

DISCUSSION.

CORRELATIONS OF POLLEN PROFILES FROM GLACIATED EASTERN NORTH AMERICA.¹

EUROPEAN students of glacial and postglacial lake sediments, and of bog sediments and peats, have given us an increasingly consistent and detailed picture of climatic fluctuations in glacial and postglacial time. Their studies have included the many different types of peats and sediments, together with their content of pollen grains, spores, and other microscopic fossils. This work has been extensively correlated with the results of the varved clay studies by DeGeer and his students, with the conclusions of students of glacial geology, with the work of plant and animal geographers, and with the calculations and conclusions of meteorologists and astronomers. These studies and correlations have made possible the dating of human cultural horizons and cultural remains, and have aided substantially in understanding the migrations and cultures of primitive peoples.

Investigation of glacial and postglacial lake sediments, and of bog sediments and peats in North America, has led to three divergent interpretations,² with the result that no generally acceptable picture of North American vegetational and climatic change has as yet been achieved. This has hindered the utilization of the stimulating results that have come from the work of the Europeans. In the eastern half of North America, the correlation of different pollen profiles with each other has met with the following difficulties: 1. The region is very large; and in the past there have been great differences in climate and vegetation within the region, as there are at the present time. Hence, any general climatic change must have resulted in correspondingly varied effects on the diverse vegetation of the different parts of the region. 2. In constructing their pollen profiles, investigators have differed as to the inclusion or exclusion of certain pollen and spore types, as, for example, certain

¹ Preliminary notice.

² See especially the following:

Artist, Russell C.: Pollen spectrum studies on the Anoka sand plain in Minnesota. *Ecol. Monog.* 9: 493-535, 1939.

Deevey, Edward S., Jr.: Studies on Connecticut lake sediments. I. A postglacial climatic chronology for southern New England. *This Journal*, 237: 691-724, 1939.

Fuller, George D.: Interglacial and postglacial vegetation of Illinois. *Trans. Ill. State Acad. Sci.*, 32: 5-15, 1939.

Sears, Paul B.: Postglacial climate in eastern North America. *Ecol.* 13: 1-6, 1932.

Voss, John: Postglacial migration of forests in Illinois, Wisconsin, and Minnesota. *Bot. Gaz.* 96: 3-43, 1934.

prairie indicators that occur in some Illinois bogs. 3. Pollen-bearing sediments were not, as a rule, laid down until some time after the glacial ice had uncovered any particular region. Hence, in giving the vegetational changes, very few or none of the pollen profiles have begun with the first formation of lake or of bog depression. This becomes very evident when one locates on a map of the substages of the Wisconsin glaciation the lakes and bogs that have already been investigated. Such a map has been constructed in connection with the present study. This was the first step in the correlation of the profiles. This map will be published with a later detailed report. 4. In the past, samples for pollen-analysis have, as a rule, been taken at vertical intervals of six inches or more, with the result that many climatic periods are inadequately represented in the profiles, some of them being absent altogether. 5. Chemical conditions necessary for the preservation of certain microfossils (notably larch pollen) vary in different bogs. 6. The forest flora in eastern North America is more complex than it is in western Europe. This is due to the fact that in western Europe many species of the Tertiary flora were exterminated during the Pleistocene glaciations, because the Alps prevented the retreat of the flora southward. In eastern North America, however, the members of the Tertiary flora could retreat before the ice to the south and southwest.

The writer has studied 148 pollen profiles from 123 bog and lake deposits in different parts of eastern North America. These pollen profiles are given in the published and unpublished works of many investigators. It was early noted that a spruce maximum occurs near the bottoms of most of the older (though not the oldest) profiles, and that this is preceded by a strong fir maximum. Following the rapid decline of the spruce maximum, fir again increases, and pine begins its rise to a maximum. During the rise of the pine, birch reaches a pronounced maximum, but rapidly decreases in most profiles just before the pine maximum. Since this sequence occurs at and just above the bottoms of most of the older profiles, it is a natural starting point for the correlation of the profiles.

The writer assigns the pine maximum to early postglacial (boreal) time. He correlates the pronounced spruce maximum with abrupt and sharp expansions of the late-Wisconsin ice sheets. The increase in fir and the birch maximum he correlates with the rather abrupt cessation of the strong expansions of the ice, and with the subsequent minor oscillations accompanying the final disappearance of the ice sheets. He calls this the pre-boreal period.

These correlations have been confirmed by a study of four profiles from the Bucyrus, Ohio, bog,³ which is the oldest investigated gla-

³ Sears, Paul B.: A record of postglacial climate in northern Ohio. *Ohio Jour. Sci.* 30: 205-217, 1930.

cial bog that runs into postglacial time. The profiles from this bog show a long series of oscillations of spruce, fir, and pine in late-glacial time, leading up to a forest in which fir was prominent, and in which oak was gradually increasing, indicative of a gradually warming climate. This mixed forest of spruce, fir, pine, and oak was very sharply terminated by a marked increase in spruce and small-pollened pine (probably jack pine), and the complete elimination of fir and oak. This clearly indicates an abrupt and pronounced change of climate, suggestive of a strong expansion of the ice near the end of the glacial period. Following the spruce maximum, there is an abrupt and relatively short-lived fir maximum, accompanied by an increase in oak and large-pollened pine (probably white and red pine). This period correlates well with the author's conception of the pre-boreal. When the pine reaches a maximum, fir and spruce are comparatively low or absent, and oak and other plants are rapidly increasing. This period, for the author, corresponds with the boreal, or first postglacial period. Pollen-analysis of other glacial bogs should bring to light similar evidence of changes that took place during the waning of the ice sheets.

Antevs⁴ has found evidence that the last strong expansions of the waning Wisconsin ice sheets came southward to the vicinity of Cochrane, Ontario; he concludes from studies of varved clays that the readvance took place approximately during the interval between 12,000 and 10,000 years ago. The spruce maximum in the pollen profiles seems, without much doubt, to have been caused by these expansions.

For the present writer, the interval between the spruce maximum and the pine maximum, characterized by a rise in fir and culminating in a final birch maximum, constitutes the pre-boreal in North America. During this period, sediments and peats were slowly deposited, with the result that the period is poorly represented in most profiles.

The pine maximum, followed by a decline in pine and rise of deciduous forest trees, characterizes a boreal period. The profiles show that the climate became warmer in the last part of this period, and the profiles from central North America east of the Mississippi and west of the Appalachians indicate that this warmer period was also drier in that region. This warming of the climate probably occurred at the same time as the first of the "climatic optimum" in western Europe. Near the Atlantic Ocean, the profiles of bogs show a maximum forest complexity and lack of differentiation at the very end of the boreal period and at the beginning of the suc-

⁴Antevs, Ernst: Late Quaternary upwarings of northeastern North America. *Jour. Geol.* 47: 707-720, 1939.

ceeding period. In central North America east of the Mississippi, on the other hand, the profiles show that the maximum development of mixed forests occurred earlier in the boreal, and that towards the end of the boreal it was too dry for the development of large mixed forests, these being replaced by more xerophytic forests.

All of the profiles agree, however, in showing an increase in species requiring greater humidity for good growth at the very first of the succeeding period. This increase seems to correspond with the beginning of the Atlantic period as defined in Europe. However, the profiles of the northern Atlantic coast bogs and of the bogs of the mid-west show certain striking differences, which help us to understand the factors involved in the climatic changes which took place during this "Atlantic" period.

The profiles of the Atlantic coast bogs indicate a somewhat "oceanic" climate during certain times in this "Atlantic" period, though not so extreme as the "oceanic" climate in western Europe. The profiles of the mid-western bogs show a succession of periods of greater and less humidity, gradually becoming less and less humid toward the end of the period. The periods of somewhat "oceanic" climate in the coastal bogs seem to correlate with periods of greater humidity in the mid-western bogs. The profiles show that in the eastern part of the region, mesophytism was more pronounced and of longer duration, while xeric conditions were increasingly stronger westward. In the latter part of this "Atlantic" period, forests in the western part of the region were partially displaced by prairie.

The next portion of the profile succession in the Atlantic coast bogs shows a period during which oak and oak-hickory forests developed greatly, while more mesophytic species declined. This would indicate a pronouncedly warmer, drier climate, probably corresponding in time with the sub-boreal period of Europe. The profiles of this period from the mid-western bogs, when present, give clear evidence of a warmer, drier period, during which bogs practically ceased to develop, or dried out, and prairies pushed much farther east and north. Thus, there was a great loss of humidity over the entire region, the humidity becoming less and less southwestward from the St. Lawrence River valley, and westward from the Appalachians. This period was drier than any other post-glacial period. It is the warm, dry, "xerothermic" period described by many investigators, but whose existence has been vigorously denied by others.

The profiles next indicate a return to greater humidity, as shown by increasing pine in the southern parts of the region, and increasing spruce in the northern parts. This corresponds with the sub-

Atlantic period of European workers. During this period, there is also a decline in the warm, dry indicators of the sub-boreal period.

The above major climatic periods are indicated in the profiles from the entire region. The profiles from the region are also consistent in showing minor variations of climate within these major periods. These minor variations, occurring almost rhythmically, show that while the European divisions of postglacial climate outlined above apply in a general way to the eastern North American profiles, postglacial climate in eastern North America is perhaps better characterized as a series of climatic pulsations of more and less humid periods. The next to the last of the less humid periods of major importance is the "xerothermic" period, described above. The profiles also indicate that the climate was warmer than now, during most of the time from the warming of late-boreal time nearly to the present.

The minor fluctuations in the percentages of plant pollen of any one bog are so consistent, that they may be correlated with increases or decreases of the same species in other bogs. The writer has found that these minor fluctuations in the profiles of different deposits cannot be compared in respect to their actual percentages, but the increases and decreases of the various species are consistent, as well as the appearances and disappearances of previously unconsidered species, especially those near the limits of their ranges. These minor fluctuations have been of great help in making the correlations. The full report will appear soon, and it is hoped that it will be useful in utilizing North American glacial and postglacial sediments and peats for studies in several branches of science.

PRESTON SMITH.

OSBORN BOTANICAL LABORATORY,
YALE UNIVERSITY,
NEW HAVEN, CONN.