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# THREE POLLEN DIAGRAMS FROM CENTRAL MASSACHUSETTS

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ABSTRACT. Three pollen diagrams are presented from central Massachusetts. The diagrams are believed to record the vegetational sequence from the time of retreat of pre-Valders ice to a time just previous to European colonization. They are interpreted to show that a narrow treeless belt along the edge of the retreating ice was rapidly colonized by forest. During Two Creeks time a cool-temperate, and perhaps dry, climate permitted the growth of a mixed spruce and deciduous forest. The climate during the Valders stadium became cooler and more moist, and brought about a change in the frequency of the forest species. An alternative interpretation, according to which a return of park-tundra vegetation, under conditions of intense solifluction, occurred in Valders time, is not favored by the weight of evidence. The succeeding pine phase has been divided into two zones, the second of which was probably warmer and drier than the first. The three deciduous forest zones described from other parts of New England have been demonstrated, although only one of the diagrams contains the entire sequence. The dominant pollen types in the three zones, starting with the earliest, are: oak and hemlock; oak, pine, and hickory; birch, oak, hemlock, and chestnut. The upper part of the pine zone and the first two deciduous forest zones are believed to represent the hypsithermal interval. On the basis of the bog plant pollen spectra, the beginning of the third deciduous forest zone is thought contemporaneous with the beginning of the Sub-Atlantic pollen zone in Europe.

## INTRODUCTION

In recent years, attention has been directed to the vegetational history of glaciated regions of North America since the retreat of the ice. A knowledge of the earliest vegetation and its subsequent changes in species composition and frequency illuminates many biogeographical problems and increases our knowledge of the climate and soils of the past.

Analysis of the pollen and spores contained in organic deposits has proved an enormously useful technique in the study of vegetational history. Pollen diagrams from southern New England (Deevey, 1939, 1943) have demonstrated that, following the retreat of the ice, there was an interval when spruce was very abundant. The spruce was later replaced by pine, which in turn was replaced by three deciduous forest zones, characterized respectively by oak and hemlock, oak and hickory, and oak and chestnut. Recent studies in Connecticut have added more detail to this sequence. Leopold (1955, 1956b) has demonstrated that there was an interval of "steppe-like" vegetation immediately after deglaciation. At the southernmost site investigated, there is evidence that the forest advanced and then retreated again during this interval. The spruce phase earlier described by Deevey has been divided into four zones. Starting with the earliest, the zones are characterized by rising spruce percentages, a spruce maximum, a spruce minimum with higher percentages of pine and deciduous trees, and a second spruce maximum. The spruce minimum has been correlated with the warmest part of the Two Creeks interstadial, and the succeeding spruce maximum is thought to represent cooling associated with glacial advance during Valders time. This correlation is supported by radiocarbon dates. Apparently the climate in southern Connecticut during the Two Creeks interval was warm enough to permit the growth of mixed spruce, pine, and hardwood forests; during Valders time climatic cooling altered the species composition of the forest (Leopold, 1956b). The diagrams from Connecticut contrast sharply with the sequence in northern Maine (Deevey, 1951), Nova Scotia (Livingstone and Livingstone, 1958), and Michigan (Andersen, 1954), where there is evidence of more severe climate during Two Creeks and Valders time. It is thought that in northern Maine and Nova Scotia the park-tundra established during the Two Creeks interstadial was replaced by tundra during the cold interval associated with the Valders glacial advance. In Michigan there is evidence that the spruce forests of Two Creeks time were replaced by park-tundra.

The purpose of this investigation has been to study the vegetational history of central Massachusetts. On the basis of three pollen diagrams from the vicinity of the Harvard Forest it has been possible to outline the vegetational history of the area, to correlate it with sequences from other parts of New England, and to speculate on the factors which could have influenced the changes in vegetation that have occurred since the melting of the ice sheet.

## ACKNOWLEDGMENTS

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## PRESENT VEGETATION, CLIMATE, AND SOILS OF THE REGION

The three sites investigated are in the vicinity of the Harvard Forest, Petersham, Mass. (see fig. 1). This region now supports a complex, species-rich hardwood forest. Ecological studies (Bromley, 1935; Lutz and Cline, 1947; Stout, 1952) show that the forest is dominated by red oak (*Quercus rubra*), ash (*Fraxinus americana*), red maple (*Acer rubrum*), black birch (*Betula lenta*), and sugar maple (*A. saccharum*). White pine (*Pinus strobus*) and hemlock (*Tsuga canadensis*) occur frequently. On some north-facing slopes and in ravines sugar maple, yellow birch (*B. lutea*), beech (*Fagus grandifolia*), and hemlock are more common. On a few well-drained slopes with thin soils, the forest is dominated by white and black oak (*Q. alba* and *Q. velutina*), hickory (*Carya ovata* and *C. glabra*), and, formerly, chestnut (*Castanea dentata*).

The climate of the region (Rasche, 1958) is continental, despite the proximity (ca. 70 mi, 110 km) of the Atlantic Ocean. The prevailing winds are westerly, so that the ocean has little modifying effect. The mean January

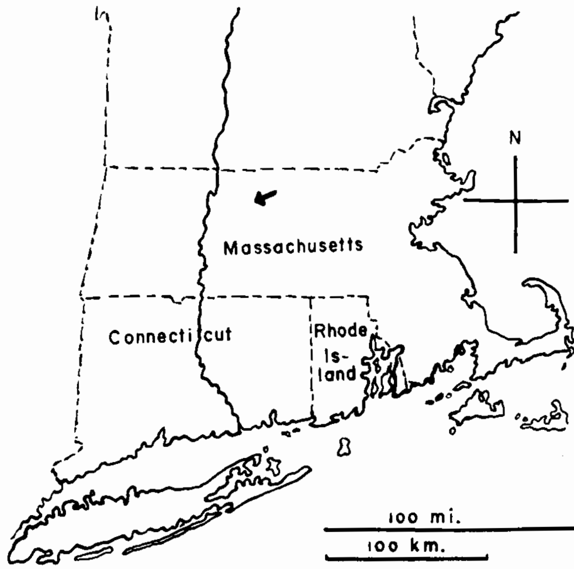



Fig. 1. Map of southern New England. Arrow indicates location of sites investigated.

temperature is about 21°F (–6°C), and the mean July temperature 69°F (21°C), a mean annual range of almost 50°F (27°C). The climate is moist: the average yearly precipitation is about 40 in. (200 mm). The irregular topography results in a variety of microclimates. Studies indicate that local temperature variations within the Harvard Forest cover from one fourth to one half the variations among stations from southern to northernmost New England.

The bedrock underlying the Petersham region is acidic granite, gneiss, and schist. Its surface is irregular and the mantle of glacial debris is thin. In the valleys, and occasionally on slopes, there are gravelly outwash deposits. The uplands are mantled with sandy till; overlying this is a loam which may be in part of eolian origin. There is evidence that frost action has modified many of the slopes. The period of most active solifluction is thought to have occurred prior to the deposition of the loam (Raup, 1951; Stout, 1952). Although the age of the till is not known with certainty, it is probably of Cary or late Cary age (Flint, 1953; MacClintock, 1954; Denny, 1956a).

## DESCRIPTION OF SITES

*Tom Swamp.*—Tom Swamp is a large sphagnum bog located in a north-south trending bedrock valley, apparently of pre-glacial origin (exact location 42°31′ N, 72°13′ W, elevation 750 ft.). The valley floor is lined with outwash, and there are gravel terraces along the slopes. Glacial meltwater from the north may have drained through the valley, depositing the outwash. It is possible that the valley was partially filled with stagnant ice during this period.

The bog is about 4 km long and 0.5 km wide. On the central portion of the bog black spruce, white pine, larch, highbush blueberry, and wild raisin form a dense forest. To the north and to the south, the vegetation is more open. To the north, shrubs grade into a sedge meadow which is rapidly building into the open water of the artificially damned Riceville Pond. To the south, ericaceous shrubs and sphagnum are building a bog mat into the open water of Harvard Pond. The outlet here has also been dammed; early maps show the area as wet meadow (Raup and Carlson, 1941). It was not possible to survey the bog surface, because of the dense vegetation. However, there are small streams on the bog surface flowing north to the Riceville outlet, and flowing south to the Harvard Pond outlet. The presence of the two outlets and the drainage streams indicates that the bog may be slightly domed.

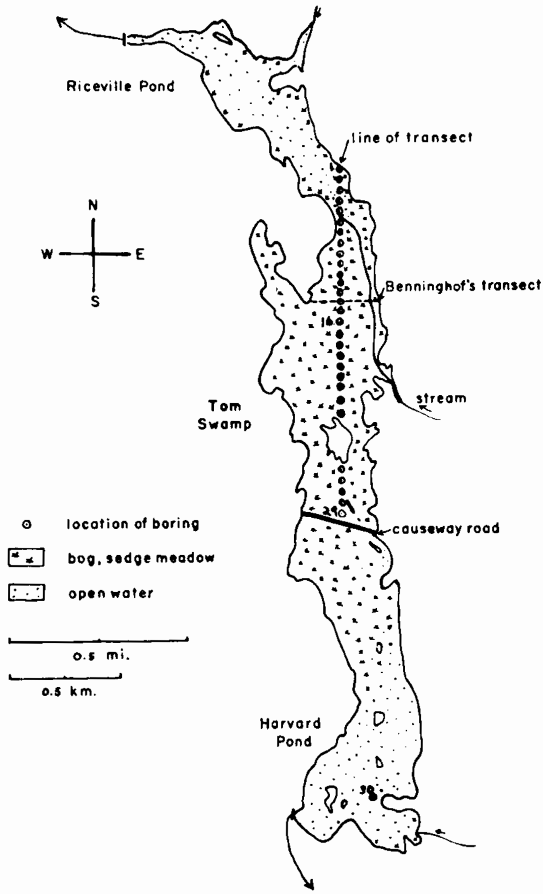



Fig. 2. Map of Tom Swamp.

A series of borings was made in an effort to determine the deepest part of the bog. A transect had previously been made across the bog by Prof. William S. Benninghoff (W. S. Benninghoff, personal communication). Accordingly, a trail was made due north and south from his deepest boring (see fig. 2). Borings were made slightly less than 50 m apart. Samples were taken with a Hiller borer at 50 cm intervals, and peat identifications were made in the field. The resulting profile (plate 1) shows that forest occurs only on deeper parts of the bog. More hydrophytic vegetation occurs on the shallower parts of the basin. The Riceville sedge meadow is underlain by only a few meters of peat. Boring 30, made through the ice on Harvard Pond, showed that the peat here is also relatively shallow—only 1.5 m of water and 3 m of dy (lake mud) and peat were encountered. The classical hydrosere concept (cf. Weaver and Clements, 1938) is insufficient to explain this vegetational distribution. Apparently the ontogeny of Tom Swamp has been complex; possibly climatic changes have been a major factor influencing its development.

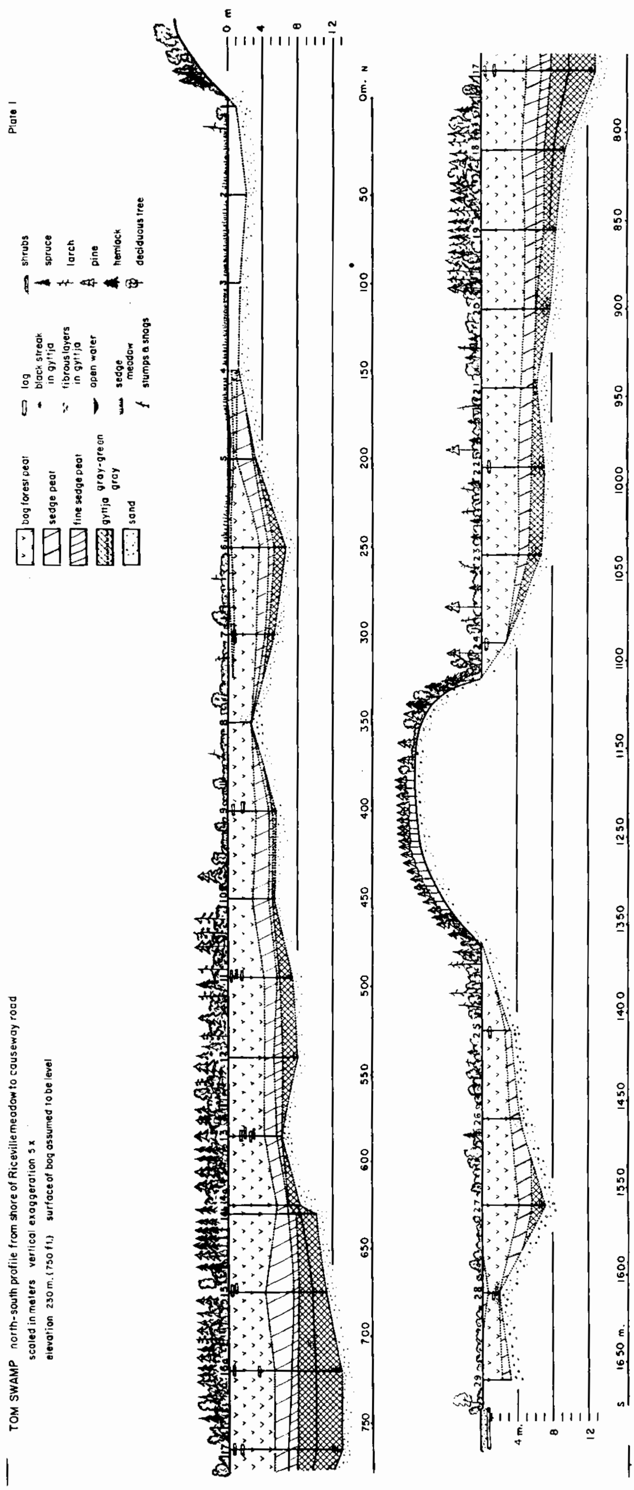
The samples used for pollen analysis were collected in August, 1955, from boring 16A. The stratigraphy here is as follows:

| | |
|---|---|
| 0-4.75 m | Bog forest peat |
| 4.75-5.00 m | Coarse sedge peat |
| 5.00-7.25 m | Sedge peat |
| 7.25-7.55 m | Fine sedge peat |
| 7.55-7.85 m | Sedge peat |
| 7.85-8.05 m | Fine sedge peat; very wet from 7.98-8.05 m |
| 8.05-9.90 m | Gray-green gyttja, slightly silty |
| 9.90-12.50 m | Gray silty gyttja; scattered white specks from 10.85-11.55 m; black streaks from 11.70-12.50 m |
| 12.50-12.91 m | Silty sand |
| 12.91-13.00 m | Medium sand; it was not possible to penetrate deeper with the Hiller borer |

The organic content of the sediments was determined by observing the percent dry weight lost upon ignition. Five of the eight samples tested were from half-meter bulk samples collected at boring 16C, located 1 m from boring 16A. Pollen from these samples was inspected to insure their contemporaneity with equivalent levels in boring 16A. The lower three samples tested were samples used for pollen analysis from boring 16A. The lowest sample weighed 3 g, the others 0.65 g each. The percent weight lost on ignition is shown in figure 3. The significance of the loss on ignition curve and the pollen zones indicated in figure 3 will be discussed below.

*Pleasant St. Bog.*—Pleasant St. Bog is located about 5 km (3 mi) NNW of Tom Swamp, in a small bedrock depression on a ridge near Athol, Mass. (exact location 42°34′ N, 72°14′ W, elevation 800 ft). The bog is ovoid, about 250 meters long, and has a maximum depth of about 5.5 m. In the summer of 1955 a road cut through the bog exposed the peat in open section. In most parts of the bog organic sediments directly overlie till, which, at least in the central portion of the bog, appears unweathered. It seems unlikely that an ice block would have persisted long in a depression of this size located near the summit of a ridge. Probably the sediments which have accumulated in the depression include the entire sequence since the retreat of the last ice sheet.

## PLATE 1




Profile of Tom Swamp.

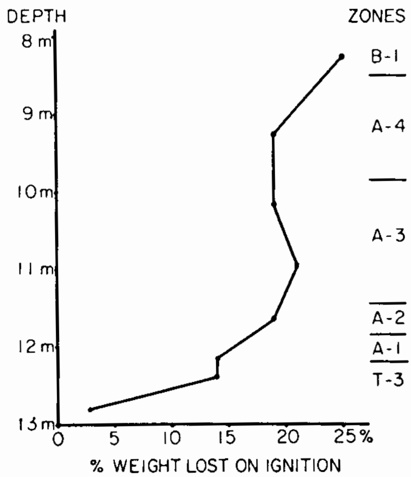



Fig. 3. Percentage loss on ignition of samples from Tom Swamp. Pollen zones are indicated to the right of figure.

Because slumping had occurred in the deeper parts of the bog, samples were collected from a peat face about 50 m east of the center of the bog. Here the stratigraphy was as follows:

| | |
|---|---|
| 0-119.5 cm | Dark brown, humified peat with logs and stumps |
| 119.5-195 cm | Fibrous, unoxidized peat |
| 195-218 cm | Gray gyttja |
| 218-225 cm | Diatomaceous gyttja, slightly sandy and silty |
| 225-240 cm | Gray gyttja, slightly sandy. A log, identified as *Populus*.[1] was found 5 cm to the east of the line of sampling at 230-240 cm depth |
| 240-270 cm | Silty and sandy gray gyttja, with sand lenses |
| 270-280 cm | Gray compact gyttja |
| 280-290 cm | Blue-gray sandy silt |
| 290 cm | Stratified sand, presumably outwash, of unknown depth, irregular surface, and maximum linear extent of about 6 m |

Ignition loss studies were carried out on the lowest three samples. The lowest gyttja sample (280 cm) was 4.8 percent organic by weight; the silt and sand samples (285 cm and 290 cm), by contrast, lost only 0.3 percent and 0.4 percent of their weight upon ignition.

The poplar log found at the 230-240 cm level was dated by radiocarbon analysis. The log, 40 cm long and 10 cm in diameter, was divided into two parts, which were submitted to the U. S. Geological Survey Radiocarbon Laboratory, Washington, D. C., and to the University of Michigan Phoenix

[1] Identification by Prof. E. S. Barghoorn, Harvard University.

Project Radiocarbon Laboratory. They were dated by the acetylene method at 10.800 ± 250 years BP (W-361) (Crane and Griffin. 1958), and by the carbon dioxide method at 10,700 ± 800 years BP (M-413) (M. Rubin, personal communication).

Flint (1956) believes that the maximum advance of Valders ice in Wisconsin occurred 10.700 years ago. The log appears to be contemporaneous with the early part of this advance, or the latter part of the preceding interstadial (Two Creeks). The layer of gyttja in which it was found (zone A-3, discussed below) is probably of the same age. The position of the log was horizontal, and there was no evidence of disturbance of the overlying layer of diatomaceous gyttja. However, we cannot exclude the possibility that the log sank through still soft gyttja to its present position, and is younger than the sediments in which it was imbedded.

*Gould's Bog.*—Gould's Bog is a small hillside swale 2.5 km (1.5 mi) NE of Tom Swamp, and about 5.5 km (3.5 mi) SE of Pleasant St. Bog (exact location 42°32′ N, 72°11′ W, elevation 1110 ft). Most of the swale supports a red maple forest, but a small area of about 500 square meters is open bog, with sedges, sphagnum, and a few low shrubs. The sluggish drainage stream is artificially dammed by a low (1 m) earthen embankment. Probings showed the deepest point in the bog to be near the center of the open area. Here samples for analysis were taken in June, 1957. The stratigraphy was as follows:

| | |
|---|---|
| 0-27 cm | Wet fibrous peat |
| 27-47 cm | Compact fibrous peat |
| 47-82 cm | Brown amorphous peat with wood fragments |
| 82-105 cm | Red-brown amorphous peat |
| 105-122.5 cm | Compact fibrous peat with grass and sedge leaves |
| 122.5-177 cm | Fine fibrous peat |
| 177-247 cm | Brown gyttja, with dark gray streaks at 230 cm, and 234-239 cm |
| 247-273 cm | Dark gray gyttja |
| 273-300 cm | Black gyttja; the color is apparently due to a ferrous sulfide which oxidizes to a rusty red color upon exposure to air |
| 300-318 cm | Black gyttja with gray silty streaks |
| 318-325 cm | Gray silt with black streaks |
| 325-350 cm | Light gray silty sand; it was not possible to penetrate deeper with the Hiller borer |

Ignition loss data based on samples from this site are shown in figure 4. The curve shows a gradual increase in the organic content of the gyttja above the 300 cm level, culminating in an abrupt increase as the sediment changes to compact fibrous peat at the 125 cm level. The significance of these changes will be discussed below.

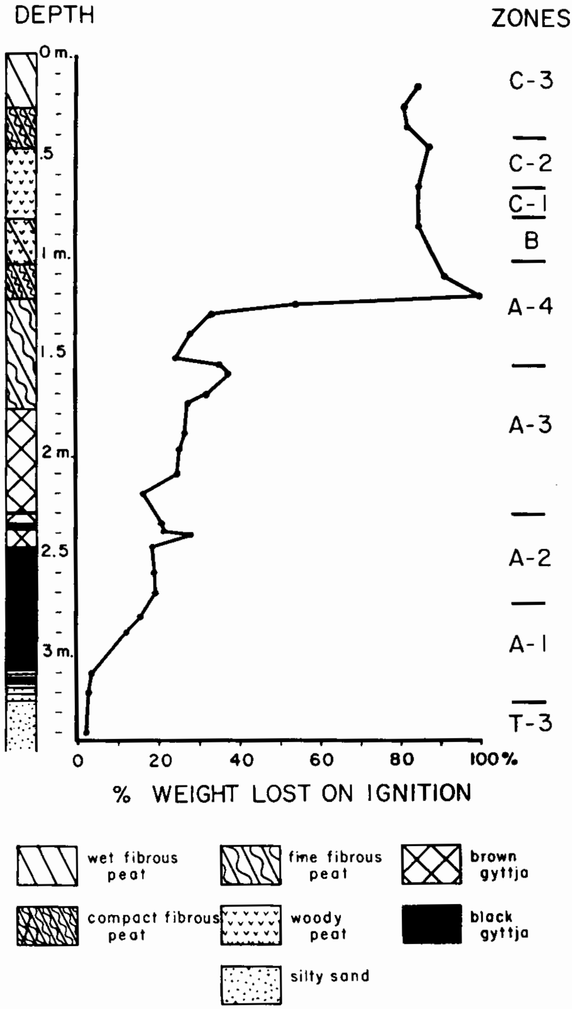



Fig. 4. Percentage loss on ignition of samples from Gould's Bog. Pollen zones are indicated to the right of figure.

## TECHNIQUES

Samples were collected from Tom Swamp and Gould's Bog with a Hiller borer equipped with a 50 cm barrel. Two holes about 25 cm apart were used alternately. Samples were collected directly with a spatula from the open section of peat at Pleasant St. Bog. Preparation of samples followed in general the procedure suggested by Faegri and Iversen (1950). Samples were treated with 70 percent HF, 10 percent KOH, and acetolysis mixture. Basic fuchsin was used as a stain. A few of the fibrous peat samples from Gould's Bog were strained through a brass screen before acetolysis.

The sand collected from the lowest levels of Tom Swamp and Pleasant St. Bog contained very little pollen. Furthermore, the minerals reacted with HF to form an insoluble residue. Warm 10 percent HCl followed by 50 percent $H_2SO_4$ was found effective in dissolving the residue. The bromoform flotation technique (Frey, 1951) was also used to separate the pollen from the residue. By these means it was possible to extract several hundred pollen grains from 2– or 3–g samples of sand. The sand beneath Gould's Bog was sufficiently rich in pollen that no special extraction techniques were necessary.

Samples were counted under a Zeiss apochromatic microscope. The oil immersion objective was used for all critical identifications, which were based on comparison with acetolyzed preparations of modern pollen. Percentages in samples from Tom Swamp and Pleasant St. Bog were calculated on the basis of a sum which includes all pollen except pollen of aquatic plants and pteridophyte spores. At Tom Swamp the percentage base includes at least 1000 grains, at Pleasant St. Bog, at least 700. At Gould's Bog, percentages were calculated on the basis of a sum which includes arboreal pollen (AP) only. At least 500 AP were counted in each sample.

## DESCRIPTION OF THE POLLEN DIAGRAMS

The pollen diagrams from Tom Swamp, Pleasant St. Bog, and Gould's Bog are presented as plates 2, 3, and 4. Percentages of minor constituents not shown on the diagrams are given in tables 1, 2, and 3. For convenience in discussion the diagrams have been divided into pollen zones, which correspond in general to those used by Deevey (1939, 1943) and Leopold (1955). The characteristics of the zones, starting with the earliest, are outlined briefly here and discussed in more detail below.

- T-3: Maximum of herbs, willow, alder, and *Juniperus-Thuja*.
- A-1: Poplar and birch maximum. Herbs and shrubs decline, spruce rises.
- A-2: Spruce maximum.
- A-3: Spruce minimum. Deciduous tree maximum, followed by maximum of pine.
- A-4: Spruce maximum.
- B-1: Rising pine. Larch, birch, and alder maximum.
- B-2: Pine maximum. Deciduous trees rising.
- C-1: Oak and hemlock maximum, beech rising.
- C-2: Hemlock minimum. Oak, pine, and hickory maximum.
- C-3: Hemlock, birch, oak, and chestnut maximum, followed by oak, pine, and chestnut.

*Zone T-3.*—Only 30 to 40 percent of the pollen in this zone is arboreal. Of the trees, pine (*Pinus*) is most abundant, with spruce (*Picea*), birch (*Betula*), and oak (*Quercus*) of secondary importance. Curiously enough, at Tom Swamp and Pleasant St. Bog the percentages of arboreal pollen, particularly pine, are higher in the sand underlying the bog than they are in the organic gyttja. This is not the case at Gould's Bog, where the entire zone is represented by comparatively pollen-rich silty sand. At Gould's Bog the percentages of oak (7 percent of total pollen), ash (*Fraxinus*), elm (*Ulmus*), and hickory (*Carya*) are slightly higher than at the other sites.

TABLE 1

Tom Swamp 16A: Pollen Percentages not Shown on Diagram

| depth in cm. | Armeria ? | Campanula | Chenopodiaceae | Coptis | Cruciferae | Impatiens | Liguliflorae | Polygonum scandens type | Rosaceae | cf. Dryas | Sanguisorba | cf. Saxifraga oppositifolia | Urticaceae | cf. Xanthium | Caprifoliaceae | Cornus | Rhus vernix | Viburnum | Castanea | Celtis | Juglans cinerea | Juglans nigra | Liquidambar | Equisetum | Liliaceae | Lycopodium selago | Lycopodium inundatum | Typha | Selaginella selaginoides | Potamogeton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 625 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .16 | .15 | — | .10 | — | — | — | — | .08 | — | — | .15 | — | — |
| 645 | — | — | .17 | — | — | — | — | — | .17 | — | — | — | — | — | — | — | — | — | — | — | .09 | — | — | — | .09 | — | — | .26 | — | .09 |
| 665 | — | — | — | — | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — |
| 685 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .08 | — | — | — | .08 | .08 | — | — | — | — | — | .08 | — | — |
| 705 | — | — | .09 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | .09 | — | — | — | .19 | — | — |
| 725 | — | — | .16 | — | .08 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | .08 | — | — | — | — | — | — | — | — | — |
| 745 | — | — | .09 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | — | — | .09 | — | — | — | — | — | — | — | — | — |
| 765 | — | — | .10 | — | — | .10 | — | — | — | — | — | — | — | — | — | — | .20 | — | — | — | — | — | — | — | — | — | — | — | — | .20 |
| 785 | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | — | .28 | — | .09 |
| 795 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | .09 | — | .09 |
| 805 | — | — | .07 | — | — | — | — | — | .07 | — | — | — | — | — | — | — | — | .07 | — | — | .22 | — | — | — | — | — | — | — | — | .07 |
| 815 | — | — | .17 | — | — | — | — | — | .17 | — | — | — | — | — | — | .11 | — | — | .17 | — | — | — | — | — | — | — | — | .17 | — | — |
| 825 | — | — | .11 | — | — | — | — | — | .32 | — | — | — | — | — | — | — | — | — | .11 | — | — | — | — | — | — | — | — | .74 | — | .42 |
| 835 | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | — | — | — | .09 | — | — | — | — | .09 | — | .18 | — | .28 |
| 845 | — | — | .08 | — | — | — | — | — | .08 | — | — | — | — | — | — | — | — | — | .26 | — | .08 | — | — | — | — | — | — | .42 | — | — |
| 855 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | .09 | — | — | — | — | — | .09 |
| 865 | — | — | — | — | — | — | — | — | .08 | — | — | — | — | — | — | — | — | — | .08 | — | — | — | — | — | — | — | — | — | — | .08 |
| 875 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | — | — | — | — | — |

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| 885 | — | — | .08 | .10 | — | — | — | .08 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .08 | — | — | — | .08 | — | — |
| 905 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | .10 | — | .10 |
| 915 | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 925 | — | — | — | — | — | — | .22 | — | — | — | — | — | — | — | — | — | — | .11 | — | — | — | — | — | — | .11 | — | — | .07 | — | .11 |
| 935 | — | .07 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .14 | — | .07 | — | — | — | — |
| 945 | — | — | — | — | — | — | — | — | .09 | — | — | — | .09 | — | — | — | — | .09 | — | — | — | — | — | — | — | .09 | — | — | — | .09 |
| 955 | — | — | — | — | — | — | — | — | .29 | — | .10 | — | — | — | .10 | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — |
| 975 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | — | .37 | — | — |
| 995 | — | — | — | — | — | — | — | — | .37 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 |
| 1015 | .06 | — | .06 | — | — | — | — | — | .18 | — | — | — | — | — | — | — | — | — | — | — | .06 | — | — | — | — | — | — | .30 | — | — |
| 1035 | — | — | .28 | — | — | — | — | — | .09 | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | — | — | — | — | .47 | — | — |
| 1055 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .28 | — | .76 |
| 1065 | — | — | .10 | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | .10 | — | — | — | — | .10 | — | — | — | .30 | — | — |
| 1075 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | .10 | — | — | .10 | — | — | — | .30 | — | .30 |
| 1095 | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | — | — | — | — | .53 | — | .10 |
| 1115 | — | — | — | — | — | — | — | — | .23 | — | — | — | — | — | — | — | — | — | — | — | .08 | — | — | — | — | — | — | .38 | — | .28 |
| 1135 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .54 | — | — | — | .77 | .15 | .77 |
| 1145 | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | — | .29 | — | — | — | .38 | — | .58 |
| 1155 | — | — | — | — | — | — | — | — | .09 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .35 | — | .18 | — | — | — | .18 |
| 1165 | — | — | .08 | — | — | — | .10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .08 | .08 | — | — | — | — | .08 |
| 1175 | — | — | — | — | — | — | — | — | .09 | — | — | .09 | — | — | — | — | — | — | — | — | .09 | — | — | .08 | .09 | — | — | .18 | — | — |
| 1185 | — | — | — | — | — | — | — | — | .20 | — | — | — | — | .10 | — | — | — | — | — | — | — | — | — | — | .10 | .10 | — | .20 | — | .10 |
| 1195 | — | — | .09 | — | — | — | — | — | .09 | .09 | — | — | — | — | — | — | — | .18 | — | — | .09 | — | — | .18 | .09 | .09 | — | .27 | — | .62 |
| 1215 | — | — | .16 | — | — | — | — | — | .16 | — | .08 | .08 | — | — | — | — | — | — | — | — | — | — | — | .31 | — | .08 | — | .39 | — | .70 |
| 1225 | — | — | — | — | .18 | — | — | — | .55 | — | .09 | — | — | — | — | — | — | .09 | .20 | — | — | — | — | .55 | — | — | .09 | .09 | — | .82 |
| 1235 | — | .10 | — | — | — | — | — | — | .70 | — | — | .20 | — | — | — | — | — | — | — | — | — | — | — | .10 | .20 | — | — | .10 | — | .50 |
| 1245 | — | .10 | .10 | — | — | — | — | — | .93 | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | .31 | — | — | — | — | — | .21 |
| 1255 | — | — | — | — | — | — | — | — | .34 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .34 |
| 1265 | — | — | — | — | — | — | — | — | .57 | — | — | .57 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .28 | — | 1.14 |
| 1270 | — | — | — | — | — | — | — | — | .72 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1285 | — | — | 1.75 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

Of the shrubs, alder (*Alnus*), willow (*Salix*), and the heaths (*Ericaceae*) are the most important. As willow tends to be underrepresented in pollen spectra (Iversen, 1947), this genus may have been the most abundant shrub. It is not known whether the Cupressineae pollen in zone T-3 represents an arctic shrub juniper (*Juniperus communis* var. *saxatilis*), a temperate shrub juniper (*J. communis* var. *depressa*), red cedar (*J. virginiana*), white cedar (*Chamaecyparis thyoides*), or arbor vitae (*Thuja occidentalis*). In any case, the percentages found here are low in comparison with the frequency of 10 percent reported from the late-glacial of Michigan (Andersen, 1954).

The dominant herbaceous types are sedges (Cyperaceae) and grasses (Gramineae). However, a wide variety of other flowering species are represented; the number of different pollen types found in each sample exceeds that found in samples from any of the other zones. The herbs found in zone T-3 fall into three categories: (1) genera or families which have both arctic and temperate species, (2) species which have a northern or arctic-alpine distribution, and (3) genera which occur in temperate regions only.

By far the largest proportion of the herbs identified fall in the first category. Many of the genera, such as *Artemisia, Thalictrum, Potentilla,* and *Rumex*, are characteristic of the Late-glacial of Europe.

Very few species can be put in the second category. *Saxifraga oppositifolia*, now arctic-alpine in distribution, has been tentatively identified from Tom Swamp and Pleasant St. Bog. A single grain of the *Polygonum bistorta* type was found at Gould's Bog. It most closely resembles *P. bistortoides*, which now grows in subalpine meadows in Newfoundland (Fernald, 1950). *Lycopodium selago* spores, distinguished tentatively on the basis of size from *L. lucidulum* (Leopold, 1955), were found in T-3 and the spruce zones. *L. selago* is arctic-alpine, but occurs on monutains as far south as North Carolina (Blomquist, 1934). Pollen of *Hippuris* cf. *vulgaris* was found at Gould's Bog in the spruce zones. This species now ranges in arctic regions and south to northern New England and northern New York state (Fernald, 1950). Microspores of *Selaginella selaginoides*, which has a similar range, were also found in the spruce zones. A few of the rosaceous pollen grains were tentatively identified as *Dryas*. Although *Dryas* is typically arctic-alpine, two of the American species range well into the boreal forest (Raup, 1947). *Sanguisorba canadensis*, although typically boreal, has a sporadic range far to the south (Fernald, 1950). On the whole, the evidence for an arctic element in the flora is rather tenuous. The species named above may indicate cool climates, but they cannot be used as conclusive evidence of a climate similar to that of the Canadian Arctic.

There is, however, good evidence for a temperate element in the herbaceous flora. *Polemonium*, for example, is a genus of temperate distribution in the northeast (except for a Greenland species). *Ambrosia, Plantago rugellii,* the Chenopodiaceae, and some of the species of the Tubuliflorae and Liguliflorae are now troublesome agricultural weeds in temperate regions. Their appearance in zone T-3 is analogous to the occurrence of a temperate element in the Late-glacial flora of Europe, where the temperate herbs disappeared almost

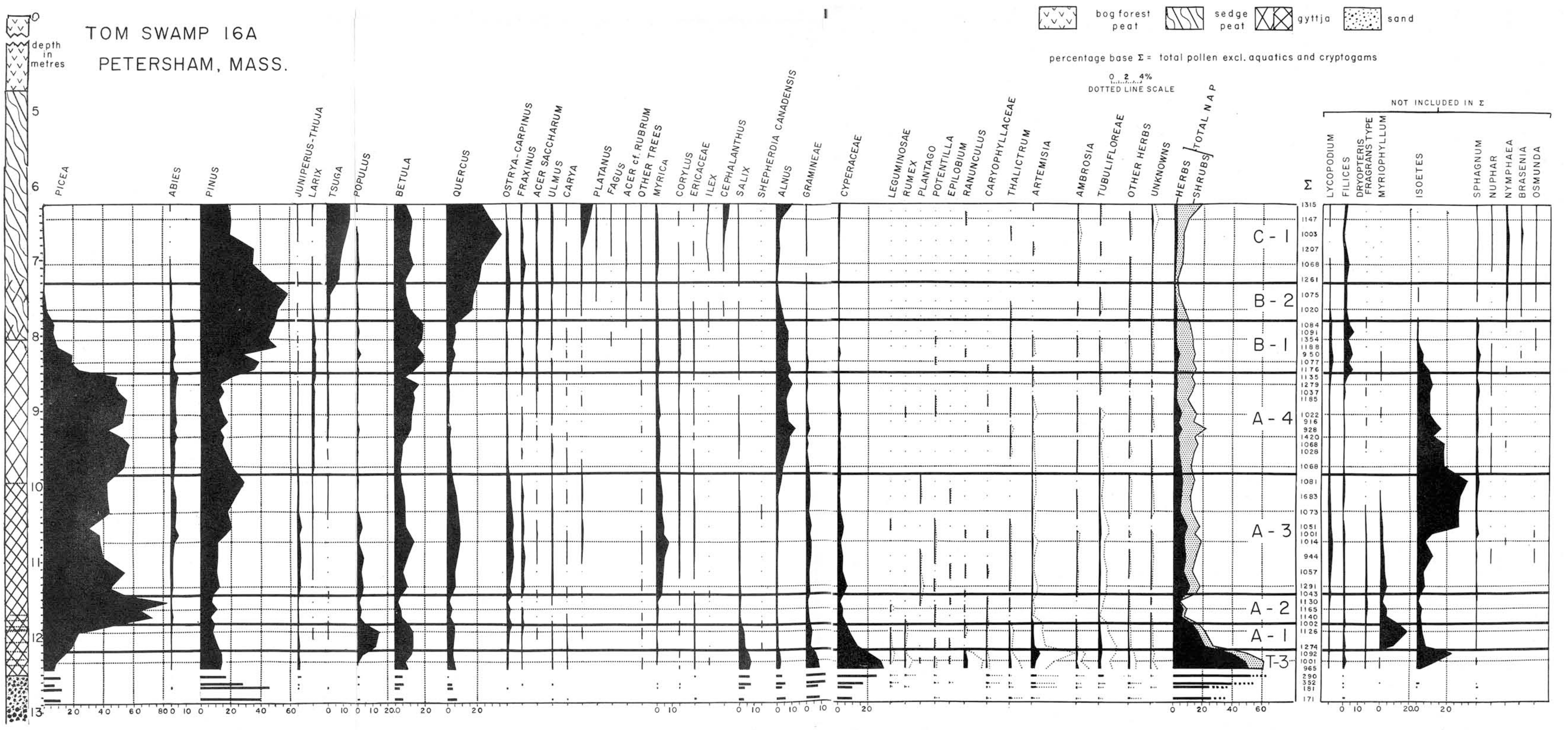


PLATE 2
Pollen diagram from Tom Swamp.

entirely with the advent of Postglacial forests, to reappear much later as agricultural weeds (Iversen, 1954).

Zone T-3, then, is characterized by (1) high percentages of non-arboreal pollen; (2) a wide variety of herbaceous types, some of them of northern distribution; and (3) genera with high light requirements, such as *Epilobium*, *Campanula*, *Ambrosia*, the Chenopodiaceae, the Caryophyllaceae, *Thalictrum*, *Artemisia*, the Cupressineae (except arbor vitae), and many of the heaths and willows.

*Zone A-1.*—This zone is characterized by a maximum of poplar (*Populus*) and birch. Most of the poplar pollen is of the *P. balsamifera* type. Willow percentages remain high. The herbs are less frequent than in the preceding zone, but still abundant; the Tubuliflorae reach a maximum. The spruce curve begins to rise; pine percentages decrease. Pollen of *Sheperdia canadensis*, a shrub which is found in open spruce forest (Raup, 1947), occurs at all three sites.

Some interesting changes take place in the spectra of aquatic plants. At Tom Swamp, the *Isoetes* which characterized the preceding zone is replaced by *Myriophyllum*; at Pleasant St. Bog there is a low maximum of *Myriophyllum* and *Potamogeton*; at Gould's Bog the sediment changes from silty sand to gyttja, and *Isoetes* attains high percentages.

*Zone A-2.*—Spruce reaches a maximum of nearly 60 percent total pollen at Pleasant St. Bog, and 51 percent total pollen (64 percent AP) at Gould's Bog. At both sites oak, hop-hornbeam or ironwood (*Ostrya-Carpinus*), and ash percentages are rising. At Tom Swamp spruce makes up 83 percent of the total pollen; other pollen percentages have minima which appear to represent relative, rather than absolute, changes in frequency.

*Zone A-3.*—In this zone spruce declines to 30-40 percent. The pollen flora is rich. Poplar, juniper (cedar or arbor vitae?), *Dryopteris fragrans* type, and many of the herbs that characterized the preceding zones are still present. Club mosses (*Lycopodium*) are abundant. Oak, hop-hornbeam, ash, beech (*Fagus*), sugar maple (*Acer sacharrum*), elm, and a few other deciduous trees are at a maximum. Fir (*Abies*) percentages increase. Pine rises to a maximum of over 20 percent in the upper part of the zone.

The frequencies of a few of the pollen types vary from one site to another, and appear to reflect local, rather than regional changes. The birch maximum at Tom Swamp appears related to the *Myrica* maximum there. At Gould's Bog, the high frequency of sedges may represent a local marsh vegetation; the increase of grasses, Tubuliflorae, sphagnum and *Myrica* appears related to the change there from gyttja to fibrous peat.

*Zone A-4.*—In this zone spruce again reaches a maximum. Fir percentages remain constant; larch (*Larix*), birch, and alder percentages increase. Oak, hop-hornbeam, ash, elm, sugar maple, and beech frequencies decline to low levels.

At Tom Swamp the gyttja changes color from gray to gray-green. *Isoetes* and sphagnum are abundant. At Pleasant St. Bog, there is a layer of diatomaceous gyttja; *Isoetes* and sphagnum are at a maximum; pollen preservation is poor. At Gould's Bog, *Myrica*, alder, grasses, Tubuliflorae, *Potentilla*, sphag-

TABLE 2

Pleasant St. Bog: Pollen Percentages not Shown on Diagram

| depth in cm. | Astragalus alpinum | Batrachium | Chenopodiaceae | Epilobium | cf. Gentiana | Liguliflorae | cf. Oxyria digyna | Rosaceae | cf. Dryas | Sanguisorba | cf. Saxifraga | Urticaceae | Xanthium | Cornus | Acer cf. rubrum | Carya | Castanea | Celtis | Juglans cinerea | Nyssa | Platanus | Tilia | Ulmus | Equisetum | Eriocaulon | Lycopodium inundatum | Lycopodium selago | Osmunda | Selaginella selaginoides |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 110 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .60 | — | — | — | — | — | .12 | — | .36 | — | — | — | — | — | — |
| 115 | — | — | — | — | — | — | — | .21 | — | — | — | — | — | — | .21 | .21 | — | — | .10 | .10 | — | .10 | 1.05 | — | — | .21 | — | — | — |
| 120 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .28 | .41 | — | .28 | .14 | — | .28 | .14 | .83 | — | — | .41 | — | — | — |
| 130 | — | — | — | — | — | — | — | .12 | — | — | — | — | — | — | .25 | — | .12 | — | — | — | .12 | .12 | 1.01 | — | .12 | — | — | — | — |
| 140 | — | — | — | — | — | — | — | .34 | — | — | — | — | — | — | .45 | .34 | .11 | .11 | — | — | — | — | .67 | — | .11 | — | — | — | — |
| 150 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .64 | .13 | .26 | — | — | — | .13 | — | 1.03 | — | — | — | — | .13 | — |
| 155 | — | — | .27 | — | — | — | — | .18 | — | — | — | — | .09 | — | .18 | .09 | — | — | — | — | — | — | .55 | — | — | — | — | — | — |
| 160 | — | — | — | — | — | — | — | .12 | — | — | — | — | — | — | — | .12 | — | — | — | — | .25 | — | 2.12 | — | — | .25 | — | — | — |
| 166 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .59 | — | .24 | — | — | — | — | — | .59 | — | — | — | — | — | — |
| 171 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .27 | — | — | — | — | — | .18 | — | 1.52 | — | — | — | — | — | — |
| 177 | — | — | — | — | — | — | — | — | — | — | — | — | — | .06 | .34 | .06 | .06 | — | — | — | .11 | — | .96 | — | — | — | — | — | — |

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| 182 | .10 | — | — | — | — | — | — | .10 | — | — | — | — | — | — | .39 | .20 | — | — | — | — | .10 | — | .98 | — | — | — | — | — | — |
| 187 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .09 | .09 | — | — | .18 | — | — | — | .72 | — | — | — | — | — | — |
| 195 | — | — | .08 | — | — | — | — | — | — | — | — | — | — | — | .33 | .04 | .04 | — | .08 | — | — | — | .70 | — | — | — | — | .04 | — |
| 200 | — | .16 | — | — | — | — | — | .08 | — | — | — | .08 | — | — | .17 | — | .08 | — | .17 | — | — | — | .60 | — | — | — | — | — | — |
| 210 | — | — | — | — | — | — | — | .20 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .27 | — | — | — | — | — | — |
| 215 | — | — | — | — | — | — | — | .47 | — | — | — | — | — | — | — | .16 | — | — | — | — | — | — | .62 | — | — | — | — | — | — |
| 220 | — | — | — | — | — | — | — | .14 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .14 | .14 |
| 225 | — | — | .16 | — | — | — | — | .31 | — | — | — | — | — | — | — | .08 | — | — | — | — | — | — | .55 | — | — | — | — | — | — |
| 230 | — | — | — | — | — | — | — | .45 | — | — | .11 | — | — | — | — | — | — | — | — | — | — | — | .23 | .11 | — | — | — | — | — |
| 235 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .10 | — | — | — | — | — | — | .40 | — | — | — | — | — | — |
| 245 | — | — | — | — | .15 | — | — | — | — | — | — | — | — | — | — | .15 | — | — | — | — | — | — | — | — | — | — | — | .15 | — |
| 250 | — | — | — | .29 | — | — | .14 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .14 | — | — | — | .14 | — | — |
| 255 | — | — | .13 | — | — | — | — | .13 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 260 | — | — | — | — | — | .12 | — | .12 | — | — | — | — | — | — | — | .12 | — | — | — | — | — | — | — | — | — | — | .12 | — | — |
| 265 | — | — | .11 | — | — | — | — | .11 | — | — | — | — | .11 | — | — | — | .11 | — | — | — | — | — | — | .11 | — | — | — | — | — |
| 270 | — | — | — | — | — | — | — | 1.69 | — | — | — | — | .15 | — | — | .15 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 275 | — | — | — | — | — | — | — | .29 | .29 | .29 | — | — | — | — | — | — | — | — | — | — | — | — | .15 | — | — | — | — | — | — |
| 280 | — | — | — | — | — | — | — | 1.10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 285 | — | — | — | — | — | — | .15 | — | .15 | — | .15 | — | .15 | — | — | — | — | — | .15 | — | — | — | .30 | — | — | — | — | — | — |
| 290 | — | — | — | — | — | — | — | .29 | — | — | — | — | — | — | — | .58 | — | — | — | — | — | — | .29 | — | — | — | — | — | — |

num, and ferns (Polypodiaceae) reach a maximum; *Isoetes* declines in frequency. As the peat becomes compact and fibrous, there is a strong maximum of sedge pollen.

*Zones B-1 and B-2.*—Zone B is characterized by a maximum of pine. At Tom Swamp and Pleasant St. Bog, where there are more samples from this zone, the pine maximum has been subdivided into two zones. In zone B-1, spruce and fir decline rapidly, pine rises, and oak and other deciduous trees begin to increase in frequency. There is a maximum of birch, alder, and larch. Club mosses, ferns, and sphagnum are abundant. At all three sites there is a change from more aquatic to a more terrestrial type of peat. At Gould's Bog, aquatic plant pollen is entirely absent; apparently the alder, ferns, and sphagnum are part of the bog vegetation.

In zone B-2, larch, birch, and alder percentages decrease, and oak and other deciduous trees become more abundant. Hemlock (*Tsuga*) frequencies begin to rise. At Gould's Bog there is a maximum of ferns (*Polypodiaceae* and *Osmunda*), and of the bog shrubs buttonbush (*Cephalanthus*), sumac (*Rhus*), and black alder (*Ilex*).

*Zone C-1.*—Zone C-1 is the first zone that is dominated by pollen of deciduous trees. Hemlock and oak are at a maximum. Sugar maple, ash, elm, and sycamore (*Platanus*) are present. Basswood (*Tilia*), hackberry (*Celtis*), and black walnut (*Juglans nigra*) occur in low frequencies (these three genera also occur in the spruce zone at Gould's Bog). Beech rises to a maximum along the C-1—C-2 border.

At Pleasant St. Bog there is a change from fibrous peat to bog forest peat in the upper part of this zone; the rising alder, birch, and Tubuliflorae percentages appear to reflect this change. At Tom Swamp, as well, the frequencies of bog plants such as buttonbush, sumac, and alder indicate that the bog was filling in rapidly. Apparently the maximum of birch and black gum (*Nyssa*) at Gould's Bog reflects a similar change.

*Zone C-2.*—Samples from this zone and zone C-3 were analyzed at Gould's Bog only. Consequently it is not known to what extent the pollen frequencies record local rather than regional vegetational changes. Zone C-2 is characterized by a hemlock minimum. Sugar maple, elm, and possibly basswood are also at a minimum. Hickory, which is so characteristic of this zone further south (Deevey, 1939, 1943, 1948), reaches a maximum frequency of 2 percent AP. Oak, followed by pine, has a strong maximum.

*Zone C-3.*—Zone C-3 is characterized by a return of hemlock, sugar maple, and elm, and a sudden rise in chestnut (*Castanea*). Ash also increases in frequency. Birch reaches a maximum in the lower part of the zone, but in the upper levels birch and hemlock decline and pine rises to a maximum. The sediment at Gould's Bog changes from bog forest peat to fibrous peat. Above the change, pollen of local bog plants (including spruce?) becomes abundant. No agricultural indicators, such as maize pollen or the pollen of European weed species, were found. Consequently the uppermost sample is thought to date from late precolonial time.

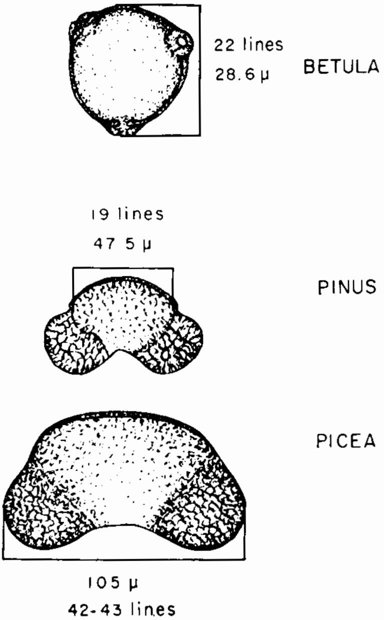


Fig. 5. Scale drawings of pollen from the 8.25 m. level of Tom Swamp, boring 16A. The black line indicates the dimension of the grain measured.

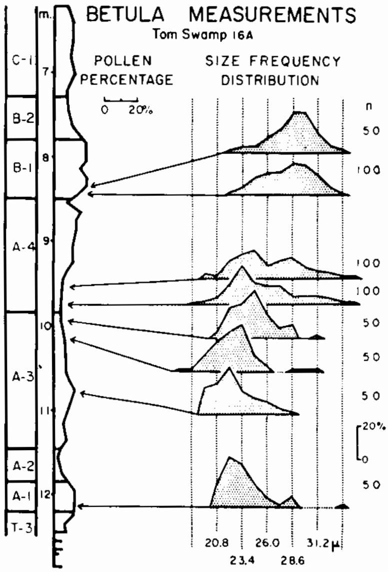


Fig. 6. Size-frequency distributions of birch pollen in 8 samples from Tom Swamp, boring 16A.

## MEASUREMENTS OF POLLEN SIZE

In an attempt to make species identifications, pollen of birch, pine, and spruce was measured in samples from Tom Swamp. The method in each case was to use thick glycerine mounts which facilitated rotation of the grains. The delta (distance between ocular lines) used for birch measurements was 1.3 μ, for pine 2.5 μ, for spruce 5μ. The way in which the micrometer was positioned over the grains is shown in figure 5. Only samples in which preservation was excellent were used. Pollen which was broken, distorted, or poorly preserved was not measured.

*Birch.*—It is clear from the size frequency data (see fig. 6) that at least two types of birch are present. A type with small to medium-sized pollen (mode at about 23 μ) predominates in zones A-1 and A-3, and is replaced gradually in zone A-4 by a type with large pollen (mode at about 29 μ). The presence of bimodal curves in zone A-4, when both types are present, indicates that these size changes are not due to differential changes incurred during fossilization. A less complete series of measurements in four samples from Pleasant St. Bog confirm these results. We can only speculate as to which species are represented. The available data on the pollen size of the northeastern American birches (see Leopold, 1956a) shows that the size distributions of many species overlap, and that the size of different individuals of the same species may vary considerably. The shrub birches and at least one of the tree birches have small to medium-sized pollen, and the tree birches have medium-sized to large pol-

TABLE 3

Gould's Bog: Pollen Percentages not Shown on Diagram

| depth in cm. | Celtis | Juglans cinerea | Juglans nigra | Cornus | Corylus | Viburnum | Vitaceae | Chenopodiaceae | Cruciferae | Gallium | Labiatae? | Liguliflorae | Plantago | Polygalaceae? | Umbelliferae | Hippuris cf. vulgaris | Liliaceae | Nymphaea | Potamogeton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | — | .35 | — | — | .18 | .18 | — | .18 | — | .18 | .18 | — | — | — | — | — | — | — | — |
| 15 | — | .20 | .10 | — | — | .10 | — | — | — | .20 | — | — | .30 | — | — | — | — | — | — |
| 20 | — | .36 | — | — | .12 | — | — | — | .24 | — | .12 | — | — | — | — | — | — | — | — |
| 25 | — | — | — | — | .31 | — | — | — | .31 | — | — | .09 | .31 | — | — | — | — | — | — |
| 30 | — | — | — | — | .18 | .18 | — | — | — | — | — | — | — | — | — | — | .31 | — | — |
| 35 | — | .19 | — | — | .19 | .57 | — | .19 | — | .19 | — | — | .19 | — | .38 | — | — | — | .38 |
| 40 | — | — | .26 | — | .13 | — | — | .13 | — | — | — | — | — | — | — | — | — | — | — |
| 45 | — | .08 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 55 | — | — | — | — | .09 | — | — | — | — | — | — | .09 | — | — | — | — | — | — | .09 |
| 60 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 65 | — | — | — | — | — | — | — | — | .07 | — | — | — | — | — | — | — | — | — | — |
| 70 | — | .16 | — | — | — | — | — | .31 | — | — | — | — | — | — | — | — | — | — | — |
| 75 | — | — | .09 | — | .09 | .09 | — | .09 | — | — | — | — | — | .09 | — | — | — | — | — |
| 80 | — | .15 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 85 | — | — | — | — | .16 | — | — | — | .16 | — | — | — | — | — | — | — | — | — | — |
| 95 | — | — | — | — | .76 | — | — | .13 | — | — | .13 | — | — | — | — | — | — | — | — |
| 102 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 105 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 110 | — | — | — | — | .22 | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 115 | — | — | — | — | — | — | — | — | — | .35 | — | — | — | — | — | — | .17 | — | — |
| 120 | — | — | — | — | .18 | — | — | — | — | .18 | — | — | — | — | — | — | — | — | — |
| 125 | — | — | — | — | .41 | .41 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 135 | — | — | — | .10 | .20 | — | — | — | — | — | — | — | — | — | — | .20 | — | .20 | — |
| 145 | — | — | — | — | .29 | — | — | — | — | .14 | — | — | — | — | — | — | — | — | — |
| 155 | — | — | — | .14 | .27 | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 165 | — | — | — | — | .34 | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 170 | — | — | — | — | — | — | — | .14 | — | — | — | .29 | — | — | — | — | — | — | — |
| 180 | — | .11 | — | .34 | .34 | — | — | — | — | — | — | — | — | — | — | — | — | — | .11 |
| 185 | — | — | — | — | — | — | .12 | — | — | — | — | — | — | — | — | .12 | — | — | — |
| 195 | — | — | — | — | .15 | .15 | — | — | — | — | — | — | — | — | .15 | — | — | — | — |
| 205 | — | — | — | .16 | .49 | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 215 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 225 | — | — | — | — | — | — | — | — | — | .23 | — | — | — | — | — | — | — | — | — |
| 235 | — | — | — | — | .19 | — | — | .19 | — | — | — | — | — | — | — | — | — | — | .19 |
| 239 | — | .16 | — | — | .31 | — | — | — | — | — | — | — | — | — | .31 | .16 | — | — | — |
| 245 | — | — | — | — | .17 | — | — | — | — | — | — | — | — | — | .17 | — | — | — | — |
| 252 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | .16 | — | — | — |
| 255 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 265 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 270 | — | — | — | — | .31 | .31 | — | — | — | — | — | — | — | — | — | — | — | — | .13 |
| 275 | .18 | — | — | — | .18 | — | — | .18 | — | — | — | — | — | — | — | — | — | — | — |
| 285 | — | — | — | — | .14 | — | .14 | — | — | .14 | — | — | — | — | — | — | — | — | — |
| 295 | — | — | — | — | .16 | — | — | — | — | — | — | — | — | — | — | .22 | — | — | .16 |
| 298 | — | — | .15 | — | — | — | — | — | — | .15 | — | — | — | — | — | — | — | — | — |
| 305 | — | .18 | — | — | — | — | — | .18 | — | — | — | — | — | — | .18 | — | — | — | — |
| 315 | .18 | — | — | — | — | .18 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 325 | — | — | — | — | — | — | — | — | — | — | — | — | .27 | — | — | .54 | — | — | — |
| 335 | — | .33 | — | — | — | — | — | — | — | — | — | — | — | — | .33 | — | — | — | — |
| 345 | — | — | — | — | 1.37 | — | — | .34 | — | — | — | — | — | — | — | — | — | — | — |

len (Leopold, 1956a). If the absolute size of modern and fossil pollen can be compared, the 29 μ mode may represent tree birches with large pollen, such as yellow birch (*Betula lutea*) and white birch (*B. papyrifera*). The 23 μ mode may represent a shrub birch with small pollen, such as *B. glandulosa*, or gray birch (*B. populifolia*), a tree birch with small pollen. The data indicate, therefore, that tree birches are present in A-4 and predominate in B-1, and that shrub birch or gray birch may be present in zones A-1, A-3, and A-4.

*Pine.*—There are also two modes in the size frequency distributions of pine pollen (see fig. 7). In A-3, A-4, and B-1 the population is dominated by a pine with a pollen size of about 47 μ. In A-4 a small proportion of the population has pollen with a mode at about 60 μ. The latter type increases rapidly in late B-1 and predominates in zone B-2. The slight shift in the mode of the small-sized pollen to a larger size-class in early A-4 is thought to be due to a difference in preservation; the birch at these levels also has a larger absolute size (cf. Wenner, 1953).

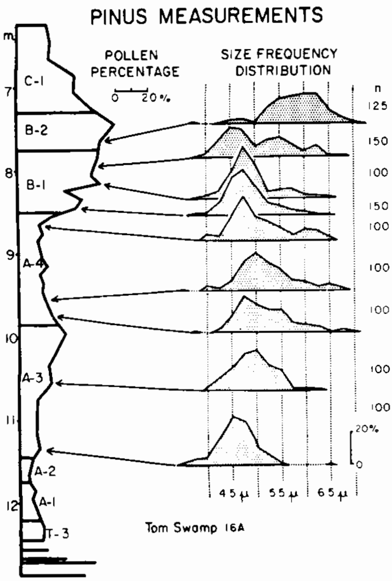


Fig. 7. Size-frequency distributions of pine pollen in 9 samples from Tom Swamp, boring 16A.

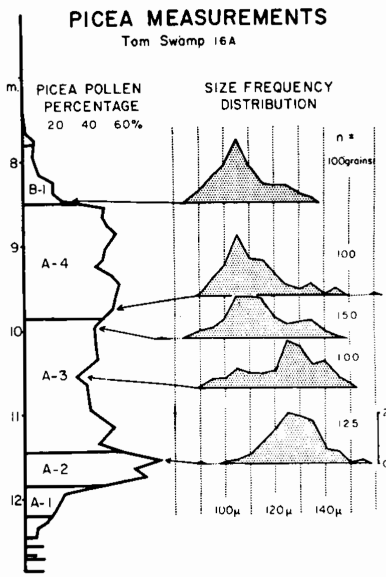


Fig. 8. Size-frequency distributions of spruce pollen in 5 samples from Tom Swamp, boring 16A.

Measurements of modern pollen indicate that certain of the eastern species of pine may be distinguished on the basis of pollen size (Cain and Cain, 1948; S. A. Cain, personal communication). These authors have found that the mean size of the internal diameter of acetolized pine pollen is as follows:

| | |
|---|---|
| *Pinus rigida* (10 collections) | 55.16 μ, σ 3.12 μ |
| *P. strobus* (9 collections) | 50.38 μ, σ 4.03 μ |
| *P. resinosa* (10 collections) | 46.00 μ, σ 2.85 μ |
| *P. banksiana* (12 collections) | 45.06 μ, σ 2.83 μ |

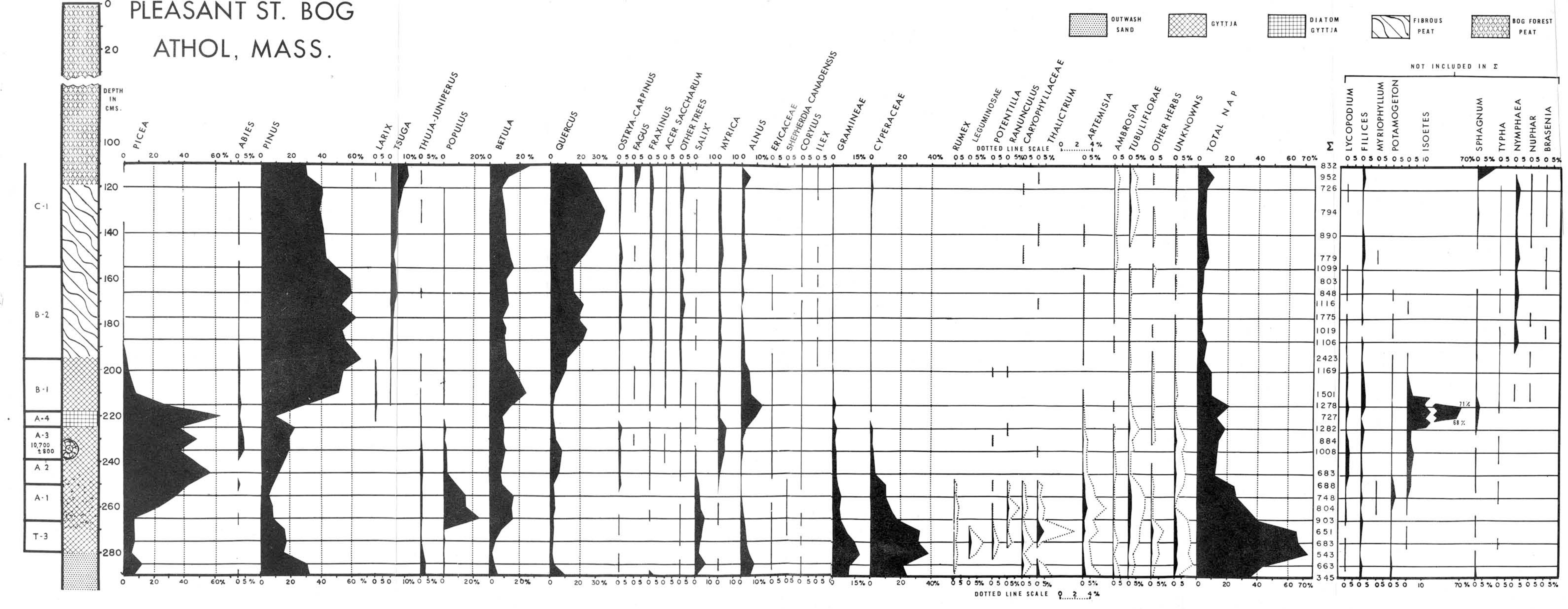


PLATE 3
Pollen diagram from Pleasant St. Bog.

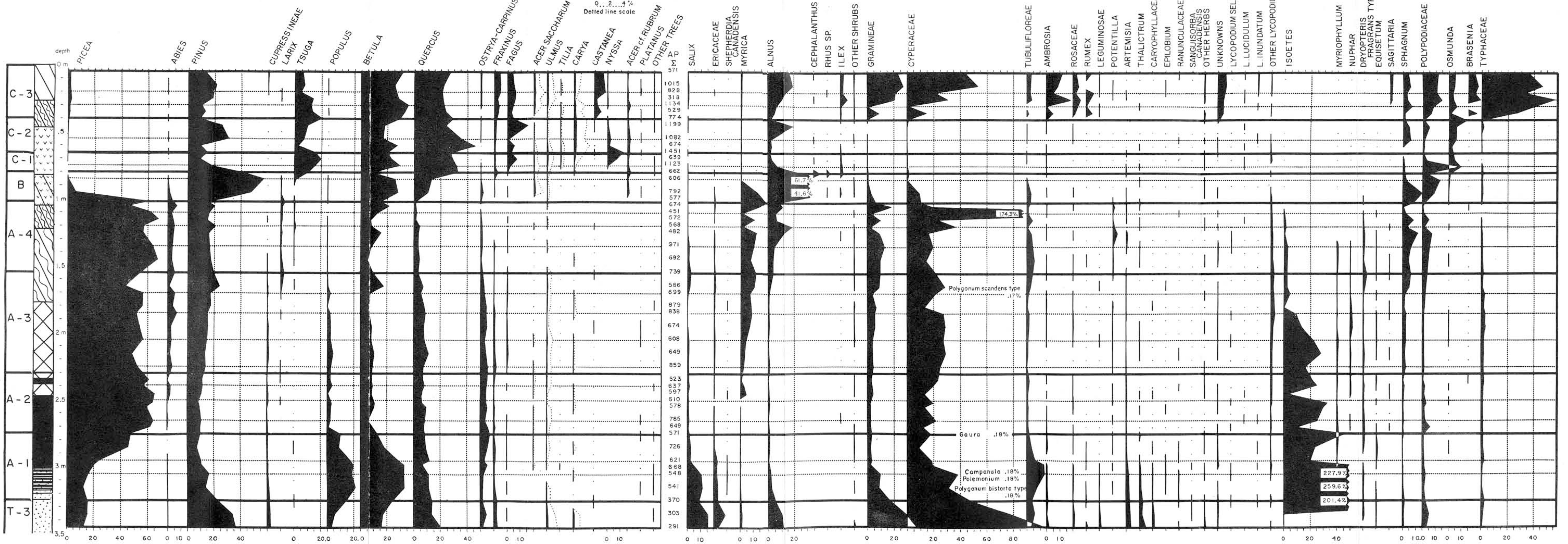


PLATE 4

Pollen diagram from Gould's Bog, Petersham, Mass. Percentage base Σ includes arboreal pollen only. Peat signatures are indicated in fig. 4.

On the basis of these data, the 47 μ mode may represent jack pine (*P. banksiana*) and/or red pine (*P. resinosa*). The mode at 60 μ may represent a mixed population of white and pitch pine (*P. strobus* and *P. rigida*).

*Spruce.*—Size measurements of spruce pollen (see fig. 8) indicate that two types of spruce are present. Spruce with large pollen predominates in the lower spruce maximum (zone A-2), and spruce with small pollen predominates in the upper spruce maximum (zone A-4). Apparently both types are present in the intervening spruce minimum (zone A-3). Studies of the size frequency distribution of modern spruce pollen indicate that the average size of white spruce (*Picea glauca*) and red spruce (*P. rubens*) pollen is significantly larger than that of black spruce (*P. mariana*). The internal diameter of acetolyzed preparations of white spruce pollen (8 collections) averages 80.36 μ, red spruce (8 collections) 76.59 μ, and black spruce (3 collections) 62.17 μ (Cain, 1948; S. A. Cain and S. T. Andersen, personal communication).

As total grain length of the fossil spruce pollen, rather than internal diameter, was measured, the data cannot be compared directly with the measurements of modern pollen. However, as there are clearly two spruce types present, it seems safe to conclude that the spruce with large pollen in the lower spruce maximum is white or red spruce, and that the spruce with small pollen in the upper spruce maximum is black spruce. Spruce pollen could not be measured systematically in samples from the other sites because of the comparatively poor pollen preservation. However, the few measurements that were made of spruce pollen from Gould's Bog support the above conclusions. All spruce pollen from the maximum in zone C-3 at this site fell within the size range of black spruce.

## INTERPRETATION OF THE POLLEN DIAGRAMS

The similarity of the three diagrams indicates that the vegetational sequence they record is regional in character. Probably a wide area in central Massachusetts had a similar vegetational history subsequent to the retreat of the ice. A knowledge of the vegetational sequence is of value in itself, but it is interesting to speculate on the factors which may have controlled it.

Interpretation of the diagrams is not easy. Because some plants produce pollen more abundantly than others, the frequency of the pollen of a genus or species in a pollen spectrum is not directly proportional to the frequency of that genus or species in the surrounding vegetation. The resulting difficulty in visualizing the vegetation represented by a pollen spectrum is illustrated by the uppermost sample from Gould's Bog. This sample is thought to date from late pre-colonial time. The tree pollen spectrum in the sample is dominated by birch and oak, with pine, chestnut, hemlock, ash, and beech of lesser importance. There is abundant pollen of non-arboreal plants, principally sedges, grasses, alder, and aquatic plants. By contrast, it is thought (Raup and Carlson, 1941) that the precolonial landscape was heavily forested, with oak, chestnut, and hickory on upland soils, and forests of birch, beech, maple, ash, elm, and hemlock on moist lowland sites. Pine was relatively unimportant. In the pollen spectrum, the pollen of herbs and aquatic plants is abundant because of their proximity to the site of deposition. Of the trees, birch and pine, which produce abundant pollen, are overrepresented, while the maples and hickories, which produce less pollen, are underrepresented. It is well to keep these facts in mind in interpreting the diagrams. Changes in the relative abundance of the different pollen types, rather than the actual percentages, must be used to reconstruct the vegetation of the past.

Additional information is given by the presence or absence of the pollen of species which are known to occur only in certain types of environments. Unfortunately it has not been possible in most cases to make positive species identifications. Most American genera are so wide-ranging that their presence or absence yields little detailed ecological information. Furthermore one must assume, probably fallaciously, that the ecological requirements of species have remained stable since the last glaciation. An additional difficulty is presented by the irregular topography of the Petersham region. A wide variety of habitats are found there today, and presumably just as great a variety existed in the past. Thus the presence of the pollen of a species which occurs today in one type of environment does not preclude the possibility that plants typical of other types of environments were able to grow in the vicinity at the same time.

In the following discussion an attempt will be made to visualize the vegetation of the Petersham region in the past, and to inspect the edaphic and climatic factors that may have been responsible for the changes that are recorded. More than one interpretation of the diagrams is possible. The interpretation presented here, in the writer's opinion, fits best with the available data. Additional pollen diagrams from southern New England, more refined techniques of pollen identification, and a better understanding of the factors that control the present distribution of the species and genera involved are needed to test the validity of the interpretation.

*Zones T-3, A-1, and A-2.*—In the writer's opinion, zone T-3 represents an interval immediately following the retreat of the ice when a pioneer vegetation of shrubs and weedy herbs predominated. Frost-stirring, encouraged by the lack of forest cover (Goodlett, 1954), and landslides caused by the melting of buried ice, made the soil unstable. Strong winds deposited silt on the uplands. Under these conditions, only sheltered habitats on well-drained soils were suitable for the growth of trees. On these sites jack (or red) pine, white (or red) spruce, birch (perhaps shrub birch?), oak, and possibly other deciduous trees may have had a scattered distribution.

The evidence for this interpretation is the strong maximum of nonarboreal pollen at all three sites. It could be argued that the herbs were growing locally on the surface of bogs, but there is no indication from the sediments that the lakes were filling in with bog vegetation. The presence of many shade-intolerant herbs and shrubs is further evidence for an open, treeless vegetation.

Was the vegetation of zone T-3 a tundra? This question is hard to answer, because of the variety of vegetational types that are included under this heading. In a floristic sense, it was not a tundra. Many genera which never grow in tundra regions were found in this zone, and no species that are characteristic of tundra regions alone were identified positively. Although the vegetation of zone T-3 may have resembled a tundra in aspect, the name tundra would be misleading. "Tundra" implies to most people a vegetation which is treeless because the climate is too cold to allow the growth of trees. There is as yet no conclusive evidence that the climate of T-3 was arctic. Only the presence of *Saxifraga oppositifolia*, which was tentatively identified argues for a tundra climate. The other species with a northerly distribution that were found in T-3 and the succeeding zones, such as *Polygonum* cf. *bistortoides*, *Lycopodium selago*, *Selaginella selaginoides*, *Sanguisorba canadensis*, *Sheperdia canadensis*, and *Hippuris* cf. *vulgaris*, indicate boreal, or possibly subarctic climates. rather than arctic ones. And there are many genera which, at least in the northeast, indicate temperate climates. Among the herbs there are *Polemonium*, *Ambrosia*, and the Chenopodiaceae, and among the trees oak, hop-hornbeam, and several other deciduous genera. Surely indicators of temperate climate should be given as much consideration as indicators of tundra.

The higher percentages of tree pollen, principally pine, in the outwash sands underlying Tom Swamp and Pleasant St. Bog are somewhat difficult to explain. It is possible that the sands were deposited by glacial melt-water in the short interval before vegetation became established in the area. Under these circumstances the only pollen deposited was windblown pollen from vegetation to the south. Several arguments support this hypothesis. First, the absolute pollen frequency in the sand at these two sites was extremely low, and special extraction techniques were necessary. The percentage weight lost on ignition was also extremely low. Second, the pollen spectra from the sand are dominated by pine, which produces abundant, buoyant pollen which is easily transported by wind. Third, studies in Lapland (Aario, 1944) have demonstrated the surprising fact that surface samples from the far north have higher pine pollen percentages than surface samples from treeless areas near the forest limit. This is because the herbaceous flora in very cold, dry tundra regions is scanty, and does not produce pollen in abundance. Therefore the ratio of windblown pollen to locally produced pollen increases with increasing distance from the forest limit. For these reasons the pollen spectra in the outwash sands underlying zone T-3 at Tom Swamp and Pleasant St. Bog are not considered reliable indicators of vegetation.

Zone A-1 records the development of a continuous forest cover. Whereas spruce dominates at the forest limit in the eastern arctic at the present time, balsam poplar formed the tree-line of the advancing forest in central Massachusetts during late-glacial time. Its light, easily-transported seed (Halliday and Brown, 1943) and its ability to pioneer on disturbed mineral soil may have been responsible for its success. Birch grew together with the poplar. *Betula glandulosa*, a northern shrub birch, may have grown as an understory in the open forest; or gray birch (*B. populifolia*), a temperate tree birch which is able to grow on disturbed soils, may have been present. Herbs and shrubs, apparently shaded by poplar, began to decline in frequency; a few may have persisted in the more exposed habitats.

The poplar was soon succeeded by a spruce forest. Size measurements of the pollen indicate the presence of white and/or red spruce. High percentages of spruce at Tom Swamp may indicate that the outwash surrounding this site was a particularly favorable habitat for spruce. Zones T-3, A-1, and A-2 appear to record a succession from herbaceous vegetation to poplar forest to spruce, similar to a succession which occurs today on flood-plains in the Mackenzie region (Raup, 1935), and on the subarctic prairies (Raup, 1941). In marked contrast to northern Europe, where treeless vegetation persisted for a long period after the retreat of the ice, the forest appears to have advanced in central Massachusetts as fast as soil stabilization and migration speed would allow. The treeless zone along the edge of the ice sheet was probably narrow. Denny (1956b) has shown that in Pennsylvania a zone only ten miles wide south of the Cary drift underwent severe periglacial frost action. Similarly, in New England, intense frost action was probably confined to a zone only a few miles wide south of the retreating ice.

Because soils and migration speed, rather than climatic changes, appear to have controlled the vegetation in zones T-3, A-1, and A-2, these zones probably are not strictly contemporaneous with T-3, A-1, and A-2 in Connecticut (Leopold, 1955, 1956b). Gyttja from zones A-1 and A-2 in Connecticut has been dated by radiocarbon analysis at 12,700 ± 280 and 13,550 ± 460 years BP (Leopold, 1956b), and 14,790 ± 160 and 13,290 ± 120 years BP (Barendsen, et al., 1957). These dates imply that zone A-2 in Massachusetts is of Two Creeks age.

*Zones A-3 and A-4.*—A poplar log from zone A-3 at Pleasant St. Bog has been dated by radiocarbon analysis at 10,700 ± 800 and 10,800 ± 280 years BP (see Description of Sites). The dates indicate that zone A-3 is contemporaneous with either late Two Creeks or early Valders deposits in the midwestern sequence. Zones A-3 and A-4 are difficult to interpret. A wide variety of species and genera, many of them plants not usually found together today, occur in these zones. There appear to be two possible interpretations of the sequence. One interpretation, following Leopold's correlation (Leopold, 1956b), assumes that all the pollen is from plants that grew in the vicinity. The other interpretation assumes that some of the pollen in zone A-3 and the preceding zones has been rebedded from older deposits. Following the former hypothesis, we find that the vegetation of zone A-3 was a mixed spruce and deciduous forest. Spruce and an occasional fir may have grown on the uplands while oak, hop-hornbeam, elm, sugar maple, and beech grew in sheltered well-drained habitats. Ground juniper or red cedar (or arbor vitae?) was common. Shrub birch may have grown on swampy sites, or gray birch and a few other tree birches may have grown together with the other deciduous trees. A similar mixing of boreal and deciduous trees south of the ice during the glacial maximum has been postulated by Drury (1956). Certainly the irregular topography and mosaic distribution of till and outwash deposits in the Petersham region would have provided a variety of habitats. Today mixed forests can be found at altitudes of 1600 ft and higher in the Berkshire mountains 80 km (50 mi) west of Petersham, and in southern New Hampshire 100 km (65 mi) to the north. In fact a type of beech, the "northern gray beech", is reported to occur in a pure genetic state only when growing together with spruce or fir (Camp, 1950). The vegetation of zone A-3 is peculiar because of the absence of hemlock (*Tsuga*), white pine (*Pinus strobus*), and red maple (*Acer rubrum*), which are common in mixed forests today, and in the abundance of hop-hornbeam (or ironwood?). However, the climatic and edaphic conditions of zone A-3 are probably not duplicated anywhere at the present time.

The pollen size frequency data indicate that jack and/or red pine are present in this zone. The maximum of pine along the A-3—A-4 border is hard to explain. Possibly a dry and cooler climate favored an expansion of pine.

A maximum of *Myrica* (and birch?) at Tom Swamp and Pleasant St. Bog, and rising percentages of sedges, *Myrica*, and grasses (and birch?) at Gould's Bog indicate the development of local bog vegetation. Apparently the lakes had begun to fill in. At the first two sites the *Myrica* maximum is followed by a rise of *Isoetes* and sphagnum. At Gould's Bog growth of the bog mat continued, and the pond was completely filled in with vegetation in late A-4 time.

Zone A-4 is marked by an expansion of black spruce and a decrease of deciduous trees. Today black spruce occurs as an upland tree on north-facing slopes in the boreal forest (Raup, 1947); perhaps it is favored there by lower temperatures, greater available moisture, or a combination of the two. We may postulate a decrease in temperature and an increase in precipitation to explain the success of this species in zone A-4. The rise of larch and hemlock, and the presence of pine and birch of larger pollen size, perhaps representing white pine and yellow birch, also may be interpreted as evidence of increased precipitation. Following this interpretation, zone A-4 is correlated with an advance of ice contemporaneous with the Valders advance in Wisconsin. The glacial border must have been far to the north; apparently the ice itself did not influence the climate of central Massachusetts. The landscape remained heavily forested; the climatic oscillation associated with the ice advance merely resulted in a change of percentage composition among the forest species.

However, there is some evidence against the interpretation that has just been presented. The pollen size measurements indicate that the pine of zone A-3 may be jack pine. If this is the case, the presence of white or pitch pine in zone A-4 (see fig. 7) may indicate a warmer climate. Similarly, if the birch in zone A-3 is shrub birch, the increase in frequency of large birch pollen in A-4 (see fig. 6) means an increase of warmth-demanding tree birches. We can interpret zone A-3 as a cold period, and A-4 as a warmer one, if we assume that some of the pollen has been rebedded from older deposits. If the tills of the Petersham region contain pollen from interglacial deposits overridden by the ice sheet, the pollen, together with particles of inorganic matter, would be carried into the lakes during periods of intense solifluction. There it would be rebedded with pollen from the local vegetation. Many deposits in Europe are thus contaminated with Tertiary or interglacial pollen (Iversen, 1936). In general, the amount of secondarily deposited pollen varies directly with the clay content of the sediment (Iversen, 1947; Krog, 1954); in purely organogenic deposits rebedded pollen may be absent entirely (Iversen, 1947). If the entire spruce zone is contaminated with rebedded pollen of temperate species, the zone with a maximum of pollen of temperate trees, A-3, represents a period of intense solifluction. Zone A-2 would thus represent spruce forests established in Two Creeks time. Zone A-3 would represent the Valders stadium, with unstable soils supporting a park-tundra of spruce and jack pine, arctic juniper, shrub birch and herbs. Zone A-4 would represent the reestablishment of forests in early postglacial time. This interpretation would yield a vegetational sequence similar to that found in southern Germany (Lang, 1952).

In the writer's opinion, the assumptions necessary for this interpretation are not justified by the evidence. The ignition loss curves (figs. 3 and 4) do not show an increase in inorganic matter in zone A-3 which can be correlated with the supposed increase of rebedded pollen. Furthermore, if the deciduous tree pollen is rebedded, the ratio of different types should be the same throughout the lower part of the diagrams. This is not the case, especially at Gould's Bog. If pollen of temperate deciduous trees is considered rebedded, then pollen of temperate herbs must also be included in this category. Subtraction of all temperate herbs would considerably lower the maximum of NAP in A-3 which is part of the evidence for a return of park-tundra. The loss on ignition data do show that zones T-3 and A-1 at all three sites are considerably less organic than the succeeding zones. There is a strong possibility that some of the pollen in these zones is rebedded. At Gould's Bog, the percentages of deciduous trees in these zones are somewhat higher than at the other sites. Basswood, sycamore, hackberry, and black walnut, which were not found below the pine zone at Tom Swamp and Pleasant St. Bog, although large numbers of pollen were counted, occur in zone A-1 at Gould's Bog. Perhaps at this site there is a very small percentage of rebedded pollen. However, there is as yet no conclusive evidence to prove the validity of this hypothesis.

*Zone B-1.*—Zone B-1 records the sudden decline of spruce. Forests of red and/or jack pine and birch were widespread. Oak and other deciduous trees, although still not abundant, had a scattered distribution. Alder, perhaps together with larch, grew on the shores of the lakes, and at Gould's Bog, replaced *Myrica* as the dominant bog shrub. The low percentages of deciduous tree pollen suggest that the climate was still cool. The rapid decline of spruce may have been caused by a change from the moist conditions of zone A-4 to a dry continental climate.

*Zone B-2.*—In B-2 time there were extensive forests of pine and oak. Size measurements of pollen (see fig. 7) indicate that white and pitch pine, rather than jack and/or red pine, were the dominant pine species. Forests of pitch pine and oak are common at present on sand plains in central Massachusetts (Bromley, 1935). Under conditions somewhat warmer and drier than the present, they may have occurred on all the well-drained soils, while hemlock and other deciduous trees, such as hop-hornbeam or ironwood, ash, elm, sugar maple, and red maple occupied the wetter sites. Dry climate is indicated by the change at all three sites from peat deposited under more hydrophytic conditions to peat deposited under less hydrophytic conditions. The lower boundary of zone B-2 is considered here to represent the beginning of the hypsithermal interval (Deevey and Flint, 1957), a period when prevailing temperatures were higher than they are today.

*Zone C-1.*—In C-1 time the climate appears to have been more moist. Pine became less common, and oak, perhaps a different species than in zone B-2, increased in frequency. Hemlock, elm, sugar maple, and basswood were abundant. Warmth-demanding trees, such as hackberry and sycamore, now only occasional in central Massachusetts, occurred in low frequencies. Beech became more common, reaching a maximum along the C-1—C-2 zone boundary.

*Zone C-2.*—Apparently zone C-2 represents the warmest part of post-glacial time. The climate was also fairly dry, as indicated by the minimum of hemlock and elm, and by the terrestrial peat deposited at all three sites. The forests were dominated first by oak, and then by oak and pine. Hickory was slightly more abundant than it is today. Sugar maple was at a minimum.

Low water level at Gould's Bog during C-2 time is implied by poor pollen preservation and highly humified peat. Apparently a bog forest of black gum, red maple, and possibly birch in early C-2 was replaced in late C-2 time by alder. Perhaps beech was also growing on the bog. The beech maximum of late C-2, although characteristic of this horizon in New England (Deevey, 1943), seems anomalous in that elm, sugar maple, and hemlock, which occur together with beech in the other pollen zones, are almost absent. It seems likely that the maximum represents a different beech type, possibly the "white beech" which is reported to be common in swamps further south (Camp, 1950). The successive maxima of beech in New England pollen diagrams have been attributed to waves of migration (Deevey, 1949). Perhaps the maximum of late C-2 time is due to the influx from the south of new genetic material which enabled the beech population to expand into different habitats.

*Zone C-3.*—Zone C-3 records the most recent stage in the history of the precolonial forests. Oak and hickory declined in frequency, and hemlock, elm, sugar maple, and birch became abundant. These changes may indicate a cooler and more humid climate. Chestnut and ash for the first time became important members of the forest complex. In the upper part of the zone, hemlock declines and pine rises to a maximum. The rise of spruce, noted in Connecticut (Deevey, 1943), probably represents the occurrence of black spruce on the bog surface. A more humid climate also is indicated by the change in the non-arboreal bog vegetation. The Typhaceae and many bog herbs and shrubs suddenly increase in frequency. The peat is fibrous and less humified, and pollen preservation is far better than in the underlying zone. This change from a dry, wooded swale to a wet, sedge and cattail bog at the beginning of zone C-3 is analogous to the sudden resumption of bog growth in northwestern Europe at the beginning of Sub-atlantic time. Recurrence horizon III, the most pronounced of the *Grenzhorizonten*, which marks the lower border of the Sub-atlantic zone in Europe, has been dated at about 600 B.C. (Granlund, 1932). The stratigraphy of Gould's Bog is evidence that a sudden change from warm-dry to cool-moist conditions occurred at about the same time in northeastern North America, as well. Probably the end of the hypsithermal interval (the end of the Sub-boreal zone, the end of zone C-2), occurred simultaneously in both continents at about 600 B.C.

*General remarks.*—It is interesting and important in considering the concept of the vegetational "climax" to realize that the pre-colonial forest of Petersham, which was rich in chestnut and ash, differentiated only recently. We may well question the idea that plant associations are continuous in time. Rather, it appears from the diagrams that each species (or ecotype) has reacted independently to changes in climate and soil. The concept of vegetational succession should also be considered in the light of this historical evidence. The history of Gould's Bog has been far more complex than its present aspect would indicate. If "the stages in the present horizontal sequence from shallow water to marginal forest become arranged in a vertical sequence as the bottom of the lake is built up" (Weaver and Clements, 1938, p. 66), we should expect only aquatic sediments below the present bog surface. Instead, there is recorded the invasion of open water by a floating sedge mat, the growth of first a *Myrica* and then an alder (and larch?) thicket, the development of a hardwood swale forest, and the subsequent invasion of the swale by hydrophytic vegetation. It is true that under certain circumstances the present vegetational zonation around the shores of a bog may represent successional stages. This is the case at the north and south margins of Tom Swamp, where the encroachment of vegetation into open water during the last 15 years is recorded by aerial photographs. However, Gould's Bog and the deeper parts of Tom Swamp represent far more typical cases of bog succession. Here the development of the bog has taken many thousands of years. During this time the water table. the surrounding vegetation, and the soils have undergone many changes. The nature of the bog vegetation, and the direction and speed of plant succession appear to have been under climatic control.

The pollen diagrams presented here are easily correlated with diagrams from Connecticut (Deevey, 1939, 1943; Leopold, 1955. 1956b) and southern New Hampshire (Krauss and Kent, 1944). However, the early part of the sequence, zones T-3—B-1, is strikingly different from the early sequences found in northern Maine (Deevey, 1951), Nova Scotia (Livingstone and Livingstone, 1958), Michigan (Andersen, 1954), and Europe (Firbas, 1950; Donner, 1951; van der Hammen, 1951; Lang, 1952; Iversen, 1954; Godwin, 1956). In these areas there is evidence of persistence of tundra for some time after the retreat of the ice, and, where forests became established, a return of tundra or park-tundra during Valders (Younger Dryas) time. Although it seems strange that the early sequence in southern New England is anomalous, should we expect it to be similar to late-glacial sequences elsewhere? In contrast to Europe, there are no east-west mountain chains to serve as barriers to migration. Boreal and temperate species were available for recolonization (Drury, 1956). As soon as the climate and soils were favorable for the growth of trees, forests were established. The Alps served as a barrier to migration in Europe, and, as a result, in some areas slow migration speed, rather than unfavorable climate, may have hindered the development of boreal forest (van der Hammen, 1951; Iversen, 1954). Furthermore, when sea levels were low, central Massachusetts was far from the ocean; the climate may have been even more continental than it is now. There were no large proglacial lakes, such as the Baltic ice-lake or ancestral Great Lakes, to exert an oceanic influence. A continental climate at the comparatively low latitude of Massachusetts (42°N) would have resulted in high summer temperatures, permitting the growth of many species that could not have survived during the same period in Europe (cf. Firbas, 1950). Rather than attempting to compare our late-glacial sequence with that of northwestern Europe, we should look to continental areas, such as eastern Europe, for a similar vegetational history.

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