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Pollen, Oxygen Isotope Content and Seasonality in an Ice Core from the Penny Ice Cap, Baffin Island

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ABSTRACT. The results of pollen analyses of 12 ice core samples, covering an eight-year period from 1972 through 1979 from the divide of the Penny Ice Cap, Baffin Island, are reported. The pollen spectra are dominated by long distance transported pollen, especially the conifers *Picea* and *Pinus*. *Alnus* pollen is generally rare. In contrast, pollen spectra from both modern polsters and fossil peat sections in the same area are both characterized by local pollen types. Pollen influx values range from 1 to 8 grains$\cdot$cm$^{-2}\cdot$yr^{-1}. Where the sampling intervals happened to coincide with established seasonal intervals (as interpreted from later oxygen isotope studies) the pollen spectra showed seasonal characteristics. This occurred in five out of the twelve samples. Comparison of these data is made with data from Devon Island Ice Cap. Such information may be useful in reconstructing paleoclimates.

Key words: pollen, ice cap, Baffin, isotope, paleoclimates

RÉSUMÉ. L'article présente les résultats des analyses de pollen de douze échantillons de carottes glaciales prélevés entre 1972 et 1979 à la ligne de partage du cap glacial Penny sur l'île de Baffin. Le pollen transporté sur de longues distances, en particulier celui des conifères *Picea* et *Pinus*, formait la majeure partie des échantillons. Le pollen *Alnus* était plutôt rare. D'autre part, le spectre pollinique provenant de massifs moussus modernes et de tourbières fossilisées dans la même région était représenté par des types de pollen locaux. Le taux d'afflux de pollen variait entre 1 et 8 grain cm^{-2}an^{-1}. Lorsque les intervalles d'échantillonnage coincidaient avec les intervalles saisonniers établis (interprétés selon des études postérieures d'isotopes d'oxygène), le spectre pollinique comportait des caractéristiques saisonnières, ce qui se produisit dans cinq des douze échantillons. Les données de cette étude sont comparées à celles du cap glacial de l'île Devon. Des reseignements de ce genre peuvent aider à reconstruire des paleoclimats.

Mots clés: pollen, cap glacial, Baffin, isotope, paleoclimats

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INTRODUCTION

Pollen analyses of snow and ice core samples, especially from arctic cores, are uncommon (Ambach *et al.*, 1966; Bortenschlager, 1970; Fredskild and Wagner, 1974; Lichti-Federovich, 1974, 1975; McAndrews, 1984), but studies have suggested the potential interest of such analyses to studies of arctic pollen dispersal and phenology (see Andrews *et al.*, 1979; Barry *et al.*, 1981). In the Austrian Alps, Bortenschlager determined that summer and winter layers could be distinguished by different pollen quantities and taxa; he also was the first to note the presence of long-distance transport pollen in the ice (Ambach *et al.*, 1966). The latter phenomenon is also well documented in the arctic ice core studies.

Twelve ice core samples from the Penny Ice Cap, Baffin Island, representing approximately eight years, were made available for preliminary analyses as a background to proposed additional coring in the region (Holdsworth, 1984). The ice core was collected in May 1979 on the divide of the ice cap at 67°14′N, 65°42′W, at an altitude of about 1980 m a.s.l. The pollen data presented here provide the first known estimate of pollen influx for an icefield on Baffin Island. Such data may be used to help in the interpretation of other ice core data which have a bearing on climate change. Evidently, regional climatology has a great influence on the application of the data and much additional work needs to be done in this area (Bourgeois *et al.*, 1984).

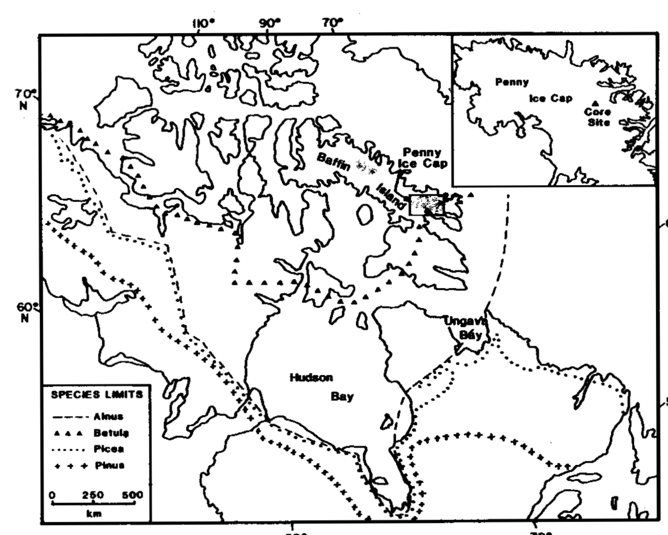

FIG. 1. Location map of Penny Ice Cap and the northern species limits, *Picea*, *Pinus*, *Alnus*, and *Betula*, eastern Canadian Arctic.

REGIONAL ENVIRONMENT

The 6000 km² Penny Ice Cap forms a 2000 m elevation barrier on Cumberland Peninsula, Baffin Island (Fig. 1), an area of deep fiords and glaciated valleys. There is a large climatic and vegetational gradient across the peninsula (Andrews *et al.*, 1979; Bradley, 1973:Table 1). Porsild stated that the peninsula contained the three tundra zones from high arctic through tran-

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sitional through low arctic (Webber, in Barry and Ives, 1974). Dwarf shrub tundra, consisting of low *Betula nana* and *B. glandulosa* (dwarf birch) and *Salix* spp. (willow), occurs to the south and west of the Ice Cap (Andrews *et al.*, 1980b:Fig. 1). These birch outliers represent the northern limit of dwarf birch in the eastern Canadian Arctic. The majority of the peninsula area is dominated by stony sedge-moss-lichen tundra elements. No vascular plants grow around the ice cap.

METHODS

The 6 m long core was obtained using a SIPRE corer. The core cutting or selection of broken core was done before detailed analysis of a companion 20 m core (Holdsworth, 1984) and hence without exact knowledge of the time-depth relationship. However, because it was observed in the field that the previous summer layer was slightly more than a metre below the surface, a sampling interval of the order of 0.5 m or less was attempted so that some quasi-seasonal variations in the pollen spectra might be observed. Any shorter interval was thought to contain insufficient pollen for analysis. In some cases core breaks dictated sample selection. The sampling interval was also influenced by the convenience in filling the 1 litre bottles for freighting to Boulder, Colorado. The interval 75–115 cm is missing due to damage of the core at the start of the coring operations at the base of the 0.75 m deep pit, the wall of which was sampled by cutting out snow blocks.

The ice core samples were melted and bottled in Ottawa, Ontario, for shipment. An empty bottle, labeled CONTROL, was left open during the melting and pouring operations to check for contamination. The chemical processing of the samples followed Lichti-Federovich (1974). The meltwater volume varied from 603 ml to 1023 ml of water, substantially smaller than the 30–35 kg of snow used by Lichti-Federovich in the Devon Ice Cap study but similar to that used by Fredskild and Wagner (1974) on the Greenland Ice Cap. The water was passed through 5 micron gauge, 25 mm diameter cellulose triacetate filters. The filters and the resulting residue were then treated with cold hydrofluoric acid (50%) overnight to dissolve the filter and the inorganic matter, glacial acetic acid, acetolysis (1 hour boiling time to allow for the altitude of the INSTAAR Palynology Laboratory) to dissolve the organic fraction, and glacial acetic acid. The exotic marker *Eucalyptus* was added with the cold hydrofluoric acid. The residue was then dried, mounted in glycerine, weighed, and counted. The CONTROL bottle was rinsed with distilled water and this was processed in the same manner as the core samples.

Three slides per level were prepared except where there was insufficient material (levels 175–206 cm, 206–229 cm, 433–473 cm, and 550–600 cm). Two or three slides per level were analyzed at 200X magnification. Pollen preservation was, in most cases, excellent, and total counts ranged from 24 to 115 grains. This information is summarized in Table 1.

TABLE 1. Pollen count data, Penny Ice Cap, Baffin Island

Sample No.	Depth	Volume (ml)	No. grains	No. pollen grains·l^{-1}
	Control	NA	8	NA
1	10-35, 35-75 cm	1023	81	123
2	115-154, 154-175 cm	830	55	65
3	175-206, 206-229 cm	913	30	46
4	229-270 cm	841	100	116
5	270-324 cm	921	115	124
6	324-350, 350-380 cm	830	85	98
7	380-402 cm	603	61	103
8	420-433 cm	712	33	46
9	433-473 cm	1015	86	85
10	473-513 cm	613	24	41
11	513-550 cm	631	24	45
12	550-600 cm	840	53	64

RESULTS

Glaciological data

An adjacent 20 m core was cut at 10 cm intervals for oxygen isotope analysis, carried out at the Geophysical Isotope Laboratory in Copenhagen under the direction of Dr. W. Dansgaard. Data for the upper 6 m is presented here as a means of determining the seasonal layers in the core. Other core sample measurements were made such as density, pH, conductivity, tritium and sodium ion concentration (Holdsworth, 1984). It is possible to state that the oxygen isotope ($\delta^{18}O$) data presented in Figure 2 is sufficient to delineate seasons and enable counting of annual layers. We identify here isotopic variations with actual seasons, although in some cases there may be a small phase shift. The core stratigraphy is shown to the right of the oxygen isotope plot.

Pollen data

The pollen data are presented in Table 2 (number of grains per litre of water) and Figure 3 (percentage pollen diagram). The pollen types are separated by presumed source: exotic

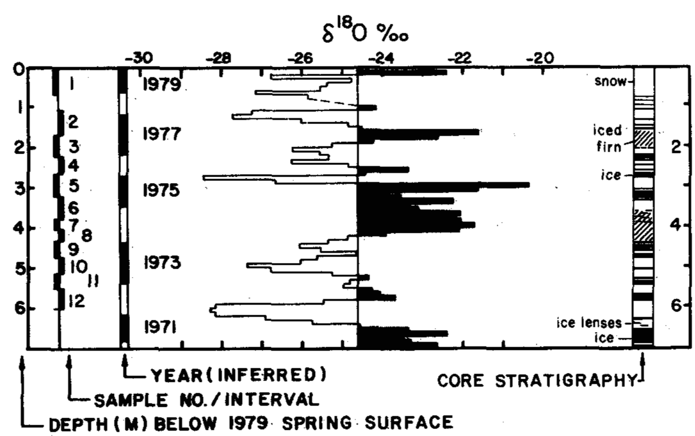

FIG. 2. Oxygen isotope data (courtesy of W. Dansgaard, Geophysical Isotope Laboratory, Copenhagen). The stratigraphy of the ice core and sample intervals as well as the interpreted time scale are also shown.

TABLE 2. Number of grains·l⁻¹ water, Penny Ice Cap

	Taxa	Sample no. 1	2	3	4	5	6	7	8	9	10	11	12
Exotic	*Abies*								3				
	Alnus		1		2	4	1	2					7
	Carya										2		
	Cupressaceae				2		1	2				2	5
	Fraxinus				1								
	Juglans cinerea		1										
	Juglans nigra									1			
	Nyssa		1										
	Picea	13	6	4	32	19	21	8	6	4	3	2	5
	Pinus	52	8	5	21	50	50	50	13	33	10	2	7
	Tsuga						1						
	Ulmus	2	1				1						
	Ambrosia	6	12	11	4	3	2	3	3		3	8	10
	Artemisia	3	4	2	2	12	4	2	3	2		2	4
	Chenopodiineae	6	1		5	3		8	1	3	3		5
	Thalictrum						1					2	
	Umbelliferae						1						
Local	*Betula*	25	16	7	4	4	4	7	8	6	2	3	4
	Salix	2			2	1		2	1				2
	Armeria				1		2				2	2	
	Compositae			2							2	5	
	Cruciferae					2							
	Gramineae	5	5	9	2	7	7	5	6	5	7	8	8
	Leguminosae							2					1
	Oxyria	2								1			
	Plantago									1			
	Polygonum viviparum						1						
	Rosaceae type	3	4	4		2	1	5	1		2		
	Cyperaceae		1	2	21	5				2	3	2	4
	Ericales				1								
	Filicales	2			1								1
	Lycopodium annotinum		1			1							
	Lycopodium selago	2											
	Pteridium type				1								
	Sphagnum	2			11	9		7	1	26	2	2	
	Trilete spore				1	2							
	Unknown		1		2			2		1			1
	Charcoal*	5		2		2	1			1	2		

*Not in count

(generally ≥ 200 km, although this category also includes *Artemisia* [sage], which reaches its northern limits in the Frobisher Bay region) and local (≤ 100 km).

Counts vary greatly, from 41 to 124 grains·litre^{-1} of water. These figures may be compared with values of from 1.7 to 13 grains·litre^{-1} of water for the Devon Ice Cap (Lichti-Federovich, 1974) and with values of from 21 to 96 grains·litre^{-1} of water for Greenland Ice Cap (Fredskild and Wagner, 1974:Table 2). In general, exotic non-Baffin pollen taxa, especially the conifers *Picea* (spruce) and *Pinus* (pine) but also *Ambrosia* (ragweed), dominate the spectra. The low *Alnus* (alder) values contrast with its importance in the Devon Ice Cap (Lichti-Federovich, 1974; McAndrews, 1984) and Greenland (Fredskild and Wagner, 1974). The range limits for *Picea*, *Pinus*, *Alnus*, and *Betula* are shown in Figure 1. *Ambrosia* reaches its northern limit in southern Quebec. The data are also characterized by the occasional record of long-distance taxa, deciduous species plus *Tsuga* (hemlock) and Cupressaceae (cypress family), which reach their northern limit in southern Canada.

Except for *Betula* (birch) and Gramineae (grass family), representation of local pollen types is irregular throughout the section. There is a general decrease in pollen concentration with depth in the core.

The dominance of exotic pollen types contrasts with both modern polster data and fossil peat pollen analyses from the same area. Five moss polster samples from Pangnirtung Pass, 60 km southwest of the Penny Ice Cap, have been analyzed for pollen (Andrews *et al.*, 1980a:Appendix). Local taxa, generally *Salix*, *Gramineae* and/or Cyperaceae, and Rosaceae (rose family) dominate those spectra and exotic percentages and concentration values are low. Similarly, exotic pollen types register low percentage and concentration values in two fossil peat sections from the area, Maktak Fiord, northeastern margin of the Penny Ice Cap (Boulton *et al.*, 1976), and Windy Lake, southern Pangnirtung Pass (Andrews *et al.*,

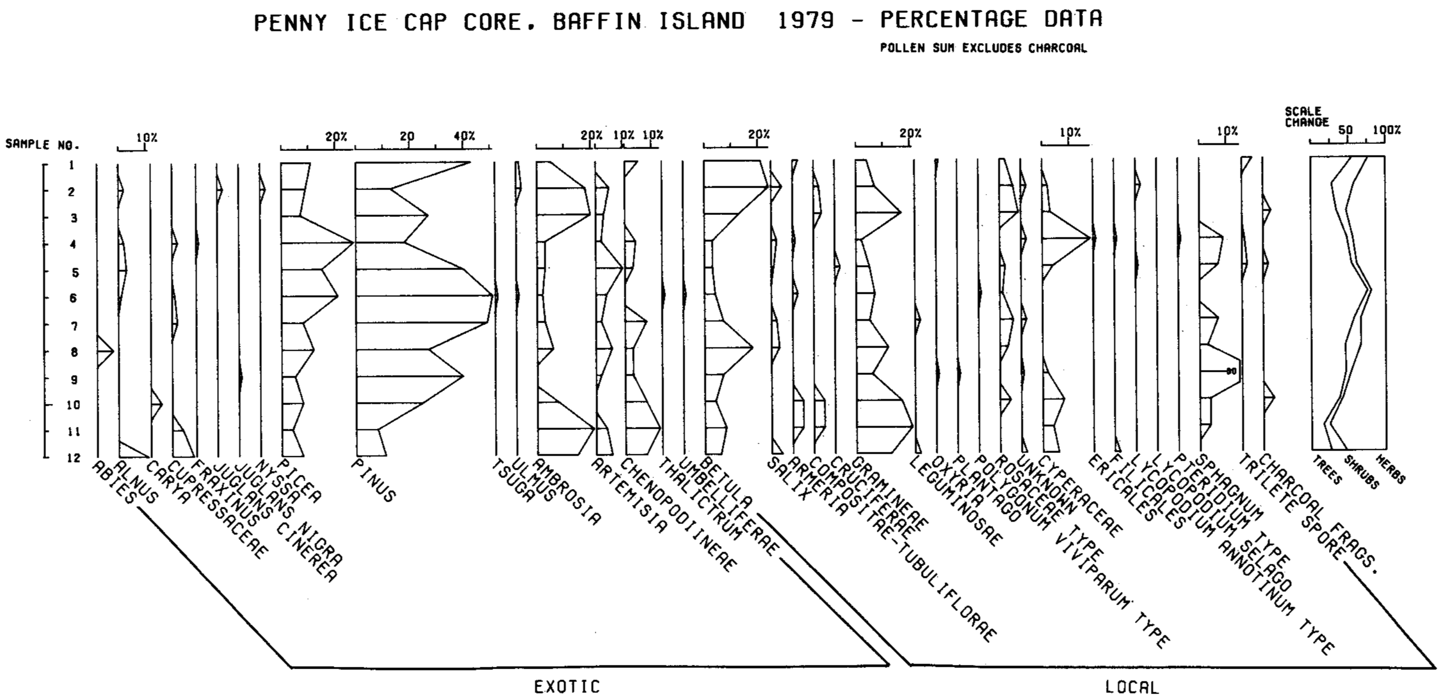

FIG. 3. Percentage pollen diagram, Penny Ice Cap, Baffin Island. Pollen sum excludes charcoal fragments.

1979); the two sites are located 20 km and 80 km from the core site respectively. Both pollen spectra are dominated by local *Salix* and Gramineae pollen. This difference reflects the "masking" ability of the local vegetation, at least in the low and middle Arctic, and suggests that ice core studies may be more suitable for the study of exotic pollen influx (*cf.* Nichols *et al.*, 1978).

Pinus values are greater than *Picea* in all but one level (229–270 cm). The greater efficiency of pine pollen in long-distance transport is supported by many modern pollen studies in the Arctic (Ritchie and Lichti-Federovich, 1967; Birks, 1973; Andrews *et al.*, 1980a,b; Nichols, unpub. data).

Pollen influx values were estimated for the 12 ice core samples; they ranged from 1 to 8 grains$\cdot$cm$^{-2}\cdot$yr^{-1}. These numbers are significantly smaller than the influx values calculated for Windy Lake peat section, which were approximately 50 grains$\cdot$cm$^{-2}\cdot$yr^{-1}.

Eight pollen grains were recorded in the CONTROL sample. The origin of these grains is uncertain, but four sources are possible: 1) during the melting and pouring separations in the lab in Ottawa; 2) during the chemical treatment at INSTAAR; 3) contamination of the distilled water used in the preparation; and 4) contamination in the exotic additive tablets. Tests on the exotic additive tablets (L. Maher, pers. comm. to H. Nichols; INSTAAR Palynology Laboratory tests) do not, however, support the fourth source.

Thus, the pollen data from the Penny Ice Cap suggest that over an eight-year period from 1972 to 1979 there have been substantial differences between the pollen spectra of the 12 samples. This suggests differences in either temporal or spatial provenance, which could be investigated by further work. Seasonality of the pollen rain was investigated through comparison with oxygen isotope data.

DISCUSSION

Referring to Table 3, which includes our interpretation of annual intervals from the $\delta^{18}0$ variations, the data indicate that five clear seasonal identifications (with no seasonal overlap) can be made. The predominantly "Isotopic Winter" samples (3, 9, 10) are characterized by low *Picea* and low to moderate *Pinus* percentages and low to moderate numbers of pollen grains$\cdot$litre^{-1} of water; high Gramineae percentages were recorded in samples 3 (17%) and 10 (17%) and maximum *Sphagnum* (30%) in sample 9. The predominantly "Isotopic Summer" samples (6, 7) are characterized by high *Pinus* percentages, low Gramineae percentages, and high numbers of pollen grains$\cdot$litre^{-1} of water; *Picea* percentages are variable in these two samples. The mixed "Winter"/"Summer" samples record variable values with no differentiated pollen spectra and are thus not considered very useful in analyzing seasonal pollen fallout, especially considering the possibility of downwash of pollen due to spring and summer snowmelt. The core stratigraphy is shown to the right of the oxygen isotope data in Figure 2. The existence of solid ice layers indicates that some vertical transport of insoluble material over distances on the order of 10 cm is possible. Also, there is no guarantee that a particular ice layer built up all at once. At deeper core locations this transport distance is exceeded (Holdsworth, 1984).

SUMMARY AND CONCLUSIONS

The analysis of pollen in 12 recent ice core samples from the Penny Ice Cap, Baffin Island, has produced some useful results. The samples are dominated by exotic pollen, which contrasts with the record preserved in terrestrial deposits in the same area. Thus, the results suggest the importance of ice core

TABLE 3. Sample identification summary, Penny Ice Cap

Sample no.	Interval depth (cm)	Year	Season(s)*
1	10-75	1979	spring/winter
2	115-175	1977/78, 1978	winter/summer
3	175-229	1976/77	winter
4	229-324	1976	summer, winter
5	270-324	1975	summer, winter
6	324-380	1975/74	mixed summers + "winter" (isotopic winter apparently not present)
7	380-402	1974	summer
8	402-433	1973/74, 1974	winter, summer
9	433-473	1973/74, 1973	winter, summer (?) (isotopic summer subdued)
10	473-513	1973/74	winter
11	513-550	1971/72, 1972	winter, summer
12	550-600	1970/71, 1971	winter, summer

*As interpreted from core stratigraphy and oxygen isotope variations

palynology in studying wind transport and wind patterns in the mid-eastern Arctic.

A study of seasonality patterns in the modern pollen rain was reasonably successful in those cases where the sampling interval was found to correspond to a summer or winter layer, as determined from variations in the $\delta^{18}O$ values. If proper sampling intervals were selected, a strong seasonal signal in the pollen rain is expected. The data suggest larger influx of exotic taxa in the summer samples than in the winter samples, which are characterized by larger numbers of Baffin Island regional pollen grains. This contrasts with the interpretation of pollen analyses of surface snow samples from the Devon Island Ice Cap (Lichti-Federovich, 1974), where exotic pollen deposition is correlated with winter deposition. However, both studies are based on a relatively small number of samples, and further work is needed on this important question.

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