[AMERICAN JOURNAL OF SCIENCE, VOL. 249, MARCH, 1951, PP. 177-207]

American Journal of Science

MARCH 1951

LATE-GLACIAL AND POSTGLACIAL POLLEN DIAGRAMS FROM MAINE

EDWARD S. DEEVEY, JR.

ABSTRACT. Pollen diagrams from three lakes and one bog in northern Aroostook County, Maine, have shown for the first time in North America that the "postglacial" advance of forests was preceded by a "late-glacial" time characterized by tundra climate. The older time corresponds in every essential respect with the late-glacial phase of northern Europe: non-arboreal vegetation, dominated by grasses and sedges, but including *Artemisia* (?) and many other herbaceous types, contributed several hundred per cent of the arboreal pollen, all of which is considered to have been wind-borne from a great distance. Resemblance to the standard European sections is enhanced by the occurrence, within the "late-glacial" segment, of a zone having considerably less non-arboreal pollen than the zones above and below and involving the intercalation of a band of marl within clay sediments. This middle zone, called *L 2,* is strikingly like the Allerød oscillation of Goti-glacial age and by analogy may date from the Cary-Mankato interval. There are reasons for believing that the tundra phase underlies the organic sediments in Connecticut and probably elsewhere, but as the author suggested in 1949, "geologic circumstances and the mental habits of pollen workers may have conspired to make them miss it."

The postglacial parts of the diagrams are sufficiently normal for New England to permit their correlation with the standard section for eastern North America, though there are many peculiarities, such as the absence of hickory and chestnut pollen and the subordination of oak to pine, hemlock, and birch. These peculiarities reinforce the resemblance to European diagrams, and the sequence from northern Maine is astonishingly similar to that from the more continental parts of Scandinavia. Table 2 gives a summary of the zonation and its probable correlation with the European section.

Two lakes in Kennebec County, about 175 miles SSW of the Aroostook County localities, were also investigated, but the diagrams are much more like those of southern New England, and neither shows "late-glacial" zones. The reasons are apparent, and different in the two cases: in one the organic sediment lies unconformably on marine clay, which so far has proved barren of pollen, and the other, being a kettle, was probably protected from lacustrine deposition during the "late-glacial" phase.

INTRODUCTION

THE sequence of postglacial climatic changes in eastern United States, as recorded by pollen assemblages in lake and bog sediments, has been the subject of intensive study in recent years, and its broad outlines have become increasingly clear. Its fundamental similarity to the much more detailed pollen stratigraphy of western Europe has been noted by several students, most recently by the author (Deevey, 1949). There is one great difference between North American and European pollen diagrams, however, which has been known for so long that most American authors have come to ignore it, evidently regarding it as a fact of nature. This is the absence, at the base of American sections, of a zone of sediment recording what European workers call "the late-glacial" (Firbas, 1934, 1939; Godwin, 1947). American diagrams begin in a "pre-boreal" cool phase marked by pollen of spruce and fir, and no undeniable indication of a tundra vegetation has come to light. Since the great majority of borings have been made in bogs that occupy kettles, it has often been suggested that deglaciation of eastern North America was followed immediately by forests of spruce and fir, which, at least locally, *i.e.* at the sites of the kettles, may have grown over masses of ice buried in outwash.

Although this conception of the early stages of retreat of the North American ice sheets gains plausibility from present-day conditions around certain Alaskan glaciers, such as the Malaspina, it rests almost entirely on negative evidence. There is some negative evidence against it: if the great outwash plains that commonly lie beyond the recessional moraines of the later Wisconsin substages in the middle West were covered by extensive forests during part of the time of their formation, one might expect far more fossil wood than has actually been found buried in outwash. But it is by no means certain, even in the kettles, that traces of tundra vegetation are missing. The fact is that most American pollen stratigraphers have not looked hard enough for it. They have largely confined their attention to the organic sediments of peat bogs, and when the pollen-poor clays and sands have been reached below the organic deposits they have generally stopped boring. It must be admitted that this attitude has been partly justified by experience, for the older, mineral sediments are often exceedingly sterile, and fail to yield pollen even to the most refined techniques of concentration. To push the postglacial pollen chronology back of the spruce-fir zone requires not merely perseverence, but geologic good fortune.

In reporting some success in this difficult task the author can claim no credit for unusual persistence, for with the example of his European colleagues always before him, it has merely been routine practice to try to extract pollen from all sediments accessible with the peat borer. Good fortune was finally achieved on a brief reconnaissance of northern Aroostook County, Maine, conducted in the summer of 1949. The field trip to Maine was undertaken in part because a study of the data obtained by Potzger and Friesner (1948) suggested that the "rock flour" underlying the peat in certain bogs of coastal Maine contains unusually high proportions of grass and other non-arboreal pollen, indicative of deposition in a treeless region. It also seemed desirable, in establishing a far-flung geographic grid of samples for the calibration of the pollen chronology by means of radiocarbon analysis, to include northern Maine as the northernmost point that could be easily and quickly reached from New Haven.

Although borings were made at eight localities in Maine, in addition to several in Massachusetts, northern Connecticut, and eastern New York, the present paper reports on only six of these, four in northern Aroostook County and two in Kennebec County, Maine. The geology of coastal Maine is so complicated by the problematic relations of land and sea in late-glacial time, that it can not be adequately represented by two borings (in which the clay samples are unfortunately almost devoid of pollen).

It is a pleasure to acknowledge indispensable assistance, financially, from the Scientific Research Society of America and from the Connecticut Geological and Natural History Survey, and in the field, from my wife, Georgiana B. Deevey. Several lake-shore residents and owners of boats, too numerous to mention individually, provided most valuable cooperation.

METHODS

The author's preference for lakes instead of bogs as sites for pollen diagrams, a matter on which Faegri (1944) is in cordial agreement, has been reinforced by experience in Maine. The State is notably rich in bogs, many of them of vast extent and of great economic importance (Bastin and Davis, 1909; Trefethen and Bradford, 1944), but exceedingly few of them offer much promise of providing a complete postglacial stratigraphy. Most of them appear shallow and densely forested, and their centers are almost inaccessible; to judge from the numerous sections given by Bastin and Davis, the majority represent recent paludification of upland soils, their origin perhaps dating from the deterioration of climate of the last two thousand years or so. Others, the great raised bogs of eastern Maine, for example, which may have a longer history as basins of deposition, have ceased depositing appreciable amounts of sediments at some time in the more or less distant past. Some sections published by Potzger and Friesner, and most of those from adjacent parts of eastern Canada published by Auer (1930), are obviously incomplete at the top as well as at the bottom. Moreover, even for the parts of the postglacial section that are actually represented in bogs, lacustrine gyttja is equal, if not superior, to peat on account of its larger proportion and better preservation of pollen. The formation of peat of various types is sensitive to minor fluctuations of climate, as the establishment of "recurrence surfaces" in European bogs makes clear (Granlund, 1932; see also recent summaries in Wenner, 1947, and von Post, 1946); at the present stage of North American investigations, however, a refined peat stratigraphy is a luxury that is more likely to confuse than to elucidate the postglacial chronology.

Five of the localities reported here are lakes, although four of them have boggy margins; all five were bored from boats and not from the bog mat. The sixth locality, Bishop Pond, is a more typical bog, and its pollen profile (fig. 5) indicates that it is incomplete at the top.

Davis peat borers of two sizes, the standard one of ¾-inch inside diameter and one of 1-inch inside diameter, were used throughout the work. The Davis borer is easier to use and to clean than the Hiller type, but is less suitable for exact stratigraphic work, particularly when it is desirable, as it would have been in Maine, to take samples 5 cm. or less apart. Attempts to improve the accuracy of the work with the Davis instrument took two forms, neither of which was wholly successful. First, since it is not practicable to take a continuous series of samples representing 25 cm. of sediment in the same hole, two holes were used alternately, with samples 50 cm. apart in each. Unfortunately, it can happen that the stratigraphy differs, even in two holes less than a meter apart. (The contemporaneity of successive samples at the "same level" in adjacent holes has been critically discussed by Deevey and Potzger, 1951 *in press*). Second, in order to refine the stratigraphic work based on samples originally 25 cm. long (before compression), a series of intermediate samples was taken, as follows: after discarding the (possibly contaminated) lower 2 or 3 centimeters of a core, a cork borer was used to sample the next 2 or 3 centimeters. The peat sampler was then partially closed, extruding about half the estimated length of the core. This half, except for the small fraction obtained by the cork borer, was discarded, and the cork borer used in the same way to sample the upper half of the core. The original stratigraphic position of the samples is impossible to state precisely, but on the average the "number 2" samples should have come from about 12.5 cm. above the "number 1" samples. In plotting pollen diagrams, however, (figs. 2-7), the "number 2" bars have been drawn above and immediately adjacent to the "number 1's." The sampling interval of about 12.5 cm. gave a far more satisfactory picture than the one-foot interval that has been customary in work with the Davis borer, but it was not short enough in critical regions of the profiles.

In making pollen preparations the ordinary KOH method was used wherever possible, HCl being employed for calcareous sediments and HF for the silts and clays. The Erdtman acetolysis method gave unsatisfactory results in the few instances where it was tried; contrary to the previous experience of many pollen workers, including the author, the process was found to destroy certain pollen grains differentially.

In general, at least 100, almost invariably 150 pollen grains were counted at each level. No statistical significance is attached to differences between successive samples when the total number counted is so small. Problems of pollen statistics have been discussed at length elsewhere (Deevey and Potzger, 1951 *in press*), with the gloomy conclusion that almost all pollen counting as hitherto practiced is devoid of statistical significance. Fortunately pollen stratigraphy does not rest on a strictly statistical foundation.

The test of the stratigraphic validity of a change in pollen flora is not the precision of estimate of pollen frequencies at any one level, but whether the change occurs consistently in a whole group of sections from a particular region and can be firmly correlated with changes even farther afield that are ecologically rather than mathematically analogous. This generally admitted fact implies that under certain circumstances it may be quixotic to count as many as 100 pollen grains, since all the information that can reasonably be expected, having regard to the effort required, can be extracted from smaller counts. In the older parts of the profiles reported here, where the pollen density is exceedingly low, counting has occasionally been terminated between 60 and 100 grains (or fewer in five cases, the minimum being 47), and in these counts only the proportion of non-arboreal to forest tree pollen is considered to have any reliability whatever.

REGIONAL GEOGRAPHY

Northern Aroostook County, the region of greatest interest in the present report, is a maturely dissected, drift-covered plateau with a general elevation of 500 to 800 feet, constructed for the most part of sedimentary rocks, including limestones, of Silurian, Devonian, and Mississippian ages. The principal river, the Aroostook, pursues a generally easterly course to join the St. John River a few miles east of the international boundary in New Brunswick. The St. John River forms the international boundary over part of its easterly reach, but its southward course to St. John on the Bay of Fundy lies wholly within New Brunswick (See sketch map, fig. 1). The country to the west of the valley of the Aroostook is higher and virtually inaccessible overland except from the Quebec side. A search of the literature suggests that northern Aroostook County has never been seriously studied by ecologists, but the author's trip to the region was too hurried to warrant an attempt at a general account.

With the improvement in communications and in living conditions during the present century the Aroostook country has been opened up rather rapidly. As the limestone rocks of the basin provide some of the best agricultural soils of New England, much of the land has been cleared of forests and cultivated intensively for potatoes, with the result that the landscape is a treeless downland similar to eastern Iowa. The resemblance vanishes abruptly in the neighborhood of local depressions, many of which are poorly drained, for here are found the spruce forests that may formerly have been much more extensive.

The role of the spruces in the natural vegetation of the region should not be overestimated from the widespread occurrence of black spruce (*Picea mariana*) in boggy situations. The climax dominant of the northern coniferous forest is not black, but white spruce (*P. canadensis*). Maps of vegetation types showing northern Maine as part of the northern coniferous forest (the "northern pine belt" of Sargent, 1884; the "St. Lawrence-Great Lake region" of Harshberger, 1911; the "northern mesophytic evergreen forest" of Shreve, 1917; the "spruce-fir" forest of Shantz and Zon, 1924; the "boreal forest" of Weaver and Clements, 1929) are in error. From the point of view of the climatic climax, the whole of New England belongs to the "hemlock-white pine-northern hardwood forest" of Nichols (1935). But this association-type itself is trans-

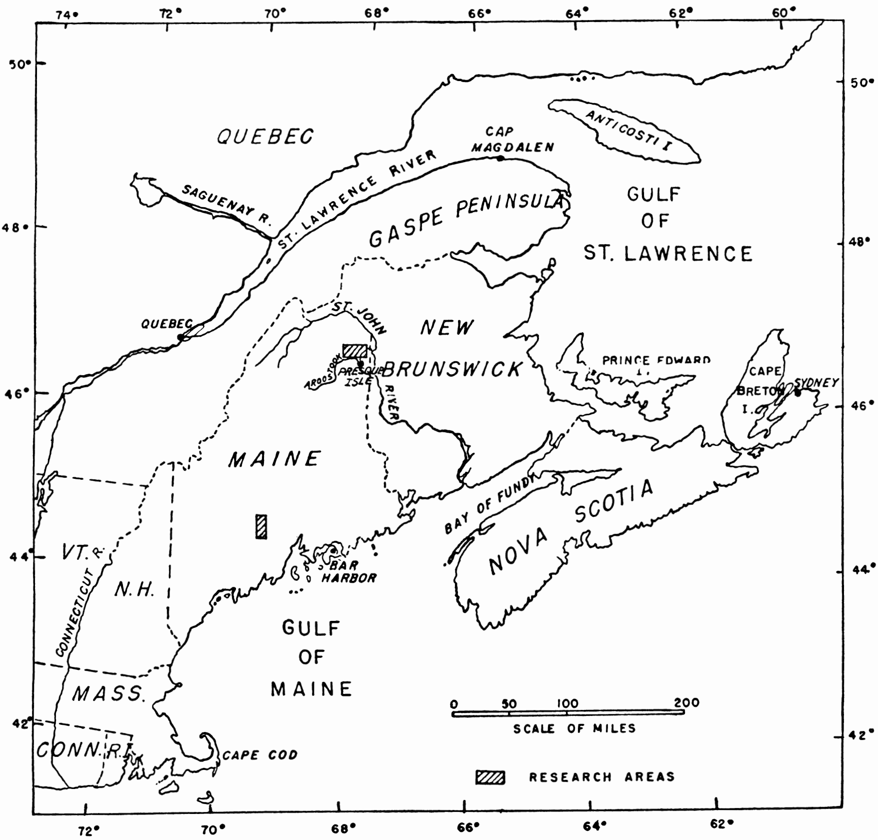

Fig. 1. Sketch map of Maine and adjacent parts of eastern Canada.

itional in many respects between the northern coniferous forest and the southern deciduous forest, as Nichols recognized, and northern Maine, like the part of Cape Breton Island that Nichols studied, is close to its northern boundary. This means that there is a confusing interdigitation of climax associations and a mixture of vegetation types that cannot be adequately represented on a small-scale map. At high altitudes, which are discontinuously present in Aroostook County and much more extensive in central Maine, there are great areas of northern coniferous forest; so, also, are spruce bogs abundant and extensive in central and southern Maine. It is therefore not surprising that most of the standard vegetation maps, which are aimed at the requirements of forestry or constructed from the data of forestry, give a misleading impression of the climax communities of northern New England. The original forest of the Aroostook basin must have been mainly composed of sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*), with hemlock (*Tsuga canadensis*) and yellow birch (*Betula lutea*) on the moister sites and white pine (*Pinus strobus*) in the clearings. Jack and red pines (*P. banksiana* and *P. resinosa*) may have occupied the flood plains and other areas of sandy or gravelly soil. A forest typical of southern New England, except for the paucity of beech and the absence of hickories (*Carya* sp.), was seen by the author on the divide between the Aroostook and the St. John Rivers, *north* of the region under consideration; this watershed lies at too low an altitude (600-800 feet) to fall in the spruce belt.

Climatically, the Aroostook Valley can hardly be matched in the United States for the length and severity of its winters, though its summers are normal for New England and noticeably hotter than those of coastal Maine. In fact the region has more continental climate than any part of North America east of the Mississippi and south of the latitude of Quebec; the moderating influence of the ocean is felt in a more even distribution of temperature and precipitation, not only to the south, in coastal New England, and to the east, in New Brunswick and Nova Scotia, but to the north, along the south shore of the Gulf of St. Lawrence. Some meteorologic data are given for comparison in table 1.

The glacial geology of Maine is poorly known, that of northern Maine especially so. Summaries of available information, resulting from work that was hardly more than reconnaissance, are given by Stone (1899) and by Leavitt and Perkins (1935). The outstanding glacial features of the coastal district are the great northward-trending esker systems, which occur there on a grander scale than anywhere else in North America. In late-glacial time the coastal region was overlapped by the sea, and marine deposits (the "Leda clays") deeply cover certain lower parts of the state, but the relation between the formation of the eskers and the marine invasion is prob-

TABLE 1

Climatic data for Presque Isle, Aroostook County, Maine, with comparative figures for Quebec to the west, Cap Magdalen to the northeast, Sydney to the east, and Bar Harbor to the south. Sources: Monthly Record, Meteorological Observations in Canada and Newfoundland, and Climatological Data (U. S. Weather Bureau).

	Presque Isle, Maine	Quebec, Quebec	Cap Magdalen, Quebec	Sydney, N. S.	Bar Harbor, Maine
		Temperature, °F			
January	10.7	9.7	11.4	22.2	22.6
February	13.3	11.5	13.8	19.8	22.1
March	23.7	22.3	21.5	27.4	31.7
April	37.4	36.4	32.0	36.3	41.2
May	50.5	50.9	43.5	46.2	52.0
June	58.8	61.3	53.0	55.7	60.0
July	65.7	66.7	61.2	63.6	66.1
August	63.3	63.6	59.2	63.8	64.8
September	54.4	55.6	52.0	57.2	58.6
October	44.1	43.5	41.7	48.0	48.0
November	30.1	29.7	29.7	38.3	38.7
December	16.0	15.6	17.2	28.7	26.8
Mean	39.0	38.5	36.4	42.3	44.4
		Precipitation, inches			
January	2.26	3.75	2.47	5.16	4.75
February	1.83	3.14	2.55	4.45	3.85
March	2.22	3.22	2.77	4.45	4.80
April	2.61	2.40	1.77	4.03	3.75
May	2.87	3.16	2.58	3.44	3.35
June	3.70	3.94	2.89	2.84	3.27
July	3.72	4.07	3.12	3.27	3.36
August	3.10	3.92	2.81	3.75	3.25
September	3.39	4.01	2.33	3.46	3.97
October	3.36	3.47	3.09	4.70	4.38
November	2.52	3.55	2.76	5.17	4.55
December	2.38	3.43	2.72	5.45	4.38
Total	33.96	42.06	31.86	50.17	47.66

lematic, since some eskers overlie the clays while others are almost blanketed by them. Subsequent to the marine stage Maine underwent differential uplift toward the north, but the isobases have not been established with certainty. Leavitt and Perkins gave a map (1935, fig. 36) purporting to show the "elevation of marine features", with its highest isobase (450 feet) in south-central Maine, striking NE-SW on a line running south of Mt. Katahdin, but a study of the text gives no confidence that the features mapped are really marine. According to the authors, "deltas record best the marine levels in the regions where they occur" (p. 199), but some or all of the deltas may have been built in lakes and not in the ocean. The marine clays themselves have of course been dissected and partly removed since the uplift, but a map showing the maximum height now attained by deposits containing marine fossils would be more useful and less misleading than the one published by Leavitt and Perkins.

The esker zone ends somewhere in the wilderness of central Maine, and no eskers are present in northern Aroostook County. Little can be said of the glacial geology of this region except that the till is thick, as would be expected in a limestone country. It is reasonably certain, as discussed below, that the late-glacial marine invasion never reached so far inland.

Two lines of evidence suggest that ice advanced over Maine more than once: two sets of glacial striae of different direction have been reported, one set being superimposed on the other in some localities; there is also the fact that some eskers antedate a time of marine deposition, while others apparently postdate one (it is not clear that there was only one marine invasion). The evidence is too scanty to establish that there were two ice advances, let alone whether they should be referred to more than one glacial age or to two sub-ages of the Wisconsin glacial age.

NOTES ON LOCALITIES STUDIED

Plissey Pond, Washburn.—This is a small lake (elevation 620 feet) with a boggy margin, occupying an uncleared depression almost surrounded by potato fields. The outlet, Kennard Brook, reaches the Aroostook River after passing through other boggy areas. The bog mat is only partially forested by black spruce and larch (*Larix laricina*); much of the mat vegetation is sedgy rather than ericaceous, and carries paper and gray birch (*Betula papyrifera* and *B. populifolia*) as well as alders (*Alnus* sp.) and red-osier dogwood (*Cornus stolonifera*). The lake is very shallow, carpeted by *Chara*, and has a few small, probably floating islands bearing cat-tails (*Typha latifolia*).

Some preliminary exploration with the peat borer indicated that the sediment is shallow, 3 to 5 meters, under most of the marginal mat, with a thin layer of high-grade shell marl intercalated between the peat and the underlying clay. A sounding in the center of the lake showed a total depth to hardpan of 8.4 meters, including a meter or so of water. The definitive boring was made just off the bog mat at the north end of the lake in a hole 10.8 meters deep and of very limited extent. Pure marl is lacking in this region, for, as is well known, the deeper, colder waters of stratified lakes can and usually do contain more dissolved carbon dioxide than the shallower waters, and marl is not so readily formed under such conditions (see the work of Groschopf (1936) on the Grosser Plöner See, for example). The lower layers of gyttja are grayish, however, and the upper clay is somewhat marly.

The existence of several stratigraphic markers of this sort added interest to the field work, but also helped to cast doubt on the validity of the geologic section obtained with the borer. The two borings synthesized in figure 2 were made as described above, the even half-meter samples being taken in one hole and the odd half-meter (one-quarter and three-quarter meter) samples in the other. Although the two holes were less than 50 cm. apart at the surface, the boundary of the marly clay came at mark 8.75 in one series and at mark 9.50 in the other. The depth to hardpan was precisely the same in both holes, and the pollen diagram (fig. 2) gives no reason to think that the stratigraphy is peculiar or confounded except in the vicinity, or conceivably everywhere below, about 9 meters. The two pairs of samples plotted at 9.40 and 9.65 meters are quite probably in reversed stratigraphic order (the curious fractions used here as elsewhere are explained by the length of the sampler head, 40 cm. closed and 65 cm. open). Unfortunately time did not permit an attempt to disentangle this confusion, which evidently arises from wedges of sediment.

After completion of the boring, three samples for radiocarbon analysis were taken half a canoe-length farther out in the lake at 3.65, 4.65, and 6.50 meters, by means of the gigantic Hiller sampler designed for the purpose (Deevey and Potzger, 1951 *in press*). A composite sample was also taken at 8.65 meters by the multiple-shot method. The total depth of deposit here was also 10.8 meters.

Caribou Lake, Washburn.—A considerably larger lake than Plissey Pond, Caribou Lake (elevation 548 feet) is otherwise

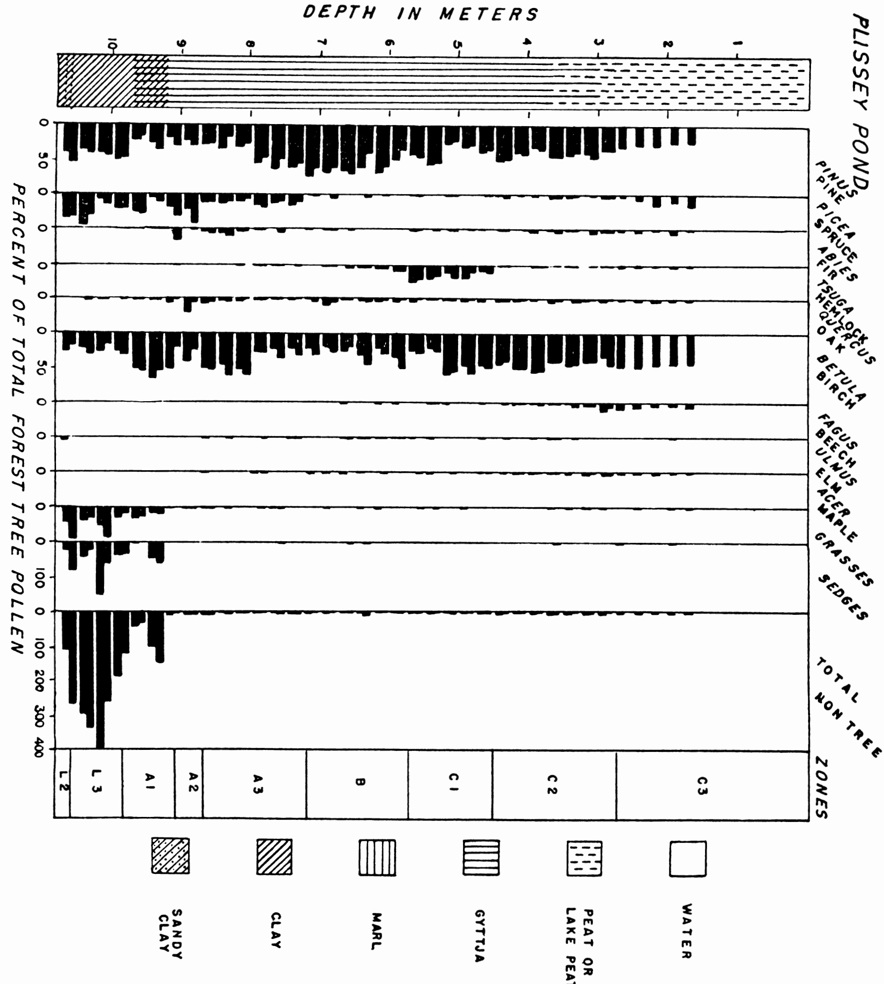

Fig. 2. Pollen diagram for Plissey Pond, Washburn, Aroostook County, Maine.

rather similar. The margin, including the outlet end, where a sluggish stream carries water to Caribou Stream, and thence to the Aroostook River, is surrounded by spruce bog. The

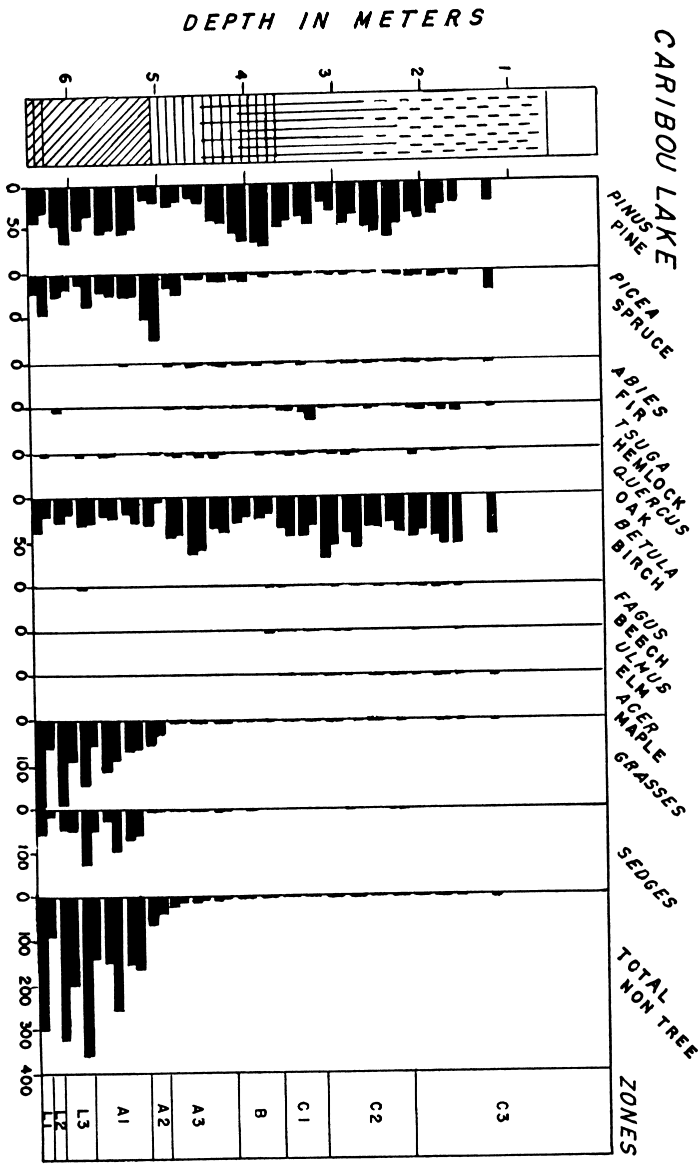

Fig. 3. Pollen diagram for Caribou Lake, Washburn, Aroostook County, Maine.

latter was not seen at close hand, for the boring was made in the deepest part of the basin that could be found. The total depth to hard bottom here was 6.45 meters, including the water, which is about the same depth (0.65 meters) all over. Few aquatic plants were seen, and the surface sediment is a reddish-brown, flocculant material that is presumably identical with the "dy-gyttja" of certain Swedish lakes. Evidently this sediment, which has been shown as lake peat in the section, figure 3, is the result of the deposition of allochthonous humic matter in hard water. Although the only boat available was a canoe, no difficulty was experienced in completing the boring, and the large Hiller sampler was then used to take two samples for radiocarbon analysis, at 2.65 and 3.90 meters.

Alder Lake, Chapman.—This lake is closely similar to Cari-

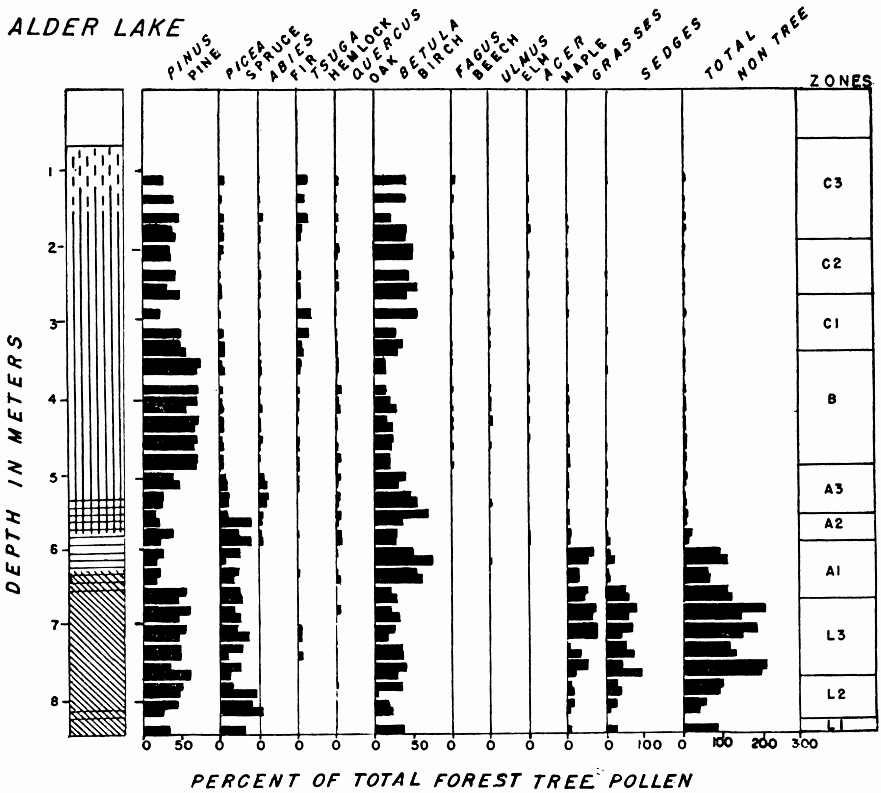

Fig. 4. Pollen diagram for Alder Lake, Chapman, Aroostook County, Maine.

bou Lake, but lies at a considerably higher altitude (663 feet), being tucked in a notch of Hedgehog Mountain in a way that suggested that it should be an ideal sediment trap. Drainage is to Alder Brook and thence to Presque Isle Stream, a tributary of the Aroostook River. The boring was made near the center in a total depth of 8.40 meters, the section being normal for the region (fig. 4).

Bishop Pond, Fort Fairfield.—Unlike the three lakes just described, Bishop Pond is little more than a wide part of a stream that wanders through a boggy valley bottom. It lies at an elevation of 660 feet, and the outlet flows to the Presquile River, which reaches the St. John River independently. This is one of the bogs investigated by Trefethen and Bradford (1944), and their sections indicate that the basin was never occupied by a lake of appreciable depth, for their deepest boring did not exceed 4 meters. The boring shown in figure 5 was made at the edge of the pond, and is only 3.80 meters long; a little farther downstream the gravelly subsoil comes to the surface. A handsome forest of black spruce and larch surrounds the pond on all sides, making access difficult.

The profile shows all the types of sediment to be expected in the region, but the pollen diagram suggests that little sediment has formed since the time of the pine zone; unfortunately the upper 65 cm., above the end of the peat borer when open at

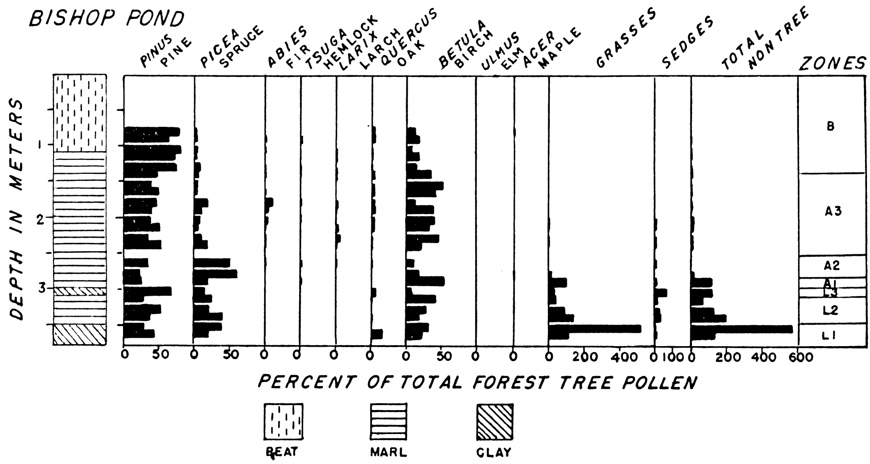

Fig. 5. Pollen diagram for Bishop Pond bog, Fort Fairfield, Aroostook County, Maine.

mark 0, could not be sampled without special pains, and they were not taken. The lower part of the section is remarkably informative, considering its small depth and the coarse sampling interval. Trefethen and Bradford reported shells occurring in the clay, and on this evidence they remarked that this "extends the limits of postglacial marine invasion into this area" (p. 9), but there can be little doubt that the shells occurred in the marl, either above or below the upper of two layers of clay, and that the shells were of fresh-water species. Shells of such species were abundant in the marly parts of the boring made by the writer, and there is no reason whatever to suppose that the clay is marine.

Muddy Pond, Oakland.—This small, bog-margined lake lies at 250 feet elevation in a minor depression near the lower (northern) end of the basin that holds Messalonskee Lake, in Kennebec County. Probably it was once an arm of the main lake, but at present the basins are separated by a sill less than 20 feet above lake level, and the spruce bog is confined to the Muddy Pond flank; Messalonskee Lake is presumably very much deeper than 15.40 meters, the maximum depth reached under Muddy Pond with the peat borer.

Muddy Pond is less than 4 meters deep, but a preliminary attempt to make a boring in the deepest part was given up on account of the impenetrability of the clay deposits below 15.40 meters. The section shown in figure 6 was taken just off the bog mat, and ended at hardpan in 10.35 meters. There is ample reason to believe that the clay encountered below the peat and gyttja was not laid down in a lake like the present Muddy Pond. The boundary of the clay at 8.40 meters was sharp, whereas lake clay ordinarily passes gradually into clay-gyttja. Below the boundary the pollen vanished abruptly; the 25 cm. core at 8.40 meters was sampled in four places, and the upper three proved to be normally polliniferous organic deposits, while the lowermost one was absolutely sterile. The character of the pollen flora also shows that an unconformity is present, for the spruce-fir zone is totally absent in this boring. (The single sample at 15.40 meters in the center of the lake, however, is a dark clay containing little pollen, but of 26 grains counted, 22 were of spruce, 2 of pine, and 2 of sedge.) The clay under the peat nearer the bog margin shows dark zones, not at the uppermost level, but lower down, about

9.0 to 9.5 meters. These zones contain little more pollen than the rest of the clay, too little to count in any case. The most convincing evidence that there is something abnormal about this clay is the occurrence of what appears to be the internal cast of a shell of *Mytilus edulis* at 9.15 meters.

More work is obviously needed, but it is reasonably evident that marine clay underlies the organic sediments of Muddy

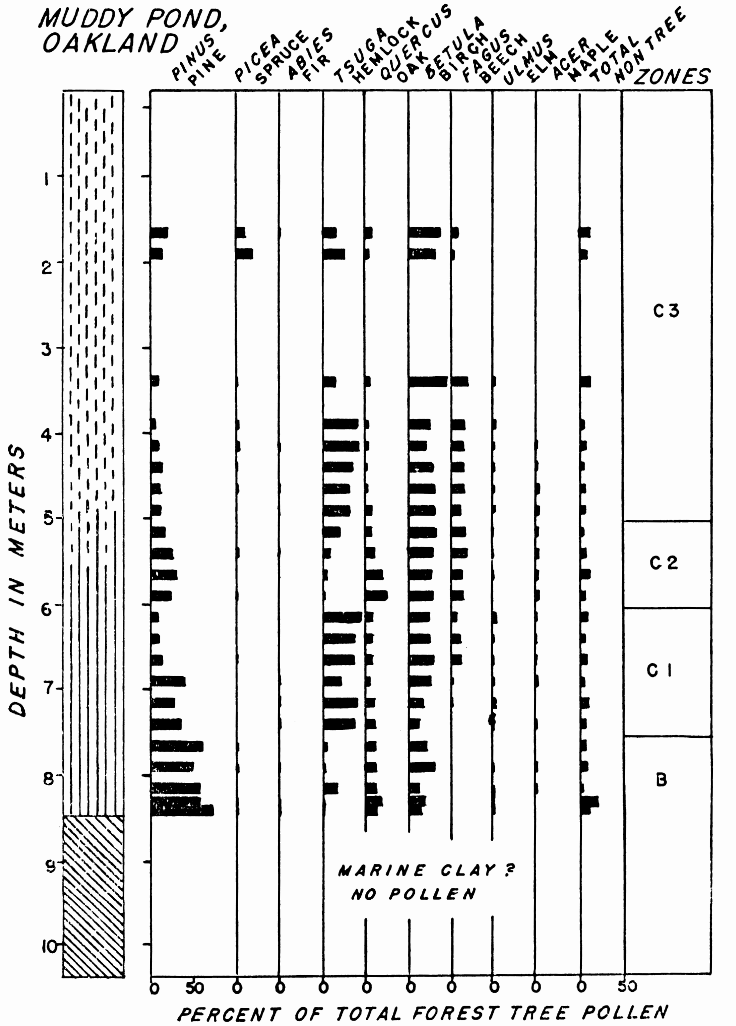

Fig. 6. Pollen diagram for Muddy Pond, Oakland, Kennebec County, Maine.

Pond. It is highly probable that it also underlies Messalonskee Lake itself. According to Leavitt and Perkins (1935), however, the lake basin is of unusual interest in lacking marine clay, and "the northern part of Messalonskee Lake at Oakland appears to have been a giant kettle . . ., in which a mass of ice may have lingered through the marine stage, preventing the entrance of the sea and the filling of the basin by marine clays which cross both ends of the valley" (p. 51).

Gould Pond, Sydney.—This is a typical seepage lake without bog margin, occupying one of a large number of magnificent kettles in the great outwash plain that lies at the southern end of Messalonskee Esker. This plain, according to Leavitt and Perkins, ends in a delta whose foreset slope falls off to the south and ends in marine clay; it marks a temporary halt of a receding ice front. The clay that underlies Gould Pond appears not to be marine, and the deepest part of it is younger, pollen-analytically, than the clays underlying the lakes of Aroostook County. From these rather inadequate observations it appears possible that Gould Pond, unlike Messalonskee Lake, may actually have been occupied by a buried mass of ice during the marine stage and thus protected from marine deposition.

Two borings proved to be necessary to establish a semblance of a complete postglacial section in the sediments of Gould Pond. The first, in the comparatively shallow north part of the lake, looked suspiciously incomplete in the field, though it ended in outwash sand. Clay appeared at deeper levels in the deeper part of the basin, and a second boring was made there, with samples less closely spaced in the upper part, in an effort to patch up the first profile. Possibly there are older deposits of clay elsewhere in the lake, or in other lakes of the series that are not so readily accessible by boat. The two sections, shown in figure 7, have been fused in such a way that the depth scale is continuous, but there is considerable overlap in age of sediments.

REGIONAL POLLEN SEQUENCE

General Statement

Although the Aroostook County pollen diagrams present some strikingly new features in comparison with those known from southern New England, their zonation is rather clear, and the fact that they are largely dominated by pine and birch pollen and are nearly or completely devoid of oak, beech, and hickory does not hinder comparisons either locally or generally. The outstanding characteristic of the four profiles (figs. 2-5) is the occurrence near the bottom in sediments composed of silt, clay, or marl, of enormous quantities of grass and sedge pollen, the total non-arboreal component representing from 100 to nearly 600 per cent of the forest tree pollen. This preponderance of herbaceous pollen (with shrubs, such as alder and willow, contributing a minor fraction) can only mean that the vegetation of the period was a tundra, and that the tree

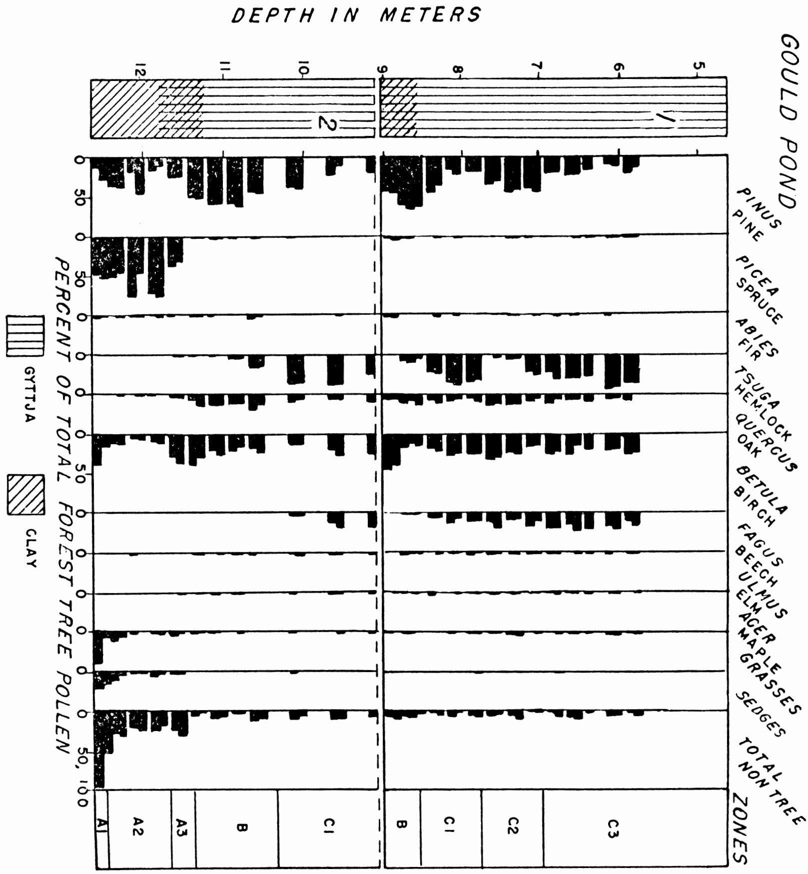

Fig. 7. Pollen diagram for two borings in Gould Pond, Sidney, Kennebec County, Maine. The two diagrams are joined at a point of equivalent depth from the lake surface, but the upper part of boring 2 overlaps boring 1 in respect to age.

pollen (composed of pine, spruce, and birch in about equal proportions, with an occasional grain of oak, beech, or hemlock) was blown from a great distance. In all essential respects this older zone corresponds to the "late-glacial" of northern Europe, and these are the first North American pollen diagrams to show a complete sequence from tundra to postglacial forest.

The two localities in Kennebec County, about 175 miles SSW of the Aroostook County group, yield much more "orthodox" New England pollen profiles, and are of interest chiefly in showing that it is not Maine as a whole, but northern Maine, that is exceptional. As it happens, neither shows a "late-glacial" pollen zone, but this does not mean that tundra conditions never prevailed in southern Maine, as pointed out in a later discussion. The two diagrams (figs. 6 and 7) must be kept sharply distinct from the first four in the following presentation.

"*Late-Glacial*" (*Zones L 1, L 2, L 3*)

The tundra vegetation recorded in the oldest lake sediments in Aroostook County appears to have been rather uniform within the region, for grasses and sedges share approximately equal dominance in three of the four profiles (the exception being Bishop Pond, fig. 5). The number of different herbaceous species represented by at least one pollen grain is rather large, but less than half of them have been identified even tentatively; the commonest type, apart from grasses and sedges, is almost certainly *Artemisia* (as it is in Europe), while other Compositae, Caryophyllaceae, Chenopodiaceae, and Rosaceae are present, in addition to the more or less positively identified genera *Plantago*, *Drosera*, *Scleranthus*, *Epilobium*, and *Typha*. Various pteridophyte spores have also been seen, including *Lycopodium* and *Equisetum*, but not *Isoetes*. Relative proportions of these various non-arboreal types are of no significance, as the total number of pollen grains and spores counted in sediments of this age was less than 100 in most samples. The tree pollen present must mainly have come from a long distance away from the localities, as shown not merely by the similar proportions of the three dominants (pine, spruce, and birch), but by the almost invariable occurrence of one obviously stray grain (usually of oak, sometimes of hemlock, beech or elm) in each count. The birch pollen, or some of it, may have been derived from thin birch woodland in the near vicinity, but it is impossible to be certain about this.

Sequences within the zone of tundra vegetation, though not established beyond doubt, owing to the coarse sampling interval, are sufficiently convincing to warrant the division into three zones, and this is the most astonishing feature of the Aroostook County diagrams, after the demonstration of the existence of the tundra itself. In three of the four sections there is a marked fall in the total non-arboreal component, usually to slightly less than 100 per cent, accompanied by a rise of birch and spruce pollen that may or may not be real. At this level the pollen density increases noticeably, although quantitative figures are not available, and the pollen frequency per unit area of smear is regarded as almost entirely without significance. More striking is the appearance, somewhere in this region of the profiles, of a band of marly sediment in the clay. Evidently the climate was a little more favorable at this time than before or immediately after, as though an ice advance somewhere in the neighborhood brought a temporary halt to the general amelioration represented both by the composition of the pollen flora and the nature of the sediment deposited.

Stratigraphic relationships within the "late-glacial," as they are inferred from this admittedly scanty evidence, are remarkably like those of northern Europe, where, in a belt of country distal to the Fennoscandian moraines and their presumed equivalents and extending from Russia to Ireland, an older and a younger zone of tundra climate (lower and upper *Dryas* zones) are separated by sediments of a warmer time, the Allerød oscillation. Many more analyses in vertical sequence will be necessary to convince a skeptic that the "Aroostook oscillation" is a reality. Even if it is real it must be shown to have had a much wider geographic distribution before its interpretation as sub-age of Wisconsin time (presumably the Cary-Mankato or Two Creeks interval) can be accepted as more than a remote possibility. For the present, however, on the grounds of its consistent occurrence in three profiles, the author has no qualms about recognizing it as a stratigraphic horizon, referring to it as *L 2*.

The Aroostook oscillation is most clearly shown at Bishop

Pond (fig. 5), where the band of marl is thickest, so that three analyses fall within it. At Plissey Pond (fig. 2), the section appears to begin in *L 2*, and *L 1* is missing. There is a possibility that the two samples at and just above 9.65 meters belong to *L 2*, but this is thought to be improbable because of the suggestion of confused stratigraphy, recounted in an earlier section.

The use of the expression "late-glacial" for the tundra zones is open to some objection, since it implies an arbitrary and logically erroneous usage for "postglacial." All pollen diagrams in formerly glaciated districts are postglacial, of course, but as the postglacial chronology gains refinement there is need to distinguish the time "when the fauna and flora were influenced by the presence of nearby ice from a time when they were not" (Deevey, 1949, p. 1325), geographically relative though these times may have been. From the point of view of pollen analysis the most convenient boundary between "late-glacial" and "postglacial" is the time marking the invasion of tundra by forest. This boundary is here considered to lie at the final and permanent fall of the non-arboreal pollen to values below 100 per cent. More than that is not implied by the term "late-glacial."

The pollen zone hitherto thought to be the oldest in North American diagrams is the spruce-fir zone, designated "*A*" by the author (Deevey, 1939, 1943) and "I" by Sears (1942). The classification must now be revised, and it seems that less confusion will arise if alphabetical order is violated and the "late-glacial" zones given the general designation "*L.*" *L 1* and *L 3* are cold zones, and are separated by the slightly warmer but probably still treeless Aroostook oscillation, *L 2*.

First Postglacial Forest (*Zones A 1, A 2, A 3*)

The relative proportions of the forest tree pollen grains during the "late-glacial" should probably be disregarded, partly because all of these grains are considered to have been blown from a distance, and partly because the total number of grains counted was too low for reliability in most cases. The first sure indication of the arrival of forests in Maine is the fall of the non-arboreal component to values around 100 per cent. In four of the five diagrams recording this advance, including Gould Pond in central Maine but not including Caribou Lake in Aroostook County, birch is the first "arboreal" type to take part in the rise. This is what would be expected during the advance of a forest onto a tundra, although the application of the term "forest" is open to debate; the forest was doubtless of the "little stick" variety.

The main rise of spruce pollen (leaving aside the rise during *L 2*, which is probably fictitious) follows the rise of birch in all profiles, and comes at the expense of birch. The non-arboreal component falls to "normal" values of around 10 per cent, the grasses and sedges disappearing almost completely and leaving the field to the usual non-tree types of local provenance, such as alders, willows, ericaceous shrubs, and pteridophytes. There can be little doubt that spruce forests were actually extensive at this time, and that Maine was part of the taiga.

The next feature of interest is a rise of fir, conspicuous in most borings despite the low percentages involved. Spruce remains high, and birch rises once more. The alder maximum (not shown in the diagrams) falls here in all of the Aroostook County sites. It is difficult to know how to interpret these events. The birch may have been a more warmth-loving species than the earlier pioneers, and the alder maximum may be the purely local result of shoaling of the lakes and the formation of swampy margins. These perfectly reasonable hypotheses imply steady climatic amelioration and advance of forests throughout the time of the spruce zone. On the other hand, fir is more likely to occupy outwash in recently deglaciated districts than is spruce, and birch and alder thickets may possibly have replaced spruce forests as a result of a slight deterioration of climate, since they are outposts on the tundra today. The question must be left open, and it may never be answered until the species of birch and alder can be identified with certainty.

The early forest time, "*A*," then, is divisible into three well-marked zones, *A 1*, birch woodland, *A 2*, spruce forest, and *A 3*, birch-fir-alder pollen maxima of uncertain climatic significance. No pollen diagrams hitherto published for North America show so clear or so complex a sequence, and the Maine zones may prove to be of only local validity. Regional correlations are discussed further below.

Pine Zone (B)

Pine pollen is generally high throughout the Maine borings, and on that account one might anticipate some difficulty in picking out a zone characterized by high pine. That this is not the case is one of the most remarkable facts about a zone that is notably easy to pick out everywhere in eastern North America. Between the decline of spruce pollen to negligible quantities and the rise of members of the deciduous forest complex is a layer of sediment having consistently and extraordinarily high pine percentages. Its ecologic interpretation is something of a puzzle, as the author has emphasized elsewhere (Deevey, 1949). Because pine pollen is produced in abundance and is exceptionally light, pollen workers have grown accustomed to discounting pine values of 50 per cent or so as due to extreme over-representation, but figures of about 80 per cent (occasionally as high as 95 per cent) are the rule in the pine zone, and must imply the presence of a great many pine trees in the vicinity. It is commonplace to regard this period as one of warm, dry, continental climate, corresponding to the Boreal phase of western Europe, but in North America, in contrast to Europe, the pines seem to have replaced a taiga community, and this is difficult for an ecologist to understand. It is possible that the pines were dominant by default, so to speak, in that they lived on poor soils—outwash plains, kames, deltas, and the like, while deciduous forests had still not succeeded in colonizing the potentially better sites, and the climate was too warm for spruce forests, at least in the summer. The long time during which the pines seemingly held sway makes this a rather unsatisfactory explanation.

At all events, the pine zone (*B*) exists in the Maine diagrams as it does elsewhere. There is little evidence of differentiation within this zone; in parts of the middle West, notably in Minnesota, there is more than a suggestion that elm pollen reached a maximum early in the period, and this may be more generally true than is commonly realized, but it will be necessary to count more than 150 pollen grains to prove it in regions, such as Maine, where elm pollen does not exceed 3 per cent. Subdivision of the pine zone on the basis of the hazel pollen curve is practicable in parts of Europe, but not in North America. A useful feature of the Maine diagrams, though one that is probably of only local importance, is that the pine period terminates at a level of minimum birch pollen, but whereas pine undergoes no significant change during the next phase (*C 1*), birch rises again rather suddenly.

Deciduous Forest Zones (*C 1*, *C 2*, *C 3*)

The threefold division of the deciduous forest phase is maintained with admirable clarity in the Maine diagrams, despite the fact that the region is outside the ranges of hickory and chestnut, types that are highly characteristic farther south. The most distinctive picture, somewhat paradoxically, is given by the curve for hemlock, which is not a deciduous species, though it belongs to the deciduous forest community. In central Maine hemlock is the dominant type both in *C 1* and in *C 3*, and this is true elsewhere in New England north of the Connecticut and Massachusetts coast, where hemlock is subordinate to oak. In the form and strength of the hemlock curve the Kennebec County diagrams closely resemble those published from New Hampshire by Krauss and Kent (1944). In Aroostook County, however, though hemlock pollen shows the same characteristic oscillation, it is much less abundant than pollen of birch and pine. While proof is lacking, it is almost certain that the birch species involved here is mainly *Betula lutea*. The middle period of hemlock minimum is characterized by the oak maximum, as usual, but hickory pollen is absent, and there is a rise of pine, presumably equivalent climatically to one of hickory. The abruptness of the hemlock decline at this level is noteworthy. The final period, *C 3*, so far as it is recorded by incomplete sampling, saw a return of hemlock, birch, and spruce, and a decline of oak and pine.

The behavior of the beech pollen curve attracts special attention, because of the author's hypothesis (Deevey, 1949) that there were three waves of migration of beech in eastern North America, probably without climatic significance. The oldest is supposed to be recorded in New Jersey, while southern New England and Ohio witnessed only the second and third. On this view the Kennebec County localities are normal for New England in showing two rises, across the boundaries, *C 1-C 2* and *C 2-C 3*, while only the last is at all prominent in northern Maine. This is what would be expected if the migration of beech was relatively slow, with its rate governed more by distance from glacial refuges than by climatic controls. It is also another faithful reflection of events in northern Europe.

DISCUSSION

The strictly postglacial parts of the Maine pollen diagrams, beginning with the time of the spruce maximum, though peculiar in some respects, offer no difficulty for correlation with the standard sequence of events in eastern North America. Attention must therefore be centered on the older zones, and an attempt made to decide the likelihood that they are uniquely characteristic of northern Maine. Certainly the climate and physiography of the region are peculiar enough to warrant the suspicion that this most continental part of the maritime peninsula of eastern Canada and United States must be in a class by itself. Moreover, the pollen diagrams from places in closest geographic proximity, those that Auer (1930) obtained in the Maritime Provinces, are as different as can well be imagined from those of the present report.

Auer's diagrams can be dismissed at once, because it is now clear that most of them are incomplete at the top. This is the result of making borings in bogs, particularly in raised bogs. They are also incomplete at the bottom, since the mineral sediments underlying the organic materials were not analyzed for pollen. So far as the wide sampling interval permits of a judgment, the published profiles agree well with the middle parts of the Maine diagrams, particularly with those from central Maine, since most of them are dominated by pine and birch, and many of them show the fall of spruce and the rise of pine, followed by the rise of hemlock, typical of Zones *A*, *B*, and *C 1*. The same features are shown by most of the diagrams from coastal Maine published by Potzger and Friesner (1948), but only one of these (Mullins Pond) can be accepted as essentially complete.

Potzger and Friesner made an effort to extract pollen from the clay underlying their bogs, but met with little success. This clay is presumably of marine origin, and so far it has proved sterile in the author's hands as well. Lake clays are not always so barren, however, and this is true in other localities beside the marl lakes of Aroostook County, which admittedly are exceptionally favorable. The oldest sediments in Linsley Pond and Upper Linsley Pond, Connecticut, for example, are not devoid of pollen; those of Upper Linsley, at least, also show the high non-arboreal pollen percentages characteristic of the "late-glacial," as a re-investigation has shown. The new diagram, which was made in connection with sampling for radiocarbon dating, has been published by Deevey and Potzger (1951 *in press*). The absence of the "*L*" zones in the earlier analyses

(Deevey, 1939, 1943) cannot be satisfactorily explained; it may have been merely due to failure to record all the non-arboreal pollen, but as some of the data sheets from the 1939 investigation show high values for grass or sedge, while none of those for the 1943 series do so, it is probable that the coarse sampling interval employed was the cause of the oversight. Be that as it may, northern Maine is evidently not unique in showing a zone of tundra climate. And if southern Connecticut once had such a climate, it is quite probable that southern Maine did also.

We are accordingly obliged to scrutinize the "*A*" zone of other North American pollen diagrams for evidence of "late-glacial" conditions. One feature in particular seems to require a completely different interpretation. In many diagrams spruce pollen rises before it falls. Where a fir maximum precedes the spruce maximum it is reasonable to suppose that ecologic succession was involved, but this is not the usual sequence. More often the fir maximum accompanies or follows the spruce maximum, and the older pollen flora is mainly of pine. Such a spruce rise has hitherto been thought to signify climatic deterioration, perhaps a re-advance of ice in the vicinity (Deevey, 1939, 1949). It now appears more probable that the spruce rise records the actual invasion of spruce into the region, the older spruce (and pine) pollen having been wind-borne from a distance. If only forest tree pollen grains are counted or recorded in pollen diagrams, the full implications of their proportions can easily be overlooked.

It follows that some or all of what has sometimes been called Zone *A 1* very probably belongs to the late-glacial "*L*" zones. Zone *A 2*, which in Connecticut has been considered to begin with the spruce maximum, may be correlated with Zone *A 2* in Maine, and the birch maximum of *A 1* as now recognized may simply have been missed before. Zone *A 3* of Maine is also discernible in southern New England.

It is unfortunately true that if some appreciable fraction of the pollen from the spruce-fir zone was blown for a long distance over a treeless belt, most of the basis for the reconstruction of glacial refuges and routes of postglacial dispersal of forest trees, as worked out particularly by Sears (1941), must fall to the ground. Sears' maps for postglacial migration of oak, hemlock, beech, and basswood were based on their relative order of appearance in a large number of pollen diagrams, but the order of appearance could easily be irrelevant at any given site if the pollen in question was not of local derivation. The fact that maverick grains, especially of oak, are comparatively abundant in the "*L*" zones of Maine points to this disappointing conclusion.

The sequence of pollen zones is summarized in table 2, which is designed to call attention to the remarkably close correlation with western Europe. The Irish stratigraphy (Jessen, 1949) has been chosen because Ireland is nearest to America

TABLE 2

Tentative correlation of pollen sequences in northern Maine with those from Newfoundland-Labrador (Wenner, 1947) and Ireland (Jessen, 1949). Horizontal lines do not imply contemporaneity of zones. NAP = non-arboreal pollen.

Maine		Newfoundland-Labrador	Ireland	
Zones	Pollen flora	Pollen flora	Zones	Pollen Flora
C3	Hemlock, spruce return; beech maximum	Return of tundra pollen	VIII	Alder-birch-oak
C2	Oak maximum, pine rises; hemlock, beech at minimum	Conifer maximum	VIIb	Alder-oak
C1	Hemlock maximum; birch rises, oak and beech present		VIIa	Alder-oak-pine
B	Pine maximum; birch falls		VI	Hazel-pine
A3	Fir and birch rise, spruce still high; alder maximum	Subarctic alder forest	V	Hazel-birch
A2	Spruce maximum; birch falls			
A1	Birch rises, NAP falls; end of tundra		IV	Birch
L3	NAP higher		III	Younger *Salix herbacea*
L2	NAP lower; spruce and birch rise		II	Birch (Allerød)
L1	NAP high; long-distance transport of pine, spruce, and birch		I	Older *Salix herbacea*

geographically, and the zonation of the Irish pollen diagrams has deliberately been brought into conformity with standard systems from elsewhere in the British Isles and from Denmark. Actually, Ireland has so maritime a climate that Jessen had some difficulty in distinguishing between zones that are much clearer in other parts of Europe. The similarity in details of pollen flora between Maine and Europe would appear much closer if Sweden had been chosen rather than Ireland. At present the details are considered to be less important than the fact of the correlation.

It should be emphasized that the transatlantic connection between zones by means of horizontal lines in table 2 implies no more than stratigraphic equivalence. Absolute contemporaneity should never be read into tables such as this, in view of the fact that similar tables are constructed for places situated on north-south lines, where we have every reason to doubt that stratigraphic equivalence means contemporaneity. Late-glacial and postglacial synchronism between eastern North America and western Europe will be discussed in another paper, when radiocarbon dates are reported.

Data from Newfoundland-Labrador are also incorporated in table 2. It is not easy to interpret the diagrams given by Wenner (1947), in part because he has used various unorthodox methods of computing pollen percentages, and has lumped all winged-grained conifer species together without tabulating their numbers. His highly interesting results have been inserted in the table in order to express a mild disagreement with the correlation set out on page 163 of his work. According to that interpretation, all of the sections, at least all those from the forested part of the region, date from Atlantic time or later, and the maximum of conifer pollen is referred to the xerothermic interval. The famous diagram published for southern Labrador by Bowman (1931) has been brought into line with its hemlock maximum falling in the xerothermic interval also (hemlock does not grow today within hundreds of miles of Bowman's site). It appears that Wenner was unduly influenced by his belief that all postglacial events in Labrador were compressed into a time-span very much shorter than postglacial time farther south. This is a reasonable belief, but it should be kept out of correlation tables until an absolute chronology is available. In the pollen-analytic sense it is more probable that Wenner's conifer maximum and Bowman's hemlock maximum belong to *B* or *C 1*, not to *C 2*, and that the first postglacial forest zone is equivalent to some or all of *A*. New investigations in Quebec and southern Labrador are badly needed to clarify the correlation, particularly since there is reason to suspect that Bowman's section, which was made in a bog, is incomplete above and below.

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Osborn Zoological Laboratory
Yale University
New Haven, Connecticut