentrionalis.*

POLLEN ZONATION

The pollen assemblage zones recognized in the pollen diagrams are shown in Figures 5, 6 and 7. The Hawke Hills zones are a composite from the cores obtained from the two sites.

A. *Sugarloaf Pond*

The pollen assemblage zones are as follows:

Pollen assemblage zone SL-1: sedge-willow (below 563 cm; ended 9270 BP)

This zone can be subdivided as follows: SL-1 (i); willow-sedge-Ericales pollen sub-zone (below 572 cm); SL-1 (ii): sedge-*Oxyria digyna* pollen sub-zone (563-572 cm).

Pollen assemblage sub-zone SL-1 (i) is characterised by *Salix* (up to 43%), Cyperaceae (up to 35%) and Ericales (up to 23%). Filicales (to 13%), Gramineae (to 11%) and *Artemisia* (to 9%) also make significant contributions. Arboreal pollen of distant origin, including *Pinus, Picea, Betula* and *Ulmus,* constitutes 10-23% of the total, but since pollen concentrations are very low (1700-9300 grains cm^{-3}) far-travelled grains are few. The highest pollen concentrations occur in laminated silty clay at 573-576 cm; since all taxa are involved, including those of distant origin, a temporary reduction in the rate of sediment accumulation is indicated. The boundary between this and the succeeding sub-zone is drawn where *Salix* falls below 15%.

In pollen assemblage sub-zone SL-1 (ii) pollen concentrations increase from less than 3000 grains cm^{-3} to more than 20,000 grains cm^{-3} with the change from clay to clay-gyttja. The pollen spectra are dominated by herbs, which make up more than 50% of the total throughout. The greatest contribution is made by Cyperaceae (up to 38%); *Oxyria digyna* and Gramineae attain respective peaks of 27% and 15%, *Lycopodium* increases to 16% and "shrub" birch to 15%. The upper boundary of pollen assemblage zone Sl-1 is drawn where the total contribution of herb pollen falls from above 50% to less than 30%.

Pollen assemblage zone SL-2: birch-shrubs-*Lycopodium* (518-563 cm; 9270-*ca* 8300 BP)

The pollen spectra of this zone are dominated by shrub taxa, the total contribution of shrub pollen rising from 56% at the base to a maximum of 67% and declining to 38% at the top of the zone. Among these taxa there are successive maxima in the percentage contributions and concentrations of Ericales (21%), "shrub" birch (30%), *Myrica gale* (32%) and *Juniperus* (16%). The pollen of *Alnus* is consistently present and toward the top of the zone its concentration rises to values which suggest its presence in the vegetation. Maxima of *Lycopodium* and *Isoetes* are also recorded.

Herb pollen declines from 29% at the base to 5% at the top of the zone, while the total percentage of arboreal pollen increases to 57%. "Tree" birch increases to 43% and spruce (both *Picea mariana* and *P. glauca)* to 12% at the top of the zone, when balsam fir begins its continuous representation. A marked increase in the pollen of this species defines the top of the zone.

The highest pollen concentrations found in the core occur at the top of this zone and the base of the next, reaching a maximum of almost 300,000 grains cm^{-3}, while pollen influx increases from 1000 to almost 16,000 grains $cm^{-2}\ a^{-1}$, largely as the result of the high input of birch pollen. Certain taxa, with maximum percentage values elsewhere in the profile, reach their highest concentrations, notably Gramineae, Ericales, *Salix* and undifferentiated Filicales spores.

Pollen assemblage zone SL-3: birch-spruce-balsam fir with poplar (335-518 cm; *ca* 8300 BP- *ca* 5400 BP).

The base of this zone is marked by an increase in arboreal percentages to more than 60%. "Arboreal" birch attains a maximum of more than 63% at 505-510 cm, decreasing to below 40% at the top of the zone. This may result from the inclusion of shrub birch pollen in the arboreal category, because of the size criterion which was adopted. *Picea mariana* increases irregularly to 30%, and *Abies balsamea* attains 10% at the top of the zone. Although the contribution of *Pinus* is generally less than 2%, its greatest concentrations occur within this zone. *Populus* is almost continuously present, but rarely in proportions greater than 2%. The first grains of *Acer* and *Fagus* were noted; the *Acer* grains may have originated with *Acer spicatum* which occurs in Newfoundland, but the *Fagus* grains indicate continued long distance transport from the southwest.

The shrub pollens which were so conspicuous in the preceding zone occur with decreasing percentages and concentrations, apart from *Alnus* which attains its highest percentage value (15%) and concentration in this zone. Pollen ascribed to *Taxus canadensis* makes its appearance. *Osmunda* spores appear and attain their maximum percentage value of 5%, and the number of aquatic taxa represented shows a marked increase.

Total pollen concentrations decline irregularly throughout the zone to less than 150,000 grains cm^{-3}. Charcoal is present in almost every sample. The top of the zone is defined by the cessation of the continuous representation of poplar and by an increase in balsam fir values to generally more than 10%.

Pollen assemblage zone SL-4: birch-spruce-balsam fir (above 335 cm; *ca* 5400 BP to present)

The pollens of "tree" birch (33-61%), *Picea* (18-28%) and *Abies balsamea* (6-20%) dominate the spectra of this zone, varying in their proportions in no systematic fashion. *Abies*, especially, varies in both percentage contribution and concentration from sample to sample. A number of criteria serve to differentiate this pollen assemblage zone from the preceding zone. *Populus* ceases to be continuously present, but total arboreal percentages are generally higher, ranging from 83% to 95%, compared with a range of from 68% to 89%. Shrub percentages are generally lower, falling below 10% for the first time in the profile, and the contribution made by "shrub" birch in particular is much reduced. Total pollen concentrations are reduced to about 100,000 grains cm^{-3} between 245 and 265 cm (*ca* 4000 BP), rising subsequently to mean values of about 130,000 grains cm^{-3}. Charcoal occurs less frequently than in the preceding zone.

B. Hawke Hills

The upper 55 cm of the partial core from the col gully site contains a pollen assemblage similar to that from the basal 55 cm of the core from the kettle site, permitting the establishment of a composite sequence of local pollen assemblage zones (Fig. 7). No equivalent of pollen assemblage zone SL-1, the lowest from the Sugarloaf Pond core, may be recognised. The earliest zone from the Hawke Hills occurs only in the col gully site, and is undated.

The pollen assemblage zones from the Hawke Hills are as follows:

Pollen assemblage zone HH-1: birch-shrubs (below 360 cm in col gully site, absent from kettle site)

The pollen of shrubs provides up to 50% of the total, and includes up to 17% of each of "shrub" birch, *Juniperus* and *Myrica gale*. Birch grains of diameter greater than 20 μm form the greatest single component of the assemblage; although classified as tree birch they may well include a proportion produced by shrubs. Herbs, dominated by Gramineae, contribute up to 22% of the total, and *Lycopodium* is present in values up to 13%. *Picea* is present throughout, attaining an early peak of 21% but declining in percentage contribution with increasing "tree" birch. *Abies* is present at the top of the zone. *Pinus*, presumably inblown, declines from an initial maximum of 11%. This zone appears to be the correlative of the upper part of pollen assemblage zone SL-2.

Pollen assemblage zone HH-2: birch-spruce-balsam fir with poplar (above 360 cm in col gully core; below 190 cm in kettle core; ended *ca* 5300 BP)

The base of this zone in the col gully core is marked by a rapid increase in "tree" birch to a peak of 75%, accompanied by sharp decreases in the shrub and herb components. *Abies* values increase to 15% at the top of the analysed section of the core, while tree birch, spruce and pine decline, the last to insignificant values. Poplar is occasionally present.

"Tree" birch values are not as high at the kettle site, reaching a maximum of 65% near the base, and balsam fir percentages are also generally lower. Values for spruce are erratic, but are generally higher than at the col gully site, and poplar is continuously present in values up to 3.3%. Pollen identified as that of *Taxus canadensis* was present in most samples; it was not counted in samples from the col gully core. *Lycopodium* and *Osmunda* values are greater than at the col gully site.

The top of the zone is defined by the end of the continuous representation of poplar, and by an increasingly discontinuous representation of most shrub taxa.

This zone has affinities with zone SL-3, from Sugarloaf Pond. However, despite the much slower rate of sediment accumulation at the kettle site, total pollen concentrations are lower (less than 100 000 grains cm^{-3}), giving pollen influx rates generally less than 3000 grains cm^{-2} a^{-1}, compared with a probable range of influx in zone SL-3 of 7000-16,000 grains cm^{-2} a^{-1}.

Pollen assemblage zone HH-3: birch-spruce-balsam fir (72-190 cm in kettle core; *ca* 5300-3200 BP)

In this zone pollen concentrations (*ca* 100,000 grains cm^{-3}), rates of pollen influx (up to *ca* 6000 grains cm^{-2} a^{-1}) and arboreal pollen percentages (77-93%) attain maxima. Percentage values for most taxa show no definite trends, with birch at about 50%, spruce at about 25% and balsam fir at about 10%. *Taxus* is reduced to low percentages by the top of the zone, and "shrub" birch is discontinuous in the middle of the zone. The pollen assemblage of this zone is similar to that of SL-4 from Sugarloaf Pond, and differences between the rates of pollen influx at the two sites are less than during the preceding zone.

Pollen assemblage zone HH-4: spruce-birch-balsam fir (0-72 cm in kettle core; 3200 to present)

The base of this zone is marked by a sharp decline in "tree" birch percentages from *ca* 50% to *ca* 35%, reflected in a corresponding decline in total arboreal pollen percentages. At the same time there is a slight reduction in pollen concentrations, and, if the radiocarbon date at the zone boundary is correct, a threefold reduction in total pollen influx. This reduction affects different taxa in varying degrees, the least affected being the wetland group. Certain taxa grouped with the

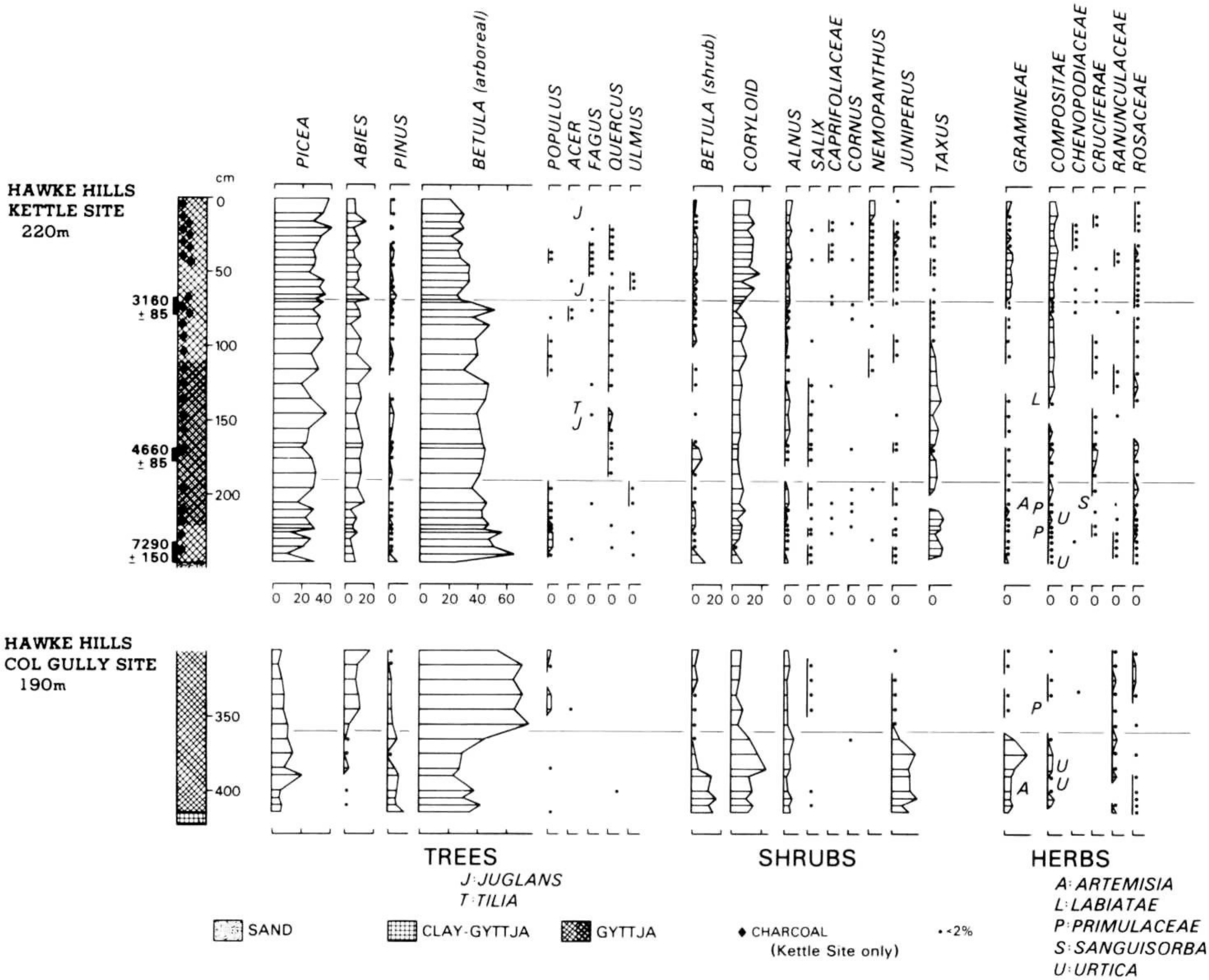


FIGURE 7. Pollen diagrams, Hawke Hills kettle and col gully sites. *Diagrammes polliniques, sites du kettle des Hawke Hills et du col gully.*

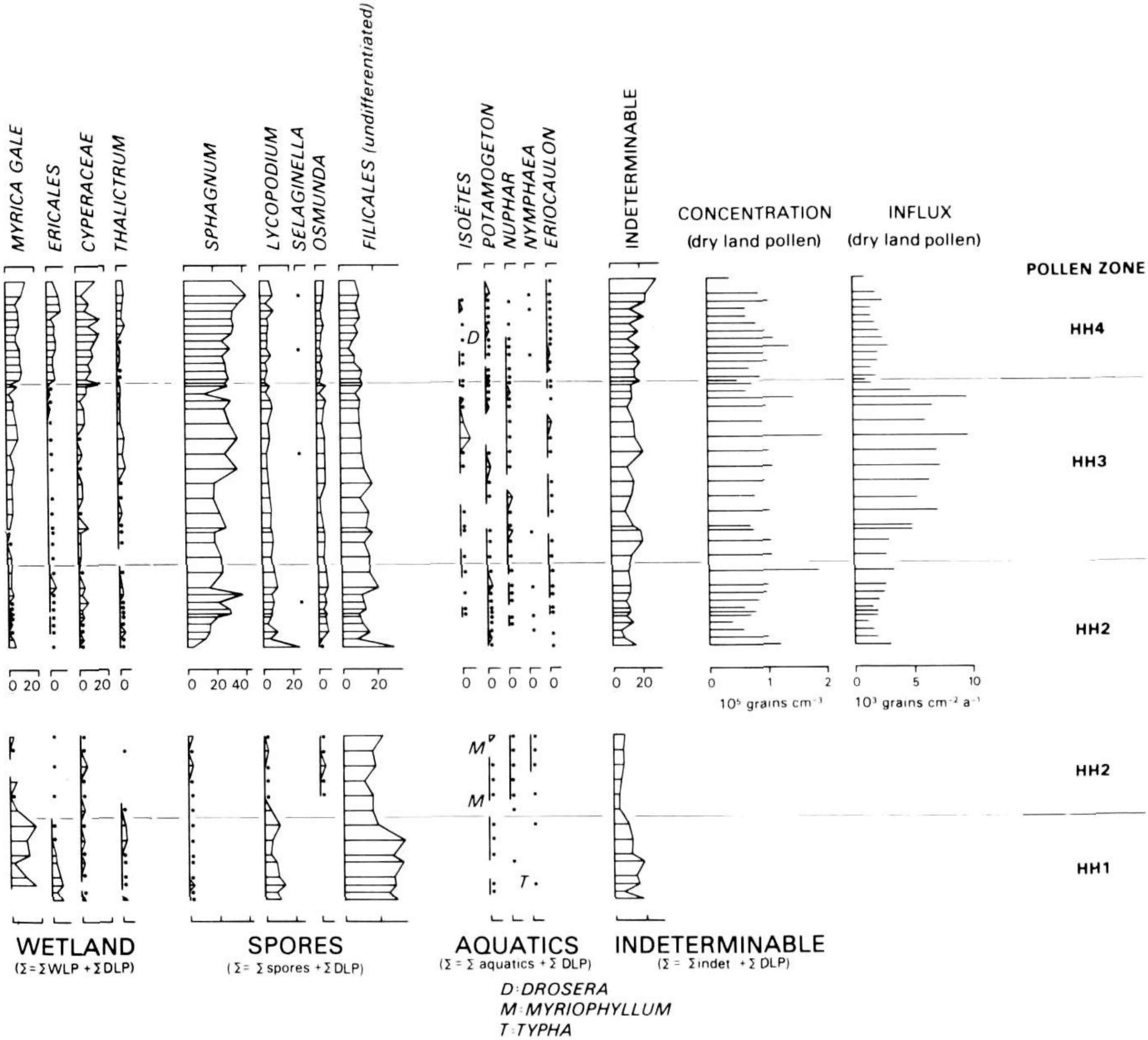
shrubs ought perhaps more properly to be included in the wetland group for this part of the core. These include coryloid pollen, which, because there is no hazel in the local area, is most probably the degraded pollen of *Myrica gale*, found commonly on the bog surrounding the kettle pond. Similarly, the birches, *Betula pumila* and *B. michauxii,* together with *Nemopanthus mucronata*, are also shrubs which occupy damp sites adjacent to the coring site. Nevertheless there are aspects of the representation of shrubs which are considered to be significant: the renewed continuous representation of *Juniperus* and the decline in *Taxus*. The implications of these changes will be discussed below.

There is no equivalent of this pollen assemblage zone in the Sugarloaf Pond core.

REGIONAL POLLEN ZONES AND VEGETATIONAL HISTORY

On the basis of the zonations discussed above it is possible to suggest a tentative sequence of regional pollen zones (Table III), not all of which are represented at any one site.

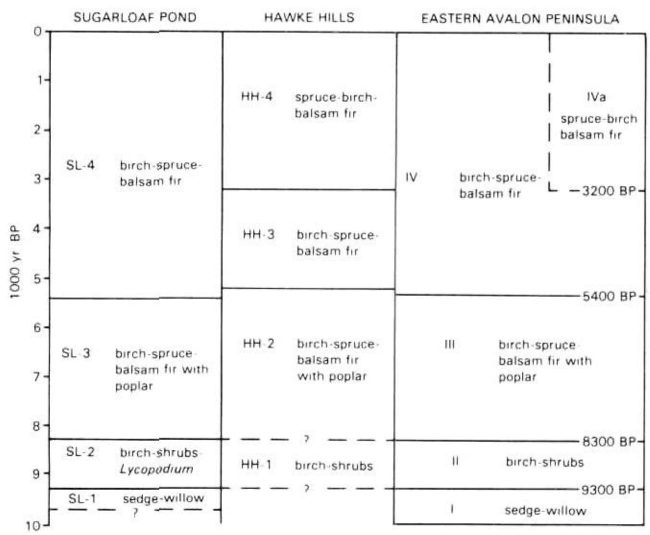
The earliest zone, the sedge-willow zone, occurs before 9300 BP at the Sugarloaf Pond site only. The birch-



shrubs zone occurred during the next millenium at the Sugarloaf Pond site, and for an unknown period in the Hawke Hills, where it had certainly terminated before 7300 BP. The following zone, the birch-spruce-balsam fir with poplar zone, terminated at both sites at about 5400-5300 BP, and was followed by the birch-spruce-balsam fir zone, which has continued to the present at Sugarloaf Pond, but which in the Hawke Hills gave way at *ca* 3200 BP to the spruce-birch-balsam fir sub-zone.

The fossil pollen assemblages of these regional pollen zones cannot be translated directly into past vegetation assemblages, for the proportions of the various taxa as represented by their pollen in samples of surface lake mud do not represent the proportions of the taxa in the present regional vegetation, except in the case of spruce. Birch is strongly over-represented, comprising 39% of the modern pollen spectrum from Sugarloaf Pond but only 7% of the productive forest. Even at the kettle site in the Hawke Hills, where birch in the vicinity is represented only by a few specimens of the shrubs *Betula pumila* and *B. michauxii*, and a few stunted specimens of *B. cordifolia* which were not seen to be flowering in the spring of 1981, the assemblage in the surface mud contains 22% of birch pollen. Balsam fir, on the other hand, the most common tree, with 55% of the productive forest, contributes only about 8% of the recent pollen input to lake sediments. Other common

Table III
Local and Proposed Regional Pollen Zones Eastern Avalon Peninsula



taxa are also poorly represented by their pollen. Ericaceae and *Empetrum* are very common in the heath vegetation of the Hawke Hills, yet there is only 5% of Ericales pollen in the surface mud of the kettle pond, together with less than 1% of juniper pollen, although *Juniperus communis* is also very common in the area. Other taxa do not appear at all in the pollen diagrams. Although larch is quite common in the poorer forests of the Avalon Peninsula, it is represented in the pollen record only by very occasional grains, and is not included in the diagrams. The *Cladonia* which is widespread in the subalpine lichen barrens of the Hawke Hills does not contribute to the pollen rain. Its presence restricts the area available to higher plants, accounting in part for the low pollen influx at the kettle site.

An alternative approach to the interpretation of the fossil pollen assemblages is to compare them with modern assemblages from different vegetation regions, an approach which in this case proved to be of limited utility, as will be seen below. Hence the vegetational reconstruction which follows is essentially intuitive, with reference being made to published interpretations of other fossil pollen assemblages which have no modern analogues.

To facilitate comparison between fossil and modern spectra, Figure 8 has been devised using representative spectra from the major vegetational regions of eastern Canada between the tundra of central Baffin Island in the north and the Acadian Forest of Cape Breton Island in the south, arranged in latitudinal order as much as possible, and grouped according to the findings of DAVIS (1980). Coastal forest-tundra sites south of the main forest-tundra belt were not included. Published spectra from lake muds were used in preference to those from air-borne or moss samples wherever possible. Cyperaceae pollen was included in the sum only in tundra zones; to the south it was considered to represent a local wetland component. All taxa in Figure 8 are represented as percentages of the total pollen sum; in certain cases this required a recalculation of published data. The sources of the data, and of the vegetational boundaries, are noted beneath the diagram.

SEDGE-WILLOW ZONE

The high *Salix*, Cyperaceae and Ericales percentages of the early part of the sedge-willow zone from the Avalon Peninsula indicate an affinity with the intermediate arctic tundra region of central Baffin Island, as typified in Figure 8, whereas the increasing shrub birch and high herb percentages of the later part of the zone invite comparison with the low arctic tundra region of northern Labrador. However, the fossil assemblage of the upper part of the sedge-willow zone differs in one major respect from modern low arctic tundra spectra: the representation in values up to 27% of *Oxyria digyna*. Pollen of this species is not uncommon in modern tundra spectra, but occurs at low values (RITCHIE and LICHTI-FEDEROVICH, 1967).

In the oceanic heath of Disko Island, West Greenland, where *Oxyria digyna* is common near long-lasting snow banks, its pollen in somewhat over-represented in modern lake samples at values of less than 4% (PENNINGTON, 1980). The peak of *Oxyria* pollen near the base of the Sugarloaf Pond profile therefore indicates a significant proportion of *Oxyria* in the vegetation. Much higher *Oxyria* pollen percentages (up to 76%) are found in the basal sediments of certain South Greenland lakes; FREDSKILD (1973) comments on the plant's role as a coloniser and its preference for damp sites. PENNINGTON (1977) has examined pollen spectra from moss polsters in areas in front of Norwegian valley glaciers which have been deglaciated within the last two centuries, and has found *Oxyria* percentages as high as 29%; MATTHEWS (1978) recognises *Oxyria* as a colonising species in such areas. Both the brief presence of *Oxyria* pollen in the Sugarloaf Pond core, and the high percentages attained, point to its presence in the vegetation as a coloniser, and support the conclusion that deglaciation of at least part of the basin occurred no earlier than 9700 BP. The coincidence of the *Oxyria* peak with decreasing *Salix* and increasing *Betula*, reminiscent of the trend from north to south in today's tundra (Fig. 8), suggests that part of the catchment, presumably the hill tops, had been deglaciated and colonised before the lake basin and its adjacent slopes became ice free. This suggestion is reinforced by examination of the profile from Lac Mimi, Charlevoix county, Québec (RICHARD et POULIN, 1976), where

5% *Oxyria* pollen is present at the base, together with Cyperaceae, Gramineae and *Salix*, representing a herb tundra vegetation. Peaks in *Salix* and then in small birch pollen followed the decline in *Oxyria*, indicating a change to shrub tundra vegetation.

Occasional grains of *Androsace septentrionalis* were encountered in this zone in the Sugarloaf core, and have been found in early Holocene samples from elsewhere on the Avalon Peninsula (MELLARS, pers. comm.). The plant is reported today from only two locations in western Newfoundland, a coastal limestone area on the Northern Peninsula (information from Agnes Marion Ayre Herbarium, Memorial University) and the ultramafic massif of Table Mountain, Bonne Bay (DEARDEN, 1979). Its former more widespread occurrence in Newfoundland is probably related to the prevalence of open habitats in the early Holocene.

BIRCH-SHRUBS ZONE

The fossil pollen assemblage of the following birch-shrubs zone, dominated by shrub pollen, has no modern analogue. Although modern spectra from the forest-tundra of north-central Labrador include a considerable component of birch pollen, this is accompanied by similar or greater contributions of both alder and spruce. On the Avalon Peninsula spruce pollen was not present in significant percentages until late in the zone, and the proportion of alder pollen has never been as great as in Labrador today. Moreover, the peaks of *Myrica gale*, *Juniperus* and *Lycopodium* in the fossil assemblages are absent from modern forest-tundra spectra, although *Myrica gale* was better represented in Labrador in the past (SHORT and NICHOLS, 1977; SHORT, 1978).

A more appropriate modern analogue of the shrub-dominated vegetation of the birch-shrubs zone, although less productive, can be found on the summits of the Hawke Hills, where these taxa occur together with other low shrubs, including various Ericaceae, *Empetrum eamsii*, shrub birches and members of the Rosaceae (DAY, 1978). Although *Myrica gale* is described as a wetland or streambank species (FERNALD, 1970; RYAN, 1978) it occupies mesic sites on these summits, and it may have occupied similar sites while it was producing its peak input of pollen to the sediment, since

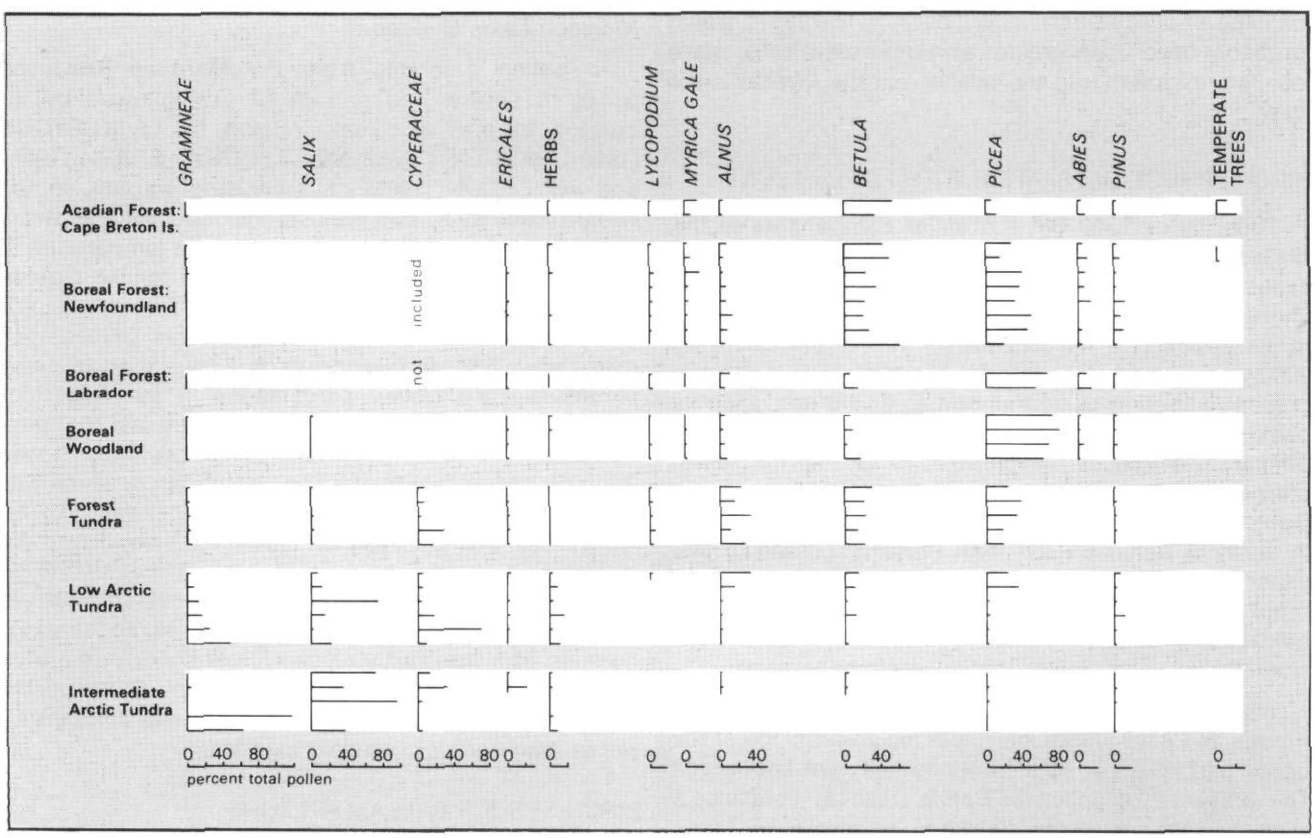


FIGURE 8. Representative modern pollen spectra, eastern Canada. Data from ANDREWS *et al.* (1980), BARTLEY (1967), JORDAN (1975), LAMB (1980 and pers. comm.), McANDREWS and SAMSON (1977), MOTT (1974), RAILTON, (1973), SHORT and NICHOLS (1977), TERASMAE (1976) and author.

Spectres polliniques actuels représentatifs de l'est du Canada. Données d'après ANDREWS et al. (1980), BARTLEY (1967), JORDAN (1975), LAMB (1980 et comm. pers.), McANDREWS et SAMSON (1977), MOTT (1974), RAILTON (1973), SHORT et NICHOLS (1977), TERASMAE (1976) et l'auteur.

there is no evidence in the pollen assemblage to suggest the widespread occurrence of wetland sites at that time.

Early postglacial peaks of *Myrica gale* and of *Juniperus* have been reported from elsewhere in eastern Canada, for example from southwestern New Brunswick (MOTT, 1975a) and from Mauricie, Québec (RICHARD, 1977a), where they are associated with or succeed a peak in *Populus*. On the Avalon Peninsula, however, peaks in *Myrica* and *Juniperus* precede the continuous presence of *Populus*.

The birch-shrubs zone is interpreted as representing a period of 1000 years of continuously changing shrub vegetation, highly productive at lower elevations, into which trees were migrating. Spruce was almost certainly present by the end of the zone, to be followed about two centuries later by balsam fir. The increasing contribution of birch pollen grains larger than 20 μm suggest that tree birches also entered the peninsula during this period, a conclusion which is reinforced by the different proportions of birch grains $>20\mu$m at the two Hawke Hills sites in local pollen zone HH-2. Had this "tree" birch component in fact included a considerable percentage of shrub birch pollen, birch percentages would probably have been greater at higher elevations, while conifers migrated into the valleys, but the reverse is the case.

BIRCH-SPRUCE-BALSAM FIR WITH POPLAR ZONE

Thus, by *ca* 8300 BP, the major components of the present forest were already in place, and it might be expected that a closed forest would have developed shortly thereafter. However, no such closing of the forest appears to have occurred during the following 3000-year period, for "shrub" birch was continuously present, although declining, and alder did not reach its peak until late in the period at the Sugarloaf Pond site. Similar evidence of the persistence of "shrub" birch after the arrival of spruce occurs in the Whitbourne and Goulds profiles of TERASMAE (1963). As these sites lie in areas of richer till soil than those discussed in this paper, they might have been expected to show a more rapid development of a closed forest. Because they do not, the retardation of forest development must be considered a regional, rather than a local phenomenon.

Was the partly open vegetation of this zone a park tundra, as LAMB (1980) interprets the assemblage of the upper part of his zone II from southeastern Labrador? The presence of pollen of *Betula lutea* at Terasmae's sites, together with the presence of pollen of *Taxus canadensis* at the Sugarloaf Pond and Hawke Hills sites, suggests rather that the vegetation was an open wood land with an understorey or glades of shrubs, having no modern analogue. *Populus*, probably *P. tremuloides*, was probably a constituent of the vegetation, because, although its pollen occurs in percentages no greater than 5%, it is continuously present. RICHARD (1977b) and MOTT (1978) have published a number of pollen profiles in which the early continuous presence of *Populus* pollen is taken to indicate the presence of the tree during the phase of afforestation. In the Avalon Peninsula, by contrast, poplar seems to have arrived after the major arboreal components of the present vegetation. *Populus tremuloides* is less common today on the Avalon Peninsula than in north-central Newfoundland where precipitation is lower (less than 1200 mm compared with more than 1600 mm), growing season temperatures are at least 1°C higher, and fire is more frequent (PAGE, 1972; DAMMAN, 1976). This suggests that effective precipitation was lower than at present during the period 8300-5300 BP, and because charcoal is present in almost every sample, fire appears to have been frequent. Openings created by fire would also have favoured the growth of alder and shrub birch. *Alnus crispa* is a vigorous coloniser of disturbed sites and burnt-over areas on the Avalon Peninsula, while TERASMAE and MOTT (1965) note the abundance of *Betula glandulosa* in burnt-over areas in the vicinity of Nichicun Lake, Québec.

In pollen diagrams from the Maritime Provinces peaks in spruce and balsam fir are followed by increases in pine and oak, related by LIVINGSTONE (1968), HADDEN (1975), MOTT (1975a), GREEN (1976) and ANDERSON (1980), to increasing warmth. In the Avalon Peninsula, however, neither species was available to take advantage of any increase in temperature. If steady rates of deposition are assumed for the Goulds and Whitbourne sites (TERASMAE, 1963), it was not before about 4500 BP that *Pinus strobus* percentages rose above 5%, suggesting its late migration into the peninsula. Pine pollen percentages in the Sugarloaf Pond and Hawke Hills profiles do not suggest that pine has ever occurred in the vicinity of those sites. It was *Populus*, together with alder and shrub birch, which was able to take advantage of the stress engendered by effective precipitation less than that of the present and the resulting frequent fires. It is of interest that RICHARD (1980b) invoked fire, resulting from decreased moisture and possibly increased temperatures, to account for opening of a previously closed forest cover in the area south of Lake Abitibi, Ontario and Québec, in the period 6000-3250 BP, although in that case it was *Juniperus*, rather than *Populus*, which expanded.

BIRCH-SPRUCE-BALSAM FIR ZONE

By interpolated dates of 5400 BP at the Sugarloaf Pond site, and 5300 BP at the Hawke Hills kettle site, the trend toward closing of the forest cover on the Avalon Peninsula was finally resumed. *Populus* ceased to be continuously present, and pollen assemblages at both sites suggest a boreal forest similar to that of today (Fig. 8). At the Hawke Hills site arboreal pollen percentages reached a maximum, as did pollen influx and the rate of sediment accumulation, the latter indicating increased lacustrine organic productivity. The zone coincides in part with the 110 cm of brown gyttja noted in the core. Thus there appears to have been a greater resemblance between general conditions in the Hawke Hills and at lower elevations in the period 5300-3200 BP than previously. It is suggested, therefore, that during this period the treeline was higher, and the kettle pond lay within the forest instead of at its margin as it does today. While this indicates increased temperatures, the increase in the representation of *Abies* in the Sugarloaf Pond core from 5300 BP to the present indicates increased availability of moisture (HALLIDAY and BROWN, 1943). There is little to indicate the effect of higher temperatures at the Sugarloaf Pond site unless it be a reduction in pollen concentrations from about 5000 BP to about 4000 BP, which may suggest an increased sedimentation rate resulting from increased lacustrine productivity.

By 3200 BP pollen influx at the kettle site was declining and the sediment had changed from brown to pale gyttja. The much reduced mean sedimentation rate after 3200 BP might be ascribed to flushing of sediment from the shallowing pond during peak spring runoff, were it not associated with a change in the nature of the sediment and with a marked change in pollen representation. These changes are accompanied by a sharp reduction in the influx of dry land pollen, most marked in the case of arboreal birch. For the first time spruce pollen dominates the arboreal component of the pollen rain, and in this respect the pollen assemblage of the spruce-birch-balsam fir sub-zone begins to resemble pollen spectra from the boreal forest and woodland regions of Labrador (Fig. 8). The decline in the arboreal component of the pollen assemblages accumulating after 3200 BP in the Hawke Hills was accompanied by a relative increase in the shrub component. As discussed earlier, certain shrub taxa ought perhaps to be included with the wetland group, but the renewed continuous representation of juniper is considered to a significant indicator of open vegetation. The decline in *Taxus* could also indicate a withdrawal of the forest, but another possibility is that the decline was associated with leaching of carbonates from the soil. No *Taxus* has been found in the vicinity of the site today.

The sensitivity of the vegetation of the Hawke Hills to declining temperatures after 3200 BP is paralleled by the sensitivity of both vegetation and soil to increased human access in recent years. The northernmost summit, accessible by motor vehicles, is subjected to the greatest amount of trampling, with the destruction of the already discontinuous vegetation cover. This results in increased frost-sorting of the soil, small-scale wind erosion, and increased mass wasting on slopes, causing the burial of organic soil beneath mineral debris. Even at the elevation of the kettle pond trampled and exposed crests of till hummocks show the development of soil polygons over a normal podzol profile. By contrast, a summit to the south, at over 315 m a.s.l., where there is less trampling, has a more continuous cover of vegetation and markedly less soil movement.

At lower elevations, as exemplified by the Sugarloaf Pond profile, there is no evidence of the effect of climatic deterioration upon the vegetation, nor is such an effect apparent in any of Terasmae's profiles. In the topmost sediments from the Sugarloaf Pond core a decline in birch is possibly associated with recent clearing for agriculture of the better soils. Terasmae found some evidence of an increase in non-arboreal pollen percentages in near-surface spectra at the Whitbourne site, attributing it to forest clearance for agriculture, but no such increase occurs at Sugarloaf Pond. However, the surface sample from this site contains the highest proportion (4.5%) of *Populus* pollen from the entire core. This is attributed to the availability of disturbed but unused sites associated with agricultural and urban development in the vicinity of St. John's; trembling aspen is common in such situations.

HOLOCENE CLIMATIC CHANGE

The evidence put forward above suggests rapid amelioration of the climate of the Avalon Peninsula after the final, late, disappearance of Wisconsin glacier ice, and certainly after 9000 BP. The period 8300-5300 BP was drier than today, and possibly somewhat warmer, but the period of maximum warmth, 5300-3200 BP, was one of increased precipitation, and moisture has continued to be abundant during the cooler period of the past three millenia.

The present abundance of precipitation results from the passage of low pressure systems across or close to Newfoundland throughout the year. These disturbances affect a zone between two high pressure systems: the continental anticyclone which dominates northern Labrador in winter, and the oceanic Bermudan anticyclone which can extend its influence north in summer to give warm dry conditions in the Maritime Provinces and southern and central Newfoundland. With the absence in summer of the continental anticyclone the zone affected by low pressure systems extends north to include northern Labrador and Baffin Island. These summer disturbances are less vigorous than those of winter when temperature contrasts are greater (BANFIELD, 1981).

The climatic changes proposed for the Avalon Peninsula will be tentatively ascribed to changes in the balance between these three controls: the transient low pressure systems, the winter continental anticyclone and the Bermudan high pressure cell. The sequence of changes is portrayed diagrammatically in Figure 9, which represents climatic inferences based on pollen analysis, lacustrine sedimentation rates and rates of peat accumulation from New England to Baffin Island and from southern and central Québec, together with indications of oceanic and atmospheric warm periods according to the sources listed. Indications of warmth or moisture are relative and are specific to each area.

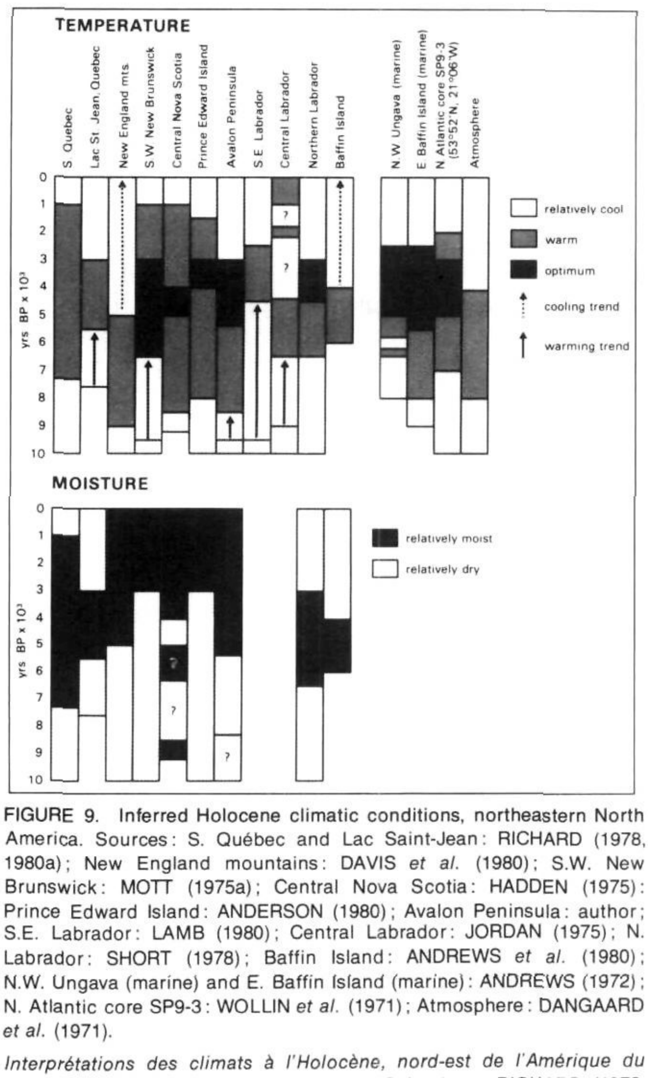


FIGURE 9. Inferred Holocene climatic conditions, northeastern North America. Sources: S. Québec and Lac Saint-Jean: RICHARD (1978, 1980a); New England mountains: DAVIS *et al.* (1980); S.W. New Brunswick: MOTT (1975a); Central Nova Scotia: HADDEN (1975): Prince Edward Island: ANDERSON (1980); Avalon Peninsula: author; S.E. Labrador: LAMB (1980); Central Labrador: JORDAN (1975); N. Labrador: SHORT (1978); Baffin Island: ANDREWS *et al.* (1980); N.W. Ungava (marine) and E. Baffin Island (marine): ANDREWS (1972); N. Atlantic core SP9-3: WOLLIN *et al.* (1971); Atmosphere: DANGAARD *et al.* (1971).

Interprétations des climats à l'Holocène, nord-est de l'Amérique du Nord. Sources: sud du Québec: et Lac-Saint-Jean: RICHARD (1978, 1980a); montagnes de la Nouvelle-Angleterre: DAVIS et al. (1980); sud-ouest du Nouveau-Brunswick: MOTT (1975a); centre de la Nouvelle-Écosse: HADDEN (1975); Île-du-Prince-Édouard: ANDERSON (1980); péninsule d'Avalon: auteur; sud-est du Labrador: LAMB (1980); centre du Labrador: JORDAN (1975); nord du Labrador: SHORT (1978); île de Baffin: ANDREWS et al. (1980); nord-ouest de l'Ungava (marin) et est de l'île de Baffin (marin): ANDREWS (1972); carotte SP9-3 du nord de l'Atlantique: WOLLIN et al. (1971); atmosphère: DANSGAARD et al. (1971).

The inferred climatic sequence for the Avalon Peninsula may be seen to have affinities with those from areas both to the north and south, and thus provides a useful link between them. Figure 9 indicates a much earlier onset of recognisably warmer conditions at terrestrial sites from southeastern Labrador southward (9000-8000 BP) than in northern Labrador and Baffin Island (6500-6000 BP). A number of factors may have been involved. Evidence from the Greenland ice sheet (DANSGAARD *et al.*, 1971) indicates that the atmospheric optimum began at about 8000 BP, and this would have led to increased warmth over land masses remote from the influence of cold ocean water. And, despite the northward retreat of the oceanic polar front from south of Newfoundland at 9300 BP to its present position south of Greenland by 7000 BP (RUDDIMAN and GLOVER, 1975), and the registration of surface temperatures greater than the present in the North Atlantic between 7000-2000 BP (WOLLIN *et al.*, 1971), there is evidence that surface waters off Labrador remained cold at least until 6500 BP. The rapid final disintegration of the Laurentide ice sheet after 8000 BP (BRYSON, *et al.*, 1969) resulted in the discharge through Hudson Strait of vast volumes of meltwater and floating glacier ice which must have contributed significantly to the Labrador Current (Fig. 1); a warming of coastal waters off eastern Baffin Island is evident by 8000 BP, preceding by 1500 years a warming off northwestern Ungava (ANDREWS, 1972).

Thus, despite the general atmospheric warming between 8000 and 6500 BP, or rather as a result of the warming, Labrador lay between a warming residual ice cap to the west and a cold ocean to the east.

As a result, the continental anticyclone would have been more extensive and may even have persisted throughout the year. Few frontal systems would have crossed northern and central Labrador, limiting the advection of heat and moisture. In winter fewer systems than at present would have passed over Newfoundland, the Maritime Provinces and New England, helping to explain the relatively dry conditions inferred for at least the early part of the climatic optimum.

There seems to have been no hindrance to the inflow of warm, moist air in the area immediately to the west of the Labrador-New England axis after 7000 BP, for RICHARD (1978, 1980a) infers a climate both warmer and moister than the present for the period 7000-1000 BP in southern Québec. Frontal systems drawing in such air from the Gulf of Mexico could have passed eastward across the Gulf of St. Lawrence in summer.

As the climatic optimum reached its climax the Bermudan anticyclone probably had a more persistent influence across the Maritime Provinces than in present summers, maintaining relatively dry conditions in that region. The final disappearance of remanent ice from central Labrador would have reduced the influence of the continental anticyclone, permitting the development of more northerly cyclone tracks and the penetration of warm, moist air to northern Labrador and Baffin Island in the summer. Such optimum conditions prevailed in Baffin Island from at least 6000 BP to 4000 BP (ANDREWS *et al.*, 1980). The longer period of warmth in northern Labrador (6500-3000 BP) included an interval of maximum warmth after 4500 BP (SHORT, 1978) which coincides in whole or in part with periods of inferred maximum warmth throughout southeastern Canada, based in southern Labrador and Newfoundland on increased pollen and lacustrine productivity and in the Maritime Provinces on increased representation of pine, oak and other hardwoods. However, evidence of changes in the altitudinal limits of trees in the mountains of New England suggests that a cooling trend had developed there shortly after 5000 BP (DAVIS *et al.*, 1980), following the climax of the atmospheric optimum as portrayed by DANSGAARD *et al.* (1971). This cooling in New England suggests an increasing frequency of outbreaks of arctic air, at the same time as the maximum advection of heat and moisture to the continental margin from Newfoundland northward. This in turn suggests vigorous cyclonic activity along the thermal gradient between cooling air over the northern part of the continent and warm air over the North Atlantic, where the response to cooling was delayed.

It was not until 3000 BP, when the oceanic optimum had been passed, that a cooling trend was registered in the terrestrial record of eastern Canada. In Labrador and at the treeline in the Avalon Peninsula this is indicated by reductions in lacustrine sedimentation rates and pollen concentrations and influx, and in the Maritime Provinces largely by a decrease in the representation of pine and hardwoods and by an increase of boreal elements in the pollen spectra. The climatic deterioration appears to have been more abrupt in Newfoundland and Labrador than in the Maritime Provinces, and recent detailed work in Baffin Island (ANDREWS *et al.*, 1980) and northern Newfoundland (McANDREWS and DAVIS, 1978) indicates that fluctuations of temperature have been superimposed on the general cooling trend. The cooling in northern Labrador and Baffin Island has been accompanied by a decrease in precipitation, but in the Maritime Provinces by increased moisture, indicating the establishment of the present pattern of cyclone tracks across the region.

CONCLUSIONS

The following conclusions may be drawn from this study:

1. Final disappearance of glacier ice from the eastern Avalon Peninsula occurred after 10,000 BP and probably as late as 9700 BP.

2. After a brief tundra period the climate ameliorated rapidly and a productive and rapidly changing vegetation of shrubs, with increasing tree birch, was present for 1000 years.

3. Spruce and balsam fir migrated into the area before 8300 BP, but the vegetation remained an open woodland, subject to fire, with a climate drier and possibly somewhat warmer than at present until about 5300 BP.

4. The period 5300-3200 BP saw the closing of the forest and a rise of the treeline in the interior upland. This was the period of maximum warmth, and precipitation was at least as heavy as at present.

5. After 3200 BP the treeline withdrew in the interior upland as a result of cooling, but no vegetational changes have been registered at lower elevations. Only minor changes in the pollen diagrams can be attributed to human activity.

6. The inferred sequence of climatic changes in the Avalon Peninsula provides a link between Labrador and the Maritime Provinces, and makes it possible to suggest a changing sequence of dominant controls upon the climate of the eastern Canadian seaboard during the Holocene. During the early Holocene the continental anticyclone over Labrador was dominant and fewer frontal systems than at present passed over Newfoundland and the Maritime Provinces. As the ice disappeared from Labrador, and as warming occurred to the south, the Bermudan anticyclone affected the Maritime Provinces. and possibly also southern Newfoundland, in summer, while weak frontal systems passed over Labrador and Baffin Island. As atmospheric temperatures began to decline the North Atlantic ocean remained warm, causing vigorous cyclonic activity which affected the whole of eastern Canada. Reduction in ocean surface temperatures has been associated with a regional deterioration of climate since 3000 BP.

ACKNOWLEDGEMENTS

The author acknowledges with thanks the assistance in the field of J. Evans of the Department of Biology and of numerous members of the Department of Geography, Memorial University of Newfoundland. Reference slides and herbarium material were kindly supplied by I.J. Bassett and C.W. Crompton, Biosystematics Research Institute, Canada Department of Agriculture; J.H. McAndrews, Royal Ontario Museum and P.J. Scott, Agnes Marion Ayre Herbarium, Memorial University. Measurements of spruce and birch pollen grains were made by Alison Dyer during the tenure of a Natural Sciences and Engineering Council of Canada Undergraduate Summer Research Award, 1981. Radiocarbon dates were provided by the Geological Survey of Canada and Dalhousie University. The climatic interpretation benefitted from discussion with C.E. Banfield, Department of Geography, Memorial University. A.H. Davis, B. Fredskild, R.J. Mott and P. Richard made useful comments upon an early abstract of the paper; A.G. Macpherson gave valuable editorial advice, and G. Brassard checked the French version of the abstract. The diagrams were drawn in the Memorial University of Newfoundland Cartographic Laboratory. The study was supported by operating grants from the Natural Sciences and Engineering Research Council of Canada.

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