RECURRENT SURFACES AND POLLEN
STRATIGRAPHY OF A POSTGLACIAL RAISED BOG,
KINGS COUNTY, NOVA SCOTIA

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ABSTRACT. Pollen analysis of a core from a postglacial raised bog at the head of the Annapolis River Valley, Kings County, Nova Scotia has revealed the presence of five periods of peat growth. These periods of peat growth are recognized by the occurrence of a light-colored waxy *Sphagnum* peat overlying a dark-colored humified *Sphagnum* peat. The stratigraphy and microfossil content of the light- and dark-colored peat layers are closely similar to those of European raised bogs. Recurrence surfaces in Europe have been dated by pollen stratigraphy, archeology, and by radiocarbon methods. Many recurrence surfaces have been found to be approximately the same age over wide areas. Periods of peat growth (as shown by the development of lighter-colored less humified peats) have been shown to correspond with periods of increased atmospheric moisture.

Testaceous rhizodons in the light-colored peat layers of Caribou Bog confirm the similarity of the recurrence surfaces of this bog with those of western Europe and Scandinavia. Chronologic equivalence of the Caribou recurrence surfaces with those of western Europe and Scandinavia can not be established from this study.

Alkali-extracts of the peat (see Overbeck, 1952) have been used to characterize the sediment color differences above and below the recurrence surface horizons. A simpler technique, based on sieved fractions of the sediment is satisfactory and less time-consuming for describing differences in sediment color density.

The pollen stratigraphy of core CAR-1 resembles the pollen sequence described by Auer (1930) from the same bog. Correlation of the Caribou Bog sequence with data from Gillis Lake on Cape Breton Island (Livingstone and Livingstone, 1958) and from Aroostook County, Maine (Deevey, 1951) is also discussed. There is no evidence for any major climatic reversal. The pollen data indicate a gradually warming climate with minor oscillations of moisture (and perhaps temperature).

INTRODUCTION

A band of highly humified peat overlain by lighter, less humified peats in sections through several raised bogs of northwest Germany was described by Weber (1900, 1926) and called the “Grenzhorizont.” Further investigation by means of pollen analysis confirmed the stratigraphic position of the “Grenz” at the Sub-Atlantic/Sub-Boreal transition. By 1932, several similar bands had been found, and Granlund was able to recognize five consistent horizons in Swedish raised bogs and date them by archaeologic finds and estimates of the rate of peat growth. These surfaces (Ry = Swedish “Rekurrensytor”) are: Ry I, 1200 A.D.; Ry II, 400 A.D.; Ry III, 600 B.C. (Grenzhorizont); Ry IV, 1200 B.C.; Ry V, 2300 B.C.

Nilsson (1935) was able to extend the list of consistent surfaces to nine, the two lowermost (Nilsson Ry 8 and Ry 9) dated at approximately 2800 B.C. and 3700 B.C., respectively. Ording (von Post, 1946) mentions thirteen recurrence surfaces from one deposit.

Radiocarbon dates from above and below recurrence surfaces in seven raised bogs in northwest Germany fall into three groups (Overbeck, et al., 1957). The averages of these dates are: 600 A.D.; 100 B.C.; and 700 B.C.

The time-stratigraphic significance of recurrence surfaces has been widely discussed (Jonas, 1935; Mitchell, 1956; Overbeck, et al, 1957; van Zeist, 1955). In pollen diagrams from the Emmererfscheidenveen, van Zeist (1955)
has shown that the stratigraphic position of the Grenz, as recognized by sediment density and pollen stratigraphy, varies from 35 cm to 107 cm in depth in different parts of the same deposit.

The mechanism of formation of a recurrence surface is not entirely clear. Granlund (1932) considers that there is a limiting height to which a raised bog can grow under a given climate. As this limiting height is reached, secondary humification of the peat begins, and the bog enters a "stillstand" condition with the overgrowth of terrestrial vegetation. This concept has been discussed by Godwin (1954).

The dark humified peats represent weathering during a reduction or cessation of bog growth, and the light-colored less humified peats represent renewed bog growth. Regeneration of peat growth above a recurrence surface therefore implies an increase in moisture. An increase in moisture may be due to an increase in precipitation or to a decrease in temperature (due to lowered evaporation). Pollen analysis of the sediments above and below a recurrence surface can usually determine the cause of the regrowth or regeneration of the bog.

Although Nichols (1919) on the coast of Maine, and Auer (1930) in southeastern Canada, have described raised bogs (sensu Kulczyński, 1949), little is known of their stratigraphy. The pollen diagrams and sediment stratigraphy described by Auer suggest that recurrence surfaces may be present in many of the raised bogs of southeastern Canada. A core from Caribou Bog, Nova Scotia was analyzed by Auer, and the most prominent recurrence surface found in this investigation was marked by him as containing the stumps of trees. Further consideration of Auer's data appears in another part of this paper.

ACKNOWLEDGMENTS

I should like to express my appreciation to Dr. Charles Hickox, who collected the core described in this paper, and who provided much of the information concerning the region around the deposit. I am indebted also to the Department of Botany of Yale University for making available the necessary facilities to perform the analysis. The stimulating advice and criticism of Professors Paul B. Sears and Edward S. Deevey, Jr. has contributed much to an understanding of the problems involved in this study.

REGIONAL GEOGRAPHY AND CLIMATE

Caribou Bog (lat 45°02' N., long 64°04' W.) is located about two miles northwest of the village of Berwick, Nova Scotia. It is situated on the divide between the northeast-flowing drainage (White Brook and Rand Brook) and the southwest-flowing drainage (Skinner, Gould, and Hutchinson Brook join to form the Annapolis River) of the Annapolis Valley. The climate is humid maritime, with an average annual rainfall of 55.5 inches. The average temperature for January is 23.0°F and for July is 65.0°F.

The valley is about five miles wide at this point and slopes gently from about 100 feet above sea level in the center to about 150 feet above sea level at the foot of the mountains on either side of the valley. The mountains rise abruptly to 600-700 feet above sea level.
Caribou bog is bordered to the south by kame terraces, the tops of which are about 150 feet above sealevel. The base of the bog is 93 feet above sealevel and the surface of the bog at the center of the dome is about 120 feet above sealevel (fig. 1). The area of the bog is 621 acres (Leverin and Cameron, 1949).

The Pleistocene geology of this region has been described by Hickox (1958).

![Map of Caribou Bog, Kings County, N.S.]

**Fig. 1.** Location, topography, and profile of Caribou Bog. Profile through bog along line A-A'.

**REGIONAL VEGETATION**

The uplands around the bog are covered with stands of balsam fir, white birch, red maple, hemlock, white pine, sugar maple, yellow birch, and beech. It is difficult to determine the original vegetation since most of the valley has been cleared for agriculture, and all of the woodlands are second-growth. Fires are frequent (Auer, 1930) and usually result in stands of white and red spruce with balsam fir.

The surface of the bog yields peat of commercial value, although no extensive peat mining operations have been carried out. The vegetation consists principally of a heavy cover of *Sphagnum* moss, with some cotton grass
(Eriophorum virginicum), crowberry (Empetrum nigrum), bog rosemary (Andromeda glaucophylla), and occasional small trees of black spruce (Picea mariana) (from Leverin and Cameron, 1949).

SEDIMENT AND POLLEN STRATIGRAPHY

Methods and materials.—The core was collected in August, 1956 by Dr. Charles S. Hickox, using a 25 cm Hiller borer. Samples were placed in aluminum liners and wrapped in heavy waxed paper in the field. At the laboratory the samples were rewrapped in plastic and stored under refrigeration until they were analyzed. Sediment samples were withdrawn with a porcelain spatula (1.0 ml). Thes laboratory methods used to separate the pollen grains from the matrix include sieving (screen mesh 150μ), defloculation in hot 10 percent potassium hydroxide, demineralization in 10 percent hydrochloric acid (first cold, then heated) and hydrofluoric acid (48 percent, 6-48 hours hot) where necessary, acetolysis (modified from Faegri and Iversen, 1950) and washing in hot 10 percent potassium hydroxide. Pollen samples were withdrawn by volumetric micropipettes (0.01 ml) and mounted in basic fuchsin-glycerine jelly.

Counting was done at 200x magnifications using apochromatic objectives. Critical identifications were made at 800x or 1930x (oil immersion). Identified specimens were tallied by traverses across square cover slips (22 mm) starting with fixed coordinates. Specimens of unusual interest were sketched and the coordinates recorded for later relocation and reproduction by camera lucida or photomicrograph. The number of pollen grains counted ranged from 150 to 600 grains at each level sampled.

Pollen diagram and sediment stratigraphy.—The pollen data from this core are presented in a diagram (plate 1) as a percentage of all pollen counted at each level. The pollen sum does not include microfossils other than pollen or the pollen of aquatic plants. Core depth is shown at the extreme left and extreme right of the diagram. The composition of the sediments, which is presented in detail below, is outlined in the second column of the pollen diagram. Sediment color-density will be discussed in connection with the characterization and interpretation of the recurrence surfaces in another part of this paper.

Pollen zones follow Deevey (1939, 1951) and Livingstone and Livingstone (1958). It must be remembered that the pollen zonation of this core implies ecological rather than chronological similarity between the separate regions.

PLATE 1

Pollen diagram for core CAR-1, Caribou Bog, Nova Scotia. Depth in cm is indicated at the extreme left and extreme right of the diagram. Sediment stratigraphy outlined in the second column is described in detail in the text. Sediment density figures explained in the text. RH indicates a maximum in optical density of sediment extracts characterizing the recurrence surfaces. The percent of trees, shrubs, and herbs is shown by the clear, single, and double hatched areas, respectively, to the right of the Pollen Zone column. Solid circles denote percentage points of pine at each level in the core, open triangles indicate spruce, and the crosses indicate the percentage points of hemlock. Non-pollen microfossils (rhizopods and algae) are plotted to the right of the Σ pollen column, and do not constitute part of the Pollen Sum. Values are expressed as the number per milliliter of wet sediment.
The stratigraphy of the peat detailed below was determined by inspection of the core as samples were removed in the laboratory.

0 - 115 cm  Coarse fibrous *Sphagnum* peat; numerous wood and root fragments.

115 - 150 cm  Dark, decomposed and humified *Sphagnum* peat; wood fragments absent or decomposed.

150 - 240 cm  Light-colored coarse *Sphagnum* peat; numerous wood fragments.

240 - 270 cm  Dark, decomposed and humified woody peat.

270 - 315 cm  Light-colored coarse *Sphagnum* peat; root and leaf fragments abundant.

315 - 365 cm  Humified peat; woody fragments absent.

365 - 410 cm  Humified peat; plant fragments present; stems and leaves of sedges; *Sphagnum*.

410 - 485 cm  Strongly humified black ooze; homogeneous.

485 - 515 cm  Carex peat; numerous plant fragments.

515 - 520 cm  Black Dy; Some well-preserved fragments of grass and sedge leaves; grades into

520 - 600 cm  Detritus gyttja; plant fragments numerous in brown ooze.

600 - 650 cm  Similar, but with increasing amounts of sand; lower 10 cm 45 percent sand.

*Pollen zone “A”.* —The A pollen zone of Caribou Bog is not subdivided for two reasons. Despite the fact that the sediments became too sandy for the Hiller borer to operate properly, the coring did not reach either till or outwash gravel. The boring made by Auer (1930) included 7.2 meters of sediment from this bog, near the site where the present boring was made. In Caribou Bog pollen stratigraphy, the A zone indicates a pre-pine zone spruce maximum. The division is not considered important in the light of the principal subject of this paper. Correlation with New England pre-pine zone spruce maxima is not attempted.

*Pollen zone “B”.* —The high frequency of pine pollen in this zone indicates a vegetation in which pine was a prominent tree. Although similar maxima in pine pollen characterizes most of the pollen diagrams of New England (Davis, 1958; Deevey, 1939, 1943, 1951; Leopold, 1958; Livingstone and Livingstone, 1958; Ogden, 1959). Danserau (1953) has pointed out that there is no completely satisfactory interpretation of the pollen data.

Size frequency measurements of pine pollen from this zone indicate that much of the pollen was derived from Jack pine (*Pinus Banksiana*). Although it has been shown that some species of pine can be distinguished by size-frequency measurements (Davis, 1958), Livingstone and Livingstone (1958) point out that the very considerable overlap in measurement of pine pollen makes species identification uncertain. In general, it must be said that species identification of pines must still be accepted with reservations.

Deevey (1951, 1959) considers that “B” zone time began at least 1000 years later in Maine than in southern New England. Livingstone and Living-
stone (1958) reach the same conclusion from the Gillis Lake data. In the absence of radiocarbon dates from Caribou Bog, it is reasonable to assume that the A/B zone transition is not older than 8000 years.

**Pollen zone “C1.”**—The B/C1 transition is marked by an increase in the pollen contribution of beech and hemlock and a sharp decline in the abundance of pine pollen. Size frequency measurements of the pine pollen in this zone indicate that red and white pine pollen types replaced jack pine during this time. The pollen diagram (plate 1) shows that profound changes were taking place in the bog at this time. The disappearance of *Pediastrum* and *Botryococcus* as well as a change in the sediments from detritus gyttja to a *Sphagnum* peat suggest a change from a wet marsh to a *Sphagnum* bog. Further evidence of a change in the character of the bog is shown by an increase in ericad pollen. The tree-shrub-herb totals in the diagram also indicate a steady encroachment of trees and shrubs onto the bog surface during this time.

The sum of this evidence, together with maxima in optical density and testaceous rhizopods, characterizes the first recurrence horizon of Caribou Bog (RH at B/C1 transition, 480 cm). The presence of a recurrence horizon at this level does not imply that the climate of C1 time was markedly drier than that of the preceding time. It is reasonable to infer from the pollen evidence presented above that C1 time was warmer than B time. Increased evaporation associated with a warming climate resulted in a slowing down of bog growth and humification of the surface sediments.

Regrowth of the bog must have been caused by an increase in precipitation rather than a decrease in temperature, for the maximum in hemlock pollen, and an increase in beech pollen indicate a warmer and moister climate than that of B time. The decline of spruce pollen and the replacement of jack pine by white and red pine pollen types support this interpretation also.

The recurrence horizon at 415 cm (pollen zone C1) is marked by a sharp increase in optical density of the peat and a minor increase in the pollen contribution of herbs and shrubs. Above this level, a decline in hemlock and beech pollen, as well as an increase in spruce and fir pollen indicate a slight cooling, which permitted regrowth of the bog.

**Pollen zone C2.**—Near the close of C1 time, bog growth slowed down, and soil forming processes began, forming the recurrence horizon at the C1/C2 transition. This level may be recognized in Auer’s (1930) diagram and was characterized by him as “highly humified woody peat, containing tree stumps.” No logs were encountered by the borer in the present core, but numerous woody fragments were recovered. Although specific identification of the wood is not available, preliminary tests using the Mäule reaction (Jane, 1956) indicate that both angiosperm and gymnosperm wood is present.

The formation of this recurrence surface indicates a considerable gap in the pollen stratigraphy. It does not imply that C2 time was of short duration in Caribou Bog. Either the bog surface was too dry to retain the pollen falling on it, or the pollen was weathered and destroyed before it could be incorporated in the sediments.

The pollen sample at 330 cm records principally the local bog flora, sedges, ericads, and other herbs. For this reason, the minima in pine, hemlock,
birch, and hornbeam pollen may not indicate a corresponding decrease in the abundance of these trees.

If it is assumed that the pollen sample at 330 cm reflects the disturbance caused by the formation of a recurrence surface, the tree pollen curves at this level may be ignored. (This may seem to be a rather Procrustean approach, but the difficulty of explaining minima in the pollen curves of pine, hemlock, birch, and hornbeam as well as increases in fir, spruce, and beech pollen at the same level is obvious).

The pollen sample at 305 cm indicates the nature of the climatic change which again permitted peat growth in the bog. The formation of a "regeneration peat" (sensu Godwin, 1954) implies an increase in moisture. The sediments alone do not indicate whether the moisture increase was due to an increase in precipitation, or to a decrease in temperature. If the formation of the regeneration peat was due to a decrease in temperature, it would be expected that the pollen contribution of spruce would increase at the expense of hemlock pollen. The fact that the reverse is true would indicate that the steadily warming climate shown by the increase in hemlock and beech pollen throughout the core continued, and that regrowth of the bog was due to an increase in precipitation.

Pollen zone C_{3a}.—Pine and hemlock show reciprocal percentage changes in pollen zones A, B, and C_{1}. In zone C_{3a}, it can be seen that the curves are approximately parallel. Size-frequency measurements indicate that the principal pine pollen contributor in the lower part of the core is jack pine, whereas white and red pine pollen types dominate in the upper parts of the core. It is to be expected that white pine and hemlock would show similar responses to changes in climate.

The increase in hemlock and beech pollen shows that the climate of C_{3a} time must have been warmer than that of C_{1} time. The fact that spruce shows a steady increase throughout C_{3a} time may indicate that the climate was cooling somewhat during this time. If the climate was cooling somewhat during C_{3a} time, but still warmer than C_{1} time, it is reasonable to infer that C_{2} time was at least as warm as C_{3a} and probably somewhat warmer. The recurrence horizon in C_{2} time indicates dryness, therefore, and it is considered that pollen zone C_{2} represents the warm-dry maximum for this deposit.

The recurrence horizon in C_{3a} represents a brief interval of decreased moisture during which bog growth slowed down. It is not easy to determine whether the decline in hemlock pollen is due to a drier climate or to a decrease in temperature. The fact that spruce reaches a maximum late in C_{3a} time indicates that regrowth of the bog was due to an increase in moisture caused by a lowering of temperature. The decline in beech pollen supports this interpretation also.

The sharp increase in hemlock pollen above 235 cm as well as an increase in beech pollen and a decline of spruce pollen suggest an increase in both temperature and precipitation.

Pollen zone C_{4b}.—The hemlock maximum at 140 cm as well as maxima in spruce, beech, and sedges represent a climate distinctly moister, and perhaps
warmer, than at present. The minimum in ericads also suggests that bog growth was unfavorable to overgrowth by heath plants.

The recurrence surface shown in this zone may be related to a change in slope of the bog. At this level (115-150 cm) the area of the bog changes sharply (fig. 1). The present surface area of the deposit is 621 acres (Leverin and Cameron, 1949). At a depth of 115 cm it is about 500 acres, and at 150 cm it is 400 acres. A change in slope at the center of the bog might result in a brief period of reduced bog growth (Kulczyński, 1949). For this reason, the recurrence horizon at 140 cm may not have climatic significance. On the other hand, the sharp decline in hemlock, and the abundance of sedges and alder as well as a rather high amount of spruce may indicate a cooler climate as the cause of the regrowth of the peat.

Although the upper parts of this core undoubtedly record post-colonial disturbance, the pollen of agricultural weeds was not recovered in the samples analyzed.

RECURRENCE SURFACES AND CLIMATIC CHANGE

The development of a recurrence surface in a raised bog may or may not have climatic significance. The “Stillstand” condition described by Weber (1906) and Granlund (1932) and the “Retardation Layers” described by Godwin (1954) illustrate the concept of a limiting height to which a raised bog can grow under a given climate.

Regrowth, or regeneration of the peat bog usually does have climatic significance. Peat growth in a raised bog is possible only with an adequate supply of moisture. Therefore, the formation of a “regeneration peat” over a recurrence surface indicates an increase in moisture. Development of a regeneration peat does not indicate whether the increase in moisture is due to an increase in precipitation or to a decrease in temperature. Fortunately, pollen and other microfossils preserved in the peat usually permit the investigator to determine the cause.

Recurrence surfaces and sediment stratigraphy.—Recurrence horizons may be recognized in sections through raised bogs by inspection in many instances. The presence of light-colored relatively unhumified peat overlying dark-colored, humified peat is good field evidence for a recurrence surface. The contact is usually sharp, although as Godwin (1954) points out, it may be as subtle as a change in the species of Sphagnum from which the peat is formed. In the laboratory there are several techniques by means of which changes in the character of the sediments may be recognized. Overbeck (1952) described a method based on colorimetric differences of alkali extracts of peat. Pollen analytic studies have demonstrated differences in fern and Sphagnum spore ratios, ericad pollen, and differential destruction of pollen grains. The accumulation of air-borne silt has been characterized microscopically by Iversen (personal communication).

In this study, the optical density of alkali-extracts of the peat (Overbeck, 1952) was compared with the optical density of sieved fractions of the peat. The alkali extracts were prepared by suspending 0.5 cc of peat in 15 ml of 10 percent potassium hydroxide and heating over a boiling water bath for 15
minutes. The sample was centrifuged, the supernatant decanted into a graduated cylinder, and distilled water was added to bring the volume to 100 ml. The solution was stirred and samples for colorimetric determination were decanted into standard colorimeter tubes. Optical density was determined with a Klett-Summerson colorimeter, using a G15 filter. The extinction value of the colorimeter is 1000.

The humified peat of the recurrence surfaces consists of more finely divided particles than the less humified peat of the regeneration layers. Therefore, the amount of humic material passing through a 150 μ screen was considered to represent the degree of humification of the peat. 0.5 cc of the peat was suspended in 100 ml of water and passed by suction through the screen. Samples were decanted into standard colorimeter tubes and turbidimetric readings were made with the Klett-Summerson colorimeter, using a G15 filter.

The results of the two methods are compared in the first two columns of table 1. The sediment density shown in the pollen diagram (plate 1) is based on the alkali-extract method.

Table 1

Optical density of potassium hydroxide extracts (10 percent) and sieved fractions of sediments from core CAR-1, Caribou Bog, Nova Scotia (Values are optical density determined with Klett-Summerson colorimeter, G15 filter). Non-pollen microfossils are tabulated as the number per milliliter of wet sediment.

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<th>Amphi- trema wrightianum</th>
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Recurrence surfaces and testaceous rhizopods.—Regeneration layers in raised bogs may be characterized by the abundance of sphagmicolous rhizopods. The tests of these small protozoans preserve quite well and may be identified to species in many cases. The ecology of these organisms is such that they are restricted to moist, rapidly growing Sphagnum. The distribution of Amphitrema flavum and Assulina seminulum is shown in plate 1. It can be seen that maxima in the abundance of these rhizopods are definitely associated with the regeneration peats shown in the sediment density column.

The numerical abundance of these rhizopods, and others not included in the pollen diagram are shown in table 1. The figures indicate the number of specimens per ml of wet sediment. Microphotographs and measurements of these organisms are shown in plate 2.

Plate 2

Photomicrographs of some non-pollen microfossils from Caribou Bog. a. Nebela lageniformis 107 x 69 μ, Amphitrema flavum beneath Nebela; b. Arcella artocera, dorsal view, 102.4 μ diameter; c. Amphitrema flavum, lateral view, 62 x 21 μ; d. Pediastrum (P. boryanum ?); 52.1 μ; e. Assulina seminulum 36 x 20 μ; f. Amphitrema wrightianum, lateral view, 62 μ diam.
CORRELATION OF CARIBOU BOG SEQUENCE WITH REGIONAL POLLEN SEQUENCES

The results of the present investigation agree quite well with Auer's (1930) pollen diagram from the same bog. Auer's boring apparently reached further into the base of the deposit than did the present boring, for Auer's pollen diagram indicates a maximum of birch pollen stratigraphically below the spruce maximum shown in plate 1 of this paper. Both diagrams show a recurrence horizon at 345 cm (although not identified by Auer). A further point of biogeographic interest may be mentioned here concerning the hemlock curve shown in Auer's paper. Hemlock pollen constitutes 55 percent of the pollen sum at 490 cm in Auer's diagram (equivalent to early C₁ pollen period in this paper). A second hemlock maximum (40 percent of the pollen sum at 230 cm) is shown by Auer and is equivalent to the hemlock maximum in pollen zone C₂b of this paper. In this respect, i.e., a bimodal hemlock pollen curve in pollen zones C₁ and C₃, the Caribou Bog pollen data resemble Deevey's (1951) data from Maine rather than Livingstone and Livingstone's (1958) Gillis Lake, Cape Breton Island, data. The Gillis Lake diagram shows a hemlock maximum in pollen zone C₂, with no indication of a bimodal hemlock pollen curve.

Livingstone and Livingstone also find much more birch in the Gillis Lake core than was recovered from the Caribou deposit. The pollen curves for birch agree quite well in the two cores (minima in pollen zones C₂ and C₃b and a maximum in zone C₃a). Spruce and fir pollen show an approximately similar distribution in the Caribou core (CAR-1) and the Gillis Lake core.

The pollen of oak and poplar was found in greater abundance in the Caribou core than in the Gillis Lake material. Maxima in oak pollen curves were found in pollen zones B and C₃a in the Caribou core, whereas the Gillis Lake core indicates a maximum of oak pollen in C₁.

In general, the Caribou data seem to resemble more closely Deevey's (1951) data from Aroostook County, Maine than Livingstone and Livingstone's (1958) data from Cape Breton Island.

REFERENCES