POSTGLACIAL FOREST SUCCESSION IN THE LANSING AREA OF MICHIGAN: A STUDY OF POLLEN SPECTRA

Thesis for the Degree of M. S.

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George Wyman Parmelee

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POSTGLACIAL FOREST SUCCESSION IN THE LANSING AREA OF MICHIGAN: A STUDY OF POLLEN SPECTRA

By

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POSTGLACIAL FOREST SUCCESSION IN THE LANSING AREA OF MICHIGAN: A STUDY OF POLLEN SPECTRA

INTRODUCTION

Students of plant distribution in regions of Pleistocene glaciation have long recognized the influence of glacial and postglacial history on present vegetational patterns and have sought by every available device to evaluate its effect. The young science of pollen analysis, while a most useful adjunct to many other lines of inquiry, has proved particularly valuable in this quest. Through its application, conclusions regarding postglacial forest history may be based upon quantitative data contemporary with the period in question, rather than largely on previously unavoidable inference from relict communities and present forest distribution. Although, as Potzger (1946) points out, pollen data have served to correct many preexisting misconceptions based on these phenomena, it is not to be assumed that pollen analysis provides a master key to the past, for it is by no means a precision tool nor is it universally applicable. Nevertheless, where conducted in a region favorable for large scale correlations, pollen profile studies provide dependable factual evidence concerning the magnitude and composition of postglacial forest formations as well as information with regard to the routes and rates of migration of the component genera.

That portion of northeastern and north-central United

States mantled with glacial drift of the Wisconsin period comprises such a favorable region. The range of latitude and longitude encompassed provides ample opportunity for broad regional correlation, as well as the tracing of migration routes, while the abundant occurrence of pollen-receptive bogs and lakes permit ready use of the group-study method to establish local profile sequences. It is from the integration and correlation of such firmly established local sequences that an evaluation of the determinative roles of climate, physiography, soil and time in molding the postglacial patterns of forest vegetation will ultimately emerge.

The aims of the present study are twofold: first, to provide a valid profile sequence for the Lansing Area, and second, to interpret therefrom the history of the postglacial vegetation of the area. The study has consisted primarily of pollen analysis of three profiles from as many bogs located in Clinton and Ingham Counties within six miles of Lansing. In addition, an attempt has been made to survey such environmental factors, other than climate, as might conceivably be reflected in the pollen spectra. While it would appear presumptuous to assume that an interpretation based on so few analyses could represent more than a working hypothesis, attainment of the first objective is claimed with some confidence. The profiles are seen to be consistent among themselves to the point that stratigraphic correlations on the basis of pollen spectra are clearly indicated. This congruity is believed sufficient to establish the validity of the area-sequence and, further, to justify the belief that, with the aid of the supplemental information provided, it may be harmonized with sequences elsewhere.

R E V I E W O F L I T E R A T U R E

According to Sears (1935), European students of postglacial history, integrating the contributions of archeology, pollen analysis and glaciology, have come to accept the climatic schedule of Von Post, who has divided postglacial time into phases of increasing, maximum, and decreasing warmth. The Blytt-Sernander hypothesis, previously widely accepted, postulates five periods in which moisture, as well as temperature, fluctuated: 1, Pre-boreal (cool-humid); 2, Boreal (warm-dry, continental); 3, Atlantic (warm-humid, climatic optimum); 4, Subboreal (drier, continental); 5, Sub-Atlantic (return to higher humidity). According to Cain (1944a), the suggestive terminology of this latter hypothesis led to rejection of the concept by Von Post.

The stimulating collaboration of investigators employing different approaches to postglacial chronology, so manifest in the Old World, is largely lacking in the New. This failure is largely due to natural causes. As pointed out by Deevey (1943), the arid West is most fruitful from the archeological standpoint, while pollen analytical methods are best adapted to the humid, glaciated regions of the East and Northwest. In the latter regions the contribution of geology toward a postglacial chronology has been limited by the paucity of varved deposits as compared with those of northern Europe (Antevs, 1936; Griggs, 1942). In consequence, chronologies based on North American pollen sequences generally lack confirmation from other sources. Nevertheless, the regional parallelism displayed by these sequences, together with their indications of widespread climatic reversion in the final period (Sears, 1938; Smith, 1940), faithfully bear out well-confirmed European trends, and so supply valid grounds for acceptance.

The deepest spectra from profiles in the north-central United States and southeastern Canada normally show an overwhelming percentage of Picea pollen. In the succeeding levels, important regional differences appear which will be briefly summarized.

Profiles from central Indiana (Houdek, 1933; Prettyman, 1937; Barnett, 1937; Smith, 1937; Otto, 1938; Howell, 1938; Richards, 1938; Swickard, 1941; Keller, 1943) and northern Illinois (Voss, 1934, 1937) indicate a long period of Picea dominance succeeded usually by a brief and weak Pinus maximum. With decline of the conifers, deciduous dominance is marked and persists to the present.

In Ohio (Sears, 1932, 1942), northern Indiana (Hamp, 1940; Moss, 1940; Swickard, 1941; Potzger and Wilson, 1941; Keller, 1943), central Wisconsin (Voss, 1934, Hansen, 1937) and southern Michigan (Potzger and Wilson, 1941; Sears, 1942; Potzger, 1946) the sequence is similar except that the Picea phase comprises fewer foot-levels, and the Pinus maximum is stronger and more prolonged. In many profiles a slight increase in Picea and Pinus pollen is evident in the upper levels.

Studies in Minnesota (Voss, 1934; Artist, 1939), northern Wisconsin (Wilson and Galloway, 1937; Wilson, 1938; Potzger and Richards, 1942; Potzger, 1942, 1943a), northern Michigan (Potzger, 1942; Wilson and Potzger, 1943b) and southeastern Canada (Auer, 1930; Bowman, 1931) show that Pinus, after succeeding Picea, remains abundant throughout. Pollen representation of deciduous species increases in the middle third of some profiles, and in areas of loamy soils (Potzger, 1942) continues to increase to the surface. In the upper layers of most bogs, Picea pollen increases concomitant with decreasing representation of deciduous types.

Pollen profiles from northeastern seaboard states fail to show the distinct initial dominance of Picea characteristic of the foregoing regions. Eight profiles from the unglaciated Pine Barrens in southern and central New Jersey (Potzger, 1945) indicate a heterogeneous forest of coniferous and deciduous genera characterized by scarcely perceptible succession during the period of peat accumulation. Pollens of Carya, Castanea and Tsuga occur in the deepest foot-levels.

In northern New Jersey (Potzger and Otto, 1943) and Connecticut (Deevey, 1939, 1943) the pollen record beings with a high representation of Picea, Pinus and Abies followed by successive maxima of Pinus, Quercus and/or Tsuga and Carya. Castanea pollen appears late in the record, and, with Tsuga, rises in the upper levels as Carya declines.

In four profiles from New Hampshire (Krauss and Kent, 1944) Pinus representation is maximal, and Tsuga pollen is present, at or near the beginning of sedimentation. Pollen of Quercus, at no point abundant, reaches highest representation in the middle foot-levels, while Tsuga attains a definite maximum in the upper levels.

Complementary to the efforts of field workers in amassing the local and regional sequences, briefly summarized above, have been the integration and correlation of profile data achieved by Sears (1932, 1935a, 1935b, 1938, 1941a, 1942a, 1942b), Smith (1940) and, on a more regional scope, by Fuller (1935, 1939), Voss (1934), and Potzger (1946).

In recent years, particularly, American workers have shown increasing ingenuity in widening the frontiers of pollen analytical research. Individual profiles have been employed to date approximately geological disturbances (Hansen, 1942a, 1942b; Potzger, 1943b), relics of prehistoric man (Deevey, 1943) and mammal bones (Potzger, 1941), as well as to demonstrate wider former ranges for certain forest genera or species (Wilson and Webster, 1942; Potzger and Thorp, 1943; Cain, 1944a) and a migration route of plants (Sears, 1941b).

Group studies, in the form of transects, have been used to detect influences of altitude (Deevey, 1943), longitude (Potzger and Keller, 1944) and latitude (Potzger, 1946). They have been further employed in unglaciated regions (Hansen, 1939; Potzger, 1945) for the purpose of comparing forest sequences therein with those on adjacent drift-mantled areas.

Local sequences have been correlated by Sears (1941a, 1942b) to determine the postglacial migration routes of prominent forest genera and, on a much reduced scale, by Potzger and Friesner (1939) as an aid in tracing plant migration in Indiana.

Several workers, cognizant of the great benefits to be obtained by refinements in pollen analytical technique, have been active in attempting to eliminate various of the sources of error or difficulty in technique and interpretation. For example, size-frequency studies (Cain, 1940, 1943, 1944b, 1944c; Deevey, 1939) on certain coniferous pollens from species native to the eastern United States have been made in an effort to evaluate the possibility of specific determinations. Geisler (1945), on the basis of a similar study of 32 species of grasses, has pointed out the overlap in size of pollens from upland and marsh species.

In the Pacific Northwest, Hansen (1940a, 1941a, 1941b) has discussed the characters used in distinguishing pollens of coniferous species whereby he has been able to reconstruct very detailed forest sequences for that region (1943, 1944).

Boring equipment designed to penetrate sandy sediments, and to eliminate the bottom-truncation so prevalent in profiles obtained by movable-cylinder borers, has resulted in significant additions to the pollen record (Potzger and Wilson, 1941; Wilson and Potzger, 1943a).

Carroll (1943), employing bryophytic polsters retentive of pollen, has devised a technique which permits direct comparison of pollen representation with existing forest composition. The usefulness of this particular study is limited by a mountain locale exhibiting altitudinal distribution of forests. However, the technique offers promise as a means of measuring over- and under-representation, as well as portability, when employed under suitable conditions.

THE LANSING AREA

An intimate relationship exists between pollen bearing sediments in a given basin and its geologic history. Scarcely less significant, in view of the mobility of wind-borne pollen, are the gross aspects of surrounding physiography, soils, and vegetation. Sears' (1941a) statement that supplementary study of the basin can wait, obviously refers to complex problems awaiting solution by specialists in other fields, and in no way repudiates a general study of the surrounding area as an aid to profile interpretation.

A positive example of the value of such supplemental information is provided by comparison of pollen profiles from the Trout Lake Area of Wisconsin and the Gillen Nature Reserve, on the Wisconsin-Michigan border (Potzger and Richards, 1942; Potzger, 1942). In the former area, characterized by sandy soils and pine forests, the profiles indicate undiminished persistence of pine, while in the Reserve, a region of loamy soils and hemlock-deciduous forests, the profiles register a distinct decline of pine in the upper one-half to one-third. Neglect to record edaphic conditions in these studies could obviously have lead to highly contradictory climatic interpretations.

It is held necessary, therefore, to include in this study such available supplemental information as might aid in interpreting profile data, which might appear otherwise to be anomalous.

PHYSIOGRAPHY AND SOILS

The Lansing Area is a component of the Southern Upland Division of Michigan, a broad glaciated plain rising from 200 to 600 feet above the bordering Great Lakes and from 200 to 400 feet above the lowland plain to the north, which traverses the state from Saginaw Bay to Lake Michigan. The drift covering is everywhere sufficiently thick to mask direct influence of the bedrock on topography, except in the vicinity of Grand Ledge, where the Grand River has cut through a ledge of outcropping Eaton Sandstone of the Grand River group (Martin, 1936). Confining the river to a narrow channel for nearly a mile, the precipitous slopes are about 50 feet high and are incised by a few short and narrow ravines, of which the mouth of Sand Creek is the largest.

GLACIOLOGY

So direct is the relation of the Cary substage of Wisconsin glaciation to the physiography of the area, and particularly to the origin of its numerous bogs and bog lakes, that it is necessary to treat this phase of the topographic development in some detail.

The physiography and glaciology of Michigan have been described by Leverett and Taylor (1915). Lansing lies near the center of the exposure of Cary drift (Late Wisconsin of Leverett) resulting from depositional activity of the Saginaw Lobe of Huron ice.

Retreat of the Cary Ice

The manner of retreat of this ice mass may be inferred, in part, from the type, magnitude and position of the drift features left in its wake. Thus, two distinct modes of retreat are implicit in the sharply contrasting drift features to the north and south of the Lansing Moraine, a low, narrow upland passing in an east-west direction through the southern environs of Lansing. To the south, the numerous eskers traversing the till plains of the Kalamazoo and Charlotte till plains, as indicated on the map of Leverett and Taylor (1924), are features thought to mark the courses of subglacial streams (Davis, 1892) or ice-walled canyons (Goldthwait, 1939) associated with extensive fields of stagnant, downwasting ice. Such a form of decay is believed by Thwaites (1946) to result in discontinuous ice remnants characterized by differential rates of melting, the latter in response to varying thickness of debris on the surface. An idea of the magnitude of this inferred ablation zone is provided by the Mason esker which, from its point of origin within Mount Hope Cemetery, near Lansing, pursues a serpentine southeasterly course for over 20 miles.

The total absence of eskers north of the Lansing moraine heightens the contrast between the area previously noted and the morainal belts to the north. In this direction the Lansing moraine comprises the southernmost of seven closely-spaced, narrow moraines arranged in concentric fashion about a center at the head of the Saginaw Lake Plain. Their spacing and width, together with relief in most places of less than 30 feet, and a universal failure to be associated with well-developed outwash plains, forcefully suggest deposition by a rapidly retreating active ice front.

Additional conditions contemporary with retreat of the Cary Ice Front from this area, and having a bearing on the ecesis of vegetation and preservation of pollen will be further discussed following presentation of the profile sequences.

Secondary Topographic Features

The mode of retreat appears to have influenced neither the type nor abundance of secondary topographic features other than eskers. Comprising landforms common to moraine and till plain, they consist of rounded, low hills with a complexity of short slopes; shallow potholes or swales alternating with gentle swells of upland; and widely distributed depressional features of diverse size and shape. The latter occur chiefly as (1) elongated basins with a north-south trend, probably resulting from glacio-fluvial activity; (2) irregular, sprawling, relatively shallow depressions of greatly varying size; and (3), of deep, strongly concave basins derived from slumping of overlying drift following melting of buried ice blocks. In the Lansing Area, the first type of basin is confined to till plain, and in Ingham County reaches best expression in Alaiedon and White Oak Townships. The irregular, shallow basins are far more numerous and more widely distributed, but reach best development on till plain also. The deeper basins, commonly termed kettles, and characteristic of morainal topography, are of rather common occurrence near Lansing on till plain as well.

Chandler Marsh, confined chiefly to DeWitt and Bath Townships, Clinton County, comprises an additional type of basin. Located between the Ionia and Grand Ledge Moraines on the till plain of the latter, it was, in Cary time, an ice-front lake receiving water from ice standing on the

Ionia Moraine. Retreat of the ice to the Portland Moraine and consequent cutting off of water supply ended its brief tenure as an ice-front lake, although a considerable volume of water remained as indicated now by marl and peat deposits to a depth of 15 feet in the center of the basin.

Drainage. In an area characterized by such complexity and disarray of land form, isolation of a considerable proportion of the basins from any drainage system was inevitable. Only streams possessed of the erosive power inherent in torrents of glacial meltwaters were able to negotiate the irregularities of the drift surface, and for the most part, the principal drainage patterns then instituted persist to the present day.

POSTGLACIAL MODIFICATIONS

Topographic changes, effected by erosion and sedimentation through the centuries of postglacial time, are considered here in the light of their capacity for inducing forest succession in this area. Of added concern are the principles and processes involved in the development of bogs and bog lakes from youth to maturity and senescence.

Geological Erosion and Stream Dissection

The present upland landforms of the area reflect in major part constructional activity of glacial origin, pointing to the relative resistance of such topography to geological erosion and stream dissection. Concerning the effectiveness of these forces on Late Wisconsin (Cary) drift, Leverett (1909) remarks that "the small hummocks and basins still preserve their sharpness of contour," and adds the estimate that "scarcely one-tenth of the surface has been reduced below the original level as a result of drainage." This follows quite logically from the vast number of water-collecting depressions or basins completely devoid of surface drainage, and hence greatly diminishing the volume of water available for stream dissection. As previously stated, the stream patterns reflect glacio-fluvial activity, and it does not seem invalid to assume that considerable of the down-cutting achieved by these streams may have occurred during that time. Incontrovertible evidence of such meltwater erosion is provided by the vast discrepancy between valley and present stream magnitudes of Hayworth and Stony Creeks in the northern half of Clinton County. These valleys are not comparable to those in the vicinity of Lansing, however, since during the Late Maumee stage of Great Lakes history they carried the entire discharge of that great glacial lake (Leverett and Taylor, 1915). Nevertheless, the narrow modern channels, flanked through much of their course by extensive muck deposits, reaffirm weak erosion and at the same time suggest more active sedimentation during postglacial time.

Sedimentation and Bog Development

The evidence of Hayworth and Stony Creeks as regards relative efficiency of erosion and sedimentation is everywhere substantiated in the Lansing Area. That this relationship has long obtained, follows from the large number of seepage lakes in the late stages of development from maturity to senescence and extinction. Sedimentation in the majority, if not all such basins, has been achieved by the bog mechanism. This, as defined by Gates (1942), is "preeminently a type of vegetation which controls a habitat and changes the habitat, in the course of its development, from an open area of water to a mat and then to a grounded mat and finally to dry land." That annihilation of open water may long antedate completion of the bog phase as thus defined is demonstrated by the partly cultivated County Line bog in Ohio, described by Rigg (1940) as having a mat four to six feet thick underlain by about 40 feet of water. This same condition, to a lesser extreme, repeatedly frustrated attempts by the writer to obtain complete core series from the bogs of the Lansing Area.

Determinants of Sedimentation Type. Studies on the developmental details of lakes can be considered valid only in the specific region of their occurrence. Developmental generalities, on the other hand, have a disproportionately wide significance. This follows, no doubt, from the monotonous uniformity of the water environment, a condition evidently carried over even to bogs, as indicated by the studies of Rigg (1940), who found more than half the common bog plants of eastern and western North America to be identical species.

Whether a given water area will evolve in the direction of a bog or a marsh appears to be determined by three interrelated factor complexes, viz., topographic, chemical, and vegetative. Wilson (1935), in a careful study of lake development in Wisconsin, attaches causal significance to the drainage isolation of bog lakes. Gates (1942), while concurring, stresses the contribution of shelter to bog initiation, stating that bogs may develop at quiet places in stream channels, or be restricted to protected bays in large basins subject to wave action.

The topographic complex, together with mineral composition of the earth materials of the watershed also influences the course of lake development by chemical means. Thus the institution of bog conditions as the usual aftermath of settling mineral salts and leaching of peripheral soils (with concomitant increase in acidity) is presumably accelerated in an undrained basin with a small, lime-impoverished watershed. However, subsequent development of such a bog is likely to be impaired by a deficiency of the leachate nutrients needed to replace those held unavailable in the accumulating organic debris. So great may be this deficiency in regions of sterile sandy soils that bog conditions may fail to develop entirely despite otherwise highly favorably conditions. Such appears to be true of Crystal Lake, Vilas County, Wisconsin, described by Twenhofel and Broughton (1939) as possessing the softest waters of the state.

Assuming the validity of such suggested edaphic control, one might employ it further in connection with the findings of Gates (1942) in northern Lower Michigan. Here the association of many bogs with drainage systems might be explained by the acid drift over which the streams flow, and from whence they derive insufficient mineral nutrients to support marsh vegetation. Through default, then, the slower growing bog vegetation is able to utilize the small but continuously renewed nutrient supply.

Antithetical conditions conducive to a marsh type of sedimentation are those in which a basin forms part of a drainage system traversing earth materials well supplied with mineral salts. Such a basin ordinarily supports a profusion of calcicolous aquatic and shore forms. However, in cases where marl is precipitated in great quantities, as in some southern Wisconsin lakes studied by Wilson (1935), vegetation may be almost completely absent. According to Welch (1935), such impoverishment is usually the result of various filling processes which periodically isolate the marl from contact with the overlying water, and thus effectively prevent conversion to the soluble bicarbonate during periods of abundant carbon dioxide production. The precipitation is thus permanent, and where it exceeds replacement by inflowing streams or leachate from contiguous uplands, productivity declines and with time reaches a level below the requirements of calcicolous plants.

Such a decline in productivity might conceivably have contributed to the development of certain of the bogs in the Lansing Area, inasmuch as marl deposits from 12 to 17 feet deep were regularly encountered during preliminary borings within the morainal plexus area northeastward from Chandler Marsh. In view of the continuing alkalinity of the drainage waters in the latter area, however, a more tenable hypothesis would attach causal significance to the shoaling effects of such deposits, rather than to the possible competitive advantage provided calcifugal plants. Such a view would then be in harmony with that expressed by Veatch (1933) who believes that once filling has progressed to the point where expanses of very shallow water occur, calcifugal plants may ecize regardless of water reaction or prior occupancy by calcicolous communities. Welch (1934) has attributed such a capacity to the lack of circulation with resultant increase in acidity, within organic accumulations formed by such vegetation. In support, he cites the frequent occurrence, in Sphagnum mats, of water having a strongly acid reaction and separated from distinctly alkaline waters of the open lake by a gradient of only a few inches.

That such a capacity to ecize might lead to bog formation even in a hardwater lake is also suggested by Gates (1942), who, after dismissing water reaction as a critical factor, states that "the type of vegetation which develops along the shore determines the fate of the area." Elaborating, he specifies *Scirpus validus*, *S. americanus*, etc. as forerunners of marshes or woody swamps, and *Carex lasiocarpa*, in sufficient abundance to form an ecological association, as necessary to initiate a bog. The extent to which the occurrence of these types is a function of previous soil and topographic development, or of pure chance, is not discussed.

In the Lansing Area, *Decodon verticillatus* appears frequently to assume the role of *Carex* as bog pioneer. It has been observed to be actively extending the mat framework on three bog lakes, with a similar function in the past suggested by its occurrence as a relict on two additional bogs now closed. Subsequent stages of the local bog priseres are typical of northern United States (Rigg, 1940), there being evolved communities dominated successively by *Chamaedaphne* in association with Sphagnum, high bog shrubs, and bog conifers. The latter community will be discussed later in connection with relict communities.

Conditions Influencing Preservation of Pollen. In bog development the cold, anaerobic, highly acid conditions conducive to mass preservation of organic debris are first encountered in the *Chamaedaphne-Sphagnum* zone. That such drastic antisepsis is not essential for the preservation of pollen, however, is demonstrated by abundant pollen deposition in oligotrophic lakes (Twenhofel and Broughton, 1939; Wilson and Cross, 1943), eutrophic lakes (Potzger and Wilson, 1941; Deevey, 1943), or at levels long antedating institution of bog conditions, as exemplified by Forestry Bog Lake (Potzger and Richards, 1942). Rather, advance of a bog mat imposes a distinct barrier to movement of pollen to the deeper levels, where inhibited bacterial activity and reduced oxidation favor more certain preservation. An apparent manifestation of this effect is provided by the profile samples from Chandler Marsh where the transition at five feet from detritus ooze to coarse sedge-peat is coincident with a sharp decrease in pollen frequency.

Low pollen frequency is occasionally associated with marl, particularly in the upper portion of thick deposits. This has been attributed by Voss (1937) to cumulating populations of calciphilous molluscs which feed on organic matter including, presumably, pollen grains. Whether the paucity of pollen at the 29th foot-level of Mud Lake Bog may have resulted from such scavenging is open to question, since the marl deposit here is only two feet thick.

SOILS

Textural and Drainage Relations

Veatch (1930) has included the Lansing Area in a natural land division designated by him the Clinton Rolling

Plains, and described as level to rolling clay plains with soils chiefly of loams over compact clay. Some indication of the predominance of imperfectly, or well drained, fine textured soils in this division is provided by reference to Table I, comprising data taken from soil surveys for the three counties of which the Lansing Area is a part (Moon, 1933; Veatch, 1941a; Johnsgard, 1942). That this preponderance of heavy soils is only partially expressed, is substantiated by the occurrence of considerable areas of a contiguous land division, the Hillsdale-Lapeer Sandy Highland, in the southern parts of Ingham and Eaton Counties. Despite this inclusion of lighter-textured soils in the data, it will be observed that, with but two exceptions, fine textured soils overwhelmingly dominate all three drainage categories of mineral soils in the three counties.

TABLE I. Percentage representation and drainage relations of principal soil types of Eaton, Ingham, and Clinton Counties. Finer textured series are on left in each drainage category.

	MINERAL SOILS									ORGANIC SOILS	
	Well Drained				Imperfectly Drained			Poorly Drained			
SOIL SERIES	Miami	Hillsdale	Bellefontaine	Fox	Conover	Brady	Bronson	Brookston	Gilford	Carlisle	Rifle
Eaton	31.2	10.8	3.0	2.6	20.5	4.6	3.7	2.7	3.9	6.3	2.3
Ingham	12.6	16.6	4.3	5.0	21.4	7.0	--	7.0	--	9.7	4.1
Clinton	27.5	3.1	2.5	3.5	23.5	3.8	2.4	11.7	1.1	3.2	3.9

Postglacial Soil Development

The youthful stage of the geologic erosion cycle in this area suggests soil development under relatively constant surface drainage conditions. That changes have occurred, nevertheless, is indicated by Veatch (1938) who cites as evidence the common occurrence of dry valleys and basins in many parts of the state. The former commonly display faint dendritic patterns attesting to postglacial origin, while the basin floors were submerged or waterlogged sufficiently long to develop mineral soil profiles characteristic of inundation. The many centuries necessary to develop a soil profile leads Veatch to correlate the disappearance of these water bodies with the well documented (Raup, 1937; Sears, 1938; Transeau, 1935, 1941) xérothermic period of relatively late postglacial time. Regarding the degree of weathering evidenced by Late Wisconsin (Cary) drift, Leverett (1909) stresses the remarkably slight depth of leaching, estimating that the average distance to unleached till is somewhat less than a meter. The foregoing evidence would indicate that soil development, other than that dependent upon climatic change or plant reaction, may be largely discounted as a factor of forest succession.

Organic deposits supply direct evidence of postglacial soil development. Besides materially contributing to the space available for ecesis (see Table I), they provide sanctuary for characteristic communities of boreal relicts, cognizance of which must be taken in interpretation of pollen spectra.

FOREST VEGETATION

To the pollen analyst, present forest cover is of interest primarily as a means of checking the fidelity with which pollen spectra record the presence and relative abundance of its components. It is, however, a check subject to limited application and difficulties of execution. Obviously, despite the evident stability of late postglacial edaphic and topographic conditions, the present generic composition of the surrounding forest is only of value for comparison with the top-most spectra of the profile. Moreover, its dependability, insofar as an indicator of pollen over- or under-representation is concerned, is further limited by the reliability of quantitative distributional data of forest species for comparison with pollen spectra percentages.

As a result of these shortcomings, the existing forest vegetation is often summarily dismissed by pollen workers. Certain phases of the present profiles, however, appear sufficiently eccentric to warrant marshalling of all available forest-cover data as an aid to interpretation.

Climatically Favored Communities

Climax forest communities display local groupings of dominants in response to edaphic variations. Veatch (1932) has pointed out that this distributional equivalency may be practicably exploited in units as small as the soil type. Later (1941a), in summarizing the probable virgin forest groupings for the larger soil bodies of Ingham County, he attained as close a degree of such correlation as appears possible from the fragmentary records and remnants of original cover available for study. It is evident from this tabulation, in which frequency is expressed in a general way by order of listing, that relative abundance of a species, rather than its presence or absence, must serve as a criterion for forest type differentiation. Thus, while elm is listed as a component on every soil series, it is only in the imperfectly and poorly drained categories that it attains controlling influence. There appears no ground for supposing that groupings so devised, while referring specifically to Ingham County soils, should not prove equally valid for similar soil types in Clinton and Eaton Counties. Accordingly, the groupings typical of the soils included in Table I, and therefore considered co-extensive with them, are here presented with the view of expressing their approximate areal extent as a percentage of the original total cover of the three counties:

Sugar maple-beech, with white oak, elm, white ash (Miami)	24%
Oak-hickory, with sugar maple, beech, elm (Hillsdale, Bellefontaine, Fox)	17%
Elm-ash-basswood, with oak, hickory, beech, sugar maple, walnut, butternut (Conover)	22%
Elm-silver maple-ash, with shagbark hickory, swamp white oak, basswood (Brady, Brookston, Carlisle muck)	19%

Tamarack-aspen, with red maple, elm, occasional black spruce, paper birch (Rifle peat)---------------------------------- 3%

Relict Communities

Postglacial advance and consolidation of deciduous forests in Clinton, Ingham, and Eaton Counties has reduced the pre-existing boreal formations to less than 4% of the total area. However, to the student of postglacial vegetation, these communities merit considerably more attention than their areal extent would indicate. Their normal bog habitat assures incidence on a receptive surface of a high proportion of the pollen produced. Moreover, the extensive and rapid expansion of mat surface coincident with the closing phases of bog development might well be reflected in contemporary pollen spectra through an increase in the area available for ecesis of boreal plants.

Bog Relicts. In the few bogs of the Lansing Area not profoundly altered by drainage and repeated fires, the seral stages for the most part parallel those described by Gates (1942) for northern Lower Michigan. Of the forest stages, the chief divergence from those of the more northern bogs lies in the restricted distribution of *Thuja* and *Picea mariana*. No *Larix*-*P. mariana*-*Thuja* sequences, and but two instances of *Larix*-*Thuja* succession are known to the writer. Although *Larix*-*P. mariana* sequences are frequent, only two cases have been observed where the latter species achieves more than the most meager representation.

Larix is common and widespread throughout the area, an occurrence perhaps correlated with its normal habitat on floating mats or otherwise waterlogged substrates beyond the zone of bog fires. *Picea mariana* is also typically found on such sites, though usually occurring out of successional order, as much stunted individuals within the high bog-shrub zone. Far better developed, however, is the nearly pure stand at Mud Lake Bog in Delta Township, Ingham County, where 20-30-foot trees occupy a quaking mat six feet thick and separated from detritus ooze by about nine feet of water. The other well developed stand of *P. mariana*, while not confined to a floating mat, occurs on an undrained area north of Park Lake in Bath Township, Clinton County. Such a present distribution pattern suggests the possibility of a much more common occurrence of this species prior to widespread bog drainage and the repeated fires that followed on dried-out, stranded mats. By their much poor growth on such mats, in comparison with peripheral stands, the aspen invaders provide further substantiation of an abbreviated bog forest tenure.

The *Thuja* stands, while located in basins whose water relations have been altered by drainage, show no indication of fire. This is most obvious at the Cedar Lake station where *Thuja* grades into a stand of mature *Betula lutea*, developed by sucker growth from large stumps showing no scars of fire. While the priseral succession was interrupted by removal of the primeval birch stand, its rapid regeneration apparently achieved stabilization quickly, as evidenced by restoration of nearly pure dominance. The shoreward Larix-Thuja-B. lutea sequence may therefore be considered normal, with only the succession from bog forest to lowland forest subject to influence by man. The preponderance of Ulmus americana, Fraxinus nigra, and Acer rubrum in the fragments of lowland forest remaining at the bog periphery probably reflects the original composition, however, and suggests ultimate preemption of the bog site by these species. Such succession is likely to be long delayed since it is "beyond the bog" and hence contingent in large degree upon the elimination of edaphic factors favoring bog forests. The effect of these compensatory factors at Cedar Lake is well expressed by the vigorous young colony of Thuja which in recent years has invaded a small peaty depression about one-quarter mile to the east.

The second Thuja stand located on the broad marshy flats north of Potter's Lake in Bath Township, Clinton County, is in an advanced state of decadence owing to heavy windthrow and perennial trampling by grazing animals.

Upland Relicts. On only two upland sites have compensating habitat factors been sufficiently operative to prevent the dominance of climatically favored genera of trees. The influence of physiography is evident at Grand Ledge in Oneida Township, Eaton County, where Tsuga persists on precipitious north and northeast facing ledges centering about the deeply incised mouth of Sand Creek.

Less obvious are the factors responsible for persistence of the second relict, a Pinus Strobus stand east of Pine Lake in Meridian Township, Ingham County. Its occurrence in a locality characterized by dry "islands" of Coloma loamy sand interspersed with Rifle peat, however, suggests the influence of both isolation and edaphic compensation. Thus, of the deciduous genera, only the more xeric species of oak might be expected to compete favorably with pine established on such soil. With falling water tables and removal of pine in recent years, oaks have been invading the site with increasing ease, especially since 1940 when the pines were decimated by lumbering operations.

LOCATION AND DESCRIPTION OF BOGS

In this study the selection of bogs for investigation was conditioned by a desire to obtain profiles sufficiently localized to yield a valid area-profile, while at the same time of adequate depth to avoid the danger of surface truncation. Of the numerous bogs visited during reconnaissance work, the three whose descriptions follow most nearly satisfy these conditions. All have developed in kettle basins more than 20 feet deep and are located less than 12 miles apart on a nearly perfect straight line oriented approximately 30° E of North.

BEAR LAKE BOG

Bear Lake and the major portion of its surrounding bog is located in Section 35, T 4N, R 2W. In area, the irregular basin together with the lake approximates a quarter section. Of this area, the lake occupies somewhat in excess of 12 acres, being located near the western margin at the broadest portion of the bog. The boring, through 23½ feet of sediments to sand, was made on the east side of the lake about 40 feet back from the bog margin. A test boring at the edge of the mat revealed 26 feet of deposition, but eight feet of this immediately below the mat lacked sufficient consistency to operate the borer mechanism.

Surrounding Topography and Soils

Bear Lake is located near the northern margin of the Lansing recessional moraine in a zone transitional from moraine to till plain. The prevailing topography is gently undulating and everywhere marked by small undrained depressions, some well above the water table, others containing small marshes or bogs. The greatest relief, about 20 feet, is provided by a series of rather abrupt slopes which form the western and southern rim of the basin. Hillsdale sandy loam on the north, west and south, and Conover loam to the east, comprise the upland soils of the vicinity.

Recent History

County records indicate that a bog forest existed intact until sometime after 1870, for at that date the County Surveyor, in commenting on his failure to run the line between Sections 34 and 35, described the area as "totally inaccessible swampland." By 1909, however, the area was at least partially cleared as it was then possible to run the line and establish the half-mile corner. This was confirmed by a conversation with Mr. Otto Andrews, for nearly 60 years a resident of the vicinity, who stated that within his memory a tamarack stand covered most of the bog, but that fence post demands at the turn of the century resulted in almost complete clear-cutting of the area.

Destruction of the bog forest led to conditions highly favorable for the advent of fires which, according to Mr. Andrews, have raged periodically for the last 40 years. Especially clear in his memory are the fires of 1907 and 1908, ashes of the former conflagration having covered the lake to considerable depth and killed fish "by the wagon load."

Present Vegetation

The least disturbed plant communities comprise those protected from fire by virtue of their habitat on the floating mat. A marginal zone of *Decodon verticillatus* completely encircles the lake and by its buoyant rootstalks provides framework for the advance of *Chamaedaphne calyculata* and a deep, resilient carpet of Sphagnum. Shoreward, this leatherleaf-sphagnum zone grades into a high bog-shrub community, forming an almost impassable tangle 25-50 feet wide, consisting of successively taller representatives of Gaylussacia baccata, Aronia melanocarpa, Vaccinium corymbosum and Nemopanthus mucronata. Less common are Rhus vernix, Ilex verticillata and Picea mariana, while in the eastern and southwestern segments mature Larix laricina and Acer rubrum occur as remnants of the former bog forest.

Beyond this marginal fringe, leatherleaf, characterized by its quick recovery following fire, occurs in pure stands, or more often, in mixture with scattered, low Vaccinium corymbosum, Aronia melanocarpa, and Nemopanthus mucronata. Although Populus tremuloides readily invades the periphery of the deposit after each fire, intensity of burning in this zone virtually assures its destruction with each succeeding conflagration.

CHANDLER MARSH

Although so designated for want of a better name, the basin confined to the NE ¼ of Sec. 32, T 5N, R 1W, differs markedly in origin and subsequent development from the contiguous Chandler Marsh proper. Only imperfectly isolated from the Chandler Marsh-Park Lake basin by low sandy divides, its status as an independent kettle basin is nevertheless confirmed by abrupt peripheral bottom slopes to depths considerably below those of the former. This is particularly manifest at the site of the boring, on the west side, just south of the drainage ditch, where 24 feet of organic sediments occur within 150 feet of the sandy rim. A further unique feature in this locality is the complete absence of marl deposition, an indication of water so deep, or perhaps so turbid, as to prevent the growth of Chara and other lime-precipitating organisms.

A long period of open water deposition, preceding a recent and rapid advance over shoaling waters, is implicit in the extent and nearly uniform thickness of the floating mat. Occupying fully three-quarters of the basin of about 80 acres, it assumes a definite quaking aspect at an average of 150-200 feet from the periphery, and though everywhere sufficiently tenacious to support a man's weight, it grows progressively more tenuous toward the center.

Surrounding Topography and Soils

This young bog forms part of the eastern margin of a peat-filled, multiple basin, attaining a depth of 15 feet and exceeding four miles in width and seven square miles in area. Park Lake, at the extreme eastern end, represents a deeper portion in which bog development has been strongly retarded by wave action except in the southwest part. Two test borings along the margin in this area revealed a nearly level bottom overlain by about 12 feet of marl and 5 feet of fibrous peat.

From north and west of the lake, an irregular salient of sandy soils, chiefly Oshtemo loamy sand and Berrien loamy sand, trends southwest for more than a mile into the marsh. Elsewhere the upland soils are of heavier texture. Moderate-sized bodies of Brady loam and Conover loam form the southern margin of the bog, with Hillsdale sandy loam of a mostly rolling phase prevailing to the east.

Recent History

The magnitude of change induced by the Remy-Chandler drain is perhaps best portrayed by the soil map for Clinton County where essentially the whole of Chandler Marsh, once famed as a mecca for migratory fowl, is now mapped as a burned phase of Rifle peat. Burning in the kettle basin was of negligible extent, however, owing to the great preponderance of floating mats which remained water-logged by subsidence to the new level. Nevertheless, important drainage effects are indicated by the rapid closure of the mat during recent years, a process accelerated by the six foot drop in water level and the consequent inhibition of wave action. Subsequently, except for such effects incidental to reclamation of the adjacent organic soils, the bog has been little disturbed, its mat and peripheral fringe of bog forest being so immature as to preclude any possible utilization by man.

Present Vegetation

Further confirmation of recent and rapid bog development is provided by the curious interpenetrations, and in places even mixtures, of calcifugal and normally calcicolous species. This is evident on the sedge mat where colonies of *Sarracenia purpurea*, *Betula pumila*, and occasionally Sphagnum, regularly alternate with socies of Typha latifolia and Scirpus validus. In more shoreward sites, particularly on the west and south, Chamaedaphne calyculata and Typha latifolia frequently occur in mixture with about equal expression of dominance.

Betula pumila is everywhere the pioneer of the shrub stage, followed at a considerable interval by Cornus stolonifera, and infrequently, by Vaccinium corymbosum. Where present, Chamaedaphne calyculata shows remarkably little aggressiveness, having been overrun usually by the advancing tamarack bog-forest. Sphagnum shows a similar tendency, even where leatherleaf is best developed, and over much of the area is supplanted by Aulacomnium palustre, and to a lesser extent, Polytrichum strictum. The peripheral belt of Larix laricina, averaging about 150-200 feet in width is not everywhere continuous and at such points Populus tremuloides and Acer rubrum invade the bog a short distance. Elsewhere these species, together with Ulmus americana and Prunus serotina, are established on the mineral soils bordering the bog and are invading the tamarack zone.

MUD LAKE BOG

The basin so named is centered about 120 rods south of Holt Road in the NE$\frac{1}{4}$ of Section 21, T 3N, R 2W. Its surface is completely closed by a mat which at the approximate center is five feet thick and underlain by nine feet of water and peat too fluid to permit sampling. Insufficient borer extensions prevented depth determination at this site, but increasing compactness and marl content of the sediments at 31 feet indicated the bottom was close at hand. The samples for analysis were collected from a 30-foot boring on the grounded mat just south of a fence 80 rods south of, and paralleling Holt Road.

Surrounding Topography and Soils

This basin, together with that of Mud Lake proper one-quarter of a mile to the north, lies in one of the shallow but very extensive swamp depressions ramifying throughout the Charlotte till plain. Originally serving as drainage ways for glacial meltwaters, such depressions became swamps with cessation of that flow and are today filled with deposits sufficiently decomposed to be mapped as Carlisle muck. The uplands of the vicinity are gently undulating and in general characterized by imperfectly to well-drained clayey soils of the Conover and Miami series.

Recent History

Although its marginal fosse has been connected by a shallow ditch with Mud Lake and an outlet to the north, the bog remains today essentially priseral, the evidence of fire following drying out being confined to a narrow peripheral portion at the northeast corner. In this sector *Chamaedaphne calyculata* and *Vaccinium corymbosum* dominate about an acre. To the north, on the senescent bog, between the two kettle basins, frequent peat fissures, fire scarred aspen stubs, and a nearly pure stand of even aged *Aronia* *melanocarpa* covering about 40 acres attest to more extensive and severe fires in the locality. Within the bog forest numerous decapitated black spruces, apparently resulting from cutting to fulfill local Christmas tree demands, comprise the only visible disturbance.

Present Vegetation

Presenting a remarkably faithful boreal aspect, the bog forest of 20-odd acres is largely dominated by *Picea mariana*. Individual trees commonly reach 20 to 30 feet in height, which, according to Otis (1931), is the maximum size for this species in Michigan. Scattered throughout are much taller specimens of *Larix laricina*, which though reproducing to a minor extent, appear relegated to relict status by the more aggressive spruce. This relationship is best exemplified in the burned area to the northeast where black spruce is vigorously invading without competition from tamarack.

Vaccinium corymbosum dominates the shrub layer within the forest, with *Chamaedaphne calyculata* and *Ledum groenlandicum* frequent throughout. Of more restricted distribution are *Vaccinium macrocarpon* and *Andromeda glaucophylla*. Sphagnum is generally distributed and especially well developed, often forming mounds as high as a foot above the deep carpet. *Aulacomnium palustre* and *Polytrichum strictum*, where present, are usually associated with such mounds.

Completely surrounding the bog forest and serving as a line of demarcation between bog and swamp forest on east, south and west, is a zone of Nemopanthus mucronata, varying in width from about 25 to 75 feet; on the north, it is wider and grades into the extensive chokeberry consocies. Co-dominants of the swamp forest encroaching on three sides are chiefly Populus tremuloides, P. grandidentata, Acer rubrum, Ulmus americana and Prunus serotina. Herbaceous members of this community include Lycopodium obscurum, L. lucidulum and Coptis groenlandica.

M E T H O D S

Field

In this study the boring technique outlined by Erdtmann (1931), in which the need for pollen samples from the deepest part of the basin was stressed, was followed so far as bottom slopes and consolidation of the overlying sediments indicated its applicability. Bottom slopes in the vicinity of all three borings were so gradual as largely to preclude sediment drifting. In consequence, slightly shallower borings from inner margins of the grounded mats appeared justified in order to avoid the six to nine-foot hiatus beneath the sub-aerial peat of the floating mats.

Sediment samples were collected at one foot intervals by means of a rotating-cylinder borer of the Hiller type, described and illustrated by Erdtmann (1943). Thirty feet of extension rod, in detachable five-foot sections, were adequate to reach sand, the functional limit of the borer. To guard against contamination of pollen from different layers, the samples were taken from the center of the core and the head of the whole borer was thoroughly washed after each sampling. The samples were immediately placed in glass containers and, on arrival at the laboratory, were sealed with paraffin to maintain their original moisture content until ready for processing.

Laboratory

During the preliminary laboratory work, attention was directed to the more widely known methods of preparing fossil pollen for counting (Sears, 1930; Geisler, 1935; Hansen, 1940b; Erdtmann, 1943). The modified alkali technique, finally selected as most efficient with respect to time and results, approximated that of Artist (1939), with the exception that a 10 percent solution of NaOH, rather than a one percent concentration, was used to free the pollen grains from their colloidal matrix.

Samples of well-decomposed peat dispersed in dilute NaOH were heated to near the boiling point for a minimum of 30 minutes, during which time sufficient safranin had been added to impart a deep color to the solution. While still hot, the latter was centrifuged. After decanting, small amounts of the surface film from the sediments in each tube were transferred to a drop of warm glycerin jelly on each of two 22 square mm. cover slips. These were then inverted on a slide, which was checked for approximate pollen frequency before discarding the sediments. In all cases the frequency was sufficiently high to indicate that no additional slides were needed.

Samples of sub-aerial peat and the contiguous coarser material, after initial heating for 30 minutes, were filtered through a 1 mm. screen prior to centrifuging. The filtering was necessary to render the centrifuged sediments sufficiently coherent to permit decantation. Subsequent procedure paralleled that for well-decomposed peat, except that declining pollen frequency toward the surface necessitated additional slides, of which as many as four per sample were prepared.

Samples composed chiefly of marl were treated with an excess of concentrated hydrochloric acid, which on cessation of carbon dioxide liberation, was washed out by centrifuging. With the calcium carbonate fraction thus removed, subsequent treatment of such samples was identical with that of well-developed peat.

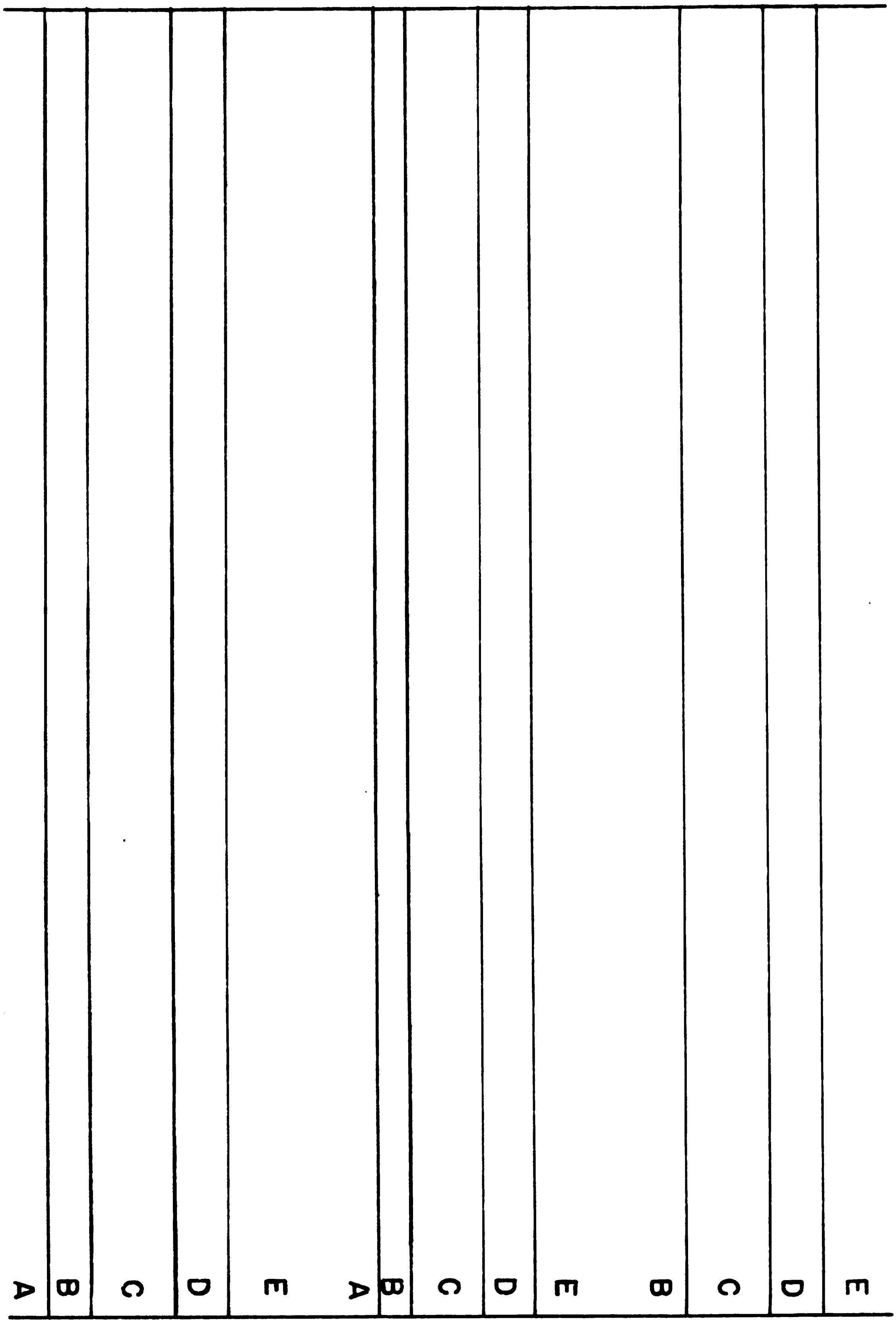
Pollen Identification and Counting

Identification of fossil pollen was facilitated by comparison with a reference set of herbarium pollens which had been treated with NaOH and stained with safranin to simulate the fossil condition. Particularly useful in directing attention to critical diagnostic features of pollen grains were the illustrated key of Sears (1930) and the works of Wodehouse (1935) and Erdtmann (1943). In the key of Sears, the omission of *Picea glauca*, pointed out by Potzger (1944), was remedied by basing the distinction between *Picea* and *Abies* on differences in the insertion, shape and relative size of the bladders. In distinguishing the pollen of Quercus and Fagus the usual size distinction was complemented by noting the presence or absence of distinct equatorial germ pores in the furrows; in Fagus, such pores are plainly evident even in polar view, whereas in Quercus they are absent or only rudimentary.

The slides were examined under a Bausch and Lomb binocular microscope equipped with condenser, mechanical stage and ocular micrometer. Counts and identifications were made at a magnification of 430 diameters, and strips across both cover glasses the width of the field were examined completely. Ordinarily, only a few traverses were necessary to obtain a minimum count of 200 pollens of trees; but in five instances, low pollen frequencies prevented attainment of this objective. Counts at two of these levels were terminated between 150 and 200 grains, but the remaining three, averaging less than 30 grains, fell well below the number required for a satisfactory coefficient of reliability (Barkley, 1934), and hence were excluded from the graphs. Non-tree pollen and spores were also recorded but were not used in the computation of percentages.

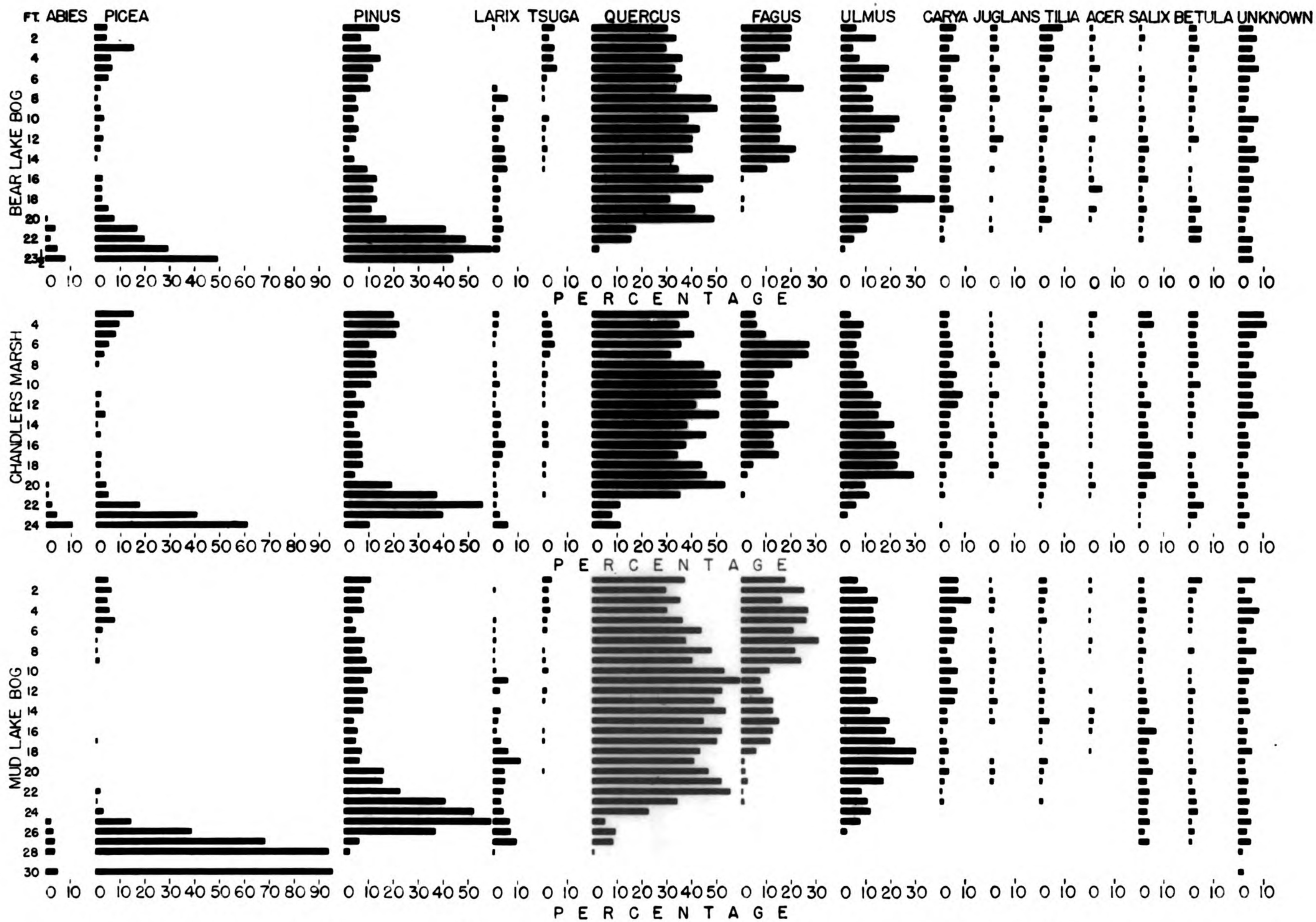
RESULTS

Results of the pollen analyses are presented in the form of bar graphs (Figs. 1 to 3) and Tables III to V. The former express the percentage of total tree pollen for 14 of the 17 arborescent genera represented in the profiles,



CLIMATIC PERIODS

1
2
3



Figs. 1, 2 and 3. Pollen profiles typical of the Lansing Area of Michigan.

while the tables record counts of all pollen grains and spores, as well as the actual percentage representation of all tree pollens.

A cursory inspection of Figures 1 to 3 reveals several gross features common to all three profiles. Abies, never significant quantitatively, but most abundant at the lowest level, declines steadily and is not represented in the profiles at or near the close of the Pinus maximum. Picea, similarly declining from a maximum at the deepest levels, differs in magnitude of representation, in persistence and in its limited re-occurrence in the upper levels. Pinus attains a marked and remarkably uniform maximum concomitant with the decrease of Picea, and then declines to a level suggestive of the origin of pollen from local relict stands or perhaps even from more northern stations. Quercus supersedes Pinus to reach an early maximum prior to establishment in force of other deciduous genera. Following a decline contemporary with the increase of Ulmus and Fagus pollen, Quercus attains a second more impressive maximum, the more significant because of the competition of other deciduous genera by now all well established. Ulmus reaches highest representation in the lower half of the profile between the two levels of Quercus maxima. Thereafter, it shows a steady decline, interrupted only by the brief and small-scale recovery following the second Quercus maximum. The increase of Fagus, last of the common deciduous genera represented in the profiles, is interrupted at an early stage by the second maximum of Quercus, as indicated by its abrupt increase concomitant with the decline of Quercus in the upper levels. Tsuga pollen enters the profile with, or slightly after, Fagus, and like the latter attains greatest representation in the upper one-third of the profiles. The whole level of representation of Tsuga, however, is so low as to render questionable its status as an indicator genus in the Lansing Area.

Generalized Profile Sequence

By more thorough examination, in which special significance is attached to shifts in dominance of indicator genera, as well as to ecologically consistent trends in their percentage representation, it is possible to divide logically the sequences observed into a number of periods. In delimiting these periods, where a definite shift in dominance is lacking, especial emphasis is laid on grouping together spectra wherein a reciprocal relation exists between two genera (or groups of genera) characterized by divergent moisture requirements.

The periods of a generalized sequence of pollen spectra will first be presented, to be followed by consideration of the individual profiles.

A. Picea and Abies decline from a pre-existing maximum.

B. Pinus attains a clearly defined maximum and wanes.

C. Quercus becomes clearly dominant, then declines sharply as Ulmus rises to a conspicuous maximum, terminated by the succeeding rise of Fagus. Quercus pollen becomes more abundant near the end of the period, as Pinus declines further to a minimum.

D. Quercus reaches a marked culmination enduring through 5 foot-levels as the pollen representation of Fagus and Ulmus declines.

E. Fagus and Tsuga rise to maxima as Quercus wanes. Picea and Ulmus rise, the latter again declining in the uppermost levels.

Individual Profile Sequences

The profiles are here examined individually to note their degree of conformity with the generalized profile and to emphasize those trends lacking unanimity and therefore excluded from that sequence.

Bear Lake Bog (Fig. 1.) The absence of a clearly defined A-period in this profile may be attributed to a bottom mixture of sand and sedimentary peat which repeatedly jammed the borer at the 24 foot-level. Not encountered to a similar extent in the other borings, the sand fraction segregated by centrifuging comprised at least 25% of the 23½-foot sample. Although the remainder of the profile corresponds fairly closely to the generalized sequence, relationships in the predominantly deciduous portion are obscured by the anomalous fluctuations of the Quercus, Fagus and Ulmus curves. These phenomena, apparently cyclic, are most evident in the Ulmus curve but on closer examination are seen to involve reciprocal fluctuation between *Ulmus* and *Quercus* in the first three periods, and a similar relationship between *Ulmus* and *Fagus* at the fourth and fifth foot-levels in period E. The curves of *Carya*, *Tsuga* and *Tilia* indicate weak maxima during period E but there are no significant variations in pollen percentages of these genera within other periods.

Chandler Marsh (Fig. 2.) This profile reflects faithfully the generalized sequence up to period E. It is unique in indicating a well-marked *Carya* maximum and a *Tsuga* minimum during period D.

The sudden shift in percentage representation of *Fagus* and *Pinus* in period E is coincident with an abrupt drop in pollen frequency occasioned by the transition, at five feet, from limnic peat to coarse sedge peat. The low magnitude of the pollen frequency in the latter material is indicated by the area of eight to ten cover slips needed to complete the counts for the third to fifth foot-levels. While counting at these levels, numerous grains of *Fagus*, *Ulmus* and, to a lesser extent, *Quercus* were encountered which displayed varying degrees of collapse and erosion of the exine. *Fagus* grains were frequently so distorted and fragmentary as to render identification uncertain unless the characteristic germinal pores were in evidence.

Mud Lake Bog (Fig. 3.) This profile, reflecting the succession of postglacial vegetation with singular clarity, might well serve as the type for delimiting the periods of the generalized sequence. Despite the defect of a marl level too poor in pollen for a reliable count, the A-period is best demonstrated here. Two feet of marl deposition interposed between bottom sands and limnic peat permit maximum penetration of the borer, so that there is demonstrable a duration and degree of Picea control not found in the other two borings where limnic peat grades into sandy sediments. In the deciduous phase, the successive rises of Quercus, Ulmus and Fagus within period C, and the reciprocal adjustments of period D are convincingly authenticated. The rise of Carya in the latter period, while well-defined, is of a lower magnitude than that occurring in period E.

Stratigraphic Correlations

The possibility that the four foot-levels of Picea dominance exhibited in Fig. 3 might merely indicate an exceptionally rapid rate of sedimentation, demonstrated a need to correlate at least some of the foot-levels in all three bogs, and so arrive at a measure of their comparative rates of sedimentation. An obvious starting point is the peak of the Pinus maximum comprising a single foot-level with percentage representation between 55 and 60 percent. The next sharply defined point of reference is the first Quercus maximum, likewise of a single foot-level occurring at 20 feet in Figs. 1 and 2, and at 23 feet in Fig. 3. No further reference levels occur before the D-period, the delimitation of which is shown by a definite trough in the *Fagus* curve and an equally definite crest in the *Quercus* curve, suggesting a mass correlation of five foot-levels.

The number of foot-levels between these three zones of reference is identical in Figs. 1 and 3, two levels occurring between the *Pinus* maximum and the first *Quercus* maximum, and seven between the latter and the D-period group. In Fig. 2, the number is one less in each case. It is seen, then, that sedimentation occurred at a remarkably uniform rate in all three basins at least as late as the end of period D.

DISCUSSION

While the pollen profiles of lakes and bogs doubtless contain the most complete and accurate record of postglacial vegetation now available, their translation by pollen analytical methods are subject to many limitations and sources of error. These, termed by Cain (1944a) "the pitfalls of pollen analysis", have been discussed in detail by that author and many others, particularly Godwin (1934), Voss (1934), Eiseley (1939) and Erdtmann (1943), and need be elaborated here only as they concern specific problems of interpretation.

While many of the sources of error in pollen analysis are inherent in the nature of pollen deposition, and so are beyond control of the investigator, others involve faulty techniques or subjective interpretation. Foremost of the latter group are those arising out of widely divergent opinions concerning interpretation of pollen data. In American literature, the extremes of such opinion are represented by the views of Artist (1939) and Smith (1940). Artist, on the one hand, follows Aario in attributing climatic significance only to the appearance or disappearance of genera. Smith, however, freely postulates climatic changes on the basis of major fluctuations in percentage representation and finds even minor variations helpful for purposes of correlation. The degree to which such latitude of opinion may influence interpretation is well illustrated by Cooper (1942b) who, on the basis of profiles reported by Voss (1934), arrives at an interpretation the complete reverse of the latter's!

Evaluation of Indicator Significance of Forest Genera

It is evident that logical interpretation of profile sequences from the standpoints of paleoecology and climatology require careful evaluation of the indicator significance of pollen fluctuations recorded therein. Such an evaluation requires at the outset the assumption that habitat relations of forest genera remain sufficiently constant that their indicator status throughout the radically different climatic periods of postglacial time may be inferred from present forest patterns. While Cain (1944b) has cited the need for caution in interpreting the past in terms of the present, such an assumption appears tenable insofar as the genera involved are of restricted ecological amplitude, or where the indicated shifts in dominance or successional trends are consistent with present patterns of forest distribution and succession. Where a genus embraces species widely divergent in moisture and temperature requirements, as exemplified by Quercus, the impossibility of species determinations leads to the further, more hazardous qualification that for such a genus a mean indicator significance may be assigned, which is applicable throughout postglacial time. Granting the possibility of establishment of such a generic mean, based upon present relative abundance of the component species, it is nevertheless extremely unlikely that the current species ratio, and therefore the mean, could have descended essentially unchanged through postglacial time. In consequence, the pollen curve of such a genus might not only fail to reflect postglacial climates with fidelity, but might conceivably even obscure a major climatic change through shifting in species representation from one moisture extreme to the other. Therefore, it seems illogical to accept unqualified the indicator significance of such a curve, but instead to permit sufficient latitude of interpretation to bring it into accord with those of more sharply delimited indicator genera. Accordingly, in this study Quercus and Carya pollen representation is considered a product of an assemblage of species varying in time as well as in space, the mean indicator significance of which changes in the different foot-levels and which may be inferred from comparison with the curves of Fagus and Ulmus.

Physiography, Soils and Normal Succession As Factors of Change or Stability in Pollen Profiles

According to Cain (1944a), the various factors other than climate which might effect changes in pollen sequences have been inadequately acknowledged by most American pollen analysts. Among the more important of these factors he lists (1) topographic changes effected by erosion or deposition; (2) soil development and (3) normal plant succession. In a survey of postglacial topographic changes and soil development in the Lansing Area in a previous section of this paper, the relative unimportance of erosion was cited (p. 14) and contrasted with the significant increase in land surface resulting from organic deposition. Soil development was held to be largely dependent upon climate, either directly as suggested by soils at present well drained but displaying waterlogged profile characteristics (p. 22), or indirectly as a result of reactions of plants. Organic soils originating by the latter means, while of limited extent (see Table I, p. 21), were considered to have disproportionate significance from the pollen analytical standpoint because of their proximity to borings of the seral forests developed thereon.

Pollen profiles themselves provide an added approach for evaluating the capacity of non-climatic factors to produce changes in pollen representation. As Hansen (1938) and Sears (1941a) have pointed out, successive maxima of pollen from progressively more mesophytic genera may be adequately explained by normal plant succession.

In the Lansing Area, however, the indicated successions not involving retrogression bear such evident relation to regional changes in temperature and moisture that normal plant succession seems not involved as a primary factor of change. Nevertheless, the reactions of pre-existing forests in facilitating ecesis of Fagus must be recognized, since, as Sears (1942b) has pointed out, Fagus is a specialized genus appearing late in succession.

The non-climatic factors which might obscure or partially mask changes in pollen representation of species responding to climatic change are in some areas a major source of error in interpretation unless recognized. Thus, all pollen profiles from within the sandy outwash plains co-extensive with the pine forests of the Lake States manifest a Pinus dominance, following initial decline of Picea pollen, which endures unbroken to the present (Voss, 1934; Artist, 1939). These remarkably uniform sequences were interpreted by the authors as indicative of equally uniform postglacial climate. However, their comparison with climatic sequences now confirmed by the results of other ecologists (Deevey, 1939, 1943; Smith, 1940; Sears, 1942a), serves instead to substantiate the degree to which very sandy soils compensate climatic changes as well as to indicate their slow rate of development toward a mesophytic condition.

Sandy oak uplands in southern Michigan, occurring in an area climatically favorable to beech-maple forest, are analogous edaphically to the pine outwash plains further north. It is evident, then, that in the spectra predominantly of deciduous genera, from the Lansing Area some masking of climatically favored changes in forest composition is likely to have occurred as a result of edaphic compensation. While no accurate means of determining the magnitude of such distortion in representation is available, the great predominance of heavy soils in the area (see Table I, p. 21) would indicate that the distortion is relatively minor. Furthermore, from the standpoint of pollen analysis, the influence of heavy soils might be considered here even more important. Thus, as perhaps best illustrated by the map of agricultural land classification, compiled by Veatch (1941b), the lighter soils (third and fourth-class) are shown to occur to the northeast, south and southeast of Lansing. These areas on this map are located at compass points unlikely to contribute much pollen to the bog deposits studied, owing to the infrequency of winds from those directions.

Post-Cary Conditions in the Lansing Area

Before undertaking an interpretation of the Lansing sequence, it is essential to attain further perspective concerning local and regional ice-influence subsequent to withdrawal of active Cary ice from the Lansing Area. Of primary concern in this regard are (1) the relation between ice recession and initiation of pollen deposition in the basins studied, and (2) regional climatic influences associated with the succeeding Mankato substage, the terminal moraine of which lies within 75 miles of Lansing.

Like most other profiles reported from glaciated North America, those from the Lansing Area were secured from depressions formerly occupied by buried ice masses. In such depressions, deposition obviously could not have begun until melting of the overlying drift had been completed. While it is thus clear that kettle basins fail to record a complete postglacial history, no reliable means of estimating the magnitude of the missing segments are available. No doubt the amount of time elapsing between glaciation and initial deposition varied through wide limits in response to differing ice bulk or thickness of overlying drift. However, in no recorded case was it so short that spruce-fir forests had not been established during the interim, as evidenced by the abundant pollen representation of these genera in the deepest foot-levels of all North American profiles.

There is a paucity of information concerning the type and distribution of vegetation at the periphery of continental glaciers. Pollen analysis fails to provide a record until the ice margin has retreated an indefinite distance, indicating only that coniferous forests are able to become established before melting of buried ice masses has been completed. In Alaska, coniferous forests rapidly invade areas uncovered by receding mountain glaciers (Cooper, 1935, 1942a; Griggs, 1934, 1942) and have even been found to occur on ablation moraine resting on stagnant ice (Cooper, 1942b).

However, many qualifications are necessary in drawing parallels between climatic conditions at the peripheries of mountain glaciers and continental ice sheets. Existing continental glaciers are characterized by anticyclones which give rise to radiating winds often attaining hurricane velocity (Thwaites, 1946). Such fierce anticyclonic winds are believed by Hobbs (1942) to constitute the dominant transportation agent within the extramarginal zones of continental glaciers. According to this view, the long winters in such zones are characterized by driving sand and dust storms, the sand coming to rest in dunes normal to the glacier front, and the dust spreading widely to be deposited in the form of loess.

It must be noted, however, that these conclusions are based upon observation of conditions in high latitude glaciers where the ablation zones are relatively close to the centers of accumulation. Thwaites (1946) contends that the ice borders during Pleistocene glaciation thrust far down into the zone of wastage, where air masses from the Gulf of Mexico might well have brought warm climate. In substantiation of this conclusion, he cites the absence of local glaciers in both the Southern Appalachians and the Driftless Area of Wisconsin, as well as the occurrence of molluscs typical of a mild climate in Iowa glacial outwash. The absence of loess on Cary drift (Leverett, 1909), as well as evidence indicating that the driftless areas of Wisconsin and New Jersey served as dispersal points for postglacial forest migration (Sears, 1942b; Potzger, 1945) would further indicate that ice front conditions in this latitude were less rigorous than those postulated by Hobbs.

Accordingly, the 75-mile zone between Lansing and the point of nearest approach of the Mankato ice sheet would appear more than adequate to contain the extramarginal forest destruction and other evidences of disturbance resulting from advance of the latter. Further, the wide range of spruce-fir forests during Pleistocene time as indicated by a pollen record from Texas (Potzger and Tharp, 1943) would suggest that these genera could have been expected to still occupy the Lansing Area at the termination of Cary retreat to the Straits of Mackinac (Thwaites, 1946). Consequently, secondary spruce maxima evident in profiles elsewhere (Hansen, 1937; Voss, 1937; Prettyman, 1937; Deevey, 1939, 1943) would not be expected to have occurred in basins of the Lansing Area receiving pollen deposition prior to the Mankato advance. Accordingly, the absence of evidences of disturbance, such as loess deposition, as well as the absence of a secondary spruce maximum, in no way controverts the postulate that initiation of pollen deposition in the Lansing Area occurred during the interglacial period between the Cary and Mankato substage. Therefore, in the absence of evidence to the contrary, and in view of the estimated 3500-year duration of the interglacial period (Antevs, 1945), as well as the probable truncation of the *Picea* period in all bogs, the Lansing sequence is here considered to include a part of pre-Mankato forest history.

Interpretation

Pollen profiles presented here indicate the postglacial forest sequences in the Lansing Area comprise a pattern whose major trends are recognizable elsewhere, and are therefore attributive to postglacial climatic changes. For convenience of interpretation, these climatically significant trends are treated individually and in chronologic order.

Period A. The spruce-fir period is indicative of a humid, microthermal climate, only a transitory phase of which is recorded by the Lansing profiles. This is no doubt due in part to profile truncation, as indicated especially in Figs. 1 and 2, but a more important factor is the late date at which pollen deposition was initiated in the Lansing basins. The long, unbroken dominance of spruce-fir forests indicated by profiles located on Tazewell drift in Indiana and Illinois, implies the prolonged influence of a powerful climatic stabilizing factor, operative even during the short interglacial periods between subsequent substages of Wisconsin glaciation. Interglacials do not necessarily imply warmer climates in the zones of wastage of ice, but only the cessation of "nourishment" in the centers of ice accumulation. Since during the Wisconsin interglacials, great masses of ice remained at such centers (Thwaites, 1946), continuing anticyclonic winds could have provided such stabilization. Thus, the Wisconsin interglacials may well have been characterized by great expansion of the spruce-fir forest effected by northward migration to occupy the newly-exposed land while maintaining a stable southern boundary, as suggested by Gleason (1923). It is seen, then, that the spruce-fir forests once occupying the Lansing Area were part of a forest characterized by widespread distribution and a previous long tenure at the ice fronts of the Wisconsin glaciation.

Period B. In sharp contradistinction to the pollen record of the postglacial spruce-fir forests, the pine maximum depicted by pollen profiles shows a striking increase in importance northward. This is well shown by a transect of nine profiles extending from southern Indiana to northern Lower Michigan (Potzger, 1946). In view of the well-known over-representation of *Pinus* pollen, this genus must have been nearly obliterated in the vicinity of Bacon's Swamp, Indiana, the southernmost station, because the percentage representation there was very low. At the next station northward, Kokomo Bog, Indiana, a very weak but well-defined maximum of *Pinus* indicates proximity to the marshalling area from whence the northward migration of this genus originated. Successive stations northward show a progressive increase in importance of *Pinus* pollen, both in percentage representation and number of spectra dominated, until from Farwell, Michigan, northward, it dominates to the surface of the profiles.

Despite the apparent absence of Pinus segregation in the glacial forests, there can be no doubt of the climatic significance of the Pine maximum developed later, owing to its widespread occurrence (Sears, 1935b, 1942a; Deevey, 1939, 1943). However, it is clearly evident from the present distribution that the greatly increased importance of Pinus pollen in profiles to the north is the result of edaphic compensation. Despite the distinct pollen-maximum of between 55 and 60 percent in the Lansing profiles, Pinus was probably of scattered distribution at the height of its abundance in the Lansing Area. In a report indicating equivalent percentages (55-60%) in surface samples from Al-Berta, Canada, Erdtmann (1943) states that Pinus "has such a local distribution that a botanist roaming about in this vast district might not notice it for weeks." It follows from the present grouping of species, of which even P. Strobus has been shown to be of minor importance in the climax forest (Nichols, 1935), that Pinus must be assigned xerophytic indicator significance during postglacial time in the Lansing Area. Accordingly, it is believed to have occurred at its maximum in isolated stands on the better drained, sandy sites rendered unfavorable for Picea by an increasingly warm climate.

Period C. While considerable prior invasion of deciduous species may likely be masked by over-representation of Pinus pollen in Period B, in Period C the invasion of deciduous genera is clearly evident. Part of the initial

Quercus maximum is interpreted to represent pollen from xerophytic species which were able, as a result of further climatic amelioration, to preempt the sites occupied by *Pinus*. The remaining *Quercus* representation is difficult to interpret, but the dryness implied by the low percentage of *Ulmus* pollen would suggest that the mean for the remaining fraction of oak pollen also lies on the xerophytic side of mesophytism. The abrupt increase in representation of *Ulmus* to a postglacial maximum is of climatic significance as indicated by a widespread, albeit less pronounced, parallel occurrence in profiles from the north-central states (Richards, 1938; Howell, 1938; Potzger, 1943a; Keller, 1943). It is interpreted here as indicative of an interval of increasing moisture, correlating with the beginning of Period III of Sears (1942b), C-1 of Deevey (1939, 1943), and with the wet period postulated by Veatch (1938) on pedologic evidence. The unusually strong development of this maximum in the Lansing profiles may be attributed to the large proportion of poorly drained soils supporting elm stands even at the present time, supposedly a drier period. (See Table I, p. 21 and p. 23) In view of such hygric indications, the *Quercus* pollen occurring at the levels of highest *Ulmus* representation is assumed to be the product of predominantly mesophytic or hydrophytic species. Drier, but still humid conditions, are indicated by the increase of *Fagus* pollen contemporaneous with a decline of *Ulmus* representation late in the period. Though it is impossible to draw definite inferences regarding the occurrence of *Acer* from the pollen profiles, it is assumed on the basis of similar habitat requirements, that maple increased in numbers corresponding to *Fagus* during this latter phase of Period C.

Period D. The xeric tendency evident at the close of Period C leads to a culminating retrogression in Period D, as shown by a definite trough in the *Fagus* curve, associated with a postglacial maximum of *Quercus* pollen. Such a xeric period, characterized by a decline of *Fagus* pollen, is amply corroborated by profiles elsewhere, correlating with Period IV of Sears (1942b), applicable to the north-central states and southeastern Canada, and with Period C-2 of Deevey (1943) for Connecticut. The reciprocal relation shown by the curves of *Quercus*-*Carya* and *Fagus* pollen may be taken to indicate that the species of *Quercus* and *Carya* were predominantly xeric.

Period E. The initial sharp rise in this period of *Fagus* pollen indicates a return to the mesophytism of late Period C. The higher percentage representation reached by *Fagus*, as compared with the latter period, suggests an increase in the amount of mesic sites available for this genus, and by inference, *Acer*. The lower amount of *Ulmus* representation as compared with Period C indicates that such a decline in elm pollen may be indicative of a drying up of the hygric sites of that time, and the invasion thereon of more mesic genera. As a group, the upper foot levels show a disappointing lack of agreement from profile to profile. This is particularly manifest in the curves of *Fagus*, *Pinus*, *Carya* and *Tilia* and appears confined to the levels of sub-aerial peat. Attention was previously directed (p. 44) to the very low pollen frequency and the evidences of distinction of the exine in grains of _Fagus_, _Quercus_ and _Ulmus_ observed in the upper levels of the profile from Chandler Marsh. Such evidence is felt to indicate that, under particularly adverse conditions for preservation, some differential preservation may occur in pollens generally considered uniformly resistant. The abrupt increase in _Pinus_ representation could thereby be explained as resulting from greater resistance to decay of pollen from that genus as compared particularly with _Fagus_.

Because a high pollen frequency was maintained to the upper foot-level, the profile from Mud Lake Bog is considered to present the most reliable recent record of pollen deposition. The postglacial maximum of _Tsuga_ pollen at the uppermost level of this profile is difficult to reconcile with the present relict status of the genus in southern Michigan, and may mean that pollen has not been preserved in the bog for a considerable period of time. This, however, is considered unlikely owing to the abundance of Sphagnum which is considered to provide conditions highly favorable for pollen preservation. The increase in _Picea_ pollen is coincident with the layers of sub-aerial peat. It is therefore interpreted to indicate invasion by _P_. _mariana_, in accord with the belief of others (Wilson and Galloway, 1937; Potzger and Richards, 1942), and hence is considered devoid of climatic significance.

Since the _Pinus_ representation at Chandler Marsh is held to be unreliable, and since the increase in pollen of Picea in all bogs is probably a consequence of invasion of solidified mats by bog spruce, it cannot be said that the Lansing profile provides evidence in support of the climatic reversion so well substantiated further north (Raup, 1941; Griggs, 1942; Cooper, 1942b). Nor, as well demonstrated by the Tsuga curve, can these pollen profiles be considered an aid in reconstructing the pre-settlement forests in the Lansing Area.

SUMMARY AND CONCLUSIONS

A pollen analytical investigation of three kettle basins in the vicinity of Lansing, Michigan is presented. In addition, an attempt has been made to include such data concerning environmental factors as might aid in interpretation of the profiles.

Postglacial erosion is shown to have been a minor factor in altering the topography of the Lansing Area, as opposed to significant increases in land area resulting from organic sedimentation. Dominance of fine-textured soils is demonstrated by data taken from soil surveys for Clinton, Ingham and Eaton Counties. Forest groupings typical of the major soil types, and therefore considered co-extensive with them, are presented with the view of expressing their approximate areal extent in terms of the area percentages available for the soil types.

The profiles are sufficiently consistent among themselves that stratigraphic correlations on the basis of pollen spectra are clearly indicated in the lower foot-levels. The forest sequences revealed by the profiles follow a pattern whose major trends are repeated elsewhere and are therefore attributive to postglacial changes. Such major trends are indicated on the overlay accompanying the pollen diagrams.

The unusually strong development of the Ulmus maximum midway in Period C of the Lansing sequence is attributed to the large proportion of poorly drained soils supporting elm stands even at the present time, supposedly a drier period. The high percentage representation reached by Fagus early in Period E, as compared with late Period C, suggests an increase in the amount of mesic sites available for this genus. Such increase is interpreted as having resulted from the drying up of some of the hygric sites of Period C, and the invasion thereon of more mesic genera. This view is supported by the lower amount of Ulmus representation in Period E as compared with Period C.

Certain inconsistencies in pollen representation, correlated with sub-aerial samples of sedge peat, are held to result from differential preservation of pollen grains generally considered uniformly resistant. This evidence, together with a postglacial maximum of Tsuga pollen in the uppermost spectra, indicates that the Lansing profiles cannot be considered a reliable aid in reconstructing the very recent forests in the area.

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A P P E N D I X

TABLES

TABLE III. Pollen data for Bear Lake Bog
(A) Combined counts and percentage representation of tree pollens based on a minimum total count of 200 grains at each level.
(B) Counts of non-tree pollens and spores tabulated while counting a minimum of 200 tree pollens.

Foot-Levels (A)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	23½
Abies																				0.5	3.8	1.8	4.5	7.6
																				1	8	4	9	16
Picea	*4.8	4.4	15.5	6.0	6.9	5.1	2.0	0.9	2.0	3.3	1.5	3.0	1.9	0.5		2.8	2.4	2.5	5.0	7.5	16.7	19.5	29.0	49.0
	10	10	31	12	15	11	4	2	4	7	3	6	4	1		6	5	5	10	16	35	43	58	103
Pinus	14.0	6.6	10.5	14.5	11.5	9.3	10.3	4.7	5.5	3.6	5.5	4.5	1.9	3.9	9.0	12.0	11.4	13.0	10.5	16.4	40.5	48.4	60.0	43.4
	29	15	21	29	25	20	21	10	11	8	11	9	4	8	18	26	24	26	21	35	85	107	120	91
Larix	0.5						1.5	5.7	1.0	4.0	2.5	2.0	4.3	4.9	5.5	1.9	2.9	2.5	2.0	3.3	3.8	2.7	2.5	
	1						3	12	2	9	5	4	9	10	11	4	6	5	4	7	8	6	5	
Tsuga	4.4	2.2	4.5	4.0	5.5	1.4	0.5	0.5		2.2	1.0	0.5	1.4	0.5	0.5									
	9	5	9	8	12	3	1	1		5	2	1	3	1	1									
Quercus	30.0	33.3	29.5	36.0	33.0	35.5	33.4	47.5	50.0	38.2	43.0	40.0	40.0	32.2	34.5	48.2	44.2	31.0	41.0	48.8	17.1	15.4	2.5	
	62	76	59	72	72	76	68	101	100	86	86	80	84	66	69	104	93	62	82	104	36	34	5	
Fagus	19.8	19.7	19.0	15.0	9.2	18.7	24.5	13.2	13.5	14.7	15.5	15.0	21.4	19.0	10.0	0.5		0.5	1.0	0.9				
	41	45	38	30	20	40	50	28	27	33	31	30	45	39	20	1		1	2	2				
Ulmus	5.8	13.6	4.5	7.0	18.8	16.8	9.8	12.3	12.5	23.1	21.0	15.5	16.2	30.3	29.0	22.7	23.8	37.5	22.5	10.8	10.0	5.0	1.5	
	12	31	9	14	41	36	20	26	25	52	42	31	34	62	58	49	50	75	45	23	21	11	3	
Carya	5.8	4.4	3.0	7.0	3.7	2.3	4.4	5.7	4.0	1.3	2.0	2.5	3.3	3.4	4.0	3.2	3.8	3.0	5.0	1.9	1.0	1.4		
	12	10	6	14	8	5	9	12	8	3	4	5	7	7	8	7	8	6	10	4	2	3		
Juglans	2.4	2.2	3.0	1.0	3.2	1.4	2.5	3.8	0.5	1.8	1.5	5.0	2.4		1.5			1.0		0.5	1.0			
	5	5	6	2	7	3	5	8	1	4	3	10	5		3			2		1	2			
Tilia	3.7	4.4	5.0	4.5	1.8	3.3	2.5	1.4	4.5	1.3	3.0	2.5	1.0	1.5	2.5	2.3	1.9	3.0	2.0	4.2	0.5			
	18	10	10	9	4	7	5	3	9	3	6	5	2	3	5	5	4	6	4	9	1			
Acer	1.0	1.8	1.0	1.5	3.7	0.5	2.9	0.9	1.5	2.7		2.0	0.5	1.0	0.5	1.4	4.8		2.5	0.5				
	2	4	2	3	8	1	6	2	3	6		4	1	2	1	3	10		5	1				
Salix	0.5	1.8	0.5		0.5	1.9	1.5	0.5	1.5	2.2	1.0	3.0	3.3	2.0	2.0	3.2	1.0	1.5	2.5	1.4	1.0	1.4		
	1	4	1		1	4	3	1	3	5	2	6	7	4	4	7	2	3	5	3	2	3		
Betula	2.4	2.6	3.5	1.5	2.3	0.9	2.9	1.4	2.0	0.9	1.5	3.5	0.5		1.0	0.5	1.0	3.0	4.5	2.3	4.8	4.5		
	5	6	7	3	5	2	6	3	4	2	3	7	1		2	1	2	6	9	5	10	10		
Alnus				0.5							1.0	0.5	0.5					0.5						
				1							2	1	1					1						
Carpinus		2.6	0.5	1.5		2.8	1.5	1.4	1.5	0.9			1.4	0.5		1.4	2.9	1.0	1.5	0.9				
		6	1	3		6	3	3	3	2			3	1		3	6	2	3	2				
Fraxinus		0.4										0.5		0.5										
		1										1		1										
Unknown	5.3	7.0	5.0	6.0	7.8	4.2	3.9	3.8	2.5	7.6	5.5	3.0	6.2	7.6	4.0	5.6	3.8	4.5	4.0	2.8	2.4	6.4	5.0	5.7
	11	16	10	12	17	9	8	8	5	17	11	6	13	16	8	12	8	9	8	6	5	14	10	12
Arborescent Total	207	228	200	200	218	214	204	212	200	225	200	200	210	205	200	216	210	200	200	213	210	221	200	210
(B)																								
Ericads (Tetrads)	16	18	12	27	38	7	5	1																
Corylus		3			3		2	1	6		1	2		3	5	26	14	27	6	7	2	2		
Cyperaceae	2		1	3	7	3	2	5		3	3	3	1		1		2		1	2		1		
Gramineae					1										2				1		1	1		
Typha (Tetrads)												1	1	1		1	1					1		
Amaranth-Chenopod				2			1			1			1				1							
Ambrosia-Iva			1					1	2	1														
Spores (Trilete)	24	38	75	162	1	2	3																	

*Percentage

TABLE IV. Pollen data for Chandler Marsh
(A) Combined counts and percentage representation of tree pollens based on a minimum total count of 200 grains at each level.
(B) Counts of non-tree pollens and spores tabulated while counting a minimum of 200 tree pollens.

Foot-Levels (A)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Abies																				0.9	0.5	2.0	4.1	10.2
																				2	1	4	9	21
Picea			*15.0	9.1	7.5	5.0	3.0	1.0			1.9	1.0	3.4	0.5	1.5		2.0	1.8	1.3	3.9	4.9	17.5	40.4	61.0
		4	23	20	15	10	6	2			4	2	7	1	3		4	4	3	9	10	35	89	125
Pinus			19.6	21.9	20.5	9.5	12.5	12.0	12.7	10.2	4.2	7.7	4.9	3.6	6.0	7.0	7.0	7.2	3.9	18.8	36.9	55.5	39.1	9.8
		9	30	48	41	19	25	24	26	23	9	16	10	8	12	14	14	16	9	43	75	111	86	20
Larix			2.0	1.8	1.0	0.5		1.0	1.0	2.2	0.9	0.5	2.5	2.7	1.5	4.5	3.5	2.2	0.4	0.9	1.5	1.0	2.3	5.9
			3	4	2	1		2	2	5	2	1	5	6	3	9	7	5	1	2	3	2	5	12
Tsuga			1.3	3.2	3.5	4.5	2.5	0.5	1.5	0.9	0.5	0.5		1.8	1.5	2.0		0.9	0.4		0.5			
		1	2	7	7	9	5	1	3	2	1	1		4	3	4		2	1		1			
Quercus			38.6	34.7	40.5	35.5	31.5	44.5	51.2	49.8	51.2	41.1	50.5	37.8	45.5	37.5	34.0	43.9	45.7	53.3	35.0	11.0	7.7	11.2
		5	59	76	81	71	63	89	105	112	109	85	103	84	91	75	68	98	105	122	71	22	17	23
Fagus			5.2	5.9	9.5	27.0	26.5	20.0	12.7	10.7	9.9	14.5	10.3	18.9	12.5	12.5	14.5	4.5	2.2		1.0			
			8	13	19	54	53	40	26	24	21	30	21	42	25	25	29	10	5		2			
Ulmus			3.9	8.7	7.5	6.0	7.0	6.0	8.8	10.2	12.7	15.9	14.7	21.2	17.5	22.0	23.0	22.4	29.1	9.6	11.3	6.0	2.3	
			6	19	15	12	14	12	18	23	27	33	30	47	35	44	46	50	67	22	23	12	5	
Carya			3.3	2.7	3.5	4.5	5.0	3.5	6.3	4.0	8.4	6.8	3.9	3.2	4.0	2.5	4.5	1.8	2.2	0.9	1.5			0.5
			5	6	7	9	10	7	13	9	18	14	8	7	8	5	9	4	5	2	3			1
Juglans			0.7	0.9	1.0	1.0	1.5	3.5	0.5	0.5	3.3	1.0	1.0	1.4	2.5	1.0	1.0	3.1	1.3					
		1	1	2	2	2	3	7	1	1	7	2	2	3	5	2	2	7	3					
Tilia				0.9	0.5	0.5	2.0	1.0	1.5	1.8	0.9	2.9	1.5	3.2	1.0	3.5	2.0	3.6	2.6	2.6	1.5	0.5		
				2	1	1	4	2	3	4	2	6	3	7	2	7	4	8	6	6	3	1		
Acer			2.6	0.9	1.5		1.0	1.5	1.0	0.5	0.9	0.5	1.5	0.9	1.0	1.0		1.3	0.9	2.2	0.5			
			4	2	3		2	3	2	1	2	1	3	2	2	2		3	2	5	1			
Salix			4.6	5.5	1.0	2.0	2.5	2.0	1.0	3.1	1.9	4.4	2.5	3.6	3.5	5.0	5.5	4.5	6.5	3.1	2.5	0.5	0.5	0.5
			7	12	2	4	5	4	2	7	4	9	5	8	7	10	11	10	15	7	5	1	1	1
Betula			3.3	3.2	2.5	3.0	3.5	3.5	1.5	4.4	1.9	1.9	2.5	1.4	1.5		2.5	1.3	1.7	3.5	2.5	6.0	3.2	0.5
			5	7	5	6	7	7	3	10	4	4	5	3	3		5	3	4	3	5	12	7	1
Alnus												1.4						0.5	0.4	0.4			0.5	0.5
												3						1	1	1			1	1
Carpinus				0.5		1.0	1.5		0.5	1.3	0.5		1.0		0.5	1.0	0.5	0.9	1.3					
		1		1		2	3		1	3	1		2		1	2	1	2	3					
Fraxinus										0.5	0.9					0.5								
										1	2					1								
Unknown			10.0	11.0	7.0	4.0	5.5	4.0	6.8	4.9	5.6	5.3	7.8	2.7	3.5	4.5	3.5	1.3	3.9	2.6	3.5	2.0	4.1	2.4
		7	16	24	14	8	11	8	14	10	12	11	16	6	7	9	7	3	9	6	7	4	9	5
Arborescent Total		20	153	219	200	200	200	200	205	225	213	207	204	222	200	200	200	223	230	229	203	200	220	205
(B)																								
Ericads (Tetrads)		1		1	1	2																		
Corylus						1	2			1	1	2	1			1		4	4	4	5	1	2	1
Cyperaceae			6	6	17	12	11	4	1	4	1	3	3						1	1				3
Gramineae			1		4					3	1	1	1						1					
Typha (Tetrads)			1	2																1				1
Amaranth-Chenopod				1	1				1	1					1			1	1	3			1	
Ambrosia-Iva			4	2			2				1	2	1					1		3	2			
Spores (Trilete)		1																1	1			1		

*Percentage

TABLE V. Pollen data for Mud Lake Bog
(A) Combined counts and percentage representation of tree pollens based on a minimum total count of 200 grains at each level.
(B) Counts of non-tree pollens and spores tabulated while counting a minimum of 200 tree pollens.

Foot-Levels	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
(A)																														
Abies																									2.0	3.0	3.5	3.5	-	4.9
																									4	6	7	7	3	8
Picea	*4.8	6.0	4.4	5.2	7.5	2.4	0.5	0.5	1.3								0.5					1.5	0.5	3.0	14.0	38.5	68.0	93.5	-	95.1
	10	12	9	11	15	5	1	1	3								1					3	1	6	28	77	136	187	25	157
Pinus	10.5	7.5	6.8	7.6	3.0	4.2	8.0	7.0	8.7	11.0	7.4	9.0	7.2	7.5	3.7	5.0	4.5	6.9	6.0	15.7	15.2	22.5	40.5	52.0	59.0	36.5	6.0	2.0		
	22	15	14	16	6	9	16	14	20	22	15	20	17	15	8	10	9	14	12	33	35	45	81	104	118	73	12	4		
Larix		0.5			1.0	0.5	1.0	0.5	0.4	1.0	5.9	2.3		2.5	1.9	1.0	3.0	5.9	11.0	4.3	4.8	4.0	3.0	4.0	6.5	7.0	9.5	0.5		
		1			2	1	2	1	1	2	12	5		5	4	2	6	12	22	9	11	8	6	8	13	14	19	1		
Tsuga	3.3	2.0	2.0	2.8	1.5	1.4		0.5	0.9	2.0		1.4	0.8			0.5	0.5			0.5										
	7	4	4	6	3	3		1	2	4		3	2			1	1			1										
Quercus	37.1	29.5	35.1	29.8	36.0	43.8	32.5	48.0	40.0	53.0	59.9	52.1	48.9	53.5	44.8	52.0	50.0	43.1	40.8	46.6	51.9	55.5	34.0	22.5	5.0	9.0	8.0	0.5		
	78	59	72	63	72	93	75	96	92	106	121	116	116	107	96	105	100	87	82	98	120	111	68	45	10	18	16	1		
Fagus	17.6	25.0	16.1	26.6	26.0	20.8	31.0	21.5	23.9	11.0	7.4	8.6	12.7	12.5	15.0	12.4	11.5	5.9	1.0	1.4	2.2	0.5	1.0							
	37	50	33	56	52	44	62	43	55	22	15	19	30	25	32	25	23	12	2	3	5	1	2							
Ulmus	6.7	10.5	14.6	12.8	13.5	12.7	11.5	10.5	13.9	9.5	9.9	9.9	14.4	11.5	19.6	17.8	21.5	30.2	28.9	14.8	16.9	8.0	10.5	11.5	7.5	2.0				
	14	21	30	27	27	27	23	21	32	19	22	22	34	23	42	36	43	61	58	31	39	16	21	23	15	4				
Carya	7.1	7.0	12.2	6.2	4.5	6.6	5.5	2.5	4.3	7.0	4.0	6.8	5.9	2.5	2.8	1.0	2.5	3.0	1.5	3.3	1.3	0.5	1.0							
	15	14	25	13	9	14	11	5	10	14	8	15	14	5	6	2	5	6	3	7	3	1	2							
Juglans	0.5	1.0	2.0	1.4		1.4	0.5	2.0	2.2	1.5	2.0	1.4	3.0	1.0	1.9				1.5	1.9	1.3									
	1	2	4	3		3	1	4	5	3	4	3	7	2	4				3	4	3									
Tilia	2.9	3.0	2.0	1.4	2.5	0.5	0.5	0.5	1.3	2.0	1.0	2.3	1.7	1.5	3.7	1.0	0.5		3.0	1.4	0.9		1.0							
	6	6	4	3	5	1	1	1	3	4	2	5	4	3	8	2	1		6	3	2		2							
Acer	1.0	1.0		0.5	0.5		1.0	0.5				0.9		2.0	1.4	1.0		0.5												
	2	2		1	1		2	1				2		11	3	2		1												
Salix	1.9	2.0	2.4	2.8	1.5	2.4	1.5	2.5	1.3	1.0	1.5	2.7	3.0	4.0	2.3	6.9	4.0	3.0	3.5	5.2	3.0	4.0	3.5	3.0	4.0	2.0	4.0			
	4	4	5	6	3	5	3	5	3	2	3	6	7	8	5	14	8	6	7	11	7	8	7	6	8	4	8			
Betula	5.2	3.0	1.5	1.9	1.5	1.4		2.0		1.0	1.0	2.3	1.3	1.5	1.9	1.5	1.0	1.5	1.5	2.9	1.2	2.5	3.0	3.5	1.0	2.0	1.0			
	11	6	3	4	3	3		4		2	2	5	3	3	4	3	2	3	3	6	4	5	6	7	2	4	2			
Alnus												0.4	0.4										0.5	0.5	1.0					
												1	1										1	1	2					
Carpinus	1.4	2.0	1.0	1.0	1.0	1.9	1.5	1.5	1.7				0.8		0.9		0.5		1.5	1.9	0.9	1.0	1.5							
	3	4	2	2	2	4	3	3	4				2		2		1		3	4	2	2	3							
Unknown	6.7	2.5	5.4	8.1	16.0	2.8	3.0	7.0	3.0	6.0	4.0	2.7	3.8	4.5	1.9	3.5	3.0	5.5	2.5	2.4	3.4	3.0	4.0	3.5	4.5	3.0	4.5	1.5	-	1.8
	14	5	11	17	12	6	6	14	7	12	8	6	9	9	4	7	6	11	5	5	8	6	8	7	9	6	9	3		3
Arborescent Total	210	200	205	211	200	212	200	200	230	200	202	222	237	200	214	202	200	202	201	210	231	200	200	200	200	200	200	200	28	165
(B)																														
Ericads (Tetrads)	4	2	3																											
Corylus	2	5	2	2		1	2	2	2		2	1	1	1		2	1	1	1	4	6	5	4	4	2	1				
Cyperaceae			1				1	3	3		1						1			3		1		1						
Gramineae						1	1	2	1			4		4	2	2	4	1	4			2	2	3	6	2				
Typha (Tetrads)											1														1	3	2			
Amaranth-Chenopod		1						2	2		1				1					2		2	1							
Ambrosia-Iva	3	4			1	1	3		1		2	2				2	2				2									
Sparganium								3	1		3	5	4	1	4		6		1	2	1	2	1	2	3	2	2			
Potamogeton																			1		1	1	1	3	2					
Spores (Trilete)	1	5							1			1																		

*Percentage