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A Consideration of Pollen, Diatoms and Other Remains in Postglacial Sediments

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Abstract. The significance of pollen and diatoms in post-glacial sediments from a shallow bay of Lake Okoboji, Iowa, is considered. The presence of other microfossils is noted with emphasis on those of Cretaceous origin: foraminifera, coccoliths, radiolarians, and hystrichosphaerids. Problems encountered and discussed include recognition of Chrysophyte statospores, redeposition, interpretation of data from lower levels, and reliability of radiocarbon dates applied to organic matter from aquatic vegetation.

We are presently engaged in a project with the title, "Ecology of diatoms in hard-water habitats." One of our endeavors has been the study of core samples from a shallow area of Lake Okoboji known as Little Miller's Bay. After several attempts an area was found where samples extending 34 feet or more into the mud could be obtained. The first samples were obtained with a Davis sampler and later ones with a Hiller type borer. These were operated manually from a barge anchored in shallow water.

Our study of the sediments of Lake Okoboji has been enlarged with a two-fold purpose in mind: (1) to gain knowledge of the post-glacial vegetative and climatic history of the region, and (2) to compare the results obtained from the pollen record with those of diatom succession to determine the potential value of a comprehensive view of both land and water habitats.

In the course of this investigation a number of problems have been encountered, the resolution of which is important for the completion of this study. Some of these problems have been discussed by other investigators in nearby states, and our consideration of them may be of interest to palynologists and geologists of the region.

Little Miller's Bay has gently sloping bottom contours and the sediment surface consists of a watery "ooze" in most places. The maximum water depth recorded during this investigation was seven feet. However, in early post-glacial times the basin must have been at least 34 feet deeper than it is now. The growths of aquatic vascular plants and filamentous algae during the summer months make the small bay almost impassable to boats by late summer. The bay is bounded on the north and west by gently sloping hills, and there are four inlets from small gulleys opening into its northern end. The amount of sediment contributed by outwash from these gulleys appears to be minimal at the core site (Figure 1). This shallow basin is a portion of Miller's Bay and is separated from it only by a sandpit of com-

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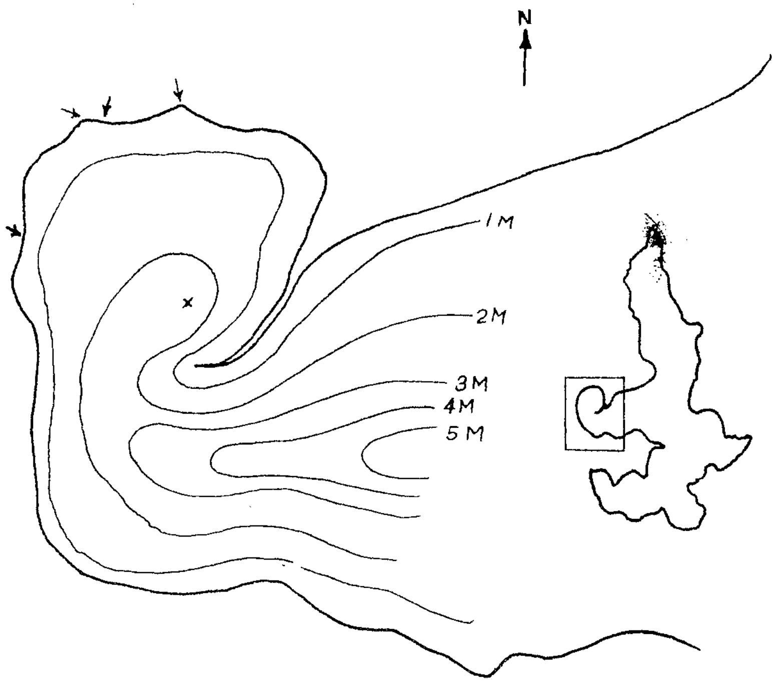

Figure 1. Map of Little Miller's Bay with contours of the bottom at one meter intervals. The inset outline of Lake West Okoboji shows the general location of the site—43° 27′ N., 95° 10′ W. The core site is indicated by an x and arrows indicate approximate locations of gulleys.

paratively recent origin. The contours of the bay are continuous with those of the main body of the lake (Stoermer, 1963).

All of our successful probes ultimately became stuck in a layer which is known to local well drillers as "blue clay." This non-scientific term applies to an aeolian deposit, presumably of Wisconsin origin, which underlies the till of the Cary lobe. We assume the sediments above this level are post-glacial and, in our various ways, we have been trying to read the post-glacial history of Lake Okoboji from these samples. One of us (Wehr) obtained the data in Table 1.

Samples used in this analysis were dried at 100° C., weighed, and then separated into two portions, one for inorganic C determination and one for total organic matter determination. Inorganic C determination was done as described by Black (1957) and provided an estimate of inorganic C percentage. An estimate method was used in favor of a precise method since available equipment was limited and only relative determinations between samples were sought. The method consisted of treating the sample with trichloroacetic acid and determining weight loss due to liberation of CO_2. From this the percentage of inorganic C was calculated.

Table 1

Analysis of Core Samples from Little Miller's Bay, Lake Okoboji, Iowa

Depth of Sediment (in feet)	CO^{-}_{3}%	Organic Matter (percent)	Dates
1	2.54	29.58	Present
2	sample	too small	
3	3.72	31.40	
4	4.31	29.53	
5	1.89	33.20	
6	1.28	32.04	
7	1.60	29.92	
8	1.30	10.89*	———— 2500 BP (est.)
9	1.41	27.32	
10	1.99	19.43	
11	1.44	19.12	
12	1.45	17.79	
13	2.02	18.62	
14	1.77	15.70	
15	1.93	15.94	
16	2.93	17.57	
17	3.33	13.60	
18	0.22	21.70	
19	1.86	15.36	———— (I-1755) 5,800 ± 130 B.P.
20	2.84	11.65	}
21	sample	too small	}*
22	1.43	06.87	}
23	2.29	09.62	}
24	5.72	25.60	———— 7600 BP (est.)
25	sample	too small	
26	4.88	25.25	
27	4.06	09.07*	
28	2.69	21.60	
29	1.95	18.72	———— 10,000 BP (est.)
30	2.65	24.71	
31	1.56	23.48	
32	4.23	32.86	
33	4.70	20.22	
34	3.08	16.72	
35	2.66	10.13	———— (I-1756) 12,700 ± 200 B.P.

Note: Radiocarbon dates I-1755 and I-1756 were determined by Isotopes, Inc., Westwood, New Jersey.

$$\frac{(CO_2)\ (.2727)\ (100)}{\text{sample weight}} = \%\ \text{inorganic C}$$

Organic matter determination was done by a modified method from Jackson (1958) and Black (1957). Samples were ignited in a 900-1000° muffle furnace for six hours per sample. Organic matter percentage was then calculated as the percentage of weight lost minus the inorganic C percentage.

Funds were available to obtain two radiocarbon dates which are included in the table. The asterisks indicate levels where substantial changes in the percent organic matter suggest that some type of major change occurred in the lake. By prorating the time intervals arbitrarily, an estimated date for each of the "change levels" is suggested.

A detailed analysis of the diatoms in these cores will be presented by one of us (Collins) elsewhere, and there will be a separate report of the detailed pollen counts (Webster).

There are no diatoms at all in the *blue clay*. They do occur in small numbers a few centimeters above the presumed interface and become increasingly more abundant as the samples are traced upward. At the 27-foot level, for instance, there is a well-defined population of diatoms which includes 22 genera and 66 taxa. We suggest that the first appearance of diatoms may be more indicative of the beginnings of biological activity in a post-glacial lake than the presence of pollen which might be blown in from some distance.

We are especially interested in species of the diatom genus, *Cocconeis*, which are particularly adapted to growing on coarse algae and vascular plants. Thus, their presence in abundance could well indicate a luxuriant growth of such plants and their absence could indicate a period when the area was completely dry or, conversely, a period when the water level rose so drastically that the environment was changed and existing plants were unable to continue as previously.

A sharp decrease in numbers of *Cocconeis* was noted at the 8- and 9-foot levels. Reference to Table 1 shows a marked change in the percent organic matter at the 8-foot level which could well be correlated with a temporary disappearance of the vascular plant flora from Little Miller's Bay. The pollen counts, which have been completed from the top to the 27-foot level at present writing, indicate that no drastic change in the surrounding land vegetation occurred at this time. Examination of Table 2 which contains a summary of the data for the 6-, 7-, 8-, 9-, 10-, and 11-foot levels shows merely a continuation of the gradual increase in tree pollen which had begun at a still lower level. This point will be discussed again but it is suggested here that the water level in Lake Okoboji had been rising slowly for centuries and at this time may have reached a high enough level to flood into Little Miller's Bay for the first time. Previously, the bay may have been no more than a separate small pond. A sudden increase in planktonic diatoms at these levels adds substance to this possibility.

Another possible assumption is that drastic changes in the water level might have an effect on the rate of decomposition of sediments. As long as the water level in the bay remained high enough to maintain anerobic conditions at the sediment surface the decomposition rate would have been relatively slow. If, however, the lake level fell enough to expose the sediments to an aerobic environment (as well as to wave action), decomposition rates would have increased and the relative organic content of such layers would have been lowered. If this is so, then some of the sediment layers with relatively low organic content might be indicative of low water level and, therefore, semi-arid conditions.

Table 2

Percent Composition of Selected Pollen Types for Comparison with Diatom Distribution at Same Levels (dates are estimates)

	1800 BP (6 ft.)	2100 BP (7 ft.)	2400 BP (8 ft.)	2700 BP (9 ft.)	3000 BP (10 ft.)	3300 BP (11 ft.)
Pine	15	19	16	15	10	11
Oak	25	28	19	15	13	16
All Deciduous Trees	37	43	30	27	19	26
Grass	9	9	12	11	16	12
Composites	32	24	35	39	49	43

The change indicated at the 23-foot level is possibly of this type. Our general observation notes indicate a vastly different type of sediment than in the layers below. The proportion of recognizable plant fragments is very low. There are many broken bits of snails and sand particles of various sizes. The diatoms present are broken or greatly eroded. All of which indicate a probable dry period. Similar conditions existed through most of the next three levels upward. A reverse trend is noted at the 19-foot level where more recognizable plant fragments, less sand, and more numerous intact diatoms which have a non-eroded appearance occur. The estimated date of the 23-foot level agrees well with other estimates of the time of a very dry period in this part of the world. See Walker (1966) for discussion and references.

At the 23-foot level we find only occasional grains of pine, grass, and composites and the suggestion that extreme dryness existed is continued upward through the next three levels. However, pollen evidence at the 20-foot level suggests that a gradual reversion to more mesic conditions had begun and this has continued with minor fluctuations ever since. The work of Oschwald et al. (1965) suggests that severe erosion took place during the dry cycle and the implications of an erosion cycle on the history of Lake Okoboji are numerous. It is our hope that an extensive, multi-disciplined attempt to obtain cores from the deep portion of this lake will be forthcoming. Stoermer (1963) obtained several 30-foot cores from sediments in the deep hole with a free-falling piston-type sampler, but his deepest cores were dated at less than 4,000 years. It is suggested here that erosion sediments may have formed the blocking layer which interfered with his coring operation on several occasions.

The original lake, which would have been much deeper than its present depth of 135 feet, may have shrunk during the dry period to within the confines of the present deep hole. Evaporation may have concentrated the dissolved nutrients to a level which could have approached salinity and had a marked effect on the diatom population. The diatom record is almost certainly there underneath the erosion sediments and we anticipate its examination with considerable interest.

It also is possible that the original drainage channel of the lake was plugged by erosion sediments and, when the water level began to rise, a much higher dam existed than prior to the erosion cycle. With the onset of more mesic conditions, the lake would have begun to fill again. As it did so it would have constantly resorted the materials of a constantly expanding beach. The sediments which then settled into the deep hole would have totally confused the sediment record for a long period. Possibly the lake reached its highest level at a period around 2500 B.P. before establishing its modern outlet.

As noted above, detailed pollen analyses will be presented elsewhere, and these will include counts made at 5-centimeter intervals. However, some comments about the general distribution of pollen in the lower levels are of significance here. From the base at 35 feet upward through the 30-foot levels, fir, spruce, and pine are common to abundant; birch is only slightly less so. Elm is abundant to the point of dominance at some levels. Oak is abundant and hickory approaches being abundant at the 33-foot level. Walnut and basswood also are present at that level. Grass, composite and chenopod pollens increase at the 33-foot level, become abundant at the 30-foot level and decrease slightly through the 25-foot level. The spores of several kinds of ferns are common from the base upward through the 25-foot level.

The presence of numerous algal remains through all these levels indicates an aquatic site, but apparently the land surrounding it was a luxuriant mixed forest. We have noted the beginning of change at the 29-foot level where spruce and fir essentially disappear. The pollen evidence corresponds well with other indications that a drying trend began about 10,000 years B.P., but the presence of algal remains, including numerous diatoms, indicates the aquatic habitat remained.

The sediments we are studying were probably laid down after the last substage in Iowa of the Cary lobe (Algona). The western boundary of the Algona is a relatively short distance from Lake Okoboji. A mixed forest may have persisted close to the leading edge of the ice during the substage and may have been the source of some of the pollen in the early post-glacial sediments.

A wide variety of recognizable plant and animal parts have been found in addition to pollen and diatoms. The bottom meter especially is rich in such materials. The most common animal remains are sponge spicules and valves of ostracods. Many of the fragmentary remains appear to belong to various microcrustaceans. Insect mouth parts and the statoblasts of bryozoans (ectoprocts) are common. Fern spores occur in the sediments from base upward to the 25-foot level and we consider most of them to be of post-glacial origin. However, it is quite possible, or even probable, that some of them were redeposited from Cretaceous materials. Algal remains are numerous. Among them are, quite surprisingly, sheaths of the blue-green algae, *Rivularia* and

Gleotrichia. Species of green algae in the genera *Botryococcus, Pediastrum*, and *Staurastrum* are sometimes abundant. Siliceous cysts of chrysophytes are abundant. Trichomes which have been tentatively identified as coming from the leaves of the bladderwort (*Utricularia* sp.) are common from the very bottom-most levels of the sediments upward. Zygotes of *Chara* are common. Fragments of grass epidermis, recognizable by the characteristic stomates, have a charred appearance suggesting they may have been blown in as ash from fires. Moss leaves occasionally are recognizable, but leaves of *Sphagnum* have not been noted.

Problems To Be Considered.

1. The Significance of Microfossils from Cretaceous Marine Sediments.

The occurrence of marine foraminifera (Figure 2) in the post-glacial sediments of a freshwater lake appears noteworthy. They are quite evidently of Cretaceous origin, were ground up by the glaciers and redeposited with the glacial till, and repeatedly were moved from place to place since then by both wind and water erosion forces. They have been described by Calvin (1893) and Bolin (1956) from Cretaceous sediments and their distribution has been discussed in surface deposits by Jones, Hay and Beaver (1963). We have established

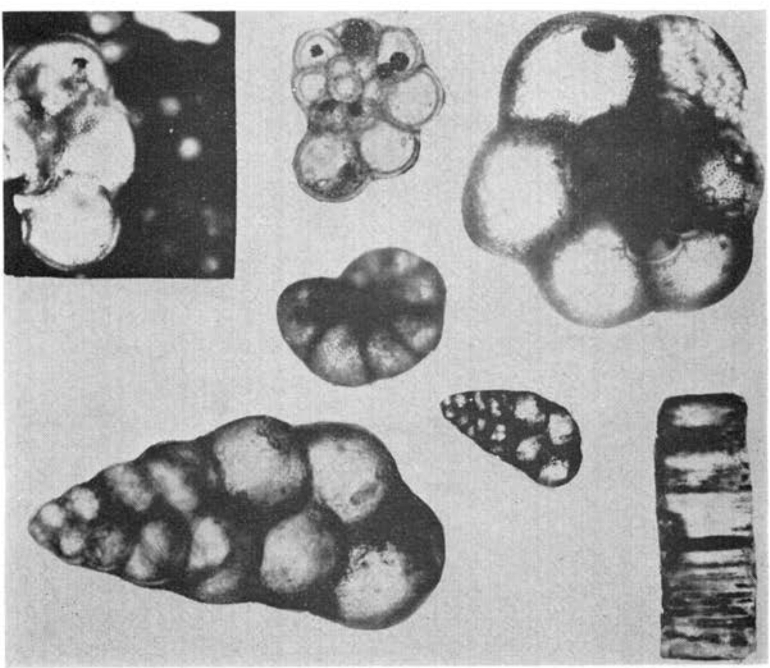

Figure 2. Examples of foraminifera of Cretaceous origin redeposited in lower levels of postglacial sediments of Lake Okoboji, Iowa.

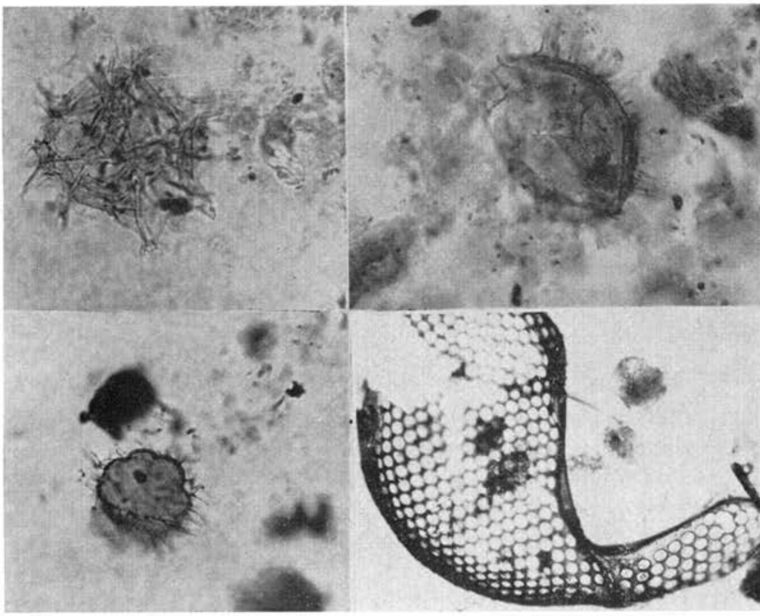

Figure 3. Radiolarian fragment (lower right) and three hystrichosphaerids, all of Cretaceous origin and redeposited in post-glacial sediments of Lake Okoboji, Iowa.

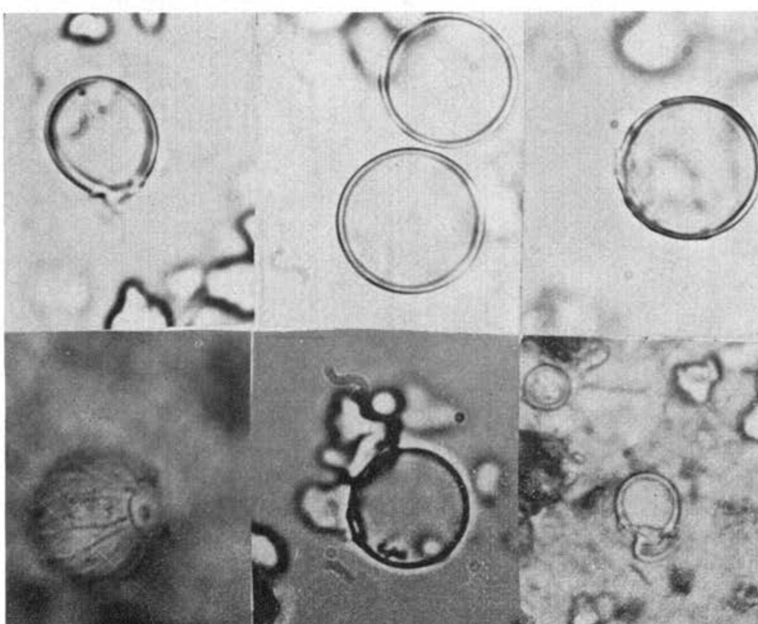

Figure 4. Statospores of chrysophytes encountered in sediments.

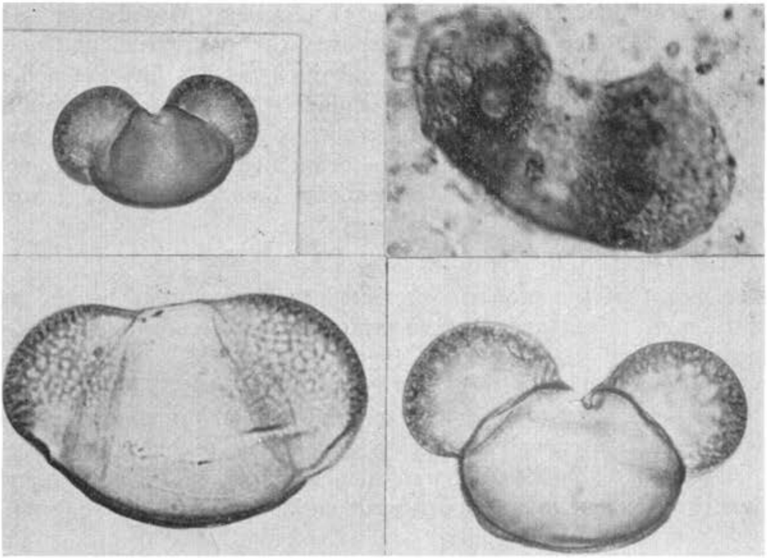

Figure 5. Gymnosperm pollen from sediments of Lake Okoboji, Iowa. Degraded appearance of grain in upper right suggests redeposition. (See text discussion.)

their presence in the subsoil of native prairie, in various roadcuts as far south as Ames, and in loess deposits from western and eastern Iowa (Cedar Rapids). They are common in the "blue clay" underlying the Cary till. We also examined a soft layer in exposed Cretaceous sediments in a quarry near LeMars, Iowa, and found them to be abundant.

Since Calvin (1893) also noted the presence of radiolarians and coccoliths in Cretaceous sediments, we became curious as to their possible presence. Radiolarian fragments (Figure 3) are present in the "blue clay," but not abundant. Coccoliths, however, are extremely abundant there and are mixed in with the lower levels of the postglacial sediments. The hystrichosphaerids shown in Figure 3 also occur in the lowermost sediments.

We have found these observations interesting, but are not yet fully prepared to evaluate their significance in the present investigation.

2. *The Problem Created by Presence of Statospores of Chrysophytes.*

The silicified cysts and statospores of freshwater chrysophytes present a special problem. There is a wide variety of these objects in cores from a nearby kettle hole, but in the lake sediments the variety is limited even though they occur in vast numbers (Figure 4). The statospores have a single pore with a collar and a plug which disappears on germination. In species of *Dinobryon* the collar is not prominent and the empty cysts might be mistaken for small grass pollen by an inexperienced (or hasty) observer. Usually the HF treatment of pollen preparation removes the cysts, but an inner organic layer may not be dissolved and often persists into the pollen slides. As implied above a worker familiar with this problem would not have difficulty in distinguishing such objects from pollen, but they mght be a source of confusion to an investigator who has not previously encountered them. The work of Bourrelly (1959) is suggested as a reference.

3. The Problem of Redeposition.

The extent of the problems presented to palynologists by the redeposition of pollen and other microfossils has become increasingly evident in recent years (Iversen, 1936; Davis, 1961, 1962; Cushing, 1964; Wilson, 1964; and others). Pierce (1957, 1961) has reported pollen and spores from Upper Cretaceous levels in Minnesota some of which are modern enough in appearance to create problems in studies of redeposited sediments. We were able to recognize fern spores and gymnosperm pollen in a cursory examination of Graneros shale obtained from a local well driller.

Enlargement of lake basins causes a resorting of soils along their margins bringing pollen of unknown history into the sediments. Erosion of soils by wind and water results in redeposition also. Pollen trapped in glacial ice might be contemporaneous with the glacier or as ancient as the ground up materials within the ice. If, as might be possible for Little Miller's Bay, a lake is formed from a melting block of ice, much of its contained material would settle out in the new lake basin. At the same time, transport of some pollen types from nearby vegetation would add them to the mixture in the early post-glacial sediments.

The wide dissemination of such redeposited materials in Iowa will make it difficult for palynologists to find sediments free of this contamination. However, with detailed study, some criteria may be developed that will provide fairly reliable results. Where microfossils are abundant, the Iversen (1936) method of subtraction may be used. Wilson (1964) has pointed out several ways of recognizing recycled fossils, two of which are evident in the Okoboji sediments. Differential stain reactions in which younger spores and pollen are bright in color while older fossils stain less vividly are readily seen within any one sample. Both Safranin O and Bismark Brown were used in observing this feature. The color of the older pollen was dull and generally less clear than the brighter younger grains. Safranin appeared to give the better results, but this may be because the authors have used it more.

Differential preservation is the second method used in distinguishing the post-glacial fossils from those of earlier age. The older fossils are flattened and compressed, forming a thin line when seen edgewise. They are also often abraded and broken. The younger pollen closely resemble modern acetolysed grains. This was especially noticeable in the coniferous pollen (Figure 5). Differential preservation also would be a feature of penecontemporaneous pollen (Cushing, 1964) and this is more difficult to distinguish. Observation of associated organic material, fungal and other plant debris, serves to aid in the recognition of this type of contamination.

4. Interpretation of the Early Post-Glacial Forest Composition.

The observed presence of a variety of deciduous tree pollen in the lower levels mixed with the gymnosperm pollen creates a problem of interpretation. We are confident that very little of this is redeposited material as the pollen is fresh in appearance, is brightly stained, and shows little or no corrosion or breakage.

We have suggested above that forest conditions may have existed to the west of the Cary lobe and we now suggest further that wind conditions may have played a significant rôle in the changing ecology of the area as the glacier retreated.

A permanent high-pressure system over the glacier would have resulted in strong, steady winds which blew more or less continuously in a northwest to southeast direction from the glacier. Such winds not only would have affected pollen distribution, but also would have affected the re-establishment of trees with wind disseminated seeds (spruce, pine, fir, birch, elm, etc.). Conditions on the eastern edge of the Cary lobe would have been quite different from those on the western edge as the winds there would not be blowing directly from a source of pollen and seeds. It is conceivable that a delay in the migration of pine may have been induced in this way. (Compare the discussions of Wright, 1964.)

Assuming that such winds existed, as they came off the glacier they would have been cool and relatively moist, but, as they proceeded in a southeasterly direction, they would have been gradually warmed and their relative humidity would have been lowered. This could have been a factor in the induction of gradual changes from coniferous forest to hardwood forest to prairie in a northwest to southeast direction.

Furthermore, as the glacier retreated northward this pattern of succession would have migrated northward in relation to the temperature-humidity pattern. When the glacier had retreated far enough northward, the influence of the glacial high would have been diminished at our latitude and replaced by the present transcontinental pattern of air mass movement which controls our weather today.

5. Problem—The Reliability of Radiocarbon Dates from Early Post-Glacial Sediments.

A newly-formed landscape such as that of post-glacial Iowa would be heavily burdened with calcareous material of Cretaceous origin (i.e., calcite casts of forams, coccoliths, etc.). Land vegetation becoming established would use CO_2 from the air during photosynthesis and the proportion of radioactive carbon in such material could be used reliably for dating purposes.

Root respiration and the respiration of organisms of decay would then release "aggressive CO_2" (with similar proportions of radioactive carbon) into the soilwater. Reactions with the radioactively "dead" carbonates from Cretaceous time would then form a mixture of soluble bicarbonates with a lower average radioactivity.

These would eventually wash out of the soil at lower levels. In some cases they would reprecipitate to form carbonate again, but if washed into the lake they would become part of the carbonate-bicarbonate buffer system. As photosynthesis of aquatic vegetation primarily uses bicarbonate ions, and there would presumably be a random mixture from "dead" and "active" carbon sources, the net effect would be to make a radiocarbon date appear older than the actual date. We do not know if this possible discrepancy would result in a significant error in dating sediments in which organic components were primarily derived from aquatic vegetation.

Acknowledgments

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