Late-glacial—Postglacial Vegetational History of the Pretty Lake Region, Northeastern Indiana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 686-B

Late-glacial—Postglacial Vegetational History of the Pretty Lake Region, Northeastern Indiana

By ALICE SIMMS WILLIAMS

HYDROLOGIC AND BIOLOGICAL STUDIES OF PRETTY LAKE, INDIANA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 686-B

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 73-600294

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 — Price $2.00 (paper cover)
Stock Number 2401-02453

CONTENTS

ILLUSTRATIONS

TABLES

LATE-GLACIAL—POSTGLACIAL VEGETATIONAL HISTORY OF THE PRETTY LAKE REGION, NORTHEASTERN INDIANA

By ALICE SIMMS WILLIAMS

ABSTRACT

Radiocarbon dates, pollen diagrams (absolute and percentage), and gross sediment stratigraphy of three long cores from Pretty Lake in northeastern Indiana indicate that deposition began there about 13,600 yr ago and has been continuous to the present at two of the sites (in deep water) and discontinuous at the third (a marl lakemount). In the marl lakemount core, sediments representing the last 2,740 yr are absent and five other discontinuities are indicated by the sediment stratigraphy and the pollen diagrams. The pollen data indicate a gross vegetational sequence as follows: Cyperaceae (at the base), *Picea, Pinus-Betula,* hardwoods, and *Ambrosia* (at the top). According to the evidence in these sedimentary records, tundra or tundralike conditions existed in this region following the retreat of Cary ice. Both the Port Huron and Valders glacial events affected this section of Indiana. Prairie advanced into the Pretty Lake area twice during postglacial time. This climatic and vegetational history, as inferred from the sediment record, is documented by a series of radiocarbon dates (15 from one deep-water core and six from the marl lakemount core).

INTRODUCTION

Pretty Lake, a eutrophic marl lake in northeastern Indiana, was selected by the U.S. Geological Survey as the site for a 3-yr (1963–65) study of physical, chemical, and biological factors and their interrelationships in the hydrology and limnology of a small lake. Papers deriving from these studies are concerned with comparing methods of computing lake evaporation (Ficke, 1966), botanical and chemical changes during the fall overturn (Lipscomb, 1966a), seasonal breakdown of thermal stratification (Ficke, 1965), and winter phytoplankton and physical and chemical characteristics (Lipscomb, 1966b).

Three cores of the lake sediments were collected with a Swedish foil sampler—two from near the deepest part of the lake and one from the marl lakemount—for the purposes of deciphering the paleolimnology of the basin and the vegetational history of the region. The cores were released by U.S. Geological Survey to D. G. Frey, who is coordinating studies on them. Studies published to date are those of Ogden (1969) comparing the pollen diagram of core A with that of Silver Lake, Ohio; of Stuiver (1968) on ^{18}O content of atmospheric precipitation during the last 11,000 yr; and of Wetzel (1970) on recent and postglacial production rates of a marl lake. The Indiana Geological Survey made an unpublished study of the sediment chemistry of selected levels. Ogden and Stuiver provided the radiocarbon dates on cores A and E, respectively.

Many pollen analyses of sediment sequences in Indiana have been done by J. E. Potzger and his associates at Butler University (largely reviewed by Frey, 1959), several have been done by Engelhardt (1965), and one, on Myers Lake, has been done by Frey (1959). These are all rather crude diagrams by modern standards, and none of them are tied into the radiocarbon chronology. The continuous cores from Pretty Lake, therefore, with their radiocarbon dates provide a unique opportunity to study in detail the vegetational history of northern Indiana. The data are presented by diagrams showing the relative percentage of pollen types and also by diagrams showing the absolute numbers of each type of pollen per unit volume of sediment.

This study is primarily concerned with (1) vegetational changes in the Pretty Lake region since deglaciation and the climate inferred by these changes, (2) a comparison of these changes with other areas in the Midwest and New England, (3) changes in vegetation and climate that might be correlated with glacial advances and retreats in late glacial time, and (4) continuity of sedimentation at the several coring sites.

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. D. G. Frey (Indiana Univ.) for his assistance throughout the periods of research and writing; to Dr. Paul Weatherwax (Indiana Univ.) for the preparation of wood thin sections from core material and to Dr. E. S. Barghoorn (Harvard Univ.) for identification of these sections; to Dr. M. B. Davis (Univ. of Michigan) for her instruction in the technique of quantitative pollen analysis; to Dr. J. G. Ogden, III (Ohio Wesleyan Univ., now at Dalhousie Univ.) for radiocarbon dates from core A; to Dr. Minze Stuiver (Yale Univ., now at Univ. of Washington) for radiocarbon dates from core E; and to Wade Cooper (Livingston Univ., Livingston, Ala.) for preparation of pollen reference slides. This work was supported in part by two U.S. Geological Survey student grants and by an Indiana University Dissertation Year Fellowship.

REGIONAL SETTING

Pretty Lake (fig. 1) is located in secs. 15 and 16, T. 36 N., R. 11 E., Lagrange County, Ind. (lat 41°35′ N.; long 85°15′ W.) in the physiographic region of Indiana referred to by Malott (1922) as the Steuben Morainal Lake Area of the Northern Lake and Moraine Region. The bedrock physiography is a broad lowland of moderate relief, the Dekalb Lowland, formed upon Upper Devonian and Lower Mississippian shales (Wayne, 1956).

GLACIATION

During the Cary Stade of the Wisconsin Glaciation (fig. 1), northern Indiana was covered by three ice lobes, which reached their maximum extent about 15,000 yr ago (Wayne, 1966). The Michigan and Saginaw Lobes moved into Indiana from the north and the Erie Lobe from the northeast. As the Saginaw Lobe melted, it formed the massive Packerton Moraine around its southern margin. Stagnant ice blocks from the Saginaw Lobe still remained when the Erie Lobe moved into Indiana and overrode the eastern border of Saginaw drift. Pretty Lake is near this region of overlap, but aerial photographs and unpublished geologic maps of the region indicate that the lake is in Saginaw drift. The present topography of this northeastern part of Indiana is characterized by kames, kettles, outwash plains, and melt-water channels resulting from the melting of these two great ice sheets (Schneider, 1966). No outcroppings of the original bedrock are in evidence.

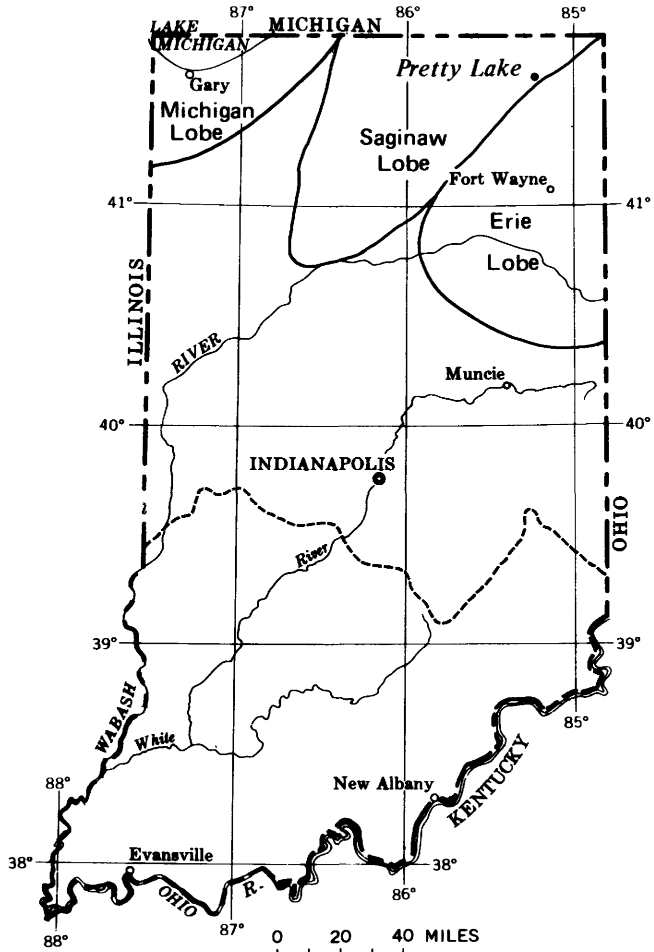


FIGURE 1.—Wisconsin Glaciation in Indiana. The location of Wisconsin ice about 15,000 yr ago is indicated by the positions of the Michigan, Saginaw, and Erie Lobes in northern Indiana. The maximum extent of Wisconsin Glaciation is indicated by the dashed line (map from Wayne, 1966).

Indiana has been free of glacial ice since Cary time, but subsequent ice advances into Michigan and Wisconsin may have affected the climate of northeastern Indiana. The Port Huron glacier advanced into Wisconsin and Michigan to the Port Huron moraine, which is within 150 miles of Pretty Lake. This moraine was dated by Hough (1958) at 13,000 yr B.P. (before present), and a bryophyte bed buried by this moraine in Cheboygan County, Mich., has a radiocarbon date of 12,500–13,300 yr B.P. (Farrand and others, 1969). The bryophyte bed is presented as evidence for the Cary–Port Huron interval and suggests a locally treeless flora in the Cheboygan County area.

A minor glacial advance, Valders, followed the retreat of the Port Huron ice. The Two Creeks forest on the western shore of Lake Michigan, which was overridden by Valders ice, has a radiocarbon age of 11,850 yr B.P. (Broecker and Farrand, 1963). Ogden and Hay (1967) obtained dates of 10,680 and 10,770 yr B.P. for peat and wood, respectively, from the Two Creeks site. Maher (1970) suggests that the Two Creeks Interstade extended from 12,500 to 11,800 yr B.P. and that the Valders interval ended prior to 11,000 yr B.P. If the Ogden and Hay (1967) dates are correct, however, Valders ice could not have overridden the Two Creeks forest until about 10,700 yr B.P., and the Valders Stade could not have ended until sometime after that. Broecker and Farrand (1963) concluded that all of Michigan was free of Valders ice about 10,000 yr B.P. The maximum extent of Valders ice has not been definitely established, but it is unlikely that it extended much farther south than did the Port Huron glacier (Farrand and others, 1969; Maher, 1970).

POSTGLACIATION

After deglaciation, soils in the Pretty Lake area developed under forest cover from the medium-textured till and sandy drift left by the Wisconsin Glaciation (Purdue University, no date). The resulting loams and sandy loams are well drained, easily worked, and of good productivity (Ulrich, 1966). They support corn, wheat, meadow, and pasture in a mixed grain- and livestock-farming system (Purdue University, no date).

Even though much of northeastern Indiana has been cleared for farming, the remaining forested areas can be characterized as being either oak-hickory or beech-maple associations (Braun, 1950). The limits of these regions are not clearly defined; in general, however, oak-hickory is located to the north and beech-maple to the south. At the time of colonization, Pretty Lake was located in an oak-hickory association (fig. 2) near the northernmost extension of the beech-maple association (Lindsey and others, 1965). Presently Pretty Lake is clearly associated with an oak-hickory region, since the patches of uncleared woodland near the lake are composed primarily of oaks (*Quercus alba, Q. rubra, Q. velutina,* and *Q. coccinea*), hickory (*Carya ovata*), sugar maple (*Acer saccharum*), poplar (*Populus deltoides*), sycamore (*Platanus occidenalis*), dogwood (*Cornus florida*), hackberry (*Celtis occidentalis*), sassafras (*Sassafras albidum*), box-elder (*Acer negundo*), and elm (*Ulmus americana*). This association seems very similar to the presettlement vegetation of northeastern Indiana about 1820,

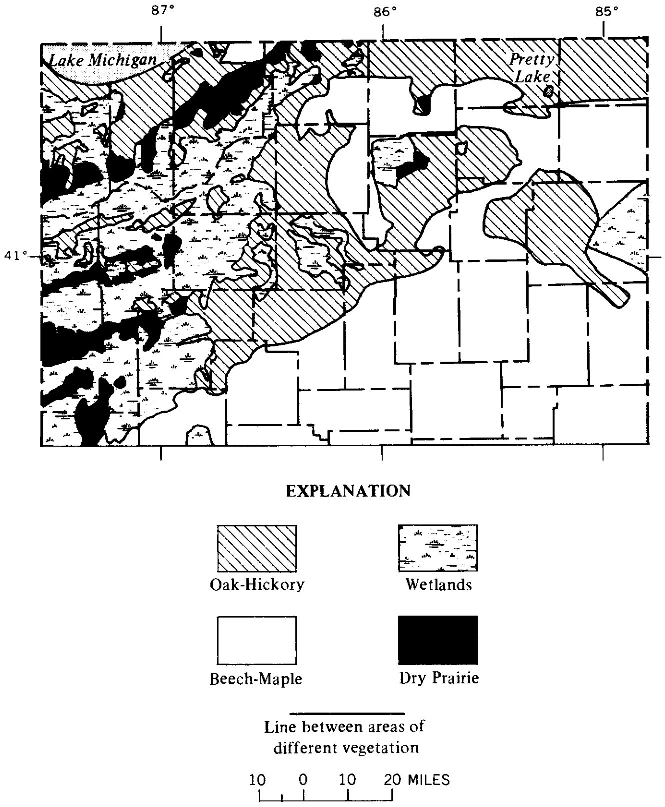


FIGURE 2.—Generalized map of the natural vegetation of northern Indiana about 1820, based on original land-survey records and modern soil maps (modified from Lindsey and others, 1965).

as described in a study based upon the original General Land Office Survey records and modern soil maps of Indiana counties (Lindsey and others, 1965).

Pretty Lake is located in one of the driest and coldest parts of the State (Schaal, 1966). The mean annual precipitation for the period 1931–60 was 35 inches (88.9 centimeters). The mean daily minimum temperature for July for this same period was 61°F (16.1°C), and the mean daily maximum temperature was 85°F (29.4°C). The mean daily minimum and maximum temperatures for February were 19°F (−7.2°C) and 35°F (1.7°C), respectively. For the period 1921–50, the average date of the last killing frost in spring was May 5–10 and the average date of the first killing frost in autumn was October 5–10, giving a frost-free season of approximately 153 days.

PRETTY LAKE

Pretty Lake is one of a discontinuous chain of kettle lakes oriented in a northwest-southeast direction. They are in line with the stress plains associated with the expansion of the Saginaw Lobe. Since the drift in the area of Pretty Lake is 300–400 feet (91.2–122 meters) thick and the underlying bedrock has only low relief (Wayne, 1966), the relatively shallow lake basin lies entirely within drift. The original morphometry of the iceblock basin has been modified by the sediments that have accumulated subsequently.

The present shape and bathymetry of the lake are shown in figure 3. Pretty Lake has a surface area of 184 acres (74.5 hectares) and a volume of 4,717 acre-feet (5.82×10^6 m^3) (Ficke, 1966). Its basin is characterized by a marl lakemount near the western shore and a large central depression with an irregular bottom. The outlet and inlet of the lake both are located near the northeast corner. The total drainage area of the lake is 2.39 sq mi (619 ha), of which approximately 1.96 sq mi (508 ha) drains into the lake from near the inlet stream, and the remaining 0.43 sq mi (111 ha) includes the lake and the surrounding land that drains directly into it. Outflow is controlled by a steel weir that maintains a surface elevation of approximately 965.5 feet (294.3 m) above mean sea level (Ficke, 1966).

Because the lake is almost completely surrounded by summer cottages, there is little natural shrub vegetation near its margin. Small patches of shrubs, mainly species of *Salix*, grow near the outlet, in the boggy areas along the western shore, and along parts of the southern shore. Rooted and floating aquatics comprise species of Cyperaceae, *Typha*, *Potamogeton*, *Sagittaria*, *Najas*, *Nuphar*, and *Nymphae*. *Chara* is locally abundant, particularly on the marl lakemount.

BOTTOM CORING

MATERIALS AND METHODS

The three long and continuous cores of sediments used in this study were obtained for the U.S. Geolyogical Survey by Sprague and Henwood, Inc. of Scranton, Pa. The Swedish foil sampler used is similar to other piston samplers, except that the coring tube becomes lined by thin metal strips attached to the piston, which move into the corer synchronously with, and enclose, the sediments (Pickering, 1966). The cores were large enough in diameter (6 cm) to permit sampling for various studies (for example, pollen analysis, chemical analysis, pigment analysis) from any given level. Vertical halves of 5-cm core lengths sufficed for radiocarbon dating.

The locations of the three long cores (designated as cores A, B, and E) are shown in figure 3. A profile of the present lake basin through the coring sites is presented in figure 4. Core E is from the flat top of the marl lakemount, core A is from a slope near the deepest part of the lake, and core B was taken 55 feet away from A on the off-shore edge of a deep-water plateau. Since all three cores reached glacial till, a partial profile of the original lake basin has been drawn (fig. 4).

After logging gross stratigraphy, the cores were cut into convenient pieces (about 70 cm long) before being wrapped in sheet plastic and placed in aluminum troughs of suitable length. Later, subsamples approximately 3 cm^3 in volume were removed from the cores at selected intervals and placed in stoppered vials for subsequent pollen and chemical analyses. The cores and subsamples were stored at 5°C.

Flocculent sediments at the top of cores A and B were lost in the coring process. As a substitute, a short core (core C) 30 cm in length and 3.5 cm in diameter was obtained in the general vicinity of cores A and B in July 1967 with a free-fall sampler. The clear plastic liner of the free-fall coring tube enables gross stratigraphy to be discerned without extruding the core. The plastic tube with its contained sediments and water was stored at −18°C. At a later date, the frozen contents were extruded and cut into 2-cm sections for analysis.

Samples from the long cores were taken for proximate chemical analysis. Dry weight was obtained by heating 0.2 cm^3 in a tared crucible at 95°C for 24 hr. The further loss of weight resulting from ashing for 1 hr at 525°C in a muffle furnace was considered to approximate the weight of organic matter in the sample. Subsequent ashing at 925°C for 2.5 hr resulted in an additional loss of weight, which was considered to be due to the loss of CO_2 primarily from $CaCO_3$ and to a lesser extent from $MgCO_3$ as well as to loss of some water of hydration from clay minerals. Assuming that this entire loss was CO_2 from $CaCO_3$, the equivalent weight of $CaCO_3$ could be obtained by multiplying the weight loss by 2.273. This product subtracted from the ash weight at 525°C yields an approximation of the noncalcareous ash or residue, which is thought to be largely SiO_2 (Frey, 1960; Mueller, 1964). Frey (1960) and Mueller (1964) concluded that this proximate method yields results agreeing quite closely with those of more precise chemical analysis, that is, the method used by Murray (1956) to obtain carbonate content of sediments by treating them with HCl and back-

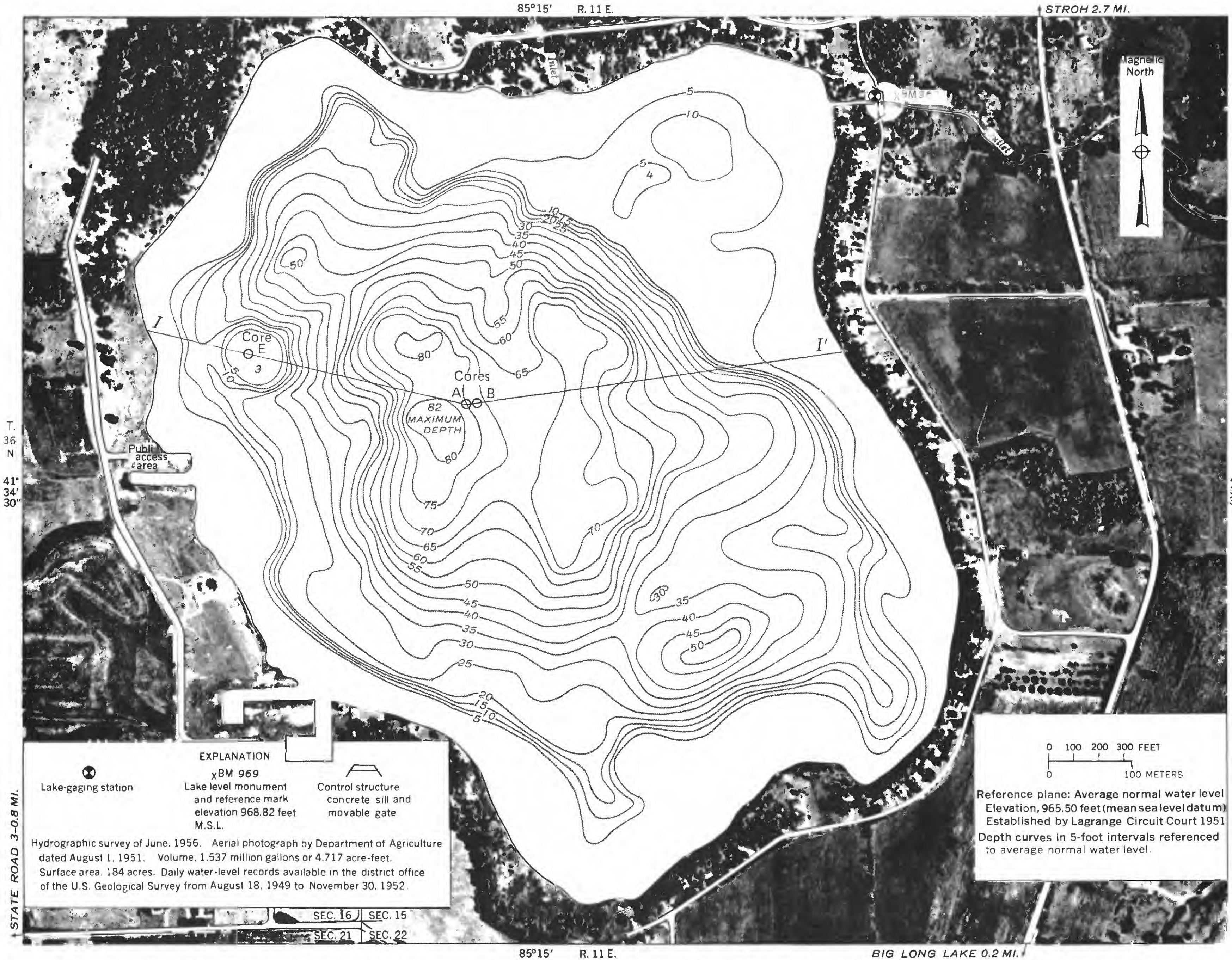


FIGURE 3.—Pretty Lake bathymetry showing coring sites for long cores A, B, and E. Line *I–I′* shows the location of the depth profile given in figure 4. Map from Indiana Department of Natural Resources, Division of Water Resources, prepared cooperatively with the U.S. Geological Survey.

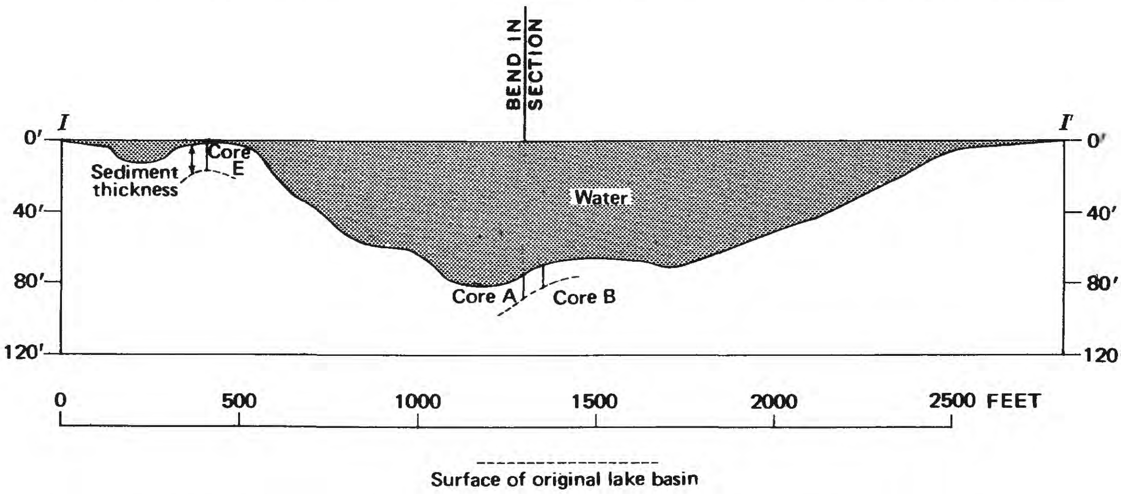


FIGURE 4.—Profile of depth and sediment thickness in Pretty Lake, Ind. through coring sites along transect shown in figure 3.

titrating with NaOH. Mueller (1964) did show, however, that for sediments with high clay content this method will yield slightly higher percentages (2.4–4.4 percent in his study) of apparent carbonate as a result of loss of water of hydration from the clay minerals.

Radiocarbon analyses of core A were made by J. G. Ogden, III, and of core E by Minze Stuiver. Dates reported in this paper have been corrected for "dead" carbonate (Paleozoic in this case) by the apparent radiocarbon age of surficial sediments.

Average rates of deposition in centimeters per year, for sections of the core were calculated by dividing the core distance between two successive dates by the time difference between the two dates. The reciprocal of this value (years per centimeter) was also calculated. From these data the age of each core level sampled was estimated. The ages of sediments that occurred below the earliest available dates were determined by extrapolation from the rates of deposition immediately above.

CORE STRATIGRAPHY

Cores A and B were logged for texture and composition by D. G. Frey on February 18, 1965, when extruded, and soil colors, keyed to Munsell Soil Color Charts (Munsell Color Co., Inc., 1954), were added by the author on November 10, 1967 based on freshly prepared surfaces (tables 1 and 2). Core E was logged and color coded by W. J. Wayne on October 6, 1967 (table 3). Core C (table 4) was logged by the author on July 25, 1967, immediately after extrusion.

Core E, collected on the marl lakemount, is characterized throughout by marl interspersed with shell fragments and plant material. Silt, clay, and sand are found in the bottom meter. A 3-cm disc of olive (algal) gyttja, with a rubbery texture, separates the lower clay-sand from the upper marl. The bottom 19 cm of the core was lost in sampling. Because till is at the bottom of the core on hand, the material lost undoubtedly was also till.

Core A is characterized by many fine and coarse horizontal laminae. The core extends continuously from near the present sediment surface into the lowermost clay sediments. The bottom 31 cm was lost when the corer was raised. The parting occurred at a horizon of wood and wood fragments, which is also present in cores B and E. This core contains no obvious calcareous layers, but consists entirely of

TABLE 1.—*Sediment stratigraphy of core A*

[Code numbers for color are from Munsell Color Co., Inc. (1954)]

Description	Depth (cm)
Gyttja, very dark grayish brown (2.5*Y* 3/2) with black (5*Y* 3/2) laminae; soft material characteristic of most of the surficial sediments of lake.	0– 49
Gyttja, very dark grayish brown (2.5*Y* 3/2)	49– 59
Gyttja, black (5*Y* 2/2), massive with few laminae	59– 77
Gyttja, very dark grayish brown (2.5*Y* 3/2)	77– 82
Gyttja, black (10*YR* 2/1), fine laminae present	82–129
Clay, very dark grayish brown (2.5*Y* 3/2), silty	129–130
Gyttja, very dark brown (10*YR* 2/2)	130–133
Gyttja, black (10*YR* 2/1) with dark grayish brown (10*YR* 4/2) bands.	133–213
Gyttja, black (10*YR* 2/1), massive banding	213–224
Gyttja, black (10*YR* 2/1), clayey	224–228
Gyttja, very dark brown (10*YR* 2/2), coarsely banded	228–258
Gyttja, black (10*YR* 2/1)	258–261
Gyttja, very dark brown (10*YR* 2/2)	261–264
Gyttja, black (10*YR* 2/1)	264–269
Gyttja, very dark grayish brown (2.5*Y* 3/2), coarsely banded; three very dark brown (10*YR* 2/2) bands, each 2 cm wide, from 286–295 cm.	269–302
Gyttja, black (10*YR* 2/1), coarsely banded with very dark brown (10*YR* 2/2) bands, clayey; clay bands at 324–325.5 cm and 372 cm; some plant fragments.	302–429
Clay, dark grayish brown, (2.5*Y* 4/2), somewhat darker in uppermost 2 cm, silty, lighter clay band diagonally across core from 439.5–442 cm; coarse plant fragments abundant.	429–479
Clay, dark grayish brown (2.5*Y* 4/2), massive with no apparent fine structure; coarse plant fragments and wood in lowest part.	479–526

TABLE 2.—*Sediment stratigraphy of core B*

[Code numbers for color are from the Munsell Color Co., Inc. (1954)]

Description	Depth (cm)
Gyttja, dark grayish brown (2.5*Y* 4/2) at the top grading into very dark gray (5*Y* 3/1); soft, not completely consolidated, rather massive and without any apparent fine structure.	0 –70
Gyttja, very dark grayish brown (2.5*Y* 3/2), clayey	70–74
Gyttja, very dark grayish brown (2.5*Y* 3/2), mottled in appearance.	74– 96
Gyttja, black (5*Y* 2/2)	96–110
Gyttja, dark olive gray (5*Y* 3/2)	110–189
Gyttja. black (5*Y* 2/2)	189–196
Gyttja, dark olive gray (5*Y* 3/2)	196–236
Gyttja, dark olive gray (5*Y* 3/2) with suggestions of two darker bands.	236–243
Gyttja, dark gray (5*Y* 4/1)	243–274
Gyttja, black (5*Y* 2/2), more coarsely textured from 302–326 cm.	274–326
Clay, dark olive gray (5*Y* 3/2) at top to dark gray (5*Y* 4/1) near the bottom; without much evidence of internal structure.	326–389
Sand-clay, dark grayish brown (2.5*Y* 4/2), silty, angular rock fragments (from till) at bottom; coarse plant debris near top.	389–405

TABLE 3.—*Sediment tratigraphy of core E*

[Code numbers for color are from the Munsell Color Co., Inc. (1954)]

Description	Depth (cm)
Marl, gray (5*Y* 5/1 to 5*Y* 6/1), silt-textured; vertically oriented plant fibers scattered throughout sample; contains a few mollusk shells.	0– 92
Marl, light brownish gray (2.5*Y* 6/2), silt-textured but looks more granular than above; vertically oriented plant fibers present, but randomly oriented seeds and plant fragments more common, shells moderately abundant.	92–122
Marl, light olive gray (5*Y* 6/2); horizontally oriented plant fragments more noticeable than vertically oriented fibers; mollusk shells moderately abundant.	122–156
Marl, olive gray (5*Y* 5/2); horizontally banded with plant fragments; shells moderately abundant to sparse.	156–260
Marl, grayish brown (2.5*Y* 5/2); mollusk shells moderately abundant	260–294
Marl, olive gray (5*Y* 5/2), slightly laminated: mollusk shells moderately abundant.	294–311
Marl, dark gray (5*Y* 4/1), slightly silty; contains finely divided plant remains; mollusk shells moderately abundant.	311–319
Marl, light olive gray (5*Y* 6/2), slightly laminated; mollusk shells moderately abundant.	319–342
Marl, gray (5*Y* 5/1), finely divided plant remains abundant; mollusk shells moderately abundant; top contact sharp.	342–370
Marl, light olive gray (5*Y* 6/2), clayey to slightly silty; mollusks abundant to moderately abundant.	370–410
Marl, olive gray (5*Y* 5/2); plant remains more abundant than in zone above; mollusk shells moderately abundant.	410–420
Marl, light gray (5*Y* 7/2), laminated with gray (5*Y* 6/1); few plant remains; shells moderately abundant.	420–441
Marl, light olive gray (5*Y* 6/2); contains abundant finely divided plant remains; moderately abundant mollusk shells.	441–461
Marl, light olive gray (5*Y* 6/2), clayey; plant and shell fragments sparse.	461–476
Marl, light gray straks embedded in olive gray (5*Y* 5/2) matrix, clayey; plant and shell fragments not evident.	476–496
Gyttja, dark olive gray (5*Y* 3/2); fine-grained, rubbery; plant and shell fragments not evident; top and bottom contacts very sharp.	496–499
Sand (medium grained), olive gray (5*Y* 4/2), slightly silty, becomes finer grained in lower part; neither plant nor shell remains evident.	499–521
Clay, dark gray (5*Y* 4/1), slightly sandy at top; contains a few scattered wood fragments.	521–550
Clay (or fine silt), black (5*Y* 2/1) at top to dark gray (5*Y* 4/1) at base; very abundant carbonized plant fragments at top, decreasing in abundance downward.	550–562
Clay, dark gray (10*YR* 4/1), silty, contains pebbles; plant fragments and a few shells evident.	562–566
Clay, dark grayish brown (10*YR* 4/2), silty, pebbly; basal part is till, upper part (566–570 cm) looks like till slightly reworked by water.	566–577

TABLE 4.—*Sediment stratigraphy of core C*

Description	Depth (cm)
Gyttja, medium dark, loose sediments	0 – 1.5
Gyttja, dark	1.5–11
Gyttja, lighter, clayey,	11 –21
Gyttja, dark	21 –24
Gyttja, lighter, clayey	24 –27
Gyttja, dark	27 –30

fine offshore sediments with some coarse plant fragments near the bottom.

In contrast, core B, which was taken only 55 feet away, originally displayed none of the horizontal banding so characteristic of core A. It was relatively uniform and exhibited only slight differences in color and texture. Many vacuoles as if from gas production were in the sediment on extrusion. The appearance of the core more strongly resembled the uppermost relatively unstabilized sediments of a lake than the compacted sediments resulting from several millenia of stabilization. After being stored at 5°C for several months, however, laminae became quite evident. The bottom section of this core, which also would have been lost at the time of coring without special precautions, was rescued. It is glacial till, consisting of a mixture of unsorted angular rock fragments, sand, and gray clay.

The entire 30 cm of core C, composed of dark gyttja containing a few lighter bands, is similar to the sediment found in the top centimeters of cores A and B.

Proximate chemical analyses of the sediments of cores A, B, C, and E are presented in association with the pollen diagrams as percentages of organic matter, calcium carbonate equivalents, and inorganic residue in the dry sediments. Percentages based only on organic matter and inorganic residue are also shown because the $CaCO_3$ content of deep-water sediments is a nonconservative parameter, dependent not only on how much is precipitated but also on how much is redissolved during stratification. The basal parts of the long cores—73 cm of core E, 92 cm of core A, and 16 cm of core B—which were logged as clay, contain the expected high percentages of inorganic residue and low percentages of organic matter and carbonate. Above these basal sections, cores A and B are characterized by higher percentages of organic matter, lower percentages of inorganic residue, and a carbonate content that exceeds 15–20 percent in only two major lengths. Core C is similar to the youngest sediments of cores A and B. In contrast, the sediments of core E above the basal clay (except for the small disc of algal gyttja) are marl throughout, and contain carbonate levels greater than 80 percent. In only a few sections do the organic- and inorganic-residue fractions exceed 10 percent.

Radiocarbon age determinations on the organic fraction of sediments from cores A and E are given in tables 5 and 6, respectively. The corrected radiocarbon ages for cores A and E plotted against core

TABLE 5.—*Radiocarbon ages of organic fraction of sediments from core A, Pretty Lake, Ind.*

[Determined by J. G. Ogden, III. The apparent age of the surface sediments (920 yr B.P.) has been subtracted from all dates as an estimate of "dead" (Paleozoic) carbon, except for sample OWU-242, which was wood. In two instances successive dates have been averaged to obtain an estimated corrected age]

Sample (OWU-)	Depth (cm)	Uncorrected age (yr B.P.)	Corrected age (yr B.P.)
230	0– 6	920±210	0
231	51– 56	1,640±165	720
232	101–107	2,750±270	1,830
262	125–130	3,615±320	2,695
233	145–150	4,505±290	3,585
263	181–186	4,785±360	3,843
234	201–206	4,740±305	
235	251–256	5,260±305	4,340
236	301–306	6,805±340	5,885
237	351–356	8,415±205	7,495
264	381–386	10,215±345	9,295
238	401–406	11,115±210	10,195
239	425–430	11,780±250	10,860
240	451–456	12,670±270	11,750
241	501–506	14,295±610	13,320
242	520–525	13,265±520	

TABLE 6.—*Radiocarbon ages of organic fraction of sediments from core E, Pretty Lake, Ind.*

[Determined by Minze Stuiver. Corrected ages were calculated by subtracting 900 years from all samples as an estimate of "dead" (Paleozoic) carbon, except for sample Y-1893, which was wood]

Sample (OWU-)	Depth (cm)	Uncorrected age (yr B.P.)	Corrected age (yr B.P.)
1887	1– 6	3,640±250	2,740
1888	101–106	6,180±240	5,280
1889	195–200	7,690±300	6,790
1890	301–306	8,470±400	7,570
1892	495–500	11,750±200	10,850
1893	551–556	13,660±200	13,660

depth are shown in figure 5. Calculated sedimentation rates in terms of centimeters per year and years per centimeter are given in tables 7 and 8 for cores A and E, respectively. The average depositional rate, assuming continuous sedimentation, for core A was 0.038 cm/yr, and for core E, 0.050 cm/yr. No radiocarbon dates are available for core B; however, if one assumes that the age of the wood horizon above till in core B is the same as that in core E, then the average rate of sediment accumulation in core B was 0.028 cm/yr.

SEDIMENTATION

In Pretty Lake, as in other hardwater lakes, the littoral sediments tend to be high in $CaCO_3$ content. Even though $CaCO_3$ is precipitated by both higher aquatics and phytoplankton during periods of active photosynthesis, the former tend to form large plates or aggregates that are less removable by currents and tend to remain in place more readily than the small crystals formed by phytoplankton. The final

TABLE 7.—*Calculated depositional rates for segments of core A between successive corrected radiocarbon dates*

[See table 5 for details of radiocarbon dates. Depth is from the top of the core to the center of the sample used for radiocarbon dating]

Depth interval (cm)	Time interval (yr B.P.)	Depositional rate (cm/yr)	Depositional time (yr/cm)
3.0– 53.5	0– 720	0.070	14.26
53.5–104.0	720– 1,830	.045	21.98
104.0–127.5	1,830– 2,695	.027	36.81
127.5–147.5	2,695– 3,585	.022	44.50
147.5–193.5	3,585– 3,843	.178	5.61
193.5–253.5	3,843– 4,340	.121	38.28
253.5–303.5	4,340– 5,885	.032	30.90
303.5–353.5	5,885– 7,495	.031	32.20
353.5–383.5	7,495– 9,295	.017	60.00
383.5–403.5	9,295–10,195	.022	45.00
403.5–427.5	10,195–10,860	.036	27.71
427.5–453.5	10,860–11,750	.029	34.23
453.5–513	11,750–13,320	.038	26.39

TABLE 8.—*Calculated depositional rates for segments of core E between successive corrected radiocarbon dates*

[See table 6 for details of radiocarbon dates. Depth is from the top of the core to the center of the sample used for radiocarbon dating]

Depth interval (cm)	Time interval (yr B.P.)	Depositional rate (cm/yr)	Depositional time (yr/cm)
3.5–103.5	2,740– 5,280	0.039	25.40
103.5–197.5	5,280– 6,790	.062	16.60
197.5–303.5	6,790– 7,570	.136	7.36
303.5–497.5	7,570–10,850	.059	16.91
497.5–553.5	10,850–13,660	.020	50.18

calcium carbonate content of the sediments, however, depends not only on how much is precipitated but also on how much is redissolved by aggressive CO_2. Because of low levels of dissolved CO_2, carbonate sediments in the epilimnion tend to remain as such, whereas those in the hypolimnion suffer variable resolution of the carbonates. For this reason marl is primarily a shallow-water deposit. In hardwater lakes then, greater rates of sedimentation would be expected in shallow water because of greater marl formation as well as less resolution. One might expect, therefore, that the total thickness of accumulated sediments in such lakes would be greater in shallow-water regions than in deepwater. However, this is generally not true. Deepwater sedimentation should not be affected by fluctuations in lake level, whereas shallow-water sediments can be brought above the wave base by a lowering of the water level. The subsequent erosion of the sediments causes a hiatus in the sedimentary record.

Wilson, in studies of two lakes in northern Indiana (Wilson, 1936 and 1938), and Wieckowski, in an investigation of Lake Mikolajki in northeast Poland (Wieckowski, 1969), found that deepwater regions generally have the greatest thickness of sediments, which results in a gradual smoothing out of the original basin (typically irregular in kettle

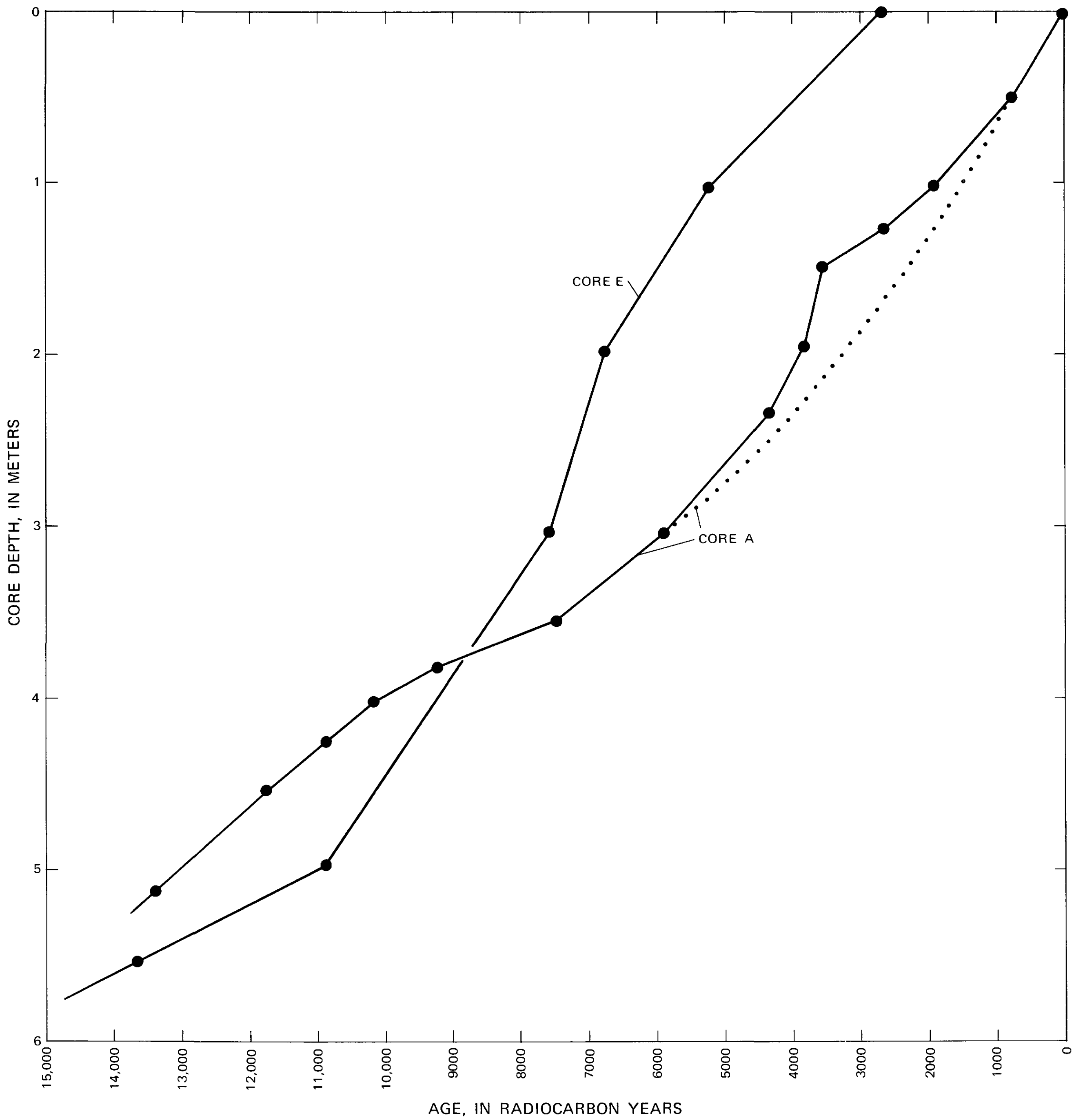


FIGURE 5.—Relationship of core depth and corrected radiocarbon ages for cores A and E. Solid lines are based on the corrected dates given in tables 5 and 6. The dotted line represents an attempt to adjust for the irregularities in the radiocarbon ages from this region of the core by drawing a smooth time versus depth curve between 300- and 50-cm levels. Assigned dates for the particular levels sampled were read from the adjusted curve.

lakes such as these). Wieckowski found that thickness of bottom deposits could vary, however, from 0 to more than 10 m. His explanation for this large variation is that bottom sediments can be maintained for a long time in a state of fluid or semifluid suspension before turning into a compact deposit. This material can either slide downslope into bottom depressions by gravity or can be transported from one place to another by water currents, resulting in some parts of the lake bottom having no sediments. Wieckowski also found great variation, specific for each basin, in the rate of accumulation of bottom deposits with respect to both space and time. Wilson (1936 and 1938) also found that thick sediments had accumulated on knobs in the original lake bottom forming "marl islands," which can rise to within a few feet of the lake surface. These "islands" are composed primarily of calcareous sediments (usually over 90 percent carbonates). Wilson postulated that the knobs on which the "marl islands" occur must have been close enough to the surface in the early stages of lake development to permit the establishment of rooted aquatics. Scott and Miner (1936) found that these "islands" were not accumulating sediments at the present, but that marl was being carried by currents into the adjacent deeper water. Sediment accumulation near the "marl islands" was almost twice that occurring in the deep water. Both Wilson (1938) and Wieckowski (1969) found that where topographic rises are sufficiently high, sedimentation has either been discontinuous or even completely absent.

The litter or woody layers found in the cores from Pretty Lake are similar to those in cores from other glaciated areas of the midwestern United States (Wright and others, 1963; Cushing, 1964, 1967; Schweger, 1969; and Maher, 1970) and Poland (Wieckowski, 1969). This debris probably represents the remains of vegetation that developed on top of glacial deposits which covered buried ice masses. As the climate became more mild, the ice gradually melted and the vegetation that covered the ice slumped into the deepening bodies of water (Cushing, 1964; and Wieckowski, 1969).

CORE E

This 577-cm core was removed from the marl lakemount, which probably developed on a topographic high in the original lake basin. The woody layer near the bottom of the core (associated with clay or fine silt) has an uncorrected radiocarbon age of 13,660 yr B.P. Overlying the basal clay is sand, which contains neither plant nor animal remains. This sand—identified as beach type by P. A. Colinvaux (oral commun., 1967)—could have been washed onto the site of the marl lakemount from a nearby sandy shore when ice under this site (and between it and the shore) melted sufficiently to produce a slight declivity. The actual amount of sand deposited cannot be given with any certainty, because the sharp contact between it and the overlying sediment suggests a period when this area was either above water or so near the surface that no deposition occurred or even that erosion took place.

Above the sand are 3 cm of algal gyttja, which probably represent many centimeters of loose sediment before compaction. This layer has a corrected radiocarbon age of 10,850 yr B.P. It was at this period in time when the buried ice had melted completely and the original lake basin was formed, for the remainder of the core is marl, a typical lacustrine deposit. The top sediments of this core have a corrected radiocarbon age of 2,740 yr. Evidently then, for the last 2,740 yr this lakemount has been too near the surface for sediments to accumulate, or, if they did, subsequent wave erosion washed them away.

It is unlikely that the period from 2,740 yr B.P. to the present is the only one for which sediments are lacking at the site of core E. Clear evidence for a break in the sedimentary record is found in the sharp contact at the 342-cm level, where gray marl is overlain by light olive-gray marl. Further, but more subtle, evidence may be found in the sedimentation rates for different time intervals since marl began accumulating about 10,900 yr B.P. (table 8). Only between 7,570 and 6,790 yr B.P. is the high rate of sedimentation normally associated with marl deposits found. If it is assumed that this rate of deposition (0.136 cm/yr) is a more valid estimate than those calculated for the other time intervals (table 8), then the marl section of this core would be expected to be about 1,360 cm long. The last 2,740 yr would account for about 370 cm of sediment, which would still leave a length of approximately 10 m expected in the present core. Since the marl section of the core is only 496 cm long, roughly 500 cm of sediment are unaccounted for. The most likely explanation is the erosion and secondary transport of sediments from the lakemount during periods of lowered lake level. The fact that only one sharp contact is found in this section of the core is not surprising, for the nature of the sediments and the conditions of deposition would tend to obscure such interfaces in a continuous marl sequence. Evidence for other erosional periods will have to come from pollen diagrams or other analyses. Hence, shallow water cores must be used with caution in palynology, as they may well be discontinuous.

CORES A AND B

Cores A and B have essentially the same sedimentary sequence—clay then gyttja. They, like core E, have a woody horizon near the base of the cores. This layer in core A has an uncorrected radiocarbon age of 13,265 yr B.P. Approximately 10 cm below the clay-gyttja interface in core A is a diagonally oriented silty clay band. No such band occurs in core B. Maher (1970) found a similar "angular unconformity" in a sand and gravel pit in Ozaukee County, Wisc., which he suggested occurred through tilting of the sediments as the buried ice melted. Possibly this idea can explain why such an angular unconformity occurs in core A and not in core B, depending on whether the early lake sediments were lowered onto a horizontal plateau (core B) or onto a slope (core A) by the melting of the underlying ice.

At the time of extrusion, core A was (and still is) well banded. Core B was not banded, even though it was taken only 55 feet from the site of A. As time passed, however, banding became apparent in core B as well. Based upon other investigations (Tutin, 1969), it could be that core B is from an area affected by slumping. The pollen stratigraphy, however, shows that this is not the explanation, as both deepwater cores show essentially the same pollen sequence. No explanation for the differences in gross appearance between these cores can be given.

Clearly, sediment types can be controlled quite closely by local conditions and are not necessarily representative of an entire lake or even a major part of it.

POLLEN ANALYSIS

MATERIALS AND METHODS

Quantitative slides for quantitative pollen and spore analysis were prepared from 0.2-cm^3 samples of sediments, using modifications of the methods recommended by Faegri and Iversen (1964). A known number of *Eucalyptus* pollen grains was added to each sample at the start, and the number recovered on each prepared slide was used to determine if a significant loss of fossil pollen had occurred during the concentration procedure (Davis, 1965a, 1966).

The sediment samples were treated sequentially with 10 percent KOH, 10 percent HCl, and 48 percent HF to remove humic acids, carbonates, and silicates, respectively. Cellulose degradation was accomplished by acetolysis. The resulting residue was stained with basic fuchsin and suspended, following the procedure recommended by Davis (1966), in a known volume (usually 50 ml) of TBA (teritary butyl alcohol) from which aliquots (usually 0.2 ml per cover glass) were taken for counting. Each aliquot was suspended in silicone oil (12,500 centistokes) on a glass slide and covered with an 18-mm cover glass after evaporation of the TBA had ceased. Usually two to four cover glasses from each level were sufficient to yield counts of more than 200 arboreal pollen grains, although about six aliquots were prepared routinely.

The entire area of each cover glass was scanned at × 400 using a Leitz Ortholux microscope with plano objectives. All pollen grains and spores under each cover glass were classified and tabulated. Critical identifications were made at × 1000 (oil immersion). Grains unknown to the author were identified by comparison with preparations in the reference collections of the author, D. G. Frey, and D. R. Whitehead or with illustrations and keys in Wodehouse (1935), Erdtman (1943; 1952; 1957), Cranwell (1953), Hyde and Adams (1958), Faegri and Iversen (1964), and Whitehead (1964). The author's reference slides consisted of pollen and spores collected from the herbaria of Indiana University, University of Alabama, Florida State University, and Livingston University in Livingston, Ala. The herbarium material was acetolized and then stained with basic fuchsin before being mounted in silicone oil.

The pollen counts from a given level were corrected for dilution and size of the original sample, yielding the number of pollen grains of each type per cubic centimeter of sediment at that level. These data were converted to percentages of the total terrestrial pollen at that level for the construction of the percentage pollen diagrams. For those samples where the depositional rates, in centimeters per year, could be estimated from successive radiocarbon dates, the data were recalculated as pollen deposited per square centimeter per year for the construction of absolute pollen frequency diagrams.

As indicated above, the pollen sum consists of the total terrestrial pollen as best representing the overall picture of the pollen rain into Pretty Lake. Only pollen of aquatic plants, unknown grains (this includes unidentifiable grains as well), and spores were omitted from the pollen sum.

Measurements of *Pinus* pollen grains and identification of *P. strobus* grains were made for certain levels of core E. Where possible, 50 fully expanded grains from each level were measured from slides made especially thick for this purpose. The dimension measured was the internal diameter of the body of the grain. *P. strobus* pollen is distinguished from other *Pinus* species by the verrucate sculpturing on the thin portion of the body wall between the air sacs (Whitehead, 1964). In core A, several slides prepared for the quantitative counts from each of two levels, were scanned to check for the presence or absence of *P. strobus.*

POLLEN DIAGRAMS

Pollen percentage diagrams have a serious shortcoming (Davis, 1963; Faegri and Iverson, 1964)—in any sample the percentage of a given pollen type is dependent upon the number of grains of all other types present, and thus an absolute increase in one type will produce apparent decreases in the others. Nevertheless, changes in percentages from one sample level to another are generally interpreted as representing the direction of vegetational change (Davis, 1963).

Absolute pollen frequency (APF) diagrams, on the other hand, are free of the constraints imposed by transforming all counts to percentages. The profile of each pollen type in such a diagram reflects the changes through time of the number of grains deposited per square centimeter per year, completely independent of all other taxa.

Errors in the APF diagrams can result from inaccuracies in the extraction and counting techniques or from the radiocarbon dates and the calculated sedimentation rates based on them. Therefore, in this study, every precaution was taken to assure that no pollen grains were thrown away with the supernatants or left on the sides of vessels during the pollen extraction procedure, that all dilutions were made and aliquots were taken with the utmost care, and that all grains under each coverslip were counted only once. The number of *Eucalyptus* grains counted per slide compared with the expected number gave confidence that procedural manipulations were not major sources of error.

A major source of error in radiocarbon dates from sediments of "hard-water" lakes is the "dead" carbon introduced from Paleozoic limestones. The apparent age of surficial sediments can be used to correct the other radiocarbon dates, but this assumes that the input of "dead" carbon has remained constant through the time interval. Three pairs of dates from cores A and E accomplished in two different laboratories are in good agreement, lending credibility to their accuracy. The early *Fagus* maximum had a corrected age of 5,885 yr B.P. in core A and 5,280 yr B.P. in core E. The dramatic change from *Picea* to *Pinus* occurred in core A about 10,860 yr B.P. and in core E about 10,850 yr B.P. The *Picea* maximum had a corrected age of 13,320 yr B.P. in core A and an uncorrected age of 13,660 yr B.P. in core E.

The number of years between any two adjacent radiocarbon dates varies from 497 to 1,800 yr B.P. in core A and from 780 to 3,280 yr B.P. in core E. Without additional intermediate dates one can only assume that the sedimentation rate (and hence the deposition rate of pollen and spores) was constant between two successive dates. This assumption seems reasonable for much of core A but not for core E, which has been disturbed by a number of episodes of erosion and nondeposition.

Three types of pollen diagrams are presented in this study. Traditional percentage diagrams based on the terrestrial pollen at each level plotted against core depth have been constructed for all cores (pl. 1). Absolute pollen frequency (APF) diagrams based on the number of pollen grains deposited per square centimeter per year and the percentages of terrestrial pollen have been plotted against time for cores A and E (pl. 2). Only the traditional percentage diagrams of cores A and E (pl. 1) include all taxa identified during the analysis. The other diagrams contain the profiles only of selected taxa.

Certain alterations in ages were necessary in the construction of some of the diagrams. When the APF diagram of core A (pl. 2*A*) was constructed using the corrected radiocarbon dates presented in table 5, an unrealistic increase in pollen deposited per square centimeter per year for all taxa was observed between 4,500 and 3,500 yr B.P., with too low values immediately above. That one or even several taxa might show such a drastic increase seems possible, but that environmental conditions could affect an increase in pollen production of all taxa does not. One possible explanation for this is that the dates in this region are too old, resulting in erroneously high rates of deposition in this age span and too low rates immediately above. If, however, a smooth time-versus-depth curve is drawn between the 300- and 50-cm levels (fig. 5) and the radiocarbon ages at the depths sampled are read from the curve (table 9), the problem is largely eliminated. The profiles generated from the adjusted ages (pl. 2*A*) show nonsynchronous increases and decreases in pollen deposition for the different taxa, which is what would be expected and what is found in the remainder of the core.

The problem is not that the radiocarbon dates are in error but that the sediments have incorporated older sediments redeposited from other parts of the

TABLE 9.—*Depositional rates based on intervals between successive adjusted radiocarbon ages for a section of core A*

[See table 7 for the depositional rates of the levels not adjusted. Depth is from the top of the core to the center of the sample used for radiocarbon dating]

Depth interval (cm)	Time interval (yr B.P.)	Depositional rate (cm/yr)	Depositional time (yr/cm)
53.5–104.0	[1]720–1,440	0.070	14.26
104.0–127.5	1,440–1,800	.065	15.32
127.5–147.5	1,800–2,080	.071	14.00
147.5–183.5	2,080–2,740	.055	18.33
183.5–203.5	2,740–3,110	.054	18.50
203.5–253.5	3,110–4,220	.045	22.20
253.5–303.5	4,220–[1]5,885	.030	33.30

[1] Not adjusted.

lake or washed in from shore. Such dilution by old carbon through redeposition poses a problem in all radiocarbon dating of lake sediments (Ogden, 1967).

The profiles of given pollen types in the APF diagrams for cores A and E (pl. 2) do not agree closely in many respects. The profiles for *Pinus* from the two cores illustrate one major discrepancy. The *Pinus* maximum spans approximately 1,000 yr in core A and 2,000 in core E, which does not seem possible since the cores are from the same lake and received the same pollen rain. This fact and the existence of an unconformity at the top of this period (342-cm level—see discussion of the cores) strongly suggest that the section of core E deposited between 10,850 and 7,570 yr B.P. is not continuous. Also, the apparent sedimentation rates (0.059 cm/yr) here are lower than would be expected on a marl-accumulating lakemount.

Profiles of *Fraxinus, Quercus,* and Cyperaceae in the segment of core E bracketed by ages of 13,660 and 10,850 yr B.P. suggest a discontinuity here also. Maxima of these taxa span 1,500 yr in core A (12,300–10,800 yr B.P.) and only 500 years in core E (11,300–10,800 yr B.P.).

The top 194 cm of core E likewise is thought to be discontinuous, as the rates of deposition are low (table 8), and the pollen profiles as plotted do not correspond to those from core A (pl. 2). Only the 106-cm sequence of core E deposited between 7,750 and 6,790 yr B.P. at an average rate of 0.136 cm/yr is considered to be uninterrupted.

Because no sediments representing the last 2,740 yr occur on the marl lakemount from which core E was collected, and because the total thickness of sediments is less than expected, other comparable episodes of erosion or nondeposition must have occurred in times past. Based on the evidence for discontinuities in the sedimentary record of core E, revised sedimentation rates (table 10) were estimated.

TABLE 10.—*Revised depositional rates for segments of core E between successive corrected radiocarbon dates*

[See table 8 for calculated depositional rates. Depth is from the top of the core to the center of the sample used for radiocarbon dating]

Depth interval (cm)	Time interval (yr B.P.)	Depositional rate (cm/yr)	Depositional time (yr/cm)
3.5–103.5	2,740–5,280	0.125	8.00
103.5–197.5	5,280–6,790	.125	8.00
197.5–303.5	6,790–7,570	[1].136	[1]7.36
303.5–497.5	7,570–10,850	.098	10.18
497.5–553.5	10,850–13,660	.035	28.75

[1] Not revised.

A depositional rate of 0.125 cm/yr has been assumed as reasonable for the top 194 cm of core E —roughly the same as that for the 106 cm immediately below, which is considered to be continuous. A rate of 0.098 cm/yr was established for the 194 cm bracketed by the corrected radiocarbon ages of 10,850 and 7,570 yr B.P. by fitting the *Pinus* and *Betula* maxima to the time period that the taxa span in core A. A depositional rate of 0.035 cm/yr for the bottom 56 cm of the core resulted from fitting the *Fraxinus, Quercus,* and Cyperaceae profiles for the 545- to 500-cm levels above the *Picea* maximum in core E to the corresponding profiles in core A above the *Picea* maximum. The radiocarbon dates for the *Picea* maxima in both cores are in good agreement.

A revised APF diagram (pl. 2) was constructed using the revised sedimentation rates. Five periods of erosion and (or) nondeposition of sediments are shown for core E, which bring the profiles of individual taxa into reasonable agreement with those of core A.

When the percentages of selected terrestrial taxa for core A and for the time-adjusted segments of core E are plotted against time on the same diagram (pl. 2), the pollen profiles fit quite satisfactorily, suggesting that the assumptions involved in adjusting the depositional rates are reasonable.

APF diagrams showing the total pollen sum and the NAP (nonarboreal pollen) for cores A and E are given in figures 6*A* and 6*B* respectively. In the construction of these diagrams the adjusted dates from core A (table 9) and the revised depositional rates for core E (table 10) were used.

POLLEN ASSEMBLAGE ZONES

All pollen diagrams constructed for this study have been divided into pollen assemblage zones based on fluctuations in dominant pollen types. These zones were established primarily from the diagrams of core A and the lower sediments of core E, where

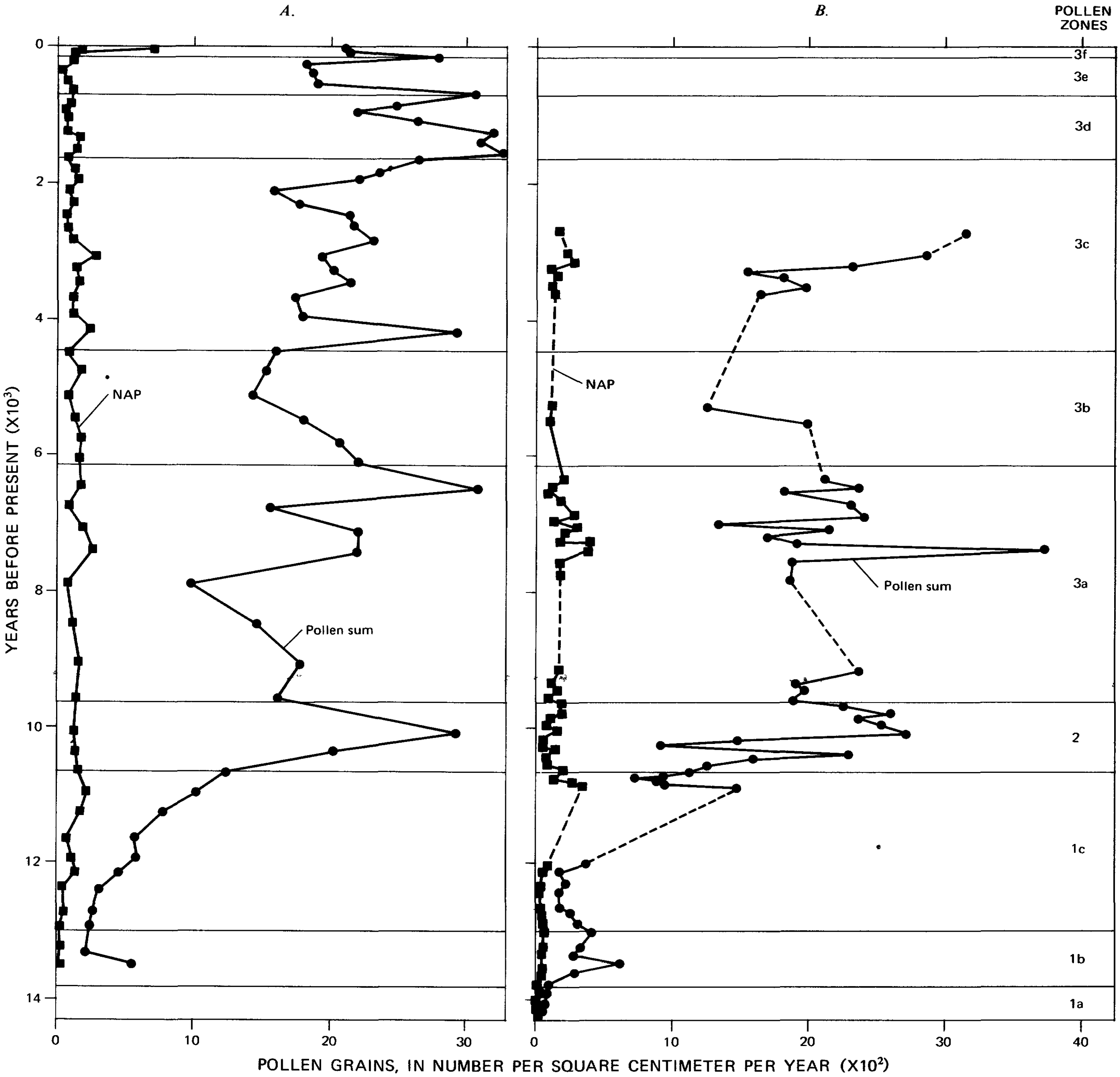


FIGURE 6.—Numbers of pollen grains deposited per square centimeter per year for the pollen sum and for NAP plotted against time. *A*, Core A—time scale incorporates the adjusted dates given in table 9. *B*, Core E—revised rates of deposition (table 10) have been used.

sedimentation was continuous. Core B was analyzed in much less detail, and there are no radiocarbon dates available for it. The boundaries of these pollen assemblage zones do not represent an attempt to fit them to zones discerned by other workers for cores from the midwestern or northeastern United States—not even to Silver Lake, Ohio (Ogden, 1965), which has a pollen stratigraphy very similar to that of Pretty Lake. The general tripartite division of postglaciation vegetational changes of the eastern United States (Davis, 1965b; Deevey, 1965) is present—late-glacial (spruce), pine, and deciduous—but the details are largely under local control. In recognition of this, the pollen zones set up are specific to this site.

A brief outline of the zones and the time interval of each in years before present are given below. These will be discussed in sequence, beginning at the bottom of the section.

Assemblage zone	Distinction	Interval (yr B.P.)
3f	Dramatic *Ambrosia* rise	0– 150
3e	*Quercus-Carya* maximum	150– 670
3d	*Fagus-Acer* maximum	670– 1,685
3c	*Quercus-Carya* maximum	1,685– 4,436
3b	*Fagus-Ulmus* maximum	4,436– 6,100
3a	*Quercus* maximum	6,100– 9,588
2	*Pinus-Betula* maximum	9,588–10,652
1c	*Picea-Fraxinus*—NAP maximum	10,652–12,978
1b	*Picea-Abies-Larix* maximum	12,978–13,800
1a	Cyperaceae maximum	13,800–14,300(?)

In the following discussion of the pollen assemblage zones, all references to the data and conclusions drawn from the data will be based upon information derived from all pollen diagrams pertinent to the specific statement except where noted.

ZONE 1A

Zone 1a is characterized by high NAP percentages and low numbers of pollen deposited per square centimeter per year—about 700 (pl. 1). Even though Cyperaceae, Gramineae, and *Artemisia* attain percentages of 40, 10, and 5, respectively, the actual numbers of grains deposited are no higher than found elsewhere in the cores. Three grains of *Saxifraga oppositifolia* type were found near the base of core E and two grains of *Elaeagnus commutata* in core B (pl. 1). These two species are indicators of open country (Andersen, 1954; Fries and others, 1961; Gleason and Cronquist, 1963; and Ogden, 1965). They also indicate a colder climate than exists in the area today. This is especially true of *S. oppositifolia,* which is considered to be circumpolar or circumboreal (Fernald, 1925; Gleason and Cronquist, 1963). Small numbers of Ericaceae were also found in this zone—a group of shrubs common in analyses from Labrador tundra (Wright and others, 1963).

Picea percentages range from 30 to 50, but the actual numbers of grains deposited per square centimeter per year are very low (100–350). *Juniperus/Thuja, Abies,* and *Alnus* are present throughout the zone, and *Larix* appears near the top. *Pinus* and *Quercus* are present in low percentages and absolute numbers, and *Fagus, Fraxinus,* and *Ostrya/Carpinus,* and *Carya* occur sporadically. The few grains of *Pinus* and *Quercus,* usually considered to be overrepresented in pollen diagrams (Davis and Goodlett, 1960; and Janssen, 1966), as well as other more mesic species, may have resulted from long distance transport or from rebedding. It is unlikely they were established in the region at this time.

No modern pollen assemblage has been found that corresponds to this zone. A somewhat comparable zone from cores in New England is considered by Davis (1969) as being similar to tundra assemblages from northernmost Quebec (surface samples were not available). Certainly zone 1a in the Pretty Lake diagrams represents tundra or tundralike conditions that existed for about 500 yr in the lake region. It corresponds in time to the Cary–Port Huron interval.

ZONE 1B

Picea reaches a maximum of 90 percent accompanied by lesser peaks of *Abies* (8 percent) and *Larix* (5 percent). Pollen accumulation rates are still relatively low in this zone (pl. 1), but *Picea* is represented by about 4,000 gr/cm^2 yr at its maximum as compared to 350 deposited in zone 1a. Percentages of NAP decrease, even though the actual number deposited per square centimeter per year is about the same as in zone 1a.

A similar pollen assemblage zone from Silver Lake, Ohio (Ogden, 1969) has a Spearman rank correlation coefficient greater than +0.800 with Nichicun Lake in the Boreal Parkland of northern Quebec. (For a discussion of this means of comparison, see Ogden, 1969.) This region is "characterized by open, park-like woodlands of black spruce, with an associated ground cover of lichens" (Terasmae and Mott, 1965). The *Picea* or spruce zone in New England diagrams also resembles present-day surface pollen assemblages from northern Quebec (Davis, 1969).

Thin sections of wood from the 510-, 512-, and 520-cm levels of core A were prepared by Paul Weatherwax. Slides of these sections were sent to E. S. Barghoorn (Harvard University) for identification. His comments (written commun., 1971) follow:

510–cm level.—"This is either a depauperate stem, or a twig (pith is very small) of either *Picea* or *Larix.* You cannot unequivocally distinguish these two genera by wood structure, despite some attempts in the literature to the contrary. The very narrow growth rings are evidence of very slow growth (8 rings) and there is some indication of a false growth, or possibly a frost injury ring."

512–cm level.—"Again *Picea* or *Latrix.* This specimen shows considerable fungus attack (not Basidiomycete)."

520–cm level.—"This is a conifer, probably *Picea* or *Larix,* but preservation is poor . . . diagnostic features are lacking . . ."

The finding of macrofossil remains of *Picea* or *Larix* in this zone is not surprising. Of great interest are Barghoorn's comments about slow growth and the possibility of frost injury to the wood from the 510-cm level of core A. As this level corresponds in time to the glacial advance of the Port Huron stade, the wood morphology gives reasonable evidence of extreme cold in the region at this time. Indirect evidence for such extreme climatic conditions is found in the low rates of pollen deposited per unit of time (fig. 6). The older part of the zone is correlated in time with the Cary–Port Huron interval and is considered to be somewhat warmer than the younger part.

ZONE 1C

Picea represents 10 percent of the pollen sum in the older part of the zone and then increases to 20–40 percent near the top. Substantial peaks of *Fraxinus, Juniperus/Thuja, Ostrya/Carpinus,* and *Quercus* are found in the lower portion of the zone. The *Picea* increase is closely associated with the percentage increase in *Abies*. The APF diagrams show the same general trends, but the increases in *Fraxinus* and *Quercus* are not so dramatic as the percentage diagrams indicate (this is also true of *Juniperus/Thuja* and *Ostrya/Carpinus,* which are not included). For instance, the number of *Quercus* grains deposited per square centimeter per year at the maximum in zone 1c is 200 as compared to about 15,000 in younger deposits. The NAP increase seen in the percentage diagrams is real, but in absolute numbers (pl. 1) the increase is more pronounced near the top of the zone, rather than throughout the entire zone as the percentage diagrams indicate. No present-day pollen assemblage has been found that corresponds to this zone in the Pretty Lake cores.

The older part of zone 1c, as likewise the younger part of zone 1b, corresponds to the Port Huron glaciation. The existence of extreme climatic conditions during this period is indicated by the low rate of deposition of all pollen types during this time period. The gradual increase in pollen grains of hardwoods and the increase in total grains deposited per square centimeter per year that occurs in the middle of the zone indicate a warming trend, although the high percentages of *Fraxinus* and *Ostrya/Carpinus* suggest that the climate was still cool and moist (Schweger, 1969). Near the top of the zone increases in absolute numbers of NAP, especially Cyperaceae, Gramineae, and *Artemisia* (not shown), followed by a decrease in hardwood pollen, are indicative of a drier period during which the landscape became more open (Schweger, 1969). Further evidence for this being a relatively dry period is the absence of sediments from this period and 1,000 yr previous to it in core E), believed to have resulted from a period of lowered lake level that facilitated erosion and nondeposition of sediments.

At the top of the zone, corresponding to the decrease in hardwood pollen, an increase in *Picea, Abies,* and *Pinus* can be seen in both the percentage and APF diagrams (*Abies* not shown on the APF diagrams). These diagrams show that for core E, which was sampled at closer intervals than core A in this interval, the *Pinus* increase lags behind that of *Picea* and *Abies*.

These data can be interpreted in at least two ways:

(1) The open vegetation, indicated by the NAP increase, was invaded by trees, leading to the development of a closed forest of *Picea, Pinus,* and deciduous hardwoods. This is the interpretation given to a similar zone in Iola Bog, Wisc., by Schweger (1969) which is equated with the modern Great Lakes mixed conifer-hardwood forest.

(2) The decrease in deciduous hardwoods and increase in *Picea* and *Abies* occurred in response to a colder and more moist climate associated with the Valders advance, which is the interpretation I prefer for Pretty Lake. The increase in *Picea* and *Abies* is very similar to the more evident increase seen during the Port Huron stade. Also, the absolute decrease in hardwoods suggests a colder time. The overall decrease in absolute numbers of pollen grains seen during the Port Huron advance is also present here except that it is masked by an absolute increase in *Pinus* pollen. This increase in *Pinus* pollen most certainly was not from trees in the immediate area, for the percentages and absolute numbers are too low. Rather it resulted from the slow migration of *Pinus* toward the Pretty Lake region. (For a discussion of the *Pinus* problem, see Wright, 1964 and 1968.)

If the date for the Two Creeks forest of 11,850 yr B.P. (Broecker and Farrand, 1963) is correct, then the older sediments in the middle of zone 1c, in which a gradual increase in hardwoods occurs, corresponds in time to the Two Creeks Interstade. The younger part, with its higher percentages and absolute numbers of hardwoods, corresponds to the Valders event. In this interpretation there is no evidence that the Valders glaciation affected the Pretty Lake region.

If, however, the date of 10,700 yr B.P. of Ogden and Hay (1967) is accepted for the time when the Two Creeks forest was overridden by Valders ice, the Valders advance is recorded in Pretty Lake by the increase in *Picea* and *Abies* at the top of zone 1c and the middle of this zone correlates with the Two Creeks event. On the basis of the data from this study the latter date is more acceptable, and the top part of zone 1c, as well as the older part of zone 2, is considered to be colder and possibly more moist than the period of NAP increase just preceding.

In the remainder of the core the total pollen deposited per square centimeter per year essentially reaches a plateau (pl. 1), and the APF diagrams closely resemble the percentage diagrams. (The major exception to this is found in zone 3c of core A, which has been discussed earlier—see table 9 and pl. 2).

ZONE 2

Zone 2 is characterized by maxima of *Pinus* and *Betula*. In core E, the *Pinus* maximum is bimodal, whereas it is unimodal in cores A and B. This bimodality in core E is very likely the result of the more rapid rate of sediment accumulation at this site, which in effect expands the pollen stratigraphy and makes possible a finer resolution of pollen changes even by sampling at rather large intervals. Measurements of *Pinus* grains from certain levels of core E (fig. 7) show that the older peak is composed of a larger number of small grains (probably *P. resinosa* and (or) *P. banksiana*) than is the younger peak. In the younger or second peak, almost 50 percent of the grains were identified as *P. strobus*, a type that occurred only rarely in the older peak. Studies of two levels of core A indicate that the same shift in species composition occurs. A similar bimodal peak of *Pinus*, in which *P. strobus* dominates the younger peak and *Betula* is dominant between the two pine peaks, was found by Maher (1970) in a sand and gravel pit in Wisconsin. If this shift in species is due to differential migration rather than climatic factors, *P. strobus* reached northern Indiana about 9,800 yr B.P. This was about 3,000 yr earlier than the species reached eastern Minnesota and about 7,000 yr before it reached northwestern Minnesota (Wright, 1968).

The *Betula* peak between the two *Pinus* peaks may represent a relatively wet period occurring during a time that is generally considered to be cool and dry (Ogden, 1966). King and Kapp (1963) found a situation existing in eastern Ontario today in the Lake Timagami region where *Betula* is well established, but where remains of many large pines killed by rising water levels are in evidence. Numerous small pines were developing among the beeches.

Picea and *Abies* decrease rapidly and essentially have disappeared by the top of the zone. *Quercus* and other deciduous trees increase near the top of the zone. Percentages of NAP are at a minimum.

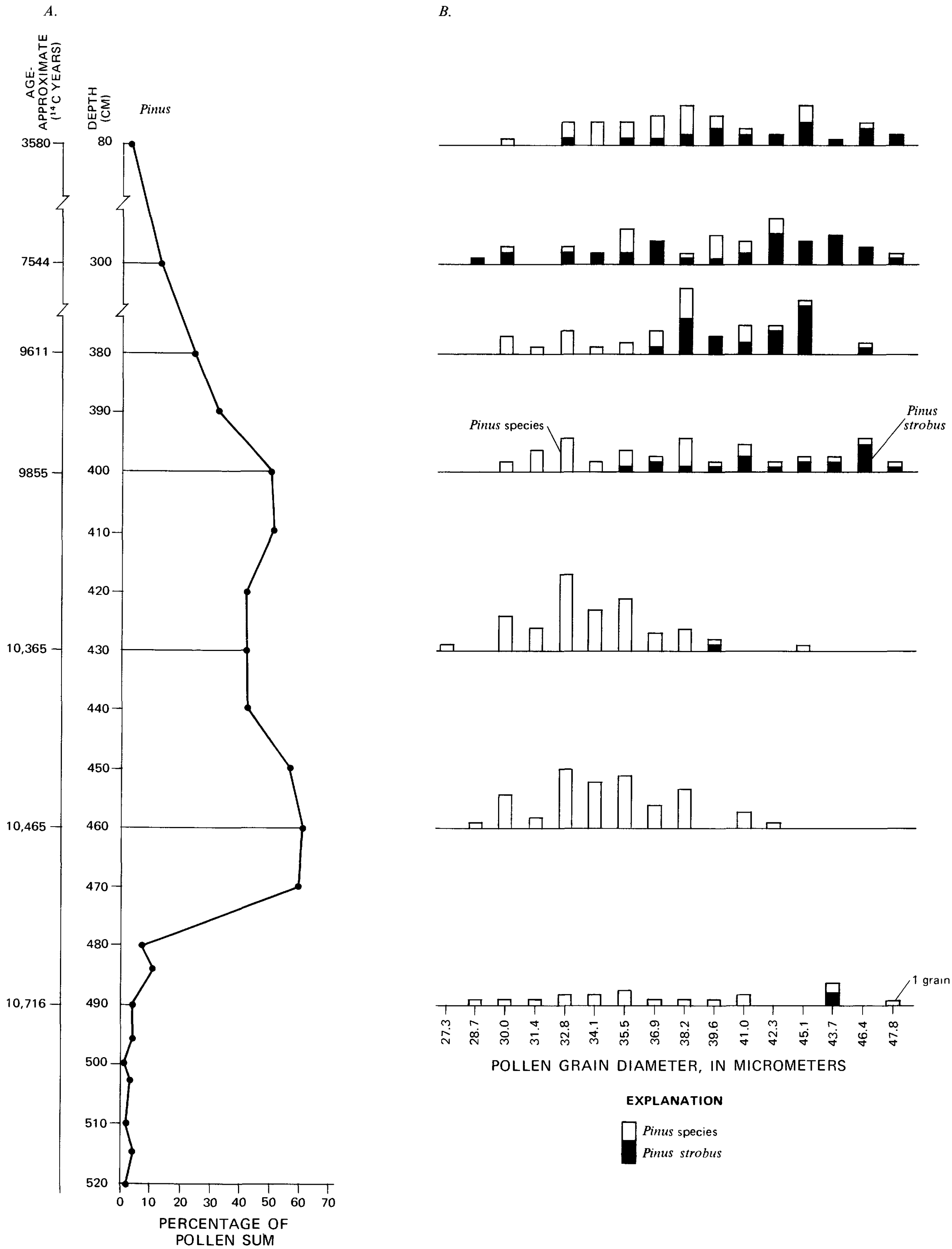
This fossil pollen zone resembles modern pollen assemblages from mixed coniferous-deciduous forest of Ontario which borders the southern margin of the boreal forest (King and Kapp, 1963; and Davis, 1969). It represents a transition period of about 1,000 years between a *Picea*-dominated landscape and one dominated by deciduous hardwoods.

ZONE 3A

In Zone 3a *Quercus* dominates and *Pinus* steadily decreases to low percentages and low absolute numbers in the upper part, which probably represent long-distant transport. *Ulmus* and *Ostrya/Carpinus*, which began to increase in zone 2, are prominent features of the older portion of the zone and then decrease toward the middle. *Ulmus* increases again near the top of the zone. The APF diagram for core A (pl. 2) shows that *Quercus* as well as *Ulmus* and *Ostrya/Carpinus* (not shown) decrease in the middle of the zone. (Core E is thought to be discontinuous here.) Both percentages and absolute numbers of NAP increase in the middle of the zone (pl. 1).

Adjustments of these data to the method employed by Janssen (1967) to obtain regional pollen percentages show that the upper part of this zone in the Pretty Lake cores corresponds to modern samples from Clearwater Lake, which is situated in a predominantly xeric *Quercus* sp. woods in west-central Minnesota (part of the Maple-Basswood Forest of Ogden, 1969). Ogden (1969) found that one level of Silver Lake, Ohio, which corresponds in pollen composition to the upper part of this zone in Pretty Lake, has a correlation greater than +0.800 with sites that cluster in the Maple-Basswood segregate of the Deciduous Forest. A zone from southeastern Minnesota cores, which is similar to the lower part of zone 3a in Pretty Lake, is considered to have its modern analog in the maple-basswood forest of southeastern Minnesota, based upon the high values of *Ulmus* and *Ostrya/Carpinus* that are present, and is interpreted as showing progressive drying (Wright and others, 1963, zone C-a).

The increase in NAP and decrease in total pollen deposited per unit of time seen in the middle of core A (pl. 1) probably resulted from the increasing drought forecast in the older part of the zone. It


A.
B.
AGE-APPROXIMATE (14C YEARS)
DEPTH (CM)
Pinus
3580
7544
9611
9855
10,365
10,465
10,716
80
300
380
390
400
410
420
430
440
450
460
470
480
490
500
510
520
0 10 20 30 40 50 60 70
PERCENTAGE OF POLLEN SUM
Pinus species
Pinus strobus
1 grain
27.3 28.7 30.0 31.4 32.8 34.1 35.5 36.9 38.2 39.6 41.0 42.3 45.1 43.7 46.4 47.8
POLLEN GRAIN DIAMETER, IN MICROMETERS
EXPLANATION
Pinus species
Pinus strobus

could well represent a time of open woodland when prairie may have become established in this section of Indiana. The absence of sediments from this time period in core E also suggests a dry period. The lowering of the lake level during the time represented by the middle of this zone could have caused sediments deposited during the older part of the zone to be eroded off the lakemount at core E and transported into the deep water. This redeposition of earlier deposited sediments with their contained pollen would have produced apparent low percentages of NAP, thus masking the high percentages of NAP types usually associated with prairie as given by Wright and others (1963), McAndrews (1966), and Cushing (1967).

Gleason and Cronquist (1964), in their discussion of the deciduous forest, state that "The number of common dominant trees in relatively undisturbed forest thin out in all directions from the southern Appalachian center. To the north, beech and sugar maple are increasingly abundant on the better soils, with oak and hickory often occupying the drier or more exposed sites. To the far northwest, in Wisconsin and Minnesota, the beech-maple community gives way to the maple-basswood community as the beech drops out and is replaced by basswood."

Zone 3a then, might be further subdivided into three subzones: (1) Older portion—maple-basswood type forest, gradual decrease in moisture, (2) middle portion—prairie(?) or oak savanna, dry, and (3) younger portion—maple-basswood type forest, increase in moisture. The entire zone is considered to be warmer than the preceding zone but cooler than present-day Indiana.

ZONE 3B

In zone 3b a decrease in *Quercus* is accompanied by maxima of *Fagus* and *Ulmus*, both in terms of percentages and accumulation rates. Slight increases in *Crya, Platanus,* and *Acer* also occur as NAP decreases. This zone, with its mixture of deciduous hardwoods, is interpreted as representing a period when a mixed mesophytic forest (Gleason and Cronquist, 1963) existed in northeastern Indiana. The climate during the period was as warm as (or probably warmer than) that of the preceding period and was still moist.

ZONE 3C

In zone 3c *Quercus* is dominant, but *Carya* shows a significant rise in the top half of the zone. *Fagus, Acer, Juglans,* and *Ulmus* all decrease in the upper part of the zone. A slight increase in absolute numbers of NAP (pl. 1) occurs in the lower half of this zone in core A (core E is not complete for this time period). A strong correlation exists between this zone (and a similar zone in Silver Lake, Ohio, Ogden, 1969) and the present pollen rain in two lakes from southwestern Illinois—a region that is warmer and drier than northeastern Indiana at the present (Ogden, 1969).

This zone represents a time when open oak-hickory forest existed in northeastern Indiana which could have been invaded by prairie. As in zone 3a, however, NAP is not so well represented as might be expected during times of partial prairie vegetation. But again there is evidence from core E that water levels were low, and hence redeposited pollen from earlier time periods could have been redeposited at the site of core A.

ZONE 3D

Zone 3d is characterized by maxima of *Fagus* and *Acer* and a decrease in *Quercus* and *Carya.* Slight increases in *Platanus, Ulmus,* and *Ostrya/Carpinus* also occur. Percentage and absolute numbers of NAP deposited per unit of time decrease.

The zone is interpreted as representing a time when a *Fagus-Acer* forest dominated the landscape and when the climate was cooler and more moist than in the preceding period. Lindsey and Schmelz (1965) found a trend toward dominance of beech-maple in a region of Indiana that had been oak-hickory. This change occurred in a 9-year period and was associated with an increase in precipitation of 1.8 inches (4.6 cm) and a decrease in temperature of 1.2°F (−0.67°C) (April 1–August 31) when compared to the preceding 54 years.

The curves generated by plotting the percentage organic matter against percentage inorganic residue in the dry sediments of these cores (pl. 1) in general show maxima during the *Fagus* peaks. These increases could represent increased nutrients being washed into the lake resulting in increased productivity in the lake (Frey, oral commun., 1969) or

FIGURE 7.—Analysis of the abundance and sizes of *Pinus* pollen grains at various levels in core E. *A*, Relative abundance (as percentage of total terrestrial pollen) of *Pinus* pollen grains at various levels of the core. The ages, in years before present, of the various levels are those found on plate 2 constructed from the revised depositional rates in table 10. *B*, Frequency diagrams showing the distribution of pollen grain diameters found in total *Pinus* and in *P. strobus* at various levels of the core. Fifty grains were measured at each level except the lowest (490 cm).

from organic matter derived from the watershed. In either case, increased precipitation seems to be indicated.

Two other increases in percentage organic matter are present in the cores. One is associated with the woody layer near the base of the cores, as would be expected, and the other is associated with the *Betula* increase during the *Pinus-Betula* maximum (zone 2). This period has already been shown to suggest a wet period on the basis of findings in Ontario (see discussion of zone 2).

ZONE 3E

The percentage diagrams show increases in *Quercus* and *Carya* and decreases in other AP (aboreal pollen). The APF diagram (core A) shows a general decrease in all AP. Percentage of NAP increases slightly.

This zone near the top of the core represents a trend toward warmer-drier climatic conditions, based upon the increase in more xeric tree types, and a return to oak-hickory forest—the type of forest that was recorded by early surveyors in the area about 150 yr B.P. (Lindsey and others, 1965).

ZONE 3F

Zone 3f is characterized by a general increase in NAP, particularly weed-types such as *Ambrosia, Plantago,* and *Rumex*. There seems little doubt that these increases represent a real increase in these genera in the landscape (Davis, 1965b) and reflect the effect that forest clearance and European agricultural practices had on the area (Davis, 1965b; Ogden, 1966). Thus, this zone represents the advent of European settlers into the Pretty Lake region.

CONCLUSIONS

A summary of the results and conclusions of study of cores A, B, and E are presented in figure 8.

During late-glacial time (15,000–10,600 yr B.P.) good agreement is found between the glacial events, the lake sediments, and the vegetational assemblage zones implied by the pollen studies. Wasting of the Cary ice about 15,000 yr B.P. at the beginning of the Cary–Port Huron interval left a debris-covered ice block on the present site of Pretty Lake. For about 700 yr no evidence is found that sediments were accumulating at the lake site or that pollen was being deposited in detectable quantities. About 14,300 yr B.P. pollen (primarily Cyperaceae) began being deposited on pebbly clay-till on top of the ice block. The pollen types deposited during the next 500 yr (to 13,800 yr B.P.) indicate a period of extreme cold, during which tundra or tundralike conditions existed in the Pretty Lake area. A gradual increase in temperature during the next 500 yr allowed *Picea, Abies,* and *Larix* to become established on and around the ice block and also permitted partial melting of the ice block to form bogs and small pools, causing the vegetation on or near these sites to slump or be washed into water-filled basins. The woody layer in these cores is evidence of this event.

The Cary–Port Huron interval ended about 13,300 yr B.P. at the beginning of the Port Huron stade. Colder temperatures are reflected in very low numbers of total pollen being deposited per unit of time and a decrease in AP percentages. The effects of Port Huron glaciation are seen for about 700 yr (13,300–12,600 yr B.P.) in the Pretty Lake cores. Evidence that a warmer-drier period followed, which lasted for about 1,700 yr (12,600–10,900 yr B.P.) and corresponded to the Two Creeks Interstade, is found in the cores:

(1) Beach sand found in core E during the early part of this period was washed down from a sandy shore acros a slope produced by partial melting of the ice block.
(2) No sediments are found in the younger part of this period in core E, which is considered evidence that erosion and (or) nondeposition resulted from a lowering of the lake level at this site. A lower level of water over the site of core E could have resulted when the ice block melted to form a new basin some distance from core E or from decreased precipitation or higher evaporation rates. In any case warmer and possibly drier climatic conditions are indicated.
(3) An increase in hardwood pollen is observed.
(4) An increase in absolute numbers of NAP occurs near the end of the period.
(5) Evidence of complete melting of the ice block is found in core A where angled sediments are associated with younger horizontal sediments.
(6) The top of the period marks the beginning of the deposition of typical lacustrine deposits—marl and gyttja.

The end of the Two Creeks Interstade and the beginning of the Valders Stade (about 10,900 yr B.P.) is associated with an increase in *Picea* and *Abies,* which lasted for about 300 yr—to 10,600 yr B.P. After the end of this colder period *Picea* and *Abies* do not appear in the pollen sum again in significant numbers. There is no evidence that any subsequent glacial events affected the climate or vegetation of this section of Indiana.

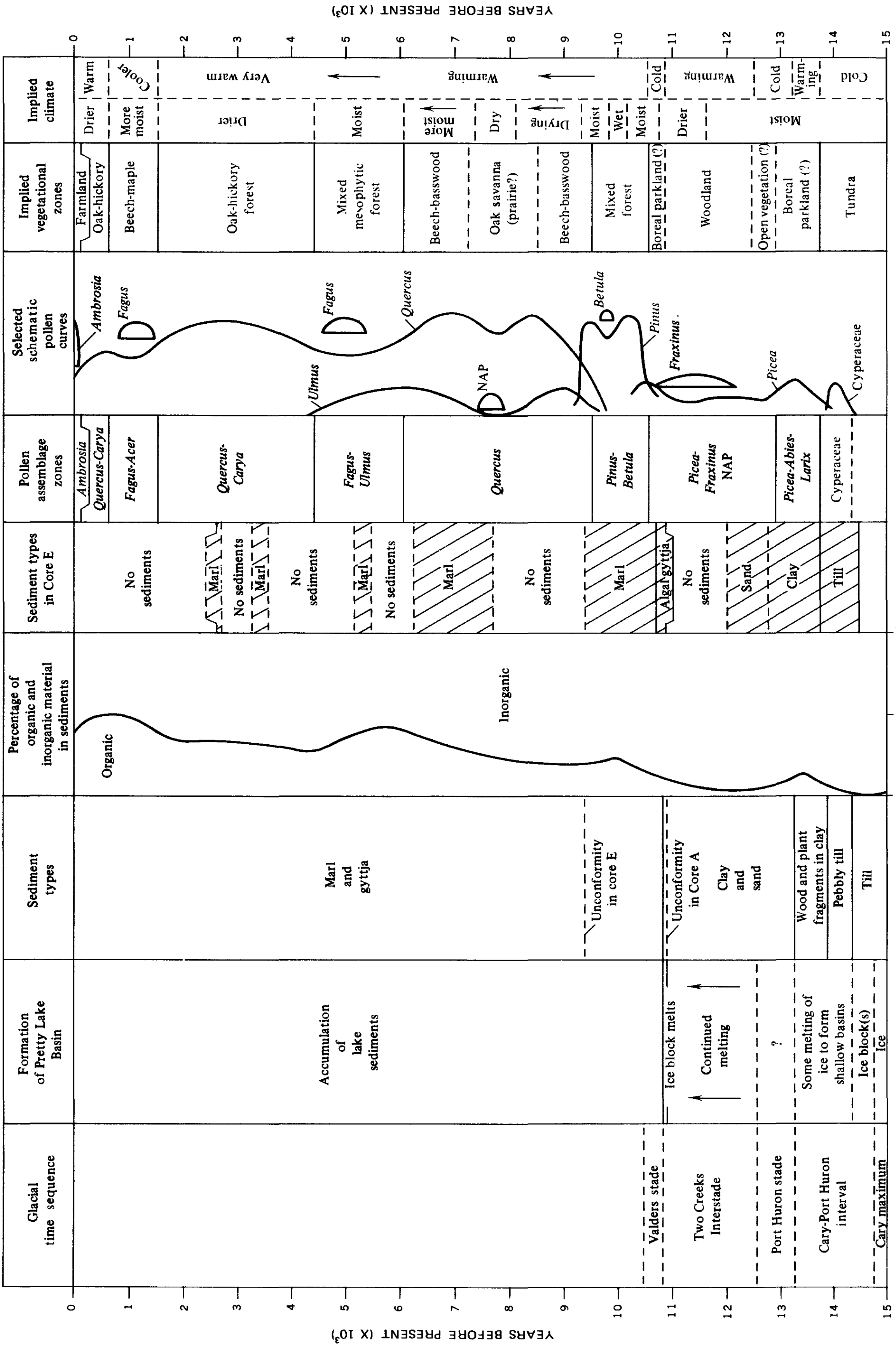


FIGURE 8.—Summary of results and conclusions derived from the study of cores A, B, and E. Glacial events are based on data from the literature.

At this time a warming trend began in the Pretty Lake region that continued for about 9,000 yr (10,600–1,500 yr B.P.), ending with a time that was warmer and drier than present-day northeastern Indiana. The shift in vegetation types from mixed forest (*Pinus* to *Betula* to *Pinus*) to beech-basswood forest to oak savana (or prairie?) to beech-basswood forest to mixed mesophytic forest to oak-hickory forest (including prairie?) is the result of a complex of factors, including (1) gradual warming, (2) intermittent dry periods, and (3) differential migration of species. The dry periods inferred from changes in pollen types (see discussion of individual zones) are more or less synchronous with the periods for which no sediments have been preserved in core E. That sediments are lacking for time periods immediately below these levels is not surprising, for if erosion as well as nondeposition took place, sediments already deposited would have been lost from the lakemount and carried into deep water. The lack of sediments during part of the mixed mesophytic period can be interpreted as representing a dry episode, but more likely it represents a period when marl accumulation had reached the wave base, as at present, preventing further accumulation of sediments.

Not until about 1,500 yr B.P. is there any indication of a significant decrease in temperature since Valders time. The replacement of the oak-hickory forest by beech-maple (as indicated by the pollen assemblages) is considered to indicate both a decrease in temperature and an increase in available moisture. Then, 600 yr B.P., a return to slightly warmer and drier climatic conditions is indicated by a return of pollen types indicative of an oak-hickory forest—the type found in the region by early surveyors. The advent of western agriculture is marked in the cores by a dramatic increase in *Ambrosia.*

LITERATURE CITED

Andersen, S. T., 1954, A late-glacial pollen diagram from southern Michigan, U.S.A.: Danmarks Geol. Unders. ser. 2, no. 80, p .140–155.

Braun, E. L., 1950, Deciduous forests of eastern North America: Philadelphia, Blakiston Co., 596 p.

Broecker, W. S., and Farrand, W. R., 1963, Radiocarbon age of the Two Creeks forest bed, Wisconsin: Geol. Soc. America Bull., v. 74, p. 795–802.

Cranwell, L. M., 1953, New Zealand pollen studies, the Monocotyledons: Cambridge, Harvard Univ. Press, 91 p.

Cushing, E. J., 1964, Redeposited pollen in late-Wisconsin pollen spectra from east-central Minnesota: Am. Jour. Sci., v. 262, p. 1075–1088.

——— 1967, Late-Wisconsin pollen stratigraphy and the glacial sequence in Minnesota, *in* Cushing, E. J., and Wright, H. E., Quaternary paleocology: New Haven, Yale Univ. Press, p. 59–97.

Davis, M. B., 1963, On the theory of pollen analysis: Am. Jour. Sci., v. 261, p. 897–912.

——— 1965a, A method for determination of absolute pollen frequency, *in* Kummel, B. and Raup, D., Handbook of paleontological techniques: San Francisco, W. H. Freeman and Co., p. 674–686.

——— 1965b, Phytogeography and palynology of northeastern United States, *in* Wright, H. E., Jr., and Frey, D. G., The Quaternary of the United States: Princeton, Princeton Univ. Press, p, 377–401.

——— 1966, Determination of absolute pollen frequency: Ecology, v. 47, p. 310–311.

——— 1969, Palynology and environmental history during the Quaternary Period: Am. Scientist, v. 57, p. 317–332.

Davis, M. B., and Goodlett, J. C., 1960, Comparison of the present vegetation with pollen-spectra in surface samples from Brownington Pond, Vermont: Ecology, v. 41, p. 346–357.

Deevey, E. S., Jr., 1965, Pleistocene nonmarine environments, *in* Wright, H. E. Jr., and Frey, D. G., The Quaternary of the United States: Princeton, Princeton Univ. Press, p. 643–652.

Englehardt, D. W., 1965, A late-glacial—postglacial pollen chronology for Indiana: Am. Jour. Sci., v. 263, p. 410–415.

Erdtman, O. G. E., 1943, An introduction to pollen analysis: Waltham, Mass., Chronica Botanica Co. 239 p.

——— 1952, Pollen morphology and plant taxonomy, Angiosperms: Waltham, Mass., Chronica Botanica Co., 539 p.

——— 1957, Pollen and spore morphology and plant taxonomy Gymnospermae, Pteridophyta, Bryophyta: New York, Ronald Press, 151 p.

Faegri, Knut, and Iversen, Johs. 1964, Textbook of pollen analysis: New York, Hafner Publishing Co., Inc., 237 p.

Farrand, W. R., Zahner, Robert, and Benninghoff, W. S., 1969, Cary-Port Huron interstade; evidence from a buried bryophyte bed, Cheboygan County, Michigan; Geol. Soc. America Spec. Paper 123, p. 249–262.

Fernald, M. L., 1925, Persistence of plants in unglaciated areas of boreal America: Harvard Univ., Gray Herb. Mem., no. 2, 103 p.

Ficke, J. F., 1965, Seasonal erasure of thermal stratification in Pretty Lake, Indiana: U.S. Geol. Survey Prof. Paper 525–C, p. 199–202.

——— 1966, Comparing methods of computing lake evaporation from Pretty Lake, Indiana, *in* A symposium of Garda: Internat. Assoc. Sci. Hydrol., pub. 70, v. 1, p. 223–232.

Frey, D. G., 1959, The Two Creeks interval in Indiana pollen diagrams: Inv. Indiana Lakes and Streams, v. 5, p. 131–139.

——— 1960, The ecological significance of cladoceran remains in lake sediments: Ecology, v. 41, no. 4 p. 684–699.

Fries, Magnus, Wright, H. E., Jr., and Rubin, Meyer, 1961, A late Wisconsin buried peat at North Branch, Minnesota: Am. Jour. Sci., v. 259, p. 679–693.

Gleason, H. A., and Cronquist, Arthur, 1963, Manual of vascular plants of northeastern United States and adjacent Canada: Princeton, D. Van Nostrand Co., Inc., 810 p.

——— 1964, The natural geography of plants: New York, Columbia Univ. Press, 420 p.

Hough, J. L., 1958, Geology of the Great Lakes: Urbana, Univ. Illinois Press, 313 p.

Hyde, H. A., and Adams, K. F., 1958, An atlas of airborne pollen grains: New York, St. Martin's Press, 112 p.

Janssen, C. R., 1966, Recent pollen spectra from the deciciduous and coniferous-deciduous forest of northeastern Minnesota: A study in pollen dispersal: Ecology, v. 47, p. 804–825.

——— 1967, A comparison between the recent regional pollen rain and the sub-recent vegetation in four major vegetation types in Minnesota (USA): Rev. Paleobotany and Palynology, v. 2, p. 331–342.

King J. E. ,and Kapp, R. O., 1963, Modern pollen rain studies in eastern Ontario: Canadian Jour. Botany, v. 41, p. 243–252.

Lindsey, A. L., and Schmelz, D. V., 1965, Comparison of Donaldson's Woods in 1964 with its 1954 forest map of 20 acres: Indiana Acad. Sci. Proc., v. 74, p. 169–177.

Lindsey, A. L., Crankshaw, W. B., and Quadir, S. A., 1965, Soil relations and distribution map of the vegetation of presettlement Indiana: Bot. Gaz., v. 126, p. 155–163.

Lipscomb, R. G., 1966a, Botanical and chemical characteristics during the fall overturn of a small eutrophic lake, Pretty Lake, Indiana: U.S. Geol. Survey Prof. Paper 550–B, p. 204–208.

——— 1966b, The winter phytoplankton and physical and chemical characteristics of Pretty Lake, Indiana: U.S. Geol. Survey Prof. Paper 550–D, p. 242–249.

Maher, L. J., Jr., 1970, Two Creeks forest, Valders glaciation, and pollen grains: Wisconsin Geol. Nat. Hist. Survey Circ. 15, p. D–1—D–8.

Malott, C. A., 1922, Physiography of Indiana, *in* Logan, W. N. and others, Handbook of Indiana geology: Indiana Dept. Conserv. Pub. no. 21, pt. 2, p. 59–256.

McAndrews, J. H., 1966, Postglacial history of prairie, savanna, and forest in northwestern Minnesota: Torrey Bot. Club Mem., v. 22, no. 2, 71 p.

Mueller, W. P., 1964, The distribution of cladoceran remains in surficial sediments from three northern Indiana lakes: Inv. Indiana Lakes and Streams, v. 7, p. 1–63.

Munsell Color Co. Inc. 1954, Munsell Soil Color Charts: Baltimore, Munsell Color Co., Inc.

Murray, R. C., 1956, Recent sediments of three Wisconsin lakes: Geol. Soc. America Bull., v. 67, p. 883–910.

Ogden, J. G., III, 1965, Pleistocene pollen records from eastern North America: Bot. Rev., v. 31, p. 481–504.

——— 1966, Forest history of Ohio; [Part] I, Radiocarbon dates and pollen stratigraphy of Silver Lake, Logan Couty, Ohio: Ohio Jour. Sci., v. 66, p. 387–400.

——— 1967, Radiocarbon and pollen evidence for a sudden change in climate in the Great Lakes region approximately 10,000 years ago, *in* Cushing, E. J., and Wright, H. E., Jr., Quaternary paleoecology: New Haven, Yale Univ. Press, p. 117–127.

——— 1969, Correlation of contemporary and late Pleistocene pollen records in the reconstruction of postglacial environments in northeastern North America: Mitt. Internat. Verein. Limnology, v. 17, p. 64–77.

Ogden, J. G., III, and Hay, R. J., 1967, Ohio Wesleyan University natural radiocarbon measurements [Part] III: Radiocarbon, v. 9, p. 316–332.

Pickering, R. J., 1966, River-bottom sediment sampling with a Swedish foil sampler: U.S. Geol. Survey Water-Supply Paper 1822, p. 94–98.

Purdue University, no date, A map of Indiana soils.

Schaal, L. A., 1966, Climate, *in* Lindsey, A. A., Natural features of Indiana: Indiana Acad. Sci., p. 156–170.

Schneider, A. F. 1966, Physiography, *in* Lindsey, A. A., Natural features of Indiana: Indiana Acad. Sci., p. 40–56.

Schweger, C. E., 1969, Pollen analysis of Iola Bog and paleoecology of the Two Creeks forest bed, Wisconsin: Ecology, v. 50, p. 859–868.

Scott, Will, and Miner, D. H., 1936, Sedimentation in Winona Lake and Tippecanoe Lake, Kosciusko County, Indiana, July 31, 1930, to July 30, 1935: Indiana Acad. Sci. Proc., v. 45, p. 275–286.

Stuiver, Minze, 1968, Oxygen-18 content of atmospheric precipitation during the last 11,000 years in the Great Lakes region: Science, v. 162, p. 994–997.

Terasmae, Jaan, and Mott, R. J., 1965, Modern pollen deposition in the Nichicun Lake area, Quebec: Canadian Jour. Botany, v. 43, p. 393–404.

Tutin, Winifred, 1969, The usefulness of pollen analysis in interpretation of stratigraphic horizons, both late-glacial and post-glacial Mitt. Internat. Verein. Limnology, v. 17, p. 154–164.

Ulrich, H. P. 1966, Soils, *in* Lindsey, A. A., Natural features of Indiana: Indiana Acad. Sci., p. 156–170.

Wayne, W. J., 1956, Thickness of drift and bedrock physiography of Indiana north of the Wisconsin glacial boundary: Indiana Geol. Survey Rept. Prog. 7, 70 p.

Wayne, W. J., 1966, Ice and land, *in* Lindsey, A. A., Natural features of Indiana: Indiana Acad. Sci., p. 21–39.

Wetzel, R. G., 1970, Recent and postglacial production rates of a marl lake: Limnology and Oceanography, v. 15, p. 491–503.

Whithead, D. R., 1964, Fossil pine pollen and full-glacial vegetation in southeastern North Carolina: Ecology, v. 45, no. 4, p. 767–777.

Wieckowski, Kazimierz, 1969, Investigations of bottom deposits in lakes of N-E Poland: Mitt. Internat. Verein. Limnology, v. 17, p. 332–342.

Wilson, I. T., 1936 A study of sedimentation of Winona Lake: Indiana Acad. Sci. Proc., v. 45, p. 295–304.

——— 1938, The accumulated sediment in Tippecanoe Lake and a comparison with Winona Lake: Indiana Acad. Sci. Proc., v. 47, p. 234–253.

Wodehouse, R. P., 1935, Pollen Grains: New York, McGraw-Hill Book Co., Inc., 574 p.

Wright, H. E., Jr., 1964, Aspects of the early postglacial forest succession in the Great Lakes region: Ecology, v. 45, p. 439–448.

——— 1968, The roles of pine and spruce in the forest history of Minnesota and adjacent areas: Ecology, v. 49, p. 937–955.

Wright, H. E., Jr., Winter, T. C., and Patten, H. L., 1963, Two pollen diagrams from southeastern Minnesota: Problems in the regional late-glacial and postglacial vegetational history: Geol. Soc. America Bull., v. 74, p. 1371–1396.

* U.S. GOVERNMENT PRINTING OFFICE: 1974—543–583/ 55