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POSTGLACIAL VEGETATION OF NORTHERN VERMONT.

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POSTGLACIAL VEGETATION OF

NORTHERN VERMONT

by

Robert Malcolm Dole, Jr.

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in
The University of Michigan
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Doctoral Committee:

Professor William S. Benninghoff, Chairman
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ABSTRACT

POSTGLACIAL VEGETATION OF
NORTHERN VERMONT

by
Robert Malcolm Dole, Jr.

Chairman: William S. Benninghoff

In Eastern North America, analyses of fossil pollen and spores in lake and bog deposits have provided much information about vegetational and environmental changes that have occurred since the recession of the Wisconsin Ice Sheet. In New England, pollen analytical studies have been concentrated in the southern portion. The post-last-ice record of the biota and environment in northern New England has received far less attention.

This study reports on investigations of three bogs situated on an east-west line in north central Vermont. The results constitute an expanded and detailed record of the vegetational history of north central Vermont since the retreat of the last glacial ice.

Cores were obtained from Bugbee Bog (8.40 meters in length) in Caledonia County near the Connecticut River Valley, and from the Colchester Bog (5.40 meters in length) at the edge of Lake Champlain and Lily Pad Pond Bog (10.10 meters in length) on higher ground in the Champlain Lowland, both in Chittenden County. In addition, nine samples for radiocarbon dating were taken from Bugbee Bog to determine earliest organic sedimentation, to permit calculation of peat accumulation rate, and to link an

an absolute time scale to postglacial pollen sequences in north central Vermont.

The mean rate of sediment accumulation in the Bugbee Bog was 7.2 cm. per century. The density of fossil pollen populations in the sediments determined by the exotic additive pollen technique indicates lower density in the oldest sediments, an increase to a maximum in the B zone or at the B/C-1 zone boundary, and a slightly decreased but constant density through the C zones to the surface. Lily Pad Pond Bog is different, as the maximum density is reached in the upper C-3 zone.

The three pollen diagrams presented in this study are believed to record the vegetational sequence from time of glacial retreat in the St. Johnsbury moraine area. The diagram show that the first recorded vegetation in north central Vermont was spruce forest about 11,000 years ago. The Colchester Bog pollen record began later than the uppermost spruce forest zone (zone A-4). Spruce forests were replaced by vegetation dominated by pine beginning about 10,200 years ago; the pine dominance lasted until 7,800 years ago. The pine zone (zone B) is succeeded by a sequence of pollen assemblages as follows: hemlock maximum-pine minimum (7,800 to 3,800 years ago, zone C-1), pine maximum-hemlock minimum (3,800 to 1,600 years ago, zone C-2), and spruce, fir, hemlock, birch, and elm (1,600 years ago to present, zone C-3). The C pollen zones, normally delineated on the basis of broadleaf deciduous tree genera in southern New England, are better characterized here by needleleaf evergreen genera.

The radiocarbon chronology established for the Bugbee Bog is used to scale similar time sequences for the Colchester and Lily Pad Pond Bogs which are correlatable by their pollen diagrams. The pollen assemblage zone boundaries, as interpreted in this study and related to the radiocarbon dates, indicate greater ages for the earlier stages in vegetation change in comparison with similar events in southern New England. The radiocarbon date on the lowermost sediments of Bugbee Bog, 11,030 $\pm$ 200 years ago, and shoreline data currently available indicate glacial Lake Hitchcock did not cover the area now occupied by the bog, but it began forming while the glacial lake was in the vicinity. The Colchester and Lily Pad Pond Bogs began forming after the Champlain Sea episode of glacial Lake Champlain. The pollen diagrams indicate the Lily Pad Pond Bog (altitude 98 meters above mean sea level) began forming before the Colchester Bog (altitude 30 meters, approximately 1.5 meters above the level of modern Lake Champlain). The similarity of the pollen diagrams for Bugbee Bog and Lily Pad Pond Bog and the earliest date for the Bugbee Bog suggest Lily Pad Pond Bog began about 11,000 years ago. The Colchester Bog is believed to have begun depositing sediment 9,000 to 9,500 years ago.

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Others who have aided me in this study are Montague Howard, Jr., Soil Conservation Service, Burlington, Vermont; Robert A. Farrington, Senior Forester, Department of Forest and Parks, State of

Vermont; Leslie L. McDowell, Soil Scientist, Sedimentation Laboratory, U. S. Department of Agriculture, Oxford, Mississippi. Dwight Leedy, Berea College, Cleveland, Ohio, and James Jinks, a high school student at Danville, Vermont, were field assistants. To all of these persons I extend my sincere thanks.

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CHAPTER I

INTRODUCTION

1. Statement of the Problem and Objectives.

Analyses of fossil pollen and spores in lake and bog sediments of New England have provided information about sediment, climatic and vegetational changes that have occurred since the recession of the Wisconsin Ice Sheet. Such studies have been concentrated primarily in southern New England. Only a few detailed studies have been made in northern New England. Thus, the chronologic record of changes in sediments, vegetation and climate in northern New England is incomplete.

Due to the paucity of detailed pollen analytical studies of postglacial sediments in northwestern New England, the author chose to make a study of three peat bogs in the State of Vermont. A portion of this study was initiated by Martin Johnson, Agriculture Research Service Director, U. S. Department of Agriculture, Danville, Vermont, who wished to establish a radiocarbon chronology for a northern Vermont peat bog to determine the rate of peat accumulation. Johnson and his supervisors decided to expand the study to include the analysis of the fossil pollen and study of the stratigraphy. I was invited (1965) to do the pollen work and was informed that the data derived from this study would be available as part of a doctoral dissertation. Mr. Johnson, Robert Farrington, Senior Forester, Department of Forests and

Parks, State of Vermont, and Montague Howard of the Soil Conservation Service, Burlington, Vermont, provided guidance in selection of the bog for study. The site chosen was the Bugbee Bog in Caledonia County in northeastern Vermont. As Farrington and Howard had previously examined this bog for thickness of the deposit, it was probable this bog would be suitable for this study. Further, the author considered the fact the bog is situated in a closed depression only 150 meters (500 feet) outside the uppermost shoreline of glacial Lake Hitchcock, altitude 215 meters (695 feet) at this point. Because of the bog's close proximity to this post-glacial lake, some influence of the lake and its relatively quick disappearance could be watched for in the fossil pollen record. Dr. Leslie McDowell of the U. S. Department of Agriculture Sedimentation Laboratory, Oxford, Mississippi, collaborated in this study by radiocarbon dating the sediments from the Bugbee Bog.

In addition to the Bugbee Bog study, the present work examines two other peat bogs in Vermont, the Colchester and Lily Pad Pond Bogs in Chittenden County. Both of these are nearly due west of the Bugbee Bog. By selecting study sites along an east-west line, it is hoped to establish a regional postglacial history for north central Vermont. Furthermore, both Chittenden County bogs probably were covered by waters of glacial Lake Champlain. Data from this study will show that the Lily Pad Pond Bog probably was uncovered before the Colchester Bog. No radiocarbon dates have been obtained for the Colchester and Lily Pad Pond Bogs.

The density of fossil pollen and spores at successive stratigraphic horizons for each of the bog deposits has been worked out.

This study, then, describes the pollen and sediment stratigraphy, radiocarbon chronology, and density of the fossil pollen and spores for the Bugbee Bog. For the Colchester and Lily Pad Pond Bogs, pollen and sediment stratigraphy and the density of the fossil pollen and spores is reported.

2. Previous Investigations.

Study of fossil pollen in Pleistocene deposits has commanded scientific attention for the past forty years in North America. Emphasis has been on postglacial vegetational history recorded in lake and bog sediments. Most Pleistocene pollen analysis has been performed on sediments deposited in glaciated areas. Recently, investigations of deposits from outside the glacial border are supplementing our knowledge of Late Cenozoic vegetation in significant ways.

The development of Palynology in North America begins with the work of Auer (1927, 1930) in southeastern Canada. Early pollen studies in America include the work of Fuller (1927, 1929), Draper (1928, 1929), Sears (1930, 1931), Houdek (1932, 1935), Voss (1931, 1933, 1934), Lewis and Cocke (1929), and Wodehouse (1935). Fuller (1935), Sears (1932, 1933, 1935a, 1935b, 1938), and Sears and Janson (1933) were the first to attempt a climatic and forest history of the Eastern United States based on early pollen analytic findings. Cain (1939) in the United States and Godwin (1934) in England provided prescient summaries of the problems and potentialities of pollen analysis as a tool of paleoecology. Some of the more recent trends in palynology have been described by Faegri (1956) and Davis (1965).

The postglacial sequences of pollen assemblage zones in eastern North America, as determined by palynology, resemble in their broadest outlines the pollen assemblage zones of western Europe (Deevey, 1949). Although early North American pollen studies generally failed to discern a tundra phase, the presence of tundra-like treeless vegetation is now being shown in some pollen diagrams by Deevey (1939, 1943, 1951) in Connecticut and Maine, by Krauss and Kent (1944) in New Hampshire, by Leopold (1955, 1956) in southern Connecticut, by Davis (1958, 1960, 1965) in Massachusetts and Vermont, by Ogden (1959) in Massachusetts, by Whitehead and Bentley (1963) in Vermont, and by Terasmae (1959, 1960) in Southeastern Canada. Figure 1 shows the location of deposits for which pollen diagrams exist in New England and adjacent states.

Until recently, no attempt had been made to establish a climatic and vegetational history for Vermont. The first published work of a pollen analytical nature concerning deposits in Vermont was by Davis and Goodlett (1960). Working the Memphremagog quadrangle in northern Vermont, they attempted to correlate pollen in surface layers of the bottoms of Brownington and Spectacle ponds with the surrounding vegetation. From this work, Davis also published (1965) the first detailed postglacial record of vegetation for northern Vermont. Whitehead and Bentley (1963) published a postglacial pollen diagram for southwestern Vermont. Pre-Pleistocene vegetation of Vermont is known only through the work of Barghoorn (1950) and Traverse (1955) on the lignite deposits at Brandon which are established to be of the order of 40 to 50 million years old and are not of significance in the study of the postglacial vegetational history of Vermont.

Figure 1. Index map to location of published pollen diagrams in New England and adjacent states. Diagrams of special interest to this study are numbered on the map and identified below. Circles mark the three bogs in northern Vermont treated in this study.

1. Deevey, 1951
2. Krauss and Kent, 1944
3. Davis, 1965
4. Whitehead and Bentley, 1963
5. Davis, 1958
6. Davis, 1960
7. Butler, 1959
8. Beethan and Niering, 1961
9. Davis, 1967
10. Leopold, 1956
11. Ogden, 1959

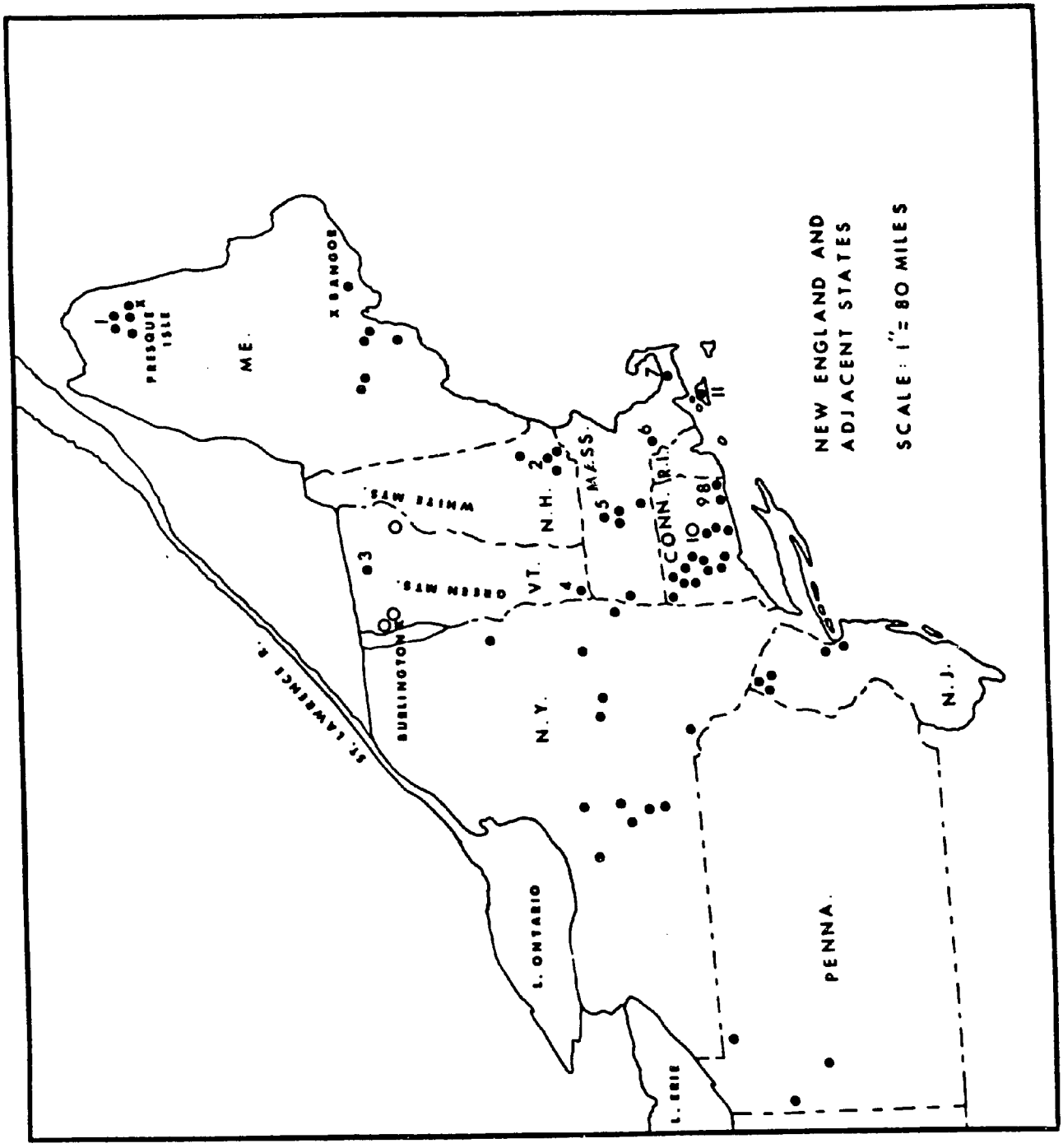
NEW ENGLAND AND
ADJACENT STATES
SCALE: 1" = 80 MILES
ME.
PRESQUE ISLE
BANGOR
WHITE MTS.
GREEN MTS.
VT.
N.H.
MASS.
CONN.
R.I.
BURLINGTON
ST. LAWRENCE R.
L. ONTARIO
N.Y.
L. ERIE
PENNA.
N.J.

Figure 1.

Any reconstruction of the late- and postglacial vegetation history of Vermont takes into account the influence of glaciation in Vermont and New England. This is necessary as the deposition in lakes and ponds could not begin and the vegetation could not develop until the ice had retreated from the area. The last ice sheet to cover New England, the Wisconsin, left in its wake the glacial features which characterize the Vermont and New England terrain. Flint (1957) has presented an extensive account of the glacial and Pleistocene history of northeastern United States and Canada.

Pleistocene geology in Vermont is difficult to study by usual field techniques. First, the mountainous terrain interfered with the advance and retreat of the glacial ice. The bedrock topography caused the stagnation of the ice and contributed to the process of downwastage in place rather than orderly retreat. Consequently, recessional moraines are scarce and outwash that was not flushed down valleys was left in restricted local deposits.

Second, the kinds of bedrock in this area are numerous. However, the composition is not so varied as to permit tracing boulder trains and till material. Recent studies in Vermont have shown advances of ice have occurred from both the northeast and the northwest (Stewart, 1961; Stewart and MacClintock, 1964). This results in a mixing of the tills since subsequent glaciations remove the till and mix it with new rock. Thus, the composition of the tills does not vary much. No plant or animal remains have been found for dating and significant weathering zones between tills are scarce. Therefore, usual field methods to deduce glacial advances and retreats such as studies of glacial striae, boulder trains, and ice contact deposits are of limited value. Instead, studies of till fabric orientation have formed

the basis of identifying, mapping and correlating till sheets in Vermont (Stewart, 1961).

Till fabric studies in various parts of Vermont have shown evidence of at least three till sheets. Stewart (1961) identified two till sheets near Shelburne, Vermont, and designated them the Burlington and Shelburne tills. The upper till, the Burlington, has a northwest till fabric orientation and the lower, the Shelburne, has a northeast fabric orientation. The bedrock under the northeast till has striae from the northwest. Stewart (1961) concluded that this evidence indicated two ice invasions from the northwest separated in time by an ice advance from the northeast. Stewart and MacClintock (1964) working along Stannard Brook near Greensboro Bend, found two tills with northwest fabric separated by alluvial gravel and lake sediment. Above the two tills of northwest fabric and separated from them by lake sediments is a third till with northeast fabric. At Greensboro, bedrock exhibits strong northeast striae. The till over this bedrock has a northwest fabric. The Stannard Brook section, then, gives evidence for at least three ice advances during the Wisconsin. Stewart and MacClintock (1964) have suggested the striae of northeast orientation on the bedrock at Greensboro may be correlated with the Shelburne till also of northeast orientation. If this assumption is correct, then evidence for four glacial advances in northern Vermont can be deduced. The two oldest tills of northwest fabric are separated by a till of northeast overlain by a final till of northwest fabric. Further, Stewart and MacClintock (1964) suggest that the surface till of northwest fabric in Vermont is correlated with the most recent or Burlington till. Correlation of these tills with

the chronology for eastern North America in general is only a matter of conjecture.

The Vermont landscape, as stated earlier, has been largely shaped by the last glaciation, the Wisconsin. It seems logical also that Vermont and New England were glaciated by ice invasions in pre-Wisconsin time. Scanty evidence is available to support conjecture such as this. Flint, because of the great depth of the weathered zone between two tills (1957, p. 359) mapped at locations near Boston, the Cap Cod region of Massachusetts, central Connecticut, and Rhode Island, has considered these to be similar and possibly of pre-Wisconsin age. If such evidence existed in Vermont, it seems likely it has been eradicated by the subsequent invasion of the Wisconsin ice sheet since no glacial geologic evidence for such events has been found. The relationship of the Wisconsin age till sheets in Vermont have already been discussed. The correlation of these till sheets with other similar events in New England and beyond is not yet feasible.

As the Wisconsin ice receded from Vermont two subsequent events are of interest to this study. First, in the Champlain Lowlands and in adjacent New York glacial Lake Champlain formed. Two of the bogs in this study could not form until the later stages of the glacial lake subsided. The lake episodes and stages that have been determined for glacial Lake Champlain are listed below including the height of the mapped shorelines important to this study. Shoreline data were determined by Chapman (1937) and Stewart (1961).

Episode	Shoreline Elevation
Lake Vermont	
Quaker Springs Stage	740 feet, Jericho, Vt.
Coveville Stage	700 feet, Milton, Vt.
Fort Ann Stage	430 feet, Mt. Philo, Shelburne, Vt.
Champlain Sea	
Beekmantown Stage	425 feet, Moors Fork, N. Y.
Port Kent Stage	225 feet, Burlington, Vt.
Burlington Stage	172 feet, Burlington, Vt.
Plattsburg Stage	120 feet, South Hero, Vt.
Port Henry Stage	Submerged

From this evidence, the Lily Pad Pond Bog, now at 98 meters (320 feet) could begin forming at an earlier time than the Colchester Bog, now at 30 meters (100 feet) elevation. Further evidence for this supposition is drawn from the pollen diagrams for each of the bogs. Discussion of this will be found under the appropriate chapter heading for each bog.

The second event of interest to this study is the formation of glacial lake or lakes in the Connecticut River Valley. The Bugbee Bog, is situated near the upper limit of the earliest glacial lake, Lake Hitchcock. As the ice sheet receded from its maximum extent of the Middletown, Connecticut, readvance (about 13,000 years ago), it built a great dam of driftjust north of Middletown. As the ice receded northward, the glacial lake expanded and at its maximum extent became glacial Lake Hitchcock. This lake is thought to have extended from Middletown, Connecticut, to Lyme, New Hampshire, a distance of 297

kilometers (157 miles), and later expanded as far north as St. Johnsbury, Vermont. There are no published shoreline data for glacial Lake Hitchcock in the St. Johnsbury area. At Norwich, Vermont, Stewart (1961) reports a shoreline at 200 to 215 meters. At Hanover, New Hampshire, Lougee (1939) mapped a shoreline at 205 meters. Stewart (1961) reported a kame terrace at Brattleboro at 100 meters (350 feet). These mapped lake sediments indicate progressively higher elevations from south to north. The Bugbee Bog at an elevation of 398 meters (1,300 feet) probably was not inundated by waters of glacial Lake Hitchcock. Work by Lougee (1939) and the Goldthwaites (1951) shows that when the receding ice margin reached Lyme, New Hampshire, the water level dropped abruptly some 27 meters (90 feet). This probably records the drainage of glacial Lake Hitchcock by the failure of the dam in Connecticut. The lake which subsequently formed has been called Lake Upham. This lake is thought to have extended some 80 to 95 kilometers (50 to 60 miles) south of Lyme, New Hampshire and to have grown north beyond St. Johnsbury as the ice retreated. Radiocarbon dates for the final draining of the south end of glacial lake Hitchcock are 10,710 B.P. and 10,650 B.P. (Schafer and Hartshorn 1965). The basal sediments for the Bugbee Bog radiocarbon date at 11,030 $\pm$ 200 B.P. This indicates the Bugbee Bog began forming more than 11,030 years ago.

CHAPTER II

METHODS

1. Vegetation Studies.

Present vegetation cover on the bogs investigated was recorded primarily for the list of vascular plant species. The list was obtained by reconnaissance walks to determine the major communities and their most conspicuous species. Plants were collected if identification needed to be checked. Dr. William S. Benninghoff aided in the identification of plants from the Lily Pad Pond Bog and Dr. Hubert W. Vogelmann, University of Vermont, helped with the plants from the Colchester and Bugbee Bogs. Lists of common and frequent plants occurring at each site are included in the chapter treating each bog. Sphagnum is the only genus of non-vascular plants considered of importance to this study and included in the lists.

2. Sampling Sediment for Pollen Analysis.

To locate the bogs most suitable for palynological work, two criteria were used. These were total depth of the peat deposit and topography of the drainage basin. If a bog has a thick accumulation of peat and is situated in a closed drainage basin (one that has little or no surface drainage into or away from it), it is probable that the bog was formed soon after the end of the last glaciation and has persisted to the present.

The first step in the sampling procedure was to probe the bog organic deposits for depth to mineral sediments thus obtaining an idea of the basin topography. Compass lines were laid out and probes for depth were sunk at specific intervals along these lines Two such lines were set up, one on a north-south orientation and the other one on an east-west line. Coring for samples was done where the organic deposits were found to be thickest.

All core samples were taken by means of a Hiller peat sampler unless otherwise noted. Material for radiocarbon dating from the Bugbee Bog was taken in 50 cm. core increments and placed in plastic bags, labeled, and then shipped to the USDA Sedimentation Laboratory, Oxford, Mississippi. Samples for pollen analysis from all three bogs were placed in sterile, clear plastic tubes, 17 by 100 mm. with clear plastic tight-fitting caps, and were labeled for site and depth. Samples were taken in the field at 5 cm. intervals. The samples were stored at 15°C until processing could be done.

The stratigraphy was recorded for each core taken. Munsell color of sediments was determined for all cores taken and pH was measured at selected intervals. These data were taken in the field by the author, Montague Howard, Soil Conservation Service, Burlington, Vermont, and a team of research assistants from the USDA, ARS Section Laboratory, Danville, Vermont.

To avoid contamination, alternate bore holes were used to secure all samples whether for pollen analysis or radiocarbon dating. After each boring was made and samples removed, the chamber of the sampling device was thoroughly cleaned before a new increment was

taken. If at any time contamination was suspected, the sample was discarded and another was taken. Every precaution was observed to avoid contamination by the modern pollen rain.

3. Laboratory Methods.

a. Processing of Samples.

Wet weight, dry weight, and volume of each sample was determined and recorded for the Bugbee Bog. Only dry weight and wet weight were obtained for samples processed from the Colchester and Lily Pad Pond Bogs. Samples were selected at either 10 cm. or 25 cm. intervals for processing.

The dry weight and volume determination for sediments from the Bugbee Bog were obtained as follows:

1. The longer and narrower half of a triple 0 gelatin capsule was packed with sediment (Stevenson, 1968). The entire capsule was weighed prior to packing.
2. Once packed the other half of the capsule was replaced and the entire unit reweighed.
3. The portion of the capsule packed has an average volume of approximately 1.30 ml. as determined using a Bellco wide bore 1 ml. pipette graduated in .02 of a ml. There is some variation as to volume from 1.28 ml. to 1.36 ml.
4. The number of capsules prepared for each sample level varied from 3 to 5. As the density of the fossil pollen and spores in a unit of this sediment was unknown, the volume of sediment to be processed had to be estimated. The density was considered to be low in the upper meters,

greater in the depths below this, and low in the lowermost depths of the core. The number of capsules prepared per level is as follows:

a. Five capsules were prepared for sample levels 0 to 1.00 m., at .10 m. intervals; 1.25 to 3.25 m., at .25 m. intervals

b. Four capsules from 3.50 to 4.25 m., at .25 m. intervals.

c. Three capsules from 4.50 to 8.00 m., at .25 m. intervals; 8.10 to 8.40 m., at .10 m. intervals.

One loaded capsule at each level was placed on half a petri dish lined with aluminum foil to air dry. The capsule was allowed to dry for 72 hours and then reweighed in order to record dry weight. The remaining packed capsules were immediately placed in 50 ml. plastic beakers containing 10 percent hydrochloric acid (HCl).

The gelatin capsule technique used above for determining dry weight and volume was not used for the Colchester and Lily Pad Pond Bog samples because (1) the gelatin capsules are very hygroscopic, and (2) the capsules quickly became soft and deformed when in contact with wet bog sediments. This led to difficulties in packing each uniformly. Reweighing the loaded capsule was most difficult because of its adhesion to the pan of the balance. From this experience, gelatin capsules seem poorly suited for obtaining volumes and dry weight on sediments which are very wet. Thus, the aluminum weighing pan was substituted for dry weight determinations as follows:

1. The aluminum dish is weighed, about 4 grams of wet sediment is placed in the dish, and then reweighed.

2. The dish with its sediment is allowed to air dry for 72 hours.
3. The dried material is then placed in a 50 ml. plastic beaker containing 10% HCl. Within 24 hours the dried sample was completely wetted and could be easily teased apart. No crushing techniques were necessary.

Following treatment of 10% HCl, all samples were treated alike according to the following schedule:

1. Samples remained in the 10% HCl for 36 to 48 hours after which they were placed into 15 ml. centrifuge tubes.
2. Samples were then washed 3 times with distilled water by centrifuging and washing and decanting.
3. After final water wash, samples were washed twice with 10% potassium hydroxide (KOH) and allowed to stand in clean cold 10% KOH overnight.
4. The suspension in KOH was then centrifuged, decanted, replaced, and the samples heated in a water bath to boiling and cooled.
5. The suspension in KOH was centrifuged, decanted, and samples are washed in distilled water 3 times and put through a one hundred mesh copper screen (sieve hole size 140 microns). The sieve was washed with distilled water to insure flushing all pollen and spores through the sieve.
6. The Erdtman acetolysis procedure was then applied (Faegri and Iversen, 1964). This treatment rendered many pollen grains very dark in color and hindered identification of critical features in some kinds of grains. Therefore,

each sample was bleached according to the following schedule modified from Erdtman (1943, page 29):

a. Wash sample twice in glacial acetic acid
b. Suspend sample in 5 ml. clean glacial acetic acid
c. Add 5 drops of saturated aqueous sodium chlorate solution and stir
d. Add 2 drops of concentrated HCl and stir
e. Allow thirty seconds to bleach
f. Flood sample with distilled water
g. Centrifuge, wash with glacial acetic acid
h. Continue with usual schedule

7. Those samples with a large component of inorganic material as sand were placed in 25 ml. 48% hydrofluoric acid (HF) for 72 hours after bleaching. The samples were then washed 3 times with distilled water.
8. After bleaching, all samples were washed with 95% ethyl alcohol, twice with absolute ethyl alcohol, and twice with either tertiary butyl alcohol (TBA) or thiophene-free benzene. The TBA was used as the final wash on all samples from the Bugbee Bog. Benzene was used as the final wash for the Colchester and Lily Pad Pond Bogs.
9. Samples were then suspended in 3 ml. of either TBA or benzene in centrifuge tubes and then transferred to one dram vials with tight-fitting plastic caps.
10. Two ml. of silicone oil, 2000 centistrokes viscosity, were then added to the vial.

11. Vials were placed under a fume hood to allow the TBA or benzene to evaporate. The TBA was very slow to evaporate even when placed in an oven at 70°C overnight. After 3 days in the oven some of the TBA still remained in the vial. All the TBA or benzene must be removed before microscope slides are made, otherwise bubbles will form under the coverslip. No such problems were encountered with the benzene which usually evaporated completely in 24 hours.
12. Silicone oil with the suspended sediment remains in the vial after the liquids evaporate. A tight-fitting cap is placed on the vial and the vial is stored in a cool, dry place to await study of the sediment.

b. Technique for Determining Density of Fossil Pollen and Spores.

The density of fossil pollen and spores in sediments can be determined in several ways (Benninghoff, 1962; Davis, 1965). The technique described by Benninghoff (1962) is used in this study with several modifications. The principle is based on the addition of a known number of exotic pollen grains or spores to a known amount of raw sediment that is to be processed for fossil pollen and spores. The exotic grains added must not be a type which would occur naturally in the sediments to be analyzed. Several kinds of additive pollens have been used including Cycas, Pisolithus (a puff-ball-like fungus) and Eucalyptus. Cycad pollen is used in this study as it is quite unlikely to be found in postglacial deposits from northeastern North America and can be distinguished from the native postglacial pollen

and spores. Cycad pollen was obtained from plants growing at the University of Michigan Botanical Gardens. The species of cycad used for collections of pollen was Dioon spinulosa. The pollen collected was suspended in one liter of tertiary butyl alcohol (TBA) in a volumetric flask. Two different suspensions were used in this study, called flask A and flask B for convenience.

Flask A was obtained from the Plant Ecology Laboratory, University of Michigan. This suspension was made up in June, 1967 and had been used previously by other workers. In this technique, usually milliliter quantities of the pollen suspension are added to raw sediment samples. Thus, it was necessary to re-determine the number of grains per milliliter to insure accuracy. To do this, the following procedure was used:

1. The volumetric one liter flash is placed on a hot plate containing a magnetic stirring device. Set the stirrer in action on slow and maintain the temperature at 31°C.
2. A drop of the suspension from the flask is placed in each cell of a Spencer (AO) Bright Line Improved Neubauer Haemocytometer. A special cover slip is added. The drop of suspension is delivered with a 1 ml. wide bore Bellco pipette.
3. The number of grains in the one square millimeter field in each cell of the haemocytometer are counted at 100 X using a binocular microscope.

One hundred seventy-eight square millimeter fields were counted. These counts were made in groups of 25 except the last group which has 28. Table 1 shows the number of grains counter per mm^2 field.

Table 1. Haemocytometer counts of cycad grains per mm^2 field, Flask A, *Cycas* pollen suspended in TBA.

Group						
I	II	III	IV	V	VI	VII
8	15	12	15	9	13	8
12	18	14	11	14	5	7
11	14	11	15	8	12	14
11	16	14	11	16	7	11
22	11	12	11	19	12	10
14	15	14	18	21	15	14
16	16	18	12	6	10	9
16	18	15	16	13	14	4
14	13	19	12	14	16	6
17	12	9	13	15	7	17
12	11	15	13	11	13	7
12	18	3	17	7	15	8
14	24	10	10	13	9	13
18	17	16	10	13	21	7
9	26	10	12	18	8	16
7	11	16	14	9	10	11
9	12	16	8	11	18	28
14	12	14	9	15	25	12
10	17	22	12	17	10	17
14	11	10	15	20	15	21
18	21	15	15	20	7	12
20	18	21	5	9	18	6
15	10	22	18	10	10	17
23	15	13	21	11	14	13
7	8	17	16	12	18	16
343	379	367	319	331	322	9
						6
13.72 ave.	15.16 ave.	14.68 ave.	12.76 ave.	13.24 ave.	12.88 ave.	6
						304
						11.96 ave.

From this, the number of grains per ml. is calculated in the following manner:

1. Divide the total number of grains counted by 178. The average number of grains per mm^2 field is 13.4606.
2. Multiply this number (13.4606) by 10^4 giving 134,606 the number of cycad grains per ml. in the suspension in the flask.

The factor 10^4 in 2 above is the number of grids in one ml. A grid is 0.1 mm. deep and has 400 small squares contained in 1 mm^2. As the grid is 0.1 mm. deep, 10 of these are required to make 1 mm^3, however there are 1,000 mm^3 in one ml., therefore 1 mm^3 X 10,000 (i.e. 10^4) gives the number of grains per ml. All additions of cycad grains to samples of the Bugbee Bog were taken from Flask A.

The accuracy of the haemocytometer was a constant concern to the author. There are indications that the error can be as high as 30 percent. Considering this and the laborious determinations necessitated using the haemocytometer, the Coulter Counter was suggested as providing a better and more accurate method of determining grains per ml. Its margin of error is 1 to 2 percent for counting a suspension of bacterial cells and probably no greater than 10 percent for the larger cycad grains.

After all additions from Flask A had been made to samples from the Bugbee Bog, the number of grains per ml. in Flask A was 123,334. This figure (123,334 grains per ml.) was arrived at by determining the number of grains removed in the total volume withdrawn and subtracting

this number of grains from the original number in the flask and then replacing the volume of liquid (TBA) removed. This procedure is followed each time withdrawals are made. Milliliter samples containing this number of grains (123,334/ml.) were counted using the Coulter Counter to check the accuracy of the haemocytometer. All determinations made were 90,000 grains per ml. or less and inconsistent. This represents a divergence of nearly 30 percent. This difference could be due to one or several of the following: (1) the original determination using the haemocytometer was erroneously high, (2) the Coulter Counter counts were low due to cell clumping, (3) the original counts (haemocytometer) were near the actual number per ml. but the counts with the Coulter Counter were low due to insufficient grains per ml. and accuracy was lost. Therefore, due to these possible sources of error, the author decided to obtain fresh pollen and suspend a greater quantity of it in a liter of TBA for additions to the Colchester and Lily Pad Pond Bog samples.

For Flask B, pollen was obtained, as was described before, from Dioon spinulosa. Once suspended, the entire suspension was freed of virtually all extraneous material by passing it through a 100 mesh copper sieve. Before making determinations with the Coulter Counter, an aliquot technique was worked out to give a "standard" for comparison as follows:

1. Prepare a mixture of benzene and silicone oil in the proportion of 8.5 ml. benzene to .5 ml. silicone oil. Mix well.
2. Remove one ml. from the 1000 ml. suspension held at 31°C at constant slow agitation by a magnetic stirrer

and place in the mixture made in 1 above in a 15 ml. graduated centrifuge tube.

3. Mix well, at least 25 times.
4. Place a clean glass microscope slide on a warming stand. Once slide is warm, 2 ml. of the mixture (a 1:10 dilution) is removed and slowly dropped on the slide. The pipette is washed 3 times with benzene by filling and dropping the benzene onto the slide.
5. Once the benzene has evaporated, the silicone oil with the pollen remains. Evaporation of the benzene occurs in 2 to 3 minutes.
6. A cover slip, 25 X 25 mm. is placed on the oil and all grains are counted at 400X on a binocular microscope. No material ran out from under the cover slip as prior trials showed using .2 ml. of original mixture was just enough to fill the area under the cover slip. Thus, all grains could be counted using this technique.
7. Repeat this procedue for each subsequent preparation.

Four slide preparations were made and counted. Table 2 gives the results. The average of the counts for the Aliquot Technique (512,837 grains per ml.) and the Coulter Counter (478,881) are within 6.7 percent of each other. The agreement of the counts from these two techniques on Flask B is certainly closer (6.7%) than the agreement between the haemocytometer and Coulter counts on Flask A (27%). It is possible that the Coulter counts on Flask B aliquots are slightly low due to cell clumping. However, in counting the slides of the 1:10 dilution no clumping was observed.

Table 2. Counts obtained by aliquot and Coulter Counter techniques, Flask B, Dioon spinulosa pollen suspended in TBA.

I. Aliquot Technique

A. Grains counted/ .2 ml.	B. Grains/ml.
1. 9,833	1. 491,650
2. 11,226	2. 561,300
3. 9,733	3. 486,650
4. 10,235	4. 511,750
	Average = 512,837

II. Coulter Counter Technique, maximum dimension gate set at 50 microns.

A. Grains counted/ ml.

1. 536,000
2. 516,000
3. 493,800
4. 504,200
5. 498,300
6. 449,950
7. 457,150
8. 457,000
9. 446,750
10. 461,550
11. 447,000

478,881 = Average grain count/ ml.

Further, when counting slides for fossil pollen and spores to which the cycad pollen had been added, no clumping was seen. Because clumping cannot be controlled with the Coulter Counter, the determination made (512,837 grains/ml.) using the aliquot-dilution technique was used as the initial starting point, as clumping, if occurring, can be accounted for.

All additions of cycad grains to samples from the Colchester and Lily Pad Pond Bogs were made from Flask B. Further, the additions were made to the samples when first placed in 10% HCl (see laboratory methods).

4. Identification and Counting of Fossil Pollen and Spores.

One of the crucial problems in palynology is the accurate identification of fossil pollen grains and spores. They must be identified by comparing them with modern pollen and spores. Therefore, it is necessary to possess or have access to a reference collection of modern pollen and spores. The reference collection of modern pollen and spores consulted in this study is maintained by the Department of Botany at the University of Michigan. Identification was materially aided by reference to certain books, notably the publications of Erdtman (1943,1952, 1957), Wodehouse (1935), and Faegri and Iversen (1964).

The certainty of identification of fossil pollen and spores often falls along a gradient from unidentified to completely satisfactory identification. The reasons for uncertainty in identification include: (1) unfamiliarity of the investigator with all kinds of pollen and spores, (2) unavailability of reference pollen

material, (3) unsatisfactory preservation of some of the sporomorphs in the fossil samples.

Microscope slides made to count the fossil pollen and spores present in processed samples are prepared using silicone oil, the storage medium, as the mounting medium (Anderson, 1960). From each sample two slides were made. The suspended sediment used to make the slide was thoroughly mixed, so that any portion studied would be representative of the entire sample. This is necessary in order to compute later the density of the fossil pollen and spores.

After slides were made, the following procedure was used for analysis:

1. The same type of microscope was used for all analyses. This was a compound binocular research microscope with a graduated mechanical stage and the apochromatic objectives: 10X, 40X, and 100X (oil). The oculars were 10X.
2. For each sample, 500 arboreal pollen grains (AP) were tabulated. All non-arboreal pollen (NAP), spores, and unknown grains were also recorded. Tabulation of the grains was done on a form prepared for this purpose. If a grain could not be readily identified, it was recorded with the axial coordinates of the mechanical stage. After analysis of a slide was completed, the unknowns were relocated and studied further.
3. Searching was done at 400 magnifications (10X ocular and 40X objective). If further study was needed to verify identification, oil immersion (1000X) was used. Identifications not readily made under oil were treated as described in 2 above.

4. All cycad grains encountered while identifying and tabulating the fossil pollen and spores were recorded on a hand tally counter and subsequently recorded. These grains are readily identified and no difficulties were presented in either identification or counting.

5. Presentation of Data.

The standard procedure for presentation of pollen analytical data involves the calculation of a percentage spectrum for each sample; this shows the natural frequency of the various sporomorphs that were encountered. These spectra are then usually plotted in stratigraphic sequence to form a pollen diagram. In forested regions, where the regional pollen rain consists almost exclusively of tree pollen, the number of arboreal grains (AP) from a sample is used as the basis for percentage calculations. This helps to insure that certain locally abundant herbaceous plants, which may occasionally produce abundant pollen, do not obscure the characteristics of the regional vegetation, the chief basis for the paleoecologic and climatic interpretations. The non-arboreal pollen (NAP) and undetermined percentages are calculated on the sum total pollen excluding aquatics and cryptogams. The pollen diagrams prepared in this manner are found under the appropriate chapter heading for each bog.

Pollen diagrams, constructed on the basis of percent, have been criticized as not accurately representing the vegetation which produces the pollen and spores. Thus, the density technique described earlier provides as opportunity to produce pollen diagrams

on the basis of grain density rather than percent which may represent more accurately the vegetation producing the grains.

The basis for calculation of the density of the grains is as follows:

1. The grains counted including the undetermined but excluding the aquatics are totaled.
2. Using the formula listed below, the number of grains per unit of dry sediment is determined.

$$\frac{\text{Number of cycad counted}}{\text{Number of cycad added per unit dry sediment}} = \frac{\text{Number of grains counted}}{\text{Number of grains per unit dry sediment or } \underline{X}}$$

3. Using the same formula, the number of grains per unit of dry sediment for each grain kind at each sample level is determined.
4. The data obtained above are converted to a form giving the number of grains per milligram dry weight. The pollen diagram is then constructed based on the number of grains per milligram dry weight.

Chapter VI presents a more detailed discussion of the density of fossil grains in sediments and a pollen diagram for the Colchester Bog based on the density data obtained in this study.

CHAPTER III

BUGBEE BOG

1. Geographic Setting and Description.

The Bugbee Bog (also known as Stoddard Swamp and Kinnerson Bog) is in Caledonia County, straddling the Danville-Peacham townline. Its geographic coordinates are latitude 44° 22' N., longitude 72° 09' W, according to the Vermont-New Hampshire-St. Johnsbury 15-minute USGS topographic quadrangle map (1949). The bog is approximately 398 meters above mean sea level and is about 5 hectares (12 acres) in area (Figure 2).

In 1968, this bog was officially designated by the New England Wildflower Preservation Society as the "Bugbee Wildflower Sanctuary and Natural Area." It is owned by the State and administered and maintained by the Vermont Department of Forest and Parks. The Society purchased the bog in 1958 to preserve selected species of rare plants, especially orchids.

The bog is located on the eastern edge of a plateau-like region designated the Vermont Piedmont by Jacobs (1950). The counties of Vermont and the physiographic subdivisions as designated by Jacobs (1950) are shown in Figure 3. The piedmont lies between the Green Mountains on the west and the Northeast Highlands and the Connecticut River on the east. Metamorphosed sediments containing many plutonic

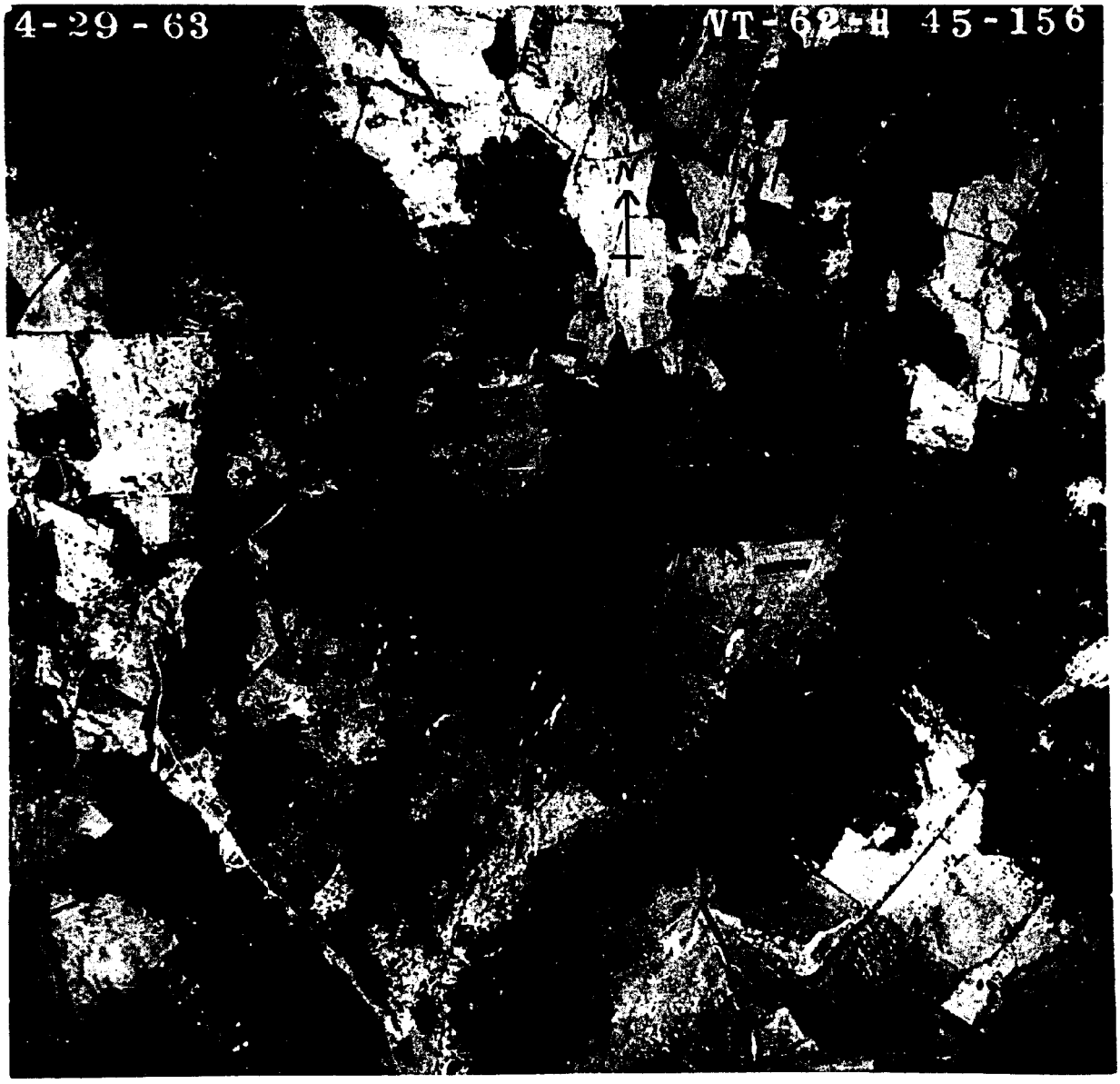

Figure 2. Aerial photograph of Bugbee Bog (outlined in black) and vicinity in vertical aerial photograph by U.S. Department of Agriculture, here reproduced at 1:31,500.

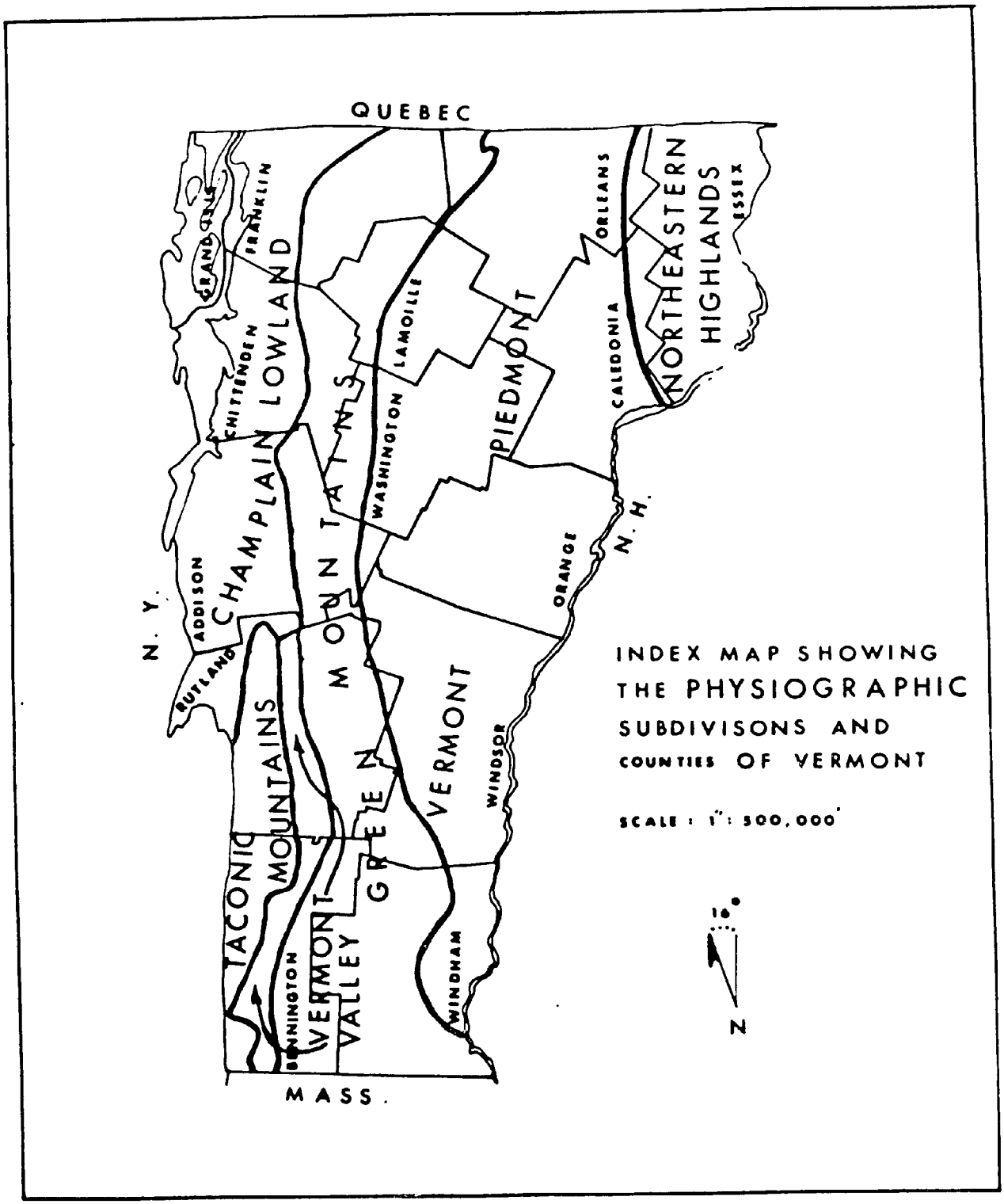

Figure 3. Index map of Vermont showing physiographic subdivisions and counties. Subdivisions are marked by the bold black lines and counties by the smaller black lines.

intrusions underlie this piedmont area. The surface is described by Jacobs (1950) as a dissected and glaciated uplifted peneplain.

Bedrock in the surrounding area has been assigned to the Waits River Formation and is Silurian/Devonian in Age (Eric, 1942; Hall 1959). Surface materials are glacial deposits of Wisconsin age.

2. Modern Vegetation of the Bog and the Neighboring Area.

As this study is primarily paleoecological in its aims, the vegetation at this bog site was surveyed for its indicators of bog history and conditions rather than for details of the communities. A reconnaissance of the bog's vascular flora was made during June, 1968. Specimens were collected only when identification could not be made with certainty in the field. Table 3 lists the plants known to occur at Bugbee Bog and those plants observed by the author in June, 1968.

Regionally, the bog is in the Hemlock-White Pine-Northern Hardwoods Forest as defined by Nichols (1935) and Braun (1950). Küchler (1965) in his map of Potential Natural Vegetation of the United States defines the regional vegetation as the "Broadleaf and Needleleaf Forest of Northern Hardwoods (Acer, Betula, Fagus, Tsuga)." Westveld et al. (1956) have divided New England into six natural forest type zones. Bugbee Bog is within "Zone 2, the Northern Hardwoods-Hemlock-White Pine." Hemlock (Tsuga canadensis) and white pine (Pinus strobus) characterize the coniferous element. Beech (Fagus grandifolia), sugar maple (Acer saccharum), red maple (Acer rubrum), and yellow birch (Betula lutea) are the hardwood dominants in the forests. Admixtures of red spruce (Picea rubens), white

Table 3. The plants listed below are known to occur at Bugbee Bog and vicinity as determined by Vogelmann (1964). The asterisk indicates the plants observed by the author in June, 1968. Plant names follow Fernald, M. L. 1950. Gray's Manual of Botany, 8th ed. American Book Co., New York, lxiv + 1932 pp.

Scientific name	Common name
Trees	
Larix laricina *	Tamarack
Picea mariana *	Black spruce
Thuja occidentalis *	Northern white cedar
Shrubs and Herbs	
Alnus rugosa *	Speckled alder
Aralia nudicaulis	Wild sarsaparilla
Arethusa bulbosa	Arethusa
Calla palustris	White calla
Calopogon pulchellus	Grass-pink
Calypso bulbosa	Calypso
Chamaedaphne calyculata *	Leatherleaf
Clintonia borealis	Dogberry
Corallorhiza trifida	Early coral root
Cornus canadensis *	Bunchberry
Cornus stolonifera *	Red osier dogwood
Coptis groenlandica *	Goldthread
Cypripedium acaule *	Pink lady's slipper
Cypripedium calceolus var. *parviflorum*	Small yellow lady's slipper
Cypripedium reginae	Showy lady's slipper
Dalibarda repens	False violet

Table 3. Continued

Scientific name	Common name
Drosera rotundifolia *	Round-leaved sundew
Gaultheria hispidula *	Snowberry
Habenaria dilatata	Leafy white orchis
Habenaria hyperborea var. *huronensis* *	Northern green orchis
Habenaria obtusata	Blunt-leaf orchis
Kalmia angustifolia *	Sheep-laurel
Ledum groenlandicum *	Laborador tea
Linnaea borealis *	Twinflower
Menyanthes trifoliata *	Buckbean
Mitella nuda	Naked miterwort
Myrica gale *	Sweet gale
Pyrola elliptica *	Shinleaf
Smilacina trifolia	Solomon's seal
Spiranthes cernua	Nodding ladies' tresses
Spiranthes romanzoffiana	Hooded ladies' tresses
Trientalis borealis *	Star flower
Vaccinium oxycoccus *	Small cranberry
Moss	
Sphagnum spp. *	Sphagnum moss

spruce (Picea glauca), balsam fir (Abies balsamea), white ash (Fraxinus americana), black cherry (Prunus serotina), sweet birch (Betula lenta), paper birch (Betula papyrifera), northern red oak (Quercus rubra), American elm (Ulmus americana), and basswood (Tilia americana) occur with light representation. The under story often has hornbeam (Carpinus caroliniana) and hop hornbeam (Ostrya virginiana). Old field successional elements are usually dominated by white pine with lesser occurrences of hemlock, spruce, and balsam fir. Stands of aspen (Populus tremuloides) and paper birch usually follow destructive fires. Sugar maple, beech, yellow birch, and hemlock are considered climax types while white pine, northern red oak, red pine (Pinus resinosa) are considered to be subclimax or or successional. Paper birch, gray birch (Betula populifolia), aspen, red maple, and black cherry are considered pioneer types (Westveld et al. 1956). The soils under these northern hardwoods are predominately of the podzolic type.

The landscape surrounding and including this bog is very similar to the regional forest type described above. The common trees in the vegetation around the bog are sugar and red maple, beech, white pine and hemlock. Trees which occur less frequently are red and white spruce, balsam fir, gray and paper birch, aspen, hornbeam, and hop hornbeam. The forested areas represent second and third growth timber. Many areas cleared for agricultural use in the early 1800's are now reverting to forest land since the majority of farms in the area have ceased operation. Land usage in the area has been primarily for vegetable and hay crops and pasture.

The Bugbee Bog occupies a depression in the landscape that is in excess of 8.5 meters (28 feet) deep and its surface is well forested with black spruce (Picea mariana), tamarack (Larix laricina), and northern white cedar (Thuja occidentalis). Bogs of this type are common in the area. Most of the bogs have not been studied for total thickness of the organic deposit. However, it is assumed many occupy depressions which are in excess of 12 meters (40 feet) in depth. Robert Farrington, Senior Forester, Department of Forest and Parks, State of Vermont, probing bogs for depth in Peacham, Victory, and Morrisville, encountered 12 meter thick accumulations without striking the bottom of the deposits. Black spruce, tamarack, and northern white cedar are the common trees in these bogs and others in the area (Farrington, 1969, personal communication).

The Bugbee Bog is in the final stages of bog formation as the forest cover on the surface is nearly complete and only a small open area near the center of the bog is not forested (Figure 4). Bog formation usually follows a series of stages from an open water pond stage through stages involving formation of a mat. The mat slowly encroaches into the water and with deposition of sediment, the entire pond area becomes filled. Once the mat is formed, a series of stages beginning with herbs is subsequently replaced with shrubs and then ultimately with trees dominating the mat surface. The Bugbee Bog is at this tree stage at the present time as increment borings show the stage is at least 50 years old.

The water table appeared to be well below the surface when the bog was studied in June, 1968. Runoff from the area immediately



Figure 4. Bugbee Bog. The cover of tamarack and black spruce trees is dense over most of the bog, but the leatherleaf and Labrador tea shrub cover is very dense in the opening in the foreground of this photograph. Sphagnum moss forms a continuous cover over the bog surface. July, 1968.

surrounding the bog occurs as slope gradients are nearly 30 percent and local relief of the land is in the order of 30 to 60 meters (100 to 200 feet).

3. Sediment Stratigraphy.

Two cores, A and B, were obtained from the Bugbee Bog from sites A and B respectively (Figure 5). Samples were taken at each site for sediment stratigraphy, radiocarbon dating and pollen analysis by the methods described in Chapter II. Core A is 8.40 meters in length; core B is 7.60 meters long. The stratigraphy and the sediment pH and color was determined in the field on moist samples (Table 4). Core A is presented in this study. Core B, which also has been processed for fossil pollen and spores is not presented in this study, as the information on that core is being published separately (McDowell, L.L., Dole, R. M., Jr., Howard, M., Jr., and Farrington, R. A., in press).

The sediment profile from core A (Table 4) shows a pronounced change from a predominately fibrous and humified peat of pH near neutral to a mixture of sedimentary peat and fine textured marl of pH above 8. This change occurs at 3.90 m. and similar sediments continue to 8.17 m. Below 8.17 m., the pH of the sediment is still alkaline. However, the fine textured marl is absent.

Shells of mollusks were found in this calcareous sediment from a depth of 3.90 m. to 6.60 m. I am indebted to Dr. Frank E. Eggleton, Professor Emeritus of Zoology, University of Michigan for identifying the shells as follows:

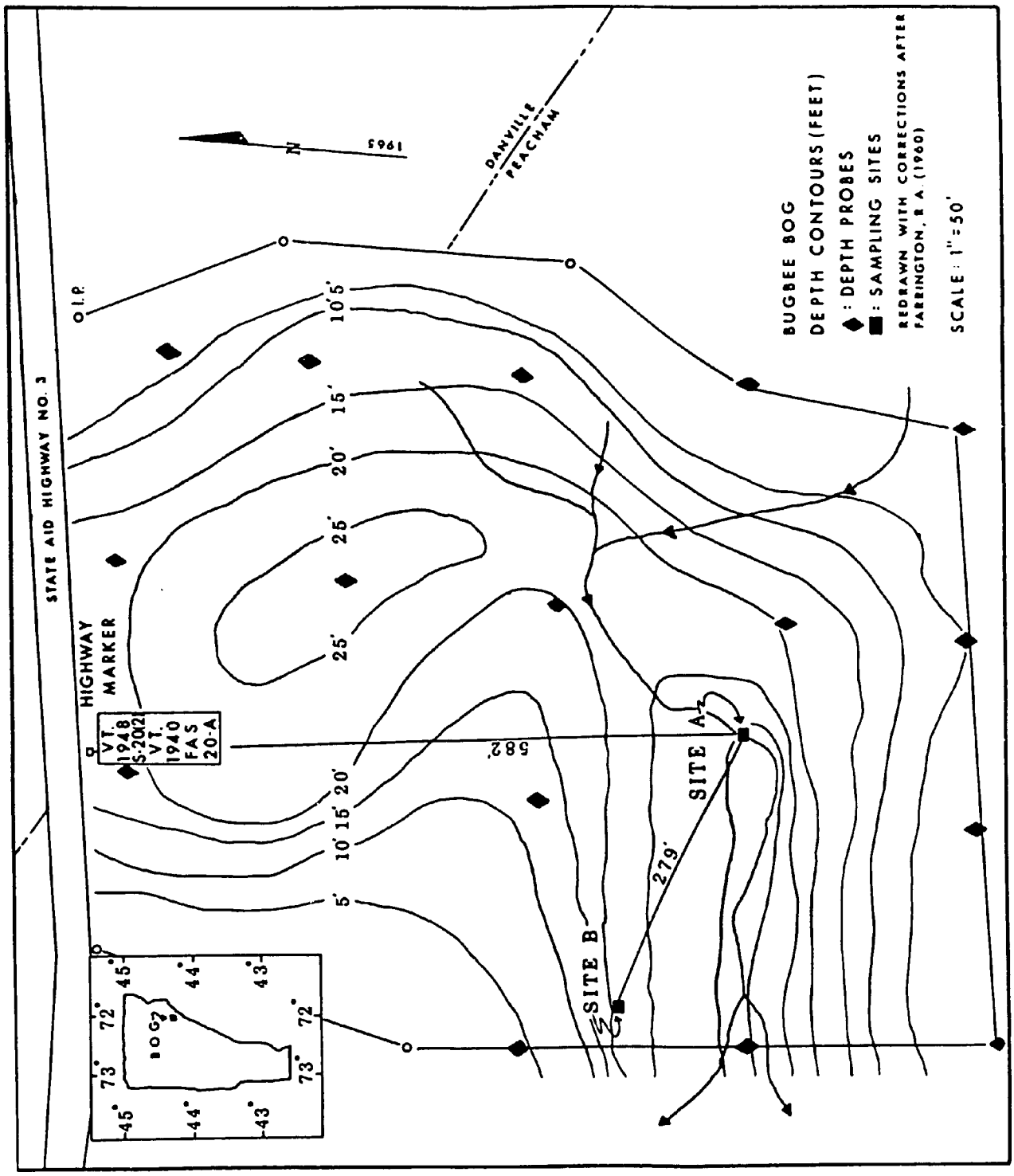
STATE AID HIGHWAY NO. 3
O.I.P.
HIGHWAY MARKER
VT. 1948 S.202
VT. 1940 FAS 20-A
DANVILLE PEACHAM
1965
N
582'
279'
SITE A
SITE B
5'
10'
15'
20'
25'
BUGBEE BOG
DEPTH CONTOURS (FEET)
◆ : DEPTH PROBES
■ : SAMPLING SITES
REDRAWN WITH CORRECTIONS AFTER FARRINGTON, R A. (1960)
SCALE : 1" = 50'
BOG
45°
44°
43°
72°
73°

Figure 5.

Table 4. Description of the sediment profile for Core A, Bugbee Bog, Caledonia County, Vermont.

Depth (m.)	Profile Description	pH	Munsell Color[1]
0 - .10	Very dark gray-brown mixture of fibrous and amorphous peat, not sticky, not plastic		10YR 3/2
.10 - .65	Dark yellow-brown mixture of fibrous and amorphous peat, not sticky, not plastic	6.6 at .40 m.	10YR 3/4
.65 - 2.50	Dark brown amorphous peat with some fibrous material, not sticky, not plastic	7.1 at 2.15 m.	10YR 3/3
2.50 - 3.90	Very dark brown amorphous peat, not sticky, not plastic	7.3 at 3.55 m.	10 YR 2/2
3.90 - 4.55	Layers of different colors from 2 - 13 cm. in thickness, mixture of sedimentary peat and fine textured marl, slightly sticky, jelly-like consistency, contains small shells, calcareous		7.5YR 6/4 7.5YR 4/2 10YR 4/3 7.5YR 5/2 10YR 5/3 10YR 6/3
4.55 - 5.90	Brown mixture of sedimentary peat and fine textured marl, jelly-like consistency, contains small shells, calcareous	8.8 at 5.60 m.	10YR 5/3

Table 4. Continued.

Depth (m.)	Profile Description	pH	Munsell Color
5.90 - 7.10	Layers of different colors from 3 - 30 cm. in thickness of sedimentary peat, jelly-like consistency, slightly sticky, contains small shells to depth of 6.60 m., calcareous.		10YR 3/2 10YR 5/3 7.5YR 4/2 10YR 2/2
7.10 - 7.90	Very dark gray brown sedimentary peat, jelly-like consistency, slightly sticky, calcareous	8.3 at 7.50 m.	2.5YR 3/2
7.90 - 8.17	Olive gray sedimentary peat, jelly-like consistency, slightly sticky, calcareous	8.4 at 7.90 m.	5Y 5/2
8.17 - 8.40	Dark greenish gray mineral matter with organic matter, slightly sticky, calcareous	7.9 at 8.40 m.	5GY 4/1
8.40+	Hard material not penetrable with Hiller sampler		

1. Colors were determined on moist samples using a standard Munsell color chart.

Class	Family	Genus and Species
Gastropoda	Valvatidae	Valvata tricarinata tricarinata
Gastropoda	Planorbidae	Gyraulus circumstriatus
Pelecypoda	Sphaeridae	Pisidium spp.

Representative specimens are shown in Figure 6. A few valves were identified as Ostrocods and may be in the genus Cypris or Candonocypris.

All forms identified are found today in fresh water ponds and lakes of alkaline or neutral pH. Valvatidae and Planorbidae can tolerate pH as low as 6.2; Sphaeridae, pH 6.0. Similar variations are found in tolerances to the amount of dissolved and available CO_2 and $CaCO_3$ from 0.1 ppm. to 15.0 ppm. These are animals of the bottom habitats and submerged surfaces and usually tolerate water depths of only 2 to 3 meters. Some Sphaeridae have been found at depths of 30 meters. The distribution of these animals is governed by the amount of dissolved salts, pH, oxygen, water depth, and temperature (Pennak, 1953).

The optimum conditions under which these animals live give some indication as to the environment of Bugbee Bog during the open water stage. In order for the animals to survive, one critical factor is a source of $CaCO_3$ for shell formation. The kind of bedrock which underlies nearly 50 percent of St. Johnsbury quadrangle also underlies Bugbee Bog and the surrounding area. This bedrock belongs to the Waits River Formation (Hall, 1959), lithologically a calcareous granulite and calcareous schist with minor amounts of micaceous

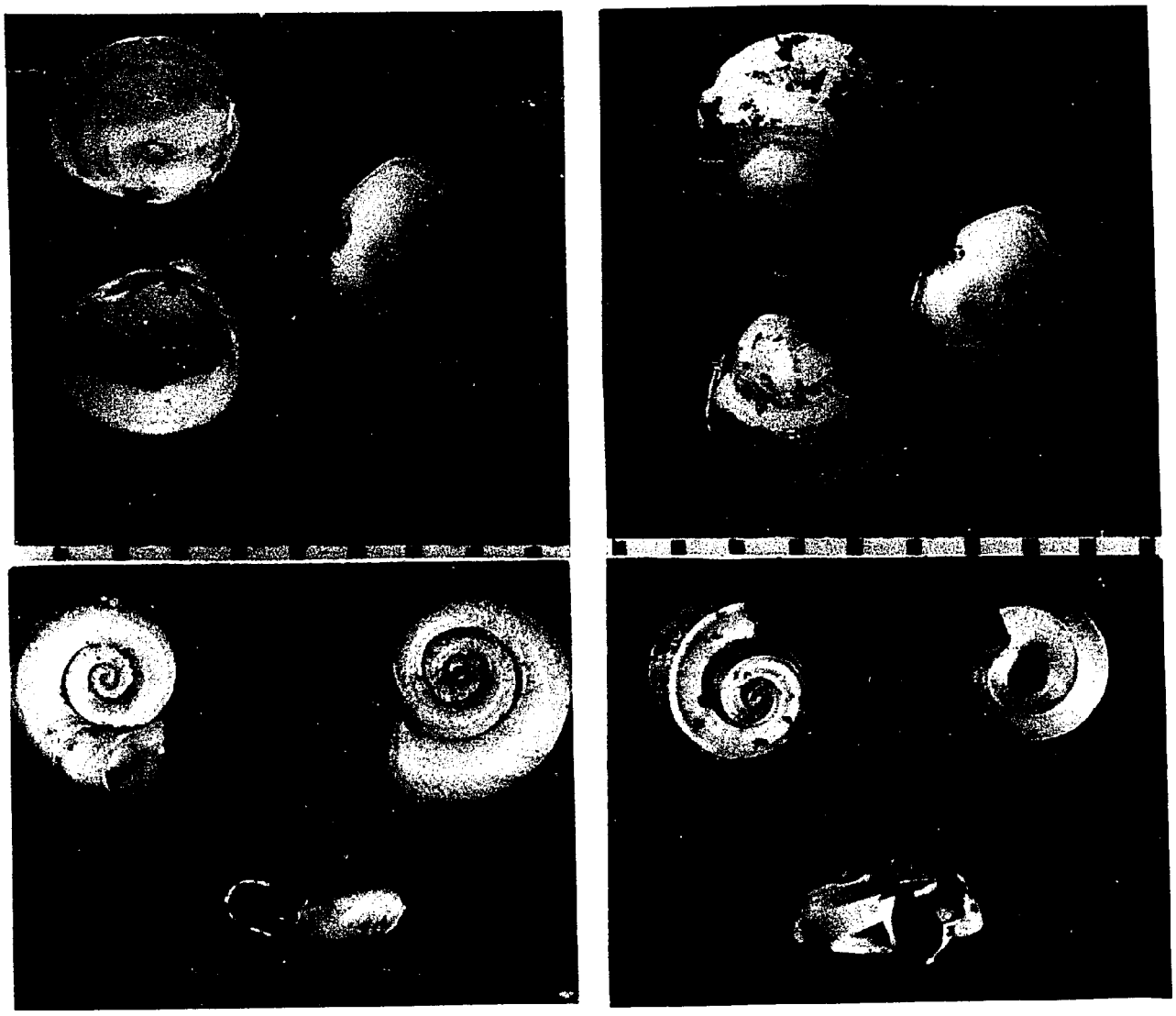

Figure 6. Shells found in sediment from Bugbee Bog. Upper left, Pisidium spp., upper right, Pisidium spp., lower left, Gyraulus circumstriatus, lower right, Valvata tricarinata tricarinata. Each mark on the scale in each photograph is 1 millimeter.

quartizite. This formation approaches 10,000 feet in thickness in eastern Vermont.

Glacial grinding of the bedrock to a rock flour and deposition as glacial till in the area probably provided the source of calcareous minerals. Glacial melt waters from the receding glacier initially dissolved these minerals during runoff into early Bugbee Bog pond. After all glacial ice melted away, rainfall and snow melt runoff in the spring from surrounding areas continued to bring calcareous minerals in solution into the pond. This does not account, however, for deposition of these minerals as marl since this is not well understood (Megard, 1968).

The term "marl" has been used in geological and agricultural reports to describe several rather widely differing materials such as chalky limestones, limey shales, and "green-sand marls." The term is used here to designate certain fresh water deposits of calcium carbonate or "bog-lime." Marl is deposited chiefly in lakes and ponds. The source of the minerals for these marl deposits in glaciated areas is commonly the calcareous glacial drift on surrounding areas from which surface water and ground water flow to the lakes and ponds where the carbonates are deposited on the bottom of these water bodies through natural warming of the water and the action of the aquatic plants and animals, particularly by certain species of stonewort algae and certain "shellfish" or mollusks.

The stoneworts are green algae belonging to the division Chlorophyta, the class Charophyceae, and the order Charales. All living genera are referred to the single family Characeae with six

genera and about 250 species. The genera are Nitella, Tolypella, Chara, Lamprothamnium, Lychnothamnus, and Nitellopsis. Nitella and Chara are the most common genera in the glaciated regions of Eastern North America.

They are widely distributed in quiet waters and inhabit sandy or muddy substrata in which anchoring rhizoids can find a suitable foothold. They are able to exist with a small amount of oxygen and in a substratum containing much decomposing matter. These plants require pure water and are scarcely found in water liable to become turbid or where there is contamination by excess nutrients. The presence of calcium is essential although the demands of the different species vary (Fritsch, 1945; Wood, 1967).

There is no generally accepted theory as to the deposition of marl. Several theories are commonly mentioned such as the Shell Theory, the Sedimentary Theory, the Chemical Theory and the Action by Plants Theory. The Chemical Theory is, however, commonly cited. Simplified, the theory states that the presence of dissolved CO_2 in the water allows the pond waters to hold in solution large amounts of calcium and magnesium carbonates. As the CO_2 and $-HCO_3^{--}$ ion concentrations are lowered, as by green plant photosynthesis, the carbonates are believed to precipitate out. No doubt all of these processes of marl deposition are involved to some extent during accumulation. The rather abrupt cessation of deposition of marl in the Bugbee Bog section cannot now be answered. The change from marl sedimentation regime to a peat sedimentation regime at 3.90 m. is abrupt and shells are absent above this level. Conditions for

marl formation obviously changed very quickly and the pond probably was filling in with organic detritus rapidly, a condition which might have shifted the balance of the whole sedimentation regime.

4. Pollen Stratigraphy.

The percentage pollen diagram for the Bugbee Bog is presented in Figure 7. Chapter II stated the method used to calculate the percentages for pollen diagrams. A change in the calculation of percentages for the non-arboreal elements is used in this diagram. Due to the general low numbers of these elements throughout the core, the percentage base is that of the sum total of vascular plant pollen and spores including the undetermined but excluding the aquatics.

In order to facilitate discussion of the pollen diagram, it has been divided into zones in keeping with the practice of Deevey (1939, 1943, 1951) and others. The criteria used to establish the pollen zones for this study are similar to those designated originally by Deevey in 1939. His terminology has been extended throughout the New England region and beyond and applied to pollen zones which, although different in pollen flora, are supposed to be stratigraphically equivalent (Ogden, 1960). In attempting to fit new pollen profiles into this sequence of pollen zones, workers are constantly looking for repetitions of the standard zones. Because the pollen flora for these zones differ from one region to another and are neither ecologically or temporally equivalent (Davis, 1965), a zone resembling the type zone has taken on a

Figure 7. Percentage pollen diagram for Bugbee Bog, Caledonia County, Vermont. Arboreal pollen percentages based on total tree pollen. Non-arboreal percentages based on total pollen and spores of vascular plants.

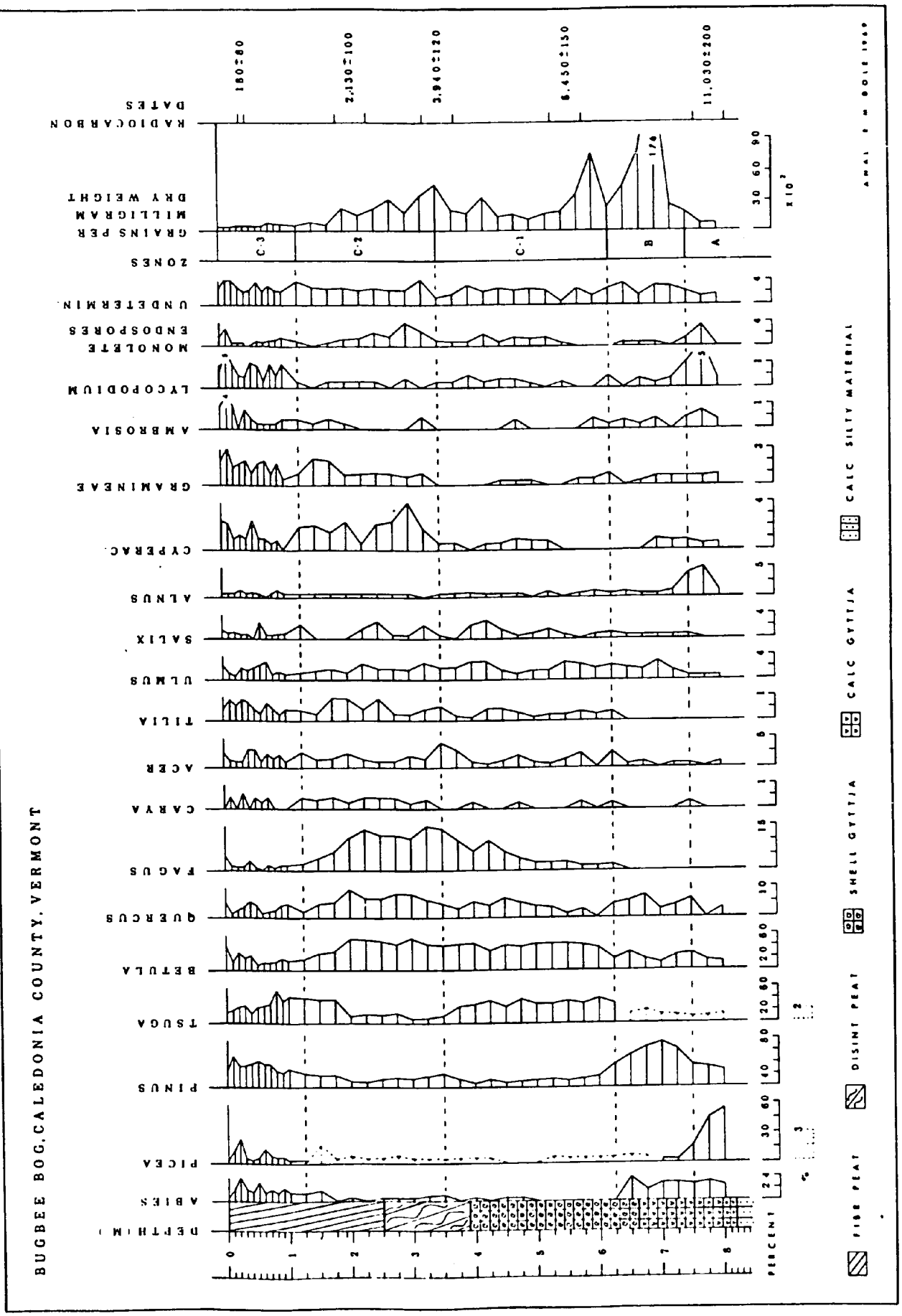
BUGBEE BOG, CALEDONIA COUNTY, VERMONT
RADIOCARBON DATES
180±80
2,130±100
3,940±120
6,450±150
11,030±200
GRAINS PER MILLIGRAM DRY WEIGHT
ZONES
C-3
C-2
C-1
B
A
UNDETERMIN
MONOLETE ENDOSPORES
LYCOPODIUM
AMBROSIA
GRAMINEAE
CYPERAC
ALNUS
SALIX
ULMUS
TILIA
ACER
CARYA
FAGUS
QUERCUS
BETULA
TSUGA
PINUS
PICEA
ABIES
DEPTH (M)
PERCENT
FIBR PEAT
DISINT PEAT
SHELL GYTTJA
CALC GYTTJA
CALC SILTY MATERIAL

Figure 7.

climatic meaning relative to the other zones in the sequence. Thus, according to Davis (1965), the zones have to some degree become climatic concepts influencing the interpretation given the pollen spectra. It is however, possible to use such data to test the hypothesis that related climatic and vegetational changes occurred simultaneously in different regions. Table 5 shows the pollen zones and pollen assemblages originally determined by Deevey (1939) for southern Connecticut compared to data from other workers in New England. The pollen zones and pollen assemblages from this study are also included. In Deevey's original designation of pollen zones, he used the symbol A to denote late-glacial time, the symbols B, C-1, C-2, C-3 to designate postglacial time. Deevey later, in 1951, divided the A zone into A-1, A-2, and A-3 and added the zones L-1, L-2, and L-3 to indicate earlier late-glacial time than A. The L designation was used to indicate fluctuations in a pollen flora of predominately non-arboreal kinds thought to be similar to tundra vegetation. The tree pollen found in these zones was theorized to have been brought in by long-distance transport (Table 5). Since 1951, the L designation has been replaced by T to recognize the same interval for which L was originally used. Thus, T-1, T-2, and T-3 have replaced L-1, L-2, and L-3. Further refinements of the A zone at present are A-4, A-3, A-2 and A-1. The A zones, in general, represent zones dominated by spruce pollen with herb pollen less abundant than tree pollen. This entire A zone is thought to be a closed spruce forest (Davis, 1965).

Table 5. Summary of Pollen Zones and associated Pollen Assemblages from selected areas in New England including the zones and assemblages deduced from this study.

Pollen Zone	Deevey, 1939, S. Conn.	Deevey, 1951, N. Maine	Davis, 1965, N. Vermont	Whitehead and Bentley, 1963, SW. Vt.	Dole, 1969 NC. Vermont
C-3	Oak-Chestnut maximum	Hemlock, spruce return; beech maximum	Hemlock max., spruce return, birch max., pine present	Hemlock max. pine and birch present, return spruce and fir	Spruce and fir return, presence pine, hemlock, oak, beech
C-2	Oak-hickory maximum	Oak max., pine rise, hemlock, beech min.	Hemlock min., low pine, high birch and beech	Hemlock min., oak max.; pine hickory, beech present	Hemlock min., high pine; oak, beech, hickory present
C-1	Oak-hemlock maximum	Hemlock max., birch rises; oak, beech present	Hemlock and birch max.; oak, beech present	Hemlock max.; rising oak, birch; beech present; pine falling	Hemlock max., pine min.; oak, beech, birch present
B	Pine max.	Pine max., birch falls	Pine max., birch falls	Pine and oak maximum	Pine max.
A-4	Spruce and fir maximum	Spruce max., fir and birch rise; alder max. (called A-3 at this time)	Spruce max., birch present	Spruce and fir max., low pine	Spruce and fir max., low pine, incr. NAP

Table 5. Continued.

Pollen Zones	Deevey, 1939, S. Conn.	Deevey, 1951, N. Maine	Davis, 1965, N. Vermont	Whitehead and Bentley, 1963, SW. Vt.	Dole, 1969 NC. Vermont
A-2	Absent	Spruce max., birch falls	Absent	Absent	Absent
A-1	Absent	Birch rises NAP falls; end of tundra	Absent	Absent	Absent
L-3	Absent	NAP higher	Absent	Absent	Absent
L-2	Absent	NAP lower, spruce and birch rise	Absent	Absent	Absent
L-1	Absent	NAP high, long distance transport of pine, spruce, and birch	Absent	Absent	Absent

The characteristics of the pollen zones for the Bugbee Bog are listed below. A more detailed discussion of each zone follows the characterization.

Zone A. Spruce and fir maxima, low pine and deciduous trees, high NAP.

Zone B. Declining spruce and fir, pine maximum, increase in deciduous trees, decrease in NAP.

Zone C-1. Pine minimum, hemlock maximum, rising birch, oak, and beech.

Zone C-2. Low pine, hemlock minimum, maxima for oak, birch, beech, and hickory. Maxima for sedge and monolete endospores.

Zone C-3. Return of spruce and fir, presence of pine, hemlock, oak, and beech. Maxima for ragweed and clubmoss.

Zone A (8.40 - 7.50 meters). This zone is characterized by high spruce percentages with maxima of more than 50 percent. Sedge pollen commonly increases and may reach a maximum at the upper limits of the zone. Deciduous tree kinds are few. The Bugbee Bog pollen diagram shows a spruce maximum of 55 percent and fir attains 3 percent and remains constant throughout this zone. The non-arboreal pollen and spores increase with alder (5%) and clubmoss (5%) reaching maxima. Ragweed, grass, and monolete endospores show increases, with sedge pollen present. Birch, oak, maple and elm percentages are low.

Forty centimeters (.4 meters) of core were recovered below 8 meters. The forty centimeters were sampled at 10 cm. (.10 meters) intervals. In processing them in the usual manner, virtually no fossil pollen and spores were found. The sediment, primarily a dark greenish-gray calcareous mineral material, was very difficult to work. In the process of using hydrofluoric acid to remove the mineral material, precipitates formed and caused the remaining material to become very hard by agglomeration. Attempts to break up the hard mass failed and no chemical was found in which the material would re-dissolve. Consequently, the samples were rendered unusuable. Zinc chloride flotation (Funkhauser and Evitt, 1959) was then used to attempt a separation of the organic from the inorganic matter. The organic fraction yielded a few spruce grains but no others, thus no counts are presented for these 4 sample intervals.

Zone B (7.50 - 6.25 meters). The B zone, in general, is delineated by high percentages of pine, this commonly reaching 70 to 80 percent. The lower boundary of the zone is delimited by a marked decrease in spruce and fir and sharp rise in pine; the upper limit of the zone by the elimination of spruce and fir, the rapid decrease in pine, the sharp rise in hemlock, and the percentages of deciduous trees begin to increase. The Bugbee Bog pollen diagram shows these characteristics for the B zone with beech, oak, maple, elm, and willow increasing in percentage. Alder, ragweed, clubmoss, and monolete endospores decrease in percentage; grass and sedge are present, but less than 1 percent.

Zone C-1 (6.25 - 3.50 meters). In this zone deciduous tree pollen percentages become greater for the first time. There is a minimum of pine Spruce and fir occur in percentages of less than 3 and sporadically. Hemlock reaches a maximum. Percentages of oak are relatively low (5 to 8%) and constant. The upper limit of the zone is marked by low pine percentages and hemlock decreasing. In addition, beech, birch, and maple rise with birch and beech reaching maxima at the C-1/C-2 zone boundary. Basswood, hickory, elm, and willow are present in small quantities. Alder, sedge, grass, and clubmoss and also present in small quantities of 1 percent or less.

Zone C-2 (3.50 - 1.25 meters). The zone is characterized by oak and hickory maxima in southern New England. However, as neither hickory is found at a maximum and an oak maximum is not always found, a hemlock minimum and a pine maximum (or at least an increase in pine percentage) has been designated as the delimiting characteristic for the C-2 zone in northern New England (Davis, 1965). The upper boundary of the zone in northern New England is usually marked by the return of spruce and fir, an increase in hemlock, and high pine percentages. The Bugbee Bog pollen diagram is similar to the characterization for the zone except pine percentages do not increase as might be expected. Birch, beech, hickory, and basswood reach maxima. The hickory maximum represents only 1 percent of the pollen counted. Although hickory is noted at a maximum, it is done simply to signify that hickory pollen is found most consistently in this zone of any of the other zones. Spruce and fir pollen become more

evident near the upper limit of the zone and hemlock and pine are increasing. Sedge pollen (4%) and monolete endospores (4%) show maxima.

Zone C-3 (1.25 - 0 meters). Originally, in southern New England, this zone was characterized by oak and chestnut maxima. Neither of these types show maxima in northern New England diagrams. It is difficult to assign a characteristic pollen assemblage to this zone since published pollen diagrams for northern New England differ. However, there are some similarities. Spruce and fir percentages usually continue to increase up to the surface, often with maxima at the surface. Percentages of pine and hemlock are variable, often with pine increasing and hemlock decreasing. Deciduous tree types as birch, beech, and oak are present with percentages nearly uniform. Further, a maximum of ragweed pollen is very characteristic at or near the surface. The Bugbee pollen diagram shows spruce and fir increasing to 4 and 23 percent respectively. Pine is generally increasing and hemlock decreasing. Percentages of larch, beech, oak, birch, maple, and elm are relatively constant. There are maxima of ragweed, clubmoss, and monolete endospores.

Table 6 lists those taxa not included on the pollen diagram for Bugbee Bog.

5. Radiocarbon Sequences.

Samples for radiocarbon dating were collected from both cores A and B. The radiocarbon determinations were made at the USDA Sedimentation Laboratory, Oxford, Mississippi, by liquid

Table 6. Taxa not included on the pollen diagram for the Bugbee Bog. Number of grains counted follow each taxon.

Sample Level (m.)	Taxa[1]
0.00	Lar.-2, Car.-Ost.-1, Cor.-2, Pla.-1, Art.-1, Nup.-4
.10	Lar.-10, Chen.-Am.-3, Com.-1, Art.-1, Osu.-3
.20	Lar.-17, Art.-1, Osu.-1, Sph.-3
.30	Lar.-8, Car.-Ost.-8, Chen.-Am.-2, Sph.-2
.40	Lar.-6, Jug.-1, Car.-Ost.-3, Chen.-Am.-2, Com.-1
.50	Lar.-2, Car.-Ost.-4, Myr.-2, Pla.-2
.60	Lar.-16, Frax.-1, Cor.-1, Chen.-Am.-2, Pla.-1, Sph.-1
.70	Lar.-4, Chen.-Am.-2, Com.-1, Nym.-1, Osu.-4, Sph.-1
.80	Lar.-3, Car.-Ost.-1, Chen.-Am.-1, Pla.-1, Art.-1, Nup.-1, Osu.-1
.90	Lar.-7, Car.-Ost.-1, Cor.-1, Art.-2, Sph.-1
1.00	Lar.-2, Cor.-2, Eri.-1, Chen.-Am.-2, Nup.-1
1.25	Lar.-12, Cor.-2, Pla.-1, Art.-1, Nup.-3, Nym.-1, Sph.-1
1.50	Lar.-7, Frax.-1, Car.-Ost.-1, Cor.-1, Pla.-1, Com.-1
1.75	Lar.-1, Frax.-2, Car.-Ost.-6, Cor.-2, Chen.-Am.-1, Pla.-1

Table 6. Continued

Sample Level (m.)	Taxa
2.00	Car.-Ost.-8, Nup.-2
2.25	Lar.-1, Frax.-2, Cor.-1, Eri.-1, Cary.-1, Pla.-2
2.50	Lar.-2, Car.-Ost.-2, Com.-1, Typ.-1, Nup.-1
2.75	Lar.-1, Car.-Ost.-2, Cary.-1, Nup.-1
3.00	Lar.-3, Car.-Ost.-3, Cor.-2, Typ.-3
3.25	Lar.-1, Frax.-1, Cary.-1, Pla.-1, Art.-1, Typ.-3, Nym.-1
3.50	Lar.-3, Car.-Ost.-1, Eri.-2, Typ.-2
3.75	Lar.-1, Jug.-1, Car.-Ost.-1, Com.-1, Typ.-1, Nup.-1
4.00	Jug.-3, Frax.-1, Chen.-Am.-1, Cary.-1, Pla.-1
4.25	Typ.-1
4.50	Lar.-1, Car.-Ost.-1, Chen.-Am.-2, Cary.-1, Typ.-1, Osu.-1
4.75	Art.-1
5.00	Jug.-1, Chen.-Am.-1
5.25	Frax.-3
5.50	Jug.-1, Car.-Ost.-1, Typ.-2, Sph.-1
5.75	Jug.-1, Car.-Ost.-1

Table 6. Continued

Sample Level (m.)	Taxa
6.00	Car.-Ost.-1
6.25	Lar.-3, Cor.-1, Chem.-Am.-1
6.50	Lar.-2, Car.-Ost.-4, Nup.-1
6.75	Lar.-2, Cor.-1
7.00	Lar.-4, Car.-Ost.-1, Chen.-Am.-1, Com.-2
7.25	Lar.-9, Car.-Ost.-4, Cor.-2, Chen.-Am.-1, Com.-2, Art.-1
7.50	Lar.-15, Jug.-1, Car.-Ost.-5, Cor.-1, Com.-1
7.75	Lar.-7, Eri.-1, Com.-1, Art.-1, Sph.-2
8.00	Lar.-1, Cor.-1, Chen.-Am.-1, Pla.-3, Com.-5, Art.-4, Typ.-1, Nup.-1

1. Lar.=Larix, Car.-Ost.=Carpinus-Ostrya, Cor.=Corylus, Pla.=Plantago, Art.=Artemisia, Nup.=Nuphar, Chen.-Am.=Chenopodiaceae-Amaranthaceae, Com.=Compositae (excluding Ambrosia and Artemisia), Osu.=Osmunda, Sph.=Sphagnum, Jug.=Juglans, Myr.=Myrica, Frax.=Fraxinus, Nym.=Nymphyea, Cor.=Corylus, Eri.=Ericaceae, Cary.=Caryophyllaceae, Typ.=Typha.

scintillation counting of benzene. Each sample processed was of sufficient size to yield 3 grams of carbon as $^{14}C_6$ H_6 for counting. Measurement of the beta emissions from the radiocarbon was performed using a modified Packard Tri-Carb liquid scintillation spectrometer (model 314 AS). In accordance with the decision of the Fifth Radiocarbon Dating Conference, Cambridge, 1962, all dates are based on the Libby value, 5570 years for the half-life of ^{14}C. The accepted year A.D. 1950 was used as the reference year in all calculations.

The radiocarbon ages of the dated sediments from the Bugbee Bog are shown in Table 7. The lowermost calcareous sediments, 7.65 to 8.15 meters, date at 11,030 $\pm$ 200 and 11,290 $\pm$ 200 years before present (B.P.). These sediments are 550 $\pm$ 210 to 800 $\pm$ 200 years younger than the Two Creeks Interstade at the type locality in Wisconsin, re-calculated to be 11,850 $\pm$ 100 years old (Broecker and Farrand, 1963). The dates on the humin (alkali insoluble) and humic acid (alkali soluble) fractions of the organic samples from the core are in good age agreement. By contrast, comparison of the carbonate and organic samples show poorer agreement (OX-210 and OX-219 vs. OX-220 and OX-229). For samples from 5.35 to 5.85 meters, the average date for the two carbonate samples is 6,115 $\pm$ 110 years old whereas the average for the two organic samples is 6,445 $\pm$ 110 years old. The difference in these two ages is 330 $\pm$ 120 years. The difference is significant with the probability of obtaining the difference by chance being 0.6 percent. Similarly, the samples from 7.65 to 8.15 meters (OX 206 vs. OX 207) differ in age as the carbonate samples are 11,290 $\pm$ 200 years old and the organic samples are 11,030 $\pm$ 200 years old.

Table 7. Radiocarbon Ages for Sediments From Bugbee Bog, Caledonia County, Vermont.[1]

Depth (m.)	USDA Lab No.	Material	Core	Fraction	Age (^{14}C yrs.)
.35 - .45	OX-217	Peat	A	Humin	110 ± 80
.35 - .45	OX-218	Peat	A	Humic Acid	180 ± 80
.50 - 1.00	OX-227	Peat	B	Humin	1110 ± 80
.50 - 1.00	OX-228	Peat	B	Humic Acid	1070 ± 80
1.90 - 2.40	OX-215	Peat	A	Humin	3590 ± 100
1.90 - 2.40	OX-216	Peat	A	Humic Acid	3590 ± 100
3.00 - 3.50	OX-225	Peat	B	Humin	3750 ± 120
3.00 - 3.50	OX-226	Peat	B	Humic Acid	3950 ± 120
3.30 - 3.80	OX-213	Peat	A	Humin	6130 ± 150
3.30 - 3.80	OX-231	Peat	A	Humic Acid	6480 ± 150
4.81 - 5.31	OX-223	Peat + Marl	B	Carbonate	6130 ± 150
4.81 - 5.31	OX-224	Peat + Marl	B	Organic	6480 ± 150
5.35 - 5.85	OX-210	Peat + Marl	A	Carbonate	6020 ± 150
5.35 - 5.85	OX-219	Peat + Marl	A	Carbonate	6210 ± 150
5.35 - 5.85	OX-220	Peat + Marl	A	Organic	6450 ± 150
5.35 - 5.85	OX-229	Peat + Marl	A	Organic	6440 ± 150
6.20 - 6.70	OX-221	Peat	B	Humin	8460 ± 180
6.20 - 6.70	OX-222	Peat	B	Humic Acid	8510 ± 180
7.65 - 8.15	OX-206	Peat + Marl	A	Carbonate	11290 ± 200
7.65 - 8.15	OX-207	Peat + Marl	A	Organic	11030 ± 200

1. Data in Table from Dr. L. L. McDowell, Sedimentation Laboratory, USDA, Oxford, Mississippi.

This is a difference in age of 260 $\pm$ 120. Contamination of sediments by ground waters of higher ^{14}C activity is the usual cause given for the older age of sediments. Carbonate samples often show an older age due to this kind of contamination. This may explain the difference in ages between the dates at 7.65 to 8.15 meters. The dates on the samples from 5.35 to 5.85 meters is opposite of that just described in that the carbonate fraction of the samples is younger than the organic fraction. This anomaly is probably due to contamination by ^{14}C of greater half-life.

The chronology of sediment accumulation in the bog is graphed in Figure 8. Sample ages are plotted on the mid-point of the sampling interval. The average rate of peat formation in Bugbee Bog is about 7.2 cm. per century. According to the curve, the rate increased in the later part of the bog's history. The rate for Bugbee Bog again calls attention to the remarkable good estimate by Sears and Janson (1933) of 10.16 cm. of peat accumulation for bogs in the Erie Basin.

For the most part, the above data on the radiocarbon age determinations and Figure 8 were kindly supplied for my use by Dr. Leslie L. McDowell, Research Soil Scientist, USDA Sedimentation Laboratory, Oxford, Mississippi.

6. Discussion.

The pollen zones, as delineated for the Bugbee Bog, are in general accord with other published findings for New England. The pollen diagram is dominated by the pollen of pine, birch, and hemlock and shows small percentages (1 - 5%) of oak, hickory, beech, elm and

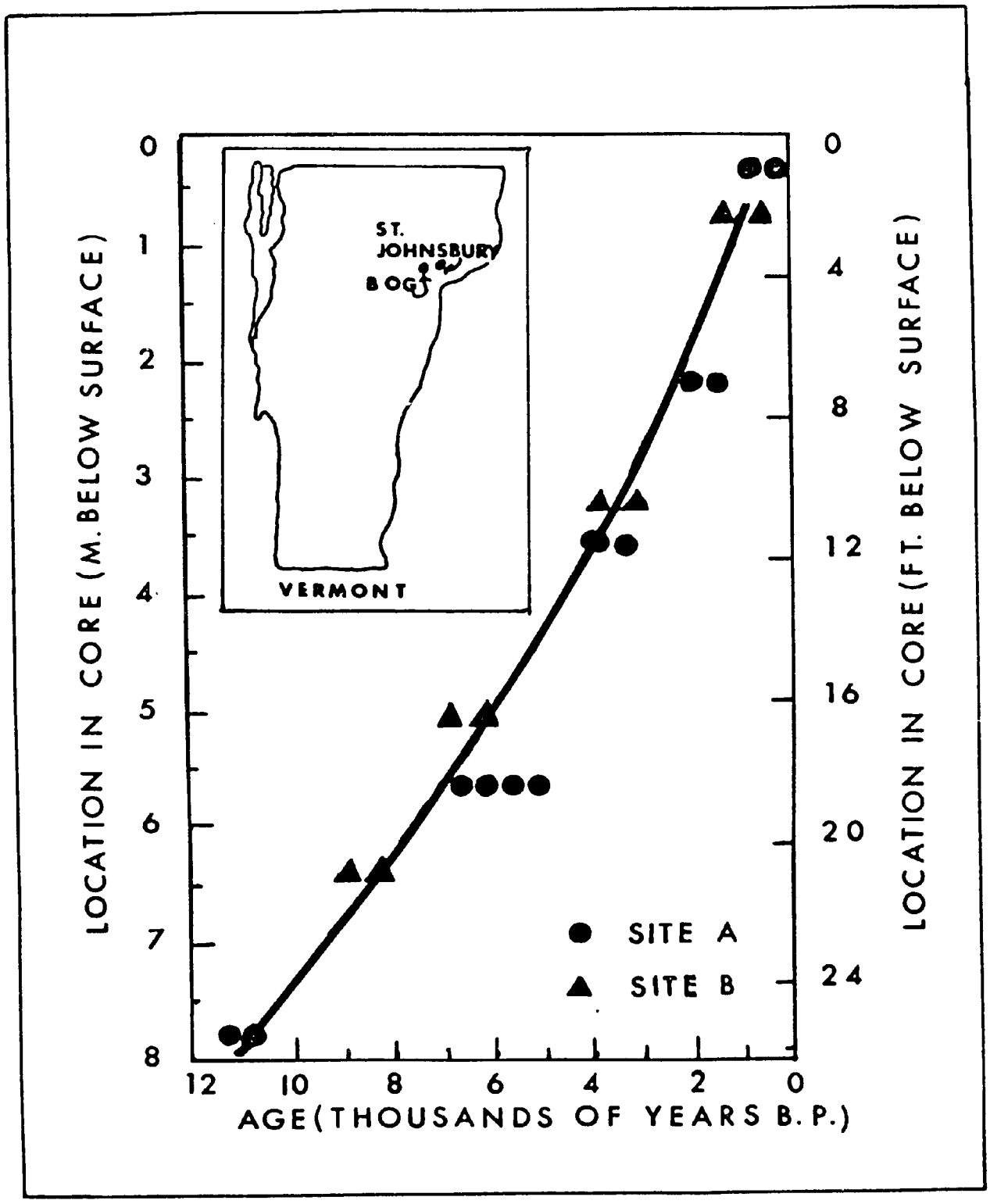

Figure 8. Rate of sediment accumulation, Bugbee Bog, Caledonia County, Vermont. This graph, including the fitted curve, was prepared by Dr. Leslie L. McDowell, USDA Sedimentation Laboratory, Oxford, Miss.

non-arboreal pollen (NAP). Since the pollen assemblages and the pollen zones are similar to other findings, it is possible to reconstruct a sequence of vegetational and climatic changes that have occurred at Bugbee Bog using published findings in New England as guides.

Pollen Zone A (8.40 - 7.50 meters). Spruce and fir characterize this zone. Bugbee Bog lacks the complete record for zone A and the tundra zones as described by Deevey (1951) in northern Maine and as subsequently shown by Davis (1958, 1960) and Ogden (1959) in Massachusetts, and Leopold (1955, 1956) in southern Connecticut. This zone in Bugbee Bog can be correlated with the upper portion of the A zone shown on the diagrams of Deevey (1951), Davis (1958, 1960, 1965), Ogden (1959), and Whitehead and Bentley (1963) for southwestern Vermont, Krauss and Kent (1944) for southeastern New Hampshire, and Terasmae (1959, 1960) for the St. Lawrence Lowlands, Canada. It is interesting to note that the diagram of Davis (1965) for Brownington Pond in northern Vermont and Whitehead and Bentley (1963) for Pownell Bog in southwestern Vermont also show only the upper part of this zone here designated for Bugbee Bog and correlated as A-4. In northeastern Vermont, spruce-fir forests were the earlist recorded and existed from at least 11,000 to about 10,000 years ago. Climatically, zone A may represent a cooler and moister climate than at present. Extensive coniferous forests grow under similar conditions today in eastern Canada. The lack of significant percentages of deciduous tree pollen also suggest that a cool climate prevailed during this period.

Sediments from core A at the 7.65 to 8.15 meter level have a radiocarbon date of 11,030 $\pm$ 200 years. The base of core A, then,

is estimated to be slightly older than 11, 030. A radiocarbon date from central Massachusetts from the A-3 zone is dated at 10,800 ± 280 years B.P. This was interpreted to be contemporaneous with late Two Creeks, then estimated to be about 11,000 years old, or with early Valders glacial substage (Davis, 1958). The A-3/A-4 zone boundary, probably absent in the Bugbee Bog pollen diagram or obscure at the very base of the organic sediments, has been radiocarbon dated at several New England sites ranging in age from 10,300 to 10,800 years B.P. (Deevey, 1958; Davis and Deevey, 1964). Marine shells dated at 10,630 ± 300 years B.P., 10,580 ± 330 years B.P., and 11,370 ± 360 years B.P. (Preston, et al. 1955), were interpreted by Terasmae (1959) to be contemporaneous with the Two Creeks Interval, then believed to be 11,000 year B.P. or perhaps correlated with the Valders substage. Re-evaluation of radiocarbon dates to give a best estimate of 11,850 ± 100 years B.P. for the Two Creeks horizon at the classic site in Wisconsin (Broecker and Farrand, 1963) discounts the previous correlations of the A-3/A-4 zone boundary. From these data, it appears that the Bugbee Bog began forming a short time after the Two Creeks event in Wisconsin or early Valders events of the upper Great Lakes region. The radiocarbon dates from the Bugbee Bog provide additional evidence that an ice advance simultaneous with the Valders ice, which followed the Two Creeks Interval, did not enter New England (MacClintock and Terasmae, 1960; Broecker and Farrand, 1963). If this is correct, then the surficial deposits in northern Vermont are older than Two Creeks (Stewart and MacClintock, 1964).

Pollen zone B (7.50 - 6.25 meters). According to the graph in Figure 8, the transition from zone A to zone B occurred at 10,200 years B.P. and zone B spanned about 2,400 years until 7,800 years ago. Such age durations for pollen zones are largely postulated on the similarity of pollen zone interpretations elsewhere as very few radiocarbon dates are available to test the validity of the correlation. According to Davis (1965), zone B occurred between 7,500 and 9,500 years B.P. in Pennsylvania and southern New England with a single date from Maine (5,962 $\pm$ 320 years B.P.) indicating a younger age for this transition there (Deevey, 1958; Davis, 1965).

This zone is recognized widely in glaciated eastern North America as the Postglacial Pine Period. Spruce and fir decline rapidly and pine increases which is postulated to indicate a shift to a warmer and drier, more continental, climate. The B zone is well represented in the Bugbee Bog pollen diagram and fits these criteria. The high frequency (75%) of pine pollen may indicate contributing vegetation in which pine was actually the dominant tree. Similar maxima for pine pollen are typical for other New England pollen diagrams. However, comparison of pollen in modern surface samples on lake bottoms with the existing vegetation indicate that pine and certain other pollen types may be over-represented (Davis and Goodlett, 1960; Davis, 1963, 1965, 1967b).

Although the Postglacial Pine Period is quite evident in the Bugbee Bog pollen diagram, the radiocarbon chronology indicates the pine period began earlier in northeastern Vermont than in southern New England, at least some 700 years earlier. Such speculation is

entirely dependent on the placement of the A/B zone boundary on the pollen diagram by the author.

Pollen Zone C-1 (6.25 - 3.50 meters). The transition from zone B to C-1, according to Figure 8, is at 7,800 years B.P. It is marked by an increase in the pollen of hemlock, birch, beech, maple, elm, and a sharp decline in the abundance of pine. Other deciduous tree pollens are present, i.e., oak, basswood, and hickory. C-1 marks the first increase of deciduous trees which are adapted to a warmer and moister climate than is postulated for zone B. Oak is present and increases slightly, but does not attain a distinct maximum as it does in southern New England pollen diagrams.

The B/C-1 transition probably is near in time to the beginning of the Hypsithermal Interval (Deevey and Flint, 1957). This interval is a period during the Postglacial when prevailing temperatures were higher than they are today. Further, the time of this transition, 7,800 years B.P., is earlier than the time proposed for southern New England, 7,500 years B.P.

Pollen Zone C-2 (3.50 - 1.25 meters). The transition between zone C-1 and C-2 is marked by a decrease in hemlock and an increase in pine at Bugbee Bog. However, the increase in pine is slight and not as marked as would be expected based on other published diagrams.

Zone C-2, interpreted to be the warmest and driest period of postglacial history, is represented by a maximum of hickory and oak in southern New England. It is represented by a maximum of pine and a minimum of hemlock in northern New England (Davis, 1965). In northern Vermont and Maine hickory is absent or present in low percentages (2%

or less), and a hemlock minimum is recognizable and used to define zone C-2 (Deevey, 1951; Walker and Hartman, 1960). The pollen distribution in zone C-2 is in general agreement with other published diagrams for northern New England.

Some detailed pollen diagrams show a beech maximum at the C-1/C-2 boundary and again at the C-2/C-3 boundary. The beech curve for Bugbee Bog shows beech rising at the C-1/C-2 boundary with a maximum in the C-2 zone. However, a second maximum at the C-2/C-3 zone boundary is absent. Deevey (1943, 1949) has attempted to explain these beech maxima as successive waves of migration in a northerly direction from a Pleistocene refuge in the Appalachian Mountains.

NAP reaches a high value early in this zone. Sedge pollen and monolete endospores increase to 4 percent. These endospores represent a Dryopterid type of fern spore. These spores have an outer covering, the perisporium, which is not present on the grain after sample processing. All that remains is the inner "kidney-bean-shaped" part of the grain. Thus, any kind of definitive identification of these grains, other than a Dryopterid type fern spore, is not possible. The increase in sedge and monolete endospores suggests a disturbance at the bog site perhaps due to fire. Core B, at approximately the same interval (2.75 meters and in the C-2 zone), has the same increase in sedge and monolete endospores. The increase in the monolete endospores is to 24 percent and sedges to 12 percent. (McDowell et al. in press). Both cores showing this event confirm that a type of disturbance did occur and is a local phenomenon.

The transition between zone C-1 and C-2 in Bugbee Bog occurred at 3,800 years B.P., according to the graph in Figure 8. According to Davis (1965) this transition occurred at 5,000 years B.P. in southern New England. This indicates the transition from C-1 to C-2 was delayed some 1,200 years in northeastern Vermont.

Pollen Zone C-3 (1.25 - 0 meters). The transition between C-2 and C-3 in Bugbee Bog occurred about 1,600 years B.P. Sediments from the C-2/C-3 boundary in Barnstable Marsh, Massachusetts have been dated at 1,880 $\pm$ 100 years B.P. (Butler, 1959). However, dates for the C-2/C-3 boundary in New England show wide variation. Davis (1965) concludes that the C-2/C-3 zone boundary probably occurred at different times in different locations in New England and insufficient evidence prohibits a general statement as to a more exact time for the C-2/C-3 boundary.

Zone C-3 in the Bugbee Bog diagram is characterized by the return of spruce and fir with percentages of 4 and 15 respectively. Pine increases and hemlock decreases with birch, oak, maple and basswood at 3 to 5 percent. Changes in pollen associated with zone C-3 may represent a cooler and moister climate, extending to the present following the Hypsithermal Interval. In Europe, this interval is postulated to have ended about 2,600 years B.P. (Granlund, 1932; Flint, 1957). It has been suggested that the increase in conifers in the uppermost levels of pollen diagrams in the Northeast is not the result of climatic changes, but is the result of forest disturbance by aboriginal and European man (Davis, 1965; Potzger and Friesner, 1948). The influence of aboriginal man on forest disturbance, however, remains largely unknown.

CHAPTER IV

COLCHESTER BOG

1. Geographic Setting and Description.

The Colchester Bog is in Chittenden County in the town of Colchester. It is on Colchester Point which projects out into Lake Champlain. The coordinates of its location are latitude 44° 33' N. longitude 73° 17' W as determined from the Plattsburg, New York-Vermont 15 minute USGS topographic quadrangle map. The bog is approximately 40 hectares (100 acres) in area and is approximately 30 meters (100 feet) above mean sea level (Figure 9).

The bog is situated in the Champlain Lowland which is a structural trough between the Green Mountains on the east and the Adirondack uplift on the west. This narrow valley contains the lowest elevations in Vermont as well as the most nearly horizontal and least metamorphosed bedrock. Bedrock in this area is black shale and blue-black dense limestone of Middle Ordivician age (Stone and Dennis, 1964) The surface is not flat, however, as hills are scattered all over the lowland. These hills, according to Jacobs (1950), are homoclinal structures separated from the Green Mountain overthrust. Others are formed from thrust blocks of the Champlain fault. Much of the lowland surface is a flat plain composed of lacustrine material deposited in the glacial lake that covered it during the waning stages of the last glacial period.



Figure 9. Aerial photograph of Colchester Bog (outlined in black) a vicinity in vertical aerial photography by U.S. Department of Agriculture, here reproduced at 1:31,500. The uniform gray areas at the top and lower left are parts of Lake Champlain.

Lake Champlain is situated within the lowland. The Vermont portion of the Champlain lowland is designated the Vermont Lowland by Jacobs (1950), and it borders the lake throughout its length. The Vermont Lowland averages slightly more than 20 kilometers (12 miles) in width, being 25 kilometers (16 miles) at Brandon, 20 kilometers at Burlington and St. Albans, and 40 kilometers (25 miles) at the Canadian border.

2. Modern Vegetation of the Bog and the Neighboring Area.

A general reconnaissance was made of the vegetation of the bog and adjacent areas. Table 8 lists those plants which occur on the bog surface and Table 9 lists those plants which occur at the bog margin and in the swamp forest on two sides of the bog.

This Sphagnum bog is well covered by a dense growth of black spruce, tamarack, high and low bush blueberries and alders. The tree species generally do not reach more than 3 to 6 meters (10 to 20 feet) in height. The southern and western marginal areas of the bog are covered with trees of larger size, particularly the peninsula of land which juts out into the bog. On this narrow sandy peninsula which extends from the south to the north at a low angle to the western edge of the bog, occur several trees of black gum (Nyssa sylvatica). This is the only known occurrence of this species in northwestern Vermont. The black gum, characteristic of more southern latitudes, probably has survived here from a period when the climate was warmer than at present and the species occurred more commonly in the region (Vogelmann, 1964). There is no open water on the bog's surface. A

Table 8. Plants on the surface of Colchester Bog, Chittenden County, Vermont. Observations by the author, June, 1968.

Scientific Name	Common Name
Trees	
Betula populifolia	Gray birch
Larix laricina	Tamarack
Picea mariana	Black spruce
Pinus rigida	Pitch pine
Pinus strobus	White pine
Shrubs and Herbs	
Arethusa bulbosa	Arethusa
Calopogon pulchellus	Grass-pink
Chamaedaphne calyculata	Leatherleaf
Drosera rotundifolia	Sundew
Kalmia polifolia	Bog laurel
Ledum groenlandicum	Labrador tea
Myrica gale	Sweet gale
Pogonia ophioglossoides	Rose pogonia
Rhododendron canadense	Rhodora
Salix spp.	Willow
Sarracenia purpurea	Pitcher plant
Vaccinium oxycoccos	Small cranberry
Vaccinium macrocarpon	Large cranberry
Moss	
Sphagnum spp.	Sphagnum moss

Table 9. Plants on the margin of the bog surface and in the swamp bordering Colchester Bog, Chittenden County, Vermont. Observations by the author, June, 1968.

Scientific Name	Common Name
Trees	
Acer rubrum	Red maple
Betula papyrifera	Paper birch
Fraxinus spp.	Ash
Nyssa sylvatica	Black gum
Pinus resinosa	Red pine
Populus tremuloides	Trembling aspen
Prunus serotina	Black cherry
Prunus virginiana	Choke cherry
Quercus rubrum	Red oak
Shrubs and Herbs	
Alnus rugosa	Speckled alder
Corylus americana	Hazelnut
Ceanothus americanus	New Jersey tea
Cephalanthus occidentalis	Buttonbush
Comptonia perigrina	Sweet fern
Cornus stolonifera	Red-osier dogwood
Epigaea repens	Trailing arbutus
Gaylussacia baccata	Huckleberry
Hamamelis virginiana	Witch-hazel
Ilex verticillata	Black alder
Lonicera spp.	Honeysuckle
Nemopanthus mucronata	Mountain holly
Parthenocissus quinquefolia	Virginia creeper
Rhus toxicodendron	Poison ivy
Rhus vernix	Poison sumac
Rubus spp.	Raspberry
Solanum dulcamara	Nightshade
Spiraea latifolia	Meadowsweet
Vaccinium corymbosum	Highbush blueberry
Vaccinium angustifolium	Lowbush blueberry

small open area, with some scattered trees, occurs near the western edge of the bog and is approximately 75 meters (250 feet) wide and 105 meters (350 feet) long (Figure 10). Outward from this area, in all directions, the vegetation is so dense penetration requires the aid of an axe.

Regionally, the bog is located in the Hemlock-White Pine-Northern Hardwoods Forest of Nichols (1935), a concept also adopted by Braun (1950). Kuchler (1965), places this region in the Northern Hardwoods Forest. According to the scheme of Westveld et al. (1956), this bog is in Zone 3. Characterization of this zone is difficult as elements of the zones to the north and south overlap. The maples, birches, and beeches of the northern zone overlap with the oaks and hickories of the southern and central zones. The majority of the hardwoods native to New England are found in this zone. Various species of oaks and hickories occupy hilltops and sandy terraces. Associated with them are white pine, paper birch, quaking and bigtooth aspen, and sporadically, red pine. On lower slopes and in coves are stands of white ash, red oak, and black birch commonly occur. Soils under these forest elements are of the brown podozolic type.

3. Sediment Stratigraphy.

One core was taken from the Colchester Bog at the deepest point in the peat deposit. Previously, transect lines had been set up and probes of the deposit were made to locate this point. Figure 11 shows the transect lines, location of the probe points, depths found, and the sampling site. The area probed for depth is approximately



Figure 10. Colchester Bog. View of the open area on the bog mat and the dense growth of trees and shrubs characteristic of the rest of the bog surface.

Figure 11. Plan of transects for sampling on Colchester Bog, with index map of Vermont in the upper right and an outline map of the bog in the upper left.

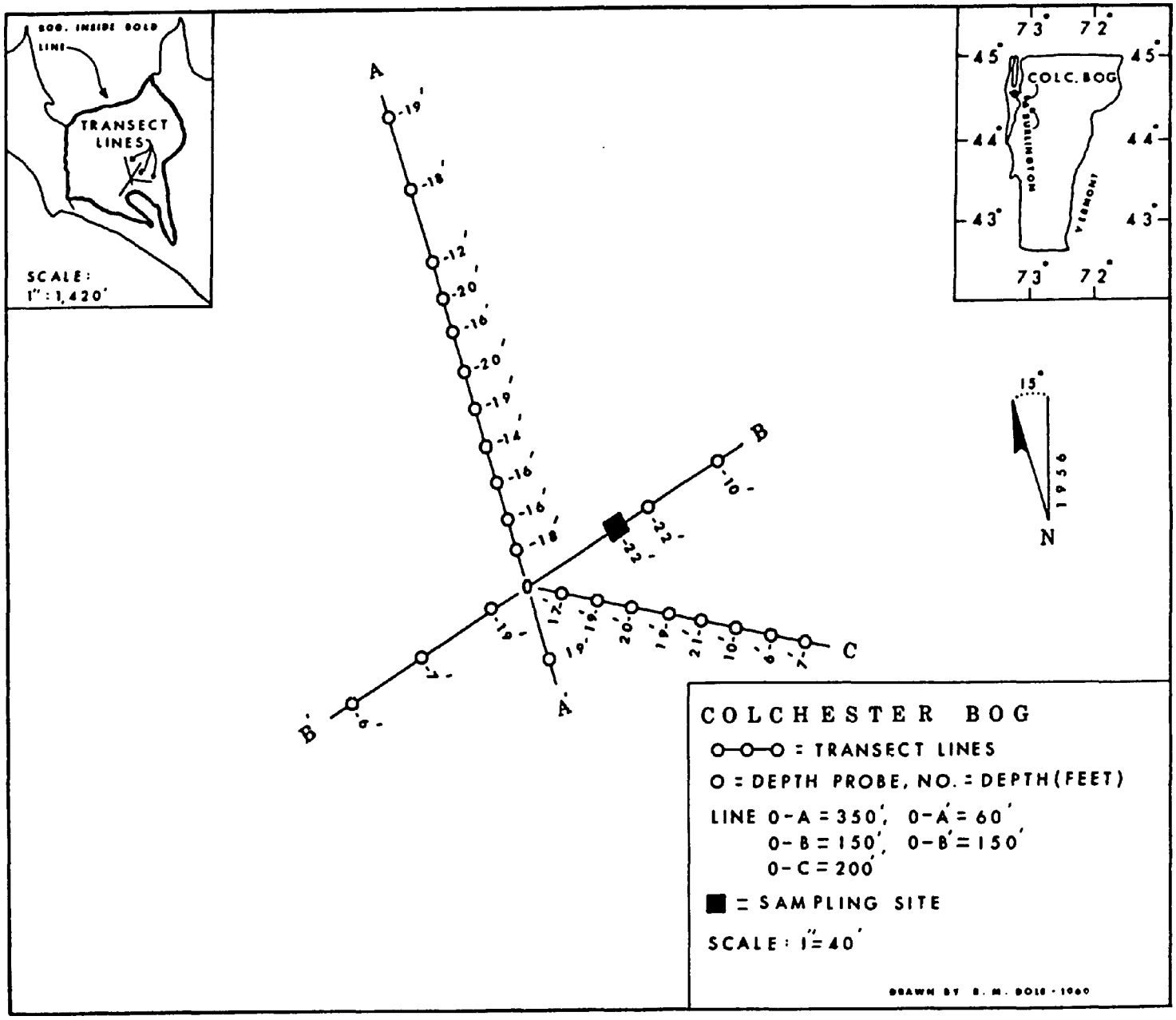
BOG. INSIDE BOLD LINE
TRANSECT LINES
SCALE: 1" : 1,420'
COLC. BOG
BURLINGTON
VERMONT
73° 72°
45° 44° 43°
15°
1956
N
A
A'
B
B'
C
COLCHESTER BOG
O—O—O = TRANSECT LINES
O = DEPTH PROBE, NO. = DEPTH (FEET)
LINE 0-A = 350', 0-A' = 60'
0-B = 150', 0-B' = 150'
0-C = 200'
■ = SAMPLING SITE
SCALE: 1" = 40'

Figure 11.

90 by 120 meters (300 to 400 feet). Attempts were made to obtain bog basin depth data over a wider area but the height and thickness of the undergrowth greatly hindered walking through it and using the sampling rods. A path would have to be cut in order to gain access to other areas of the bog. From the depths obtained and plotted, it seems unlikely that a point deeper than feet (5.4 meters) would be found outside the area probed.

Samples were taken for sediment stratigraphy and pollen analysis by the methods described in Chapter II. The total length of the core recovered is 5.4 meters. The stratigraphy is given in Table 10 along with color (Munsell) and pH at selected levels. These data were obtained in the field with observations on moist samples.

Down to 4.50 meters the sediment is predominately a mixture of fibrous and amorphous peat. Below the 4.50 meter mark, silty-sandy material is mixed with organic matter. At the bottom of the core, entirely blue-gray clay-sandy material was recovered. A few pebbles were incorporated into this material.

The pH of the sediments is acid, 6.0 to 6.8 except at the very base of the core where the pH is 7.0.

4. Pollen Stratigraphy.

The percentage pollen diagram for the Colchester Bog is presented in Figure 12. In Chapter II the method was described for calculating percentages for pollen diagrams. A departure from that usual method was used for the non-arboreal elements presented in this

Table 10. Description of the sediment profile for core taken from Colchester Bog, Chittenden County, Vermont.

Depth (m.)	Profile Description	pH	Munsell Color[1]
0 - .10	Dark brown fibrous Sphagnum peat, not sticky, not plastic	6.1 at .10 m.	5YR 2/2
.10 - 2.75	Dark brown mixture of fibrous and amorphous peat, slightly sticky, not plastic	6.6 at 2.50 m.	10YR 3/3
2.75 - 4.50	Dark brown amorphous peat structureless, slightly sticky, not plastic	6.8 at 4.25 m.	10YR 3/2
4.50 - 5.30	Dark green-gray silty-sandy material with some organic matter, no effervescence with HCl.		5GY 4/2
5.40 +	Blue-gray sandy material with pebbles, no organic matter, no effervescence with HCl	7.0 at 5.40 m.	

1. Colors were determined on moist samples with aid of standard Munsell color chart for soils.

Figure 12. Percentage pollen diagram for the Colchester Bog. Arboreal pollen percentages based on total tree pollen. Non-arboreal percentages based on total pollen and spores of vascular plants.

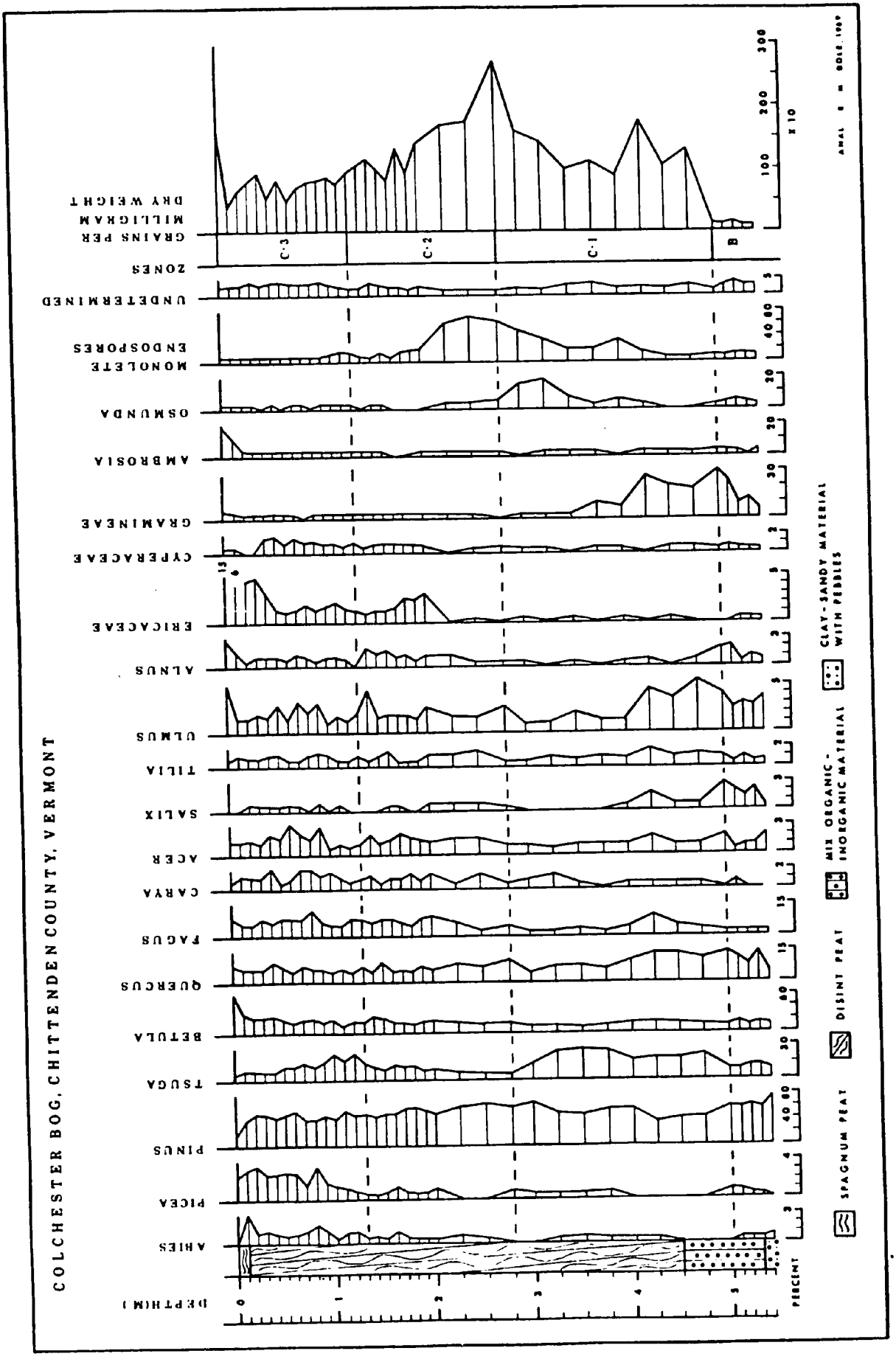
COLCHESTER BOG, CHITTENDEN COUNTY, VERMONT
DEPTH(M)
PERCENT
ABIES
PICEA
PINUS
TSUGA
BETULA
QUERCUS
FAGUS
CARYA
ACER
SALIX
TILIA
ULMUS
ALNUS
ERICACEAE
CYPERACEAE
GRAMINEAE
AMBROSIA
OSMUNDA
MONOLETE ENDOSPORES
UNDETERMINED
ZONES
GRAINS PER MILLIGRAM DRY WEIGHT
C-3
C-2
C-1
B
SPAGNUM PEAT
DISINT PEAT
MIX ORGANIC - INORGANIC MATERIAL
CLAY-SANDY MATERIAL WITH PEBBLES

Figure 12.

diagram. The percentage base is the sum total of vascular plant pollen and spores including the undetermined but excluding the aquatics.

In order to facilitate discussion of the diagram, it has been divided into zones as described in Chapter III. The following are the main characteristics of the zones for Colchester Bog; a more detailed discussion of each zone follows the characterization.

Zone B.	Pine maximum, oak maximum, presence of other deciduous trees, grass maximum.
Zone C-1.	H lock maximum, pine slight decrease, rising birch, oak, hickory, elm and grass maxima, rising monolete endospores.
Zone C-2.	Hemlock minimum, high pine, oak, beech, hickory present, maximum monolete endospores.
Zone C-3.	Spruce and fir return, substantial percentages of pine, hemlock, oak, and beech maintained, maple maxima, maxima for heath shrubs and ragweed at the surface.

Zone B (5.40 - 5.00 meters). Zone B, in the Colchester Bog, is delineated by high pine percentages, with a maximum of 80 percent of the total arboreal pollen. Spruce and fir are present but occur at less than 2 percent with fir absent at the upper limit of the zone and spruce decreasing. Oak shows a maximum at 5.30 meters and again at 5.00 meters. Maple, willow, elm and alder show maxima in this zone. Birch, beech, hickory, and basswood are present. Deciduous tree pollen becomes dominant at the closing part of zone B.

Grass pollen increases and attains the profile maximum at the B/C-1 zone boundary. Heath, sedge, ragweed, pollen, and Osmunda and monolete endospores are present. The upper boundary of the zone for the Colchester Bog is delimited by the elimination of fir, decrease of spruce, decline of pine, the increase in hemlock, and the beginnings of increases in beech and elm.

Zone C-1 (5.00 - 2.75 meters). In this zone deciduous tree pollen becomes dominant. Pine decreases from 75 to 40 percent in the zone and then fluctuates from 40 to 60 percent up to the C-1/C-2 zone boundary. Hemlock reaches a maximum. Oak is present consistently throughout the zone. Beech is present, showing a minor peak at 4.25 meters. Hickory, maple, basswood and birch are present in small quantities. Elm reaches a maximum early in the zone, then decreases and rises to a minor peak at the C-1/C-2 boundary. Grass pollen remains high in percentage from 5.00 to 4.25 meters then declines rapidly and disappears at the zone's upper limit. During this interval in which the grass percentages decline, the percentages of Osmunda and monolete endospores rise. Osmunda reaches a maximum at 3.25 meters and then decreases and the monolete endospores are rising at the zone's upper boundary. Ragweed, sedge, alder and heaths are present in small quantities and their occurrences are scattered throughout the zone. The upper limit of the C-1 zone boundary is marked by a decrease in hemlock and Osmunda and an increase in monolete endospores. Pine percentages remain steady at the C-1/C-2 limit.

Zone C-2 (2.75 - 1.30 meters). This zone is characterized by a hemlock minimum and high pine percentages. Spruce and fir are present in small quantities. The deciduous tree elements, birch, oak, hickory, maple, and basswood are present but show no major or minor peaks. Elm shows a peak at 1.40 meters and beech shows only a minor increase at 2.00 meters. Alder, sedge, grass and ragweed are present in small quantities. Heath pollen reaches a maximum at 2.00 meters and monolete endospores show a maximum at 2.50 meters. The upper boundary of the C-2 zone is marked by an increase in fir, spruce, and hemlock and a decrease in elm, alder and monolete endospores in the Colchester Bog diagram.

Zone C-3 (1.30 - 0 meters). Spruce and fir increase markedly in this zone but fir pollen has disappeared at the surface level and spruce has declined slightly. Pine is present and its percentages are steady, 40 to 50 percent, showing a slight decrease at the surface. Hemlock reaches a peak near the base of the zone and then declines steadily to 6 percent at the surface. Birch, oak, beech, hickory, and basswood are steady. Maple and elm are present and show fluctuations throughout the zone with elm reaching a peak at the surface. Alder, heaths, and ragweed reach maxima at the surface. Sedge, grass, Osmunda, and monolete endospores are present.

Table 11 shows those taxa counted but not included on the pollen diagram.

Table 11. Taxa not included on the pollen diagram for Colchester Bog. The number of grains counted follows each taxon.

Sample Level (m.)	Taxa[1]
0.00	Frax.-1, Nys.-2, Ile.-4, Car.Ost.-11, Cor.-2, Cru.-1, Chen.-Am.-3, Pla.-1, Lyc.-3, Sph.-1
.10	Lar.-1, Ile.-1, Nys.-1, Car.-Ost.-1, Chen.-Am.-1, Com.-1, Art.-1, Lyc.-3, Sph.-17
.20	Lar.-2, Jug.-2, Nys.-1, Ile.-2, Car.-Ost.-5, Cas.-3, Chen.-Am.-1, Com.-1, Lyc.-1, Sph.-7
.30	Nys.-2, Ile.-1, Car.-Ost.-5, Umb.-1, Lyc.-1, Sph.-19
.40	Lar.-2, Jug.-1, Frax.-1, Nys.-1, Ile.-1, Car.-Ost.-1, Sph.-17
.50	Frax.-1, Nys.-1, Car.-Ost.-1, Cor.-1, Pla.-1, Lyc.-1, Sph.-2
.60	Nys.-3, Car.-Ost.-2, Sph.-3
.70	Jug.-3, Nys.-3, Ile.-2, Car.-Ost.-1, Sph.-5
.80	Frax.-1, Nys.-2, Chen.-Am.-1, Sph.-3
.90	Nys.-3, Ile.-1
1.00	Lar.-1, Jug.-2, Nys.-1, Cary.-1, Nym.-1
1.10	Lar.-1, Car.-Ost.-1, Cas.-1, Com.-1
1.20	Jug.-1, Nys.-2, Lyc.-1, Sph.1

Table 11. Continued.

Sample Level (m.)	Taxa
1.30	Nys.-3, Ile.-1, Lyc.-1, Sph.-2
1.40	Nys.-3, Car.-Ost.-1, Cor.-1, Chen.Am.-1, Com.-1, Dro.-1
1.50	Lar.-2, Jug.-1, Frax.-2, Nys.-1, Myr.-1, Car.-Ost.-3, Chen.-Am.-1, Com.-1, Nup.-1, Lyc.-1
1.60	Chen.-Am.-1, Nup.-1, Lyc.-1, Sph.-13
1.70	Jug.-1, Lyc.-1, Sph.-13
1.80	Nys.-1, Car.-Ost.-3, Dro.-1, Lyc.-1, Sph.-20
1.90	Nys.-2, Sph.-6
2.00	Lar.-1, Jug.-1, Nys.-1, Car.-Ost.-3, Ile.-1, Sph.-5
2.25	Nys.-1, Ile.-1, Cas.-2
2.50	Lar.-1, Jug.-2, Nys.-3, Car.-Ost.-1, Ile.-9, Cary.-1, Com.-2, Lyc.-2
2.75	Jug.-1, Frax.-1, Nys.-1, Cas.-11, Ile.-1, Sph.-2
3.00	Lyc.-1
3.25	Cas.-22, Ile.-5, Com.-2
3.50	Cas.-15, Nys.-2, Ile.-3

Table 11. Continued.

Sample Level (m.)	Taxa
3.75	Cas.-5, Com.-1
4.00	Umb.-1, Nym.-1
4.25	Lar.-2, Cas.-5, Nys.-1, Ile.-3, Cary.-1, Com.-1, Nup.-1, Nym.-1
4.50	Lar.-1, Nys.-2, Ile.-5, Car.Ost.-1, Chen.-Am.-1, Cary.-1
4.75	Lar.-2, Ile.-7, Com.-1
5.00	Lar.-2, Cas.-2, Myr.-2, Sph.-1
5.10	Lar.-2, Pla.-2, Lyc.-3
5.20	Lar.-1, Lyc.-1
5.30	Lar.-1, Ile.-1, Lyc.-3
5.40	Lar.-2, Car.Ost.-1, Ile.-3

1. Frax.= Fraxinus, Nys.=Nyssa, Ile.= Ilex, Car.-Ost.= Carpinus-Ostrya, Cor.= Corylus, Cru.= Cruciferae, Chen.-Am.= Chenopodiaceae-Amaranthaceae, Pla.= Plantago, Lyc.= Lycopodium, Sph.= Sphagnum, Lar.=Larix, Com.= Compositae (other than Ambrosia and Artemisia), Art.= Artemisia, Jug.= Juglans, Cas.= Castanea, Dro.= Drosera, Myr.= Myrica, Nup.= Nuphar, Nym.= Nymphea, Cary.= Caryophyllaceae, Umb.= Umbelliferae

5. Discussion.

It is clear that forests were well established in the Colchester Bog region at the beginning of the time interval represented by the pollen diagram (Figure 12). Based on percentages pine is the dominant tree with spruce, fir, birch, beech, hickory, and basswood of secondary importance. Oak, elm, and maple are well represented. This stratigraphically earliest fossil pollen assemblage has been assigned to Zone B which generally is referred to as the Postglacial Pine Period. It appears the time interval represented by this zone is in the order of 2,000 years or from approximately 9,500 to 7,500 years ago in southern New England (Davis, 1965). The portion of the A zone found in the Bugbee Bog is missing. Thus, the pollen diagram represents only post-glacial time.

The time when the Colchester Bog began to form is a matter of speculation. The present-day bog is at an elevation of 30 meters above mean sea level. This indicates the bog probably began forming after glacial Lake Champlain had been lowered to nearly its present day level which is at 28 meters above mean sea level. The last episode of glacial Lake Champlain was the Champlain Sea. Evidence indicates that the bog was covered by the Champlain Sea, however no sediments or shells indicative of this event were found in the core taken from the Colchester Bog. Broecker and Farrand (1963) have dated this episode from 11,300 to 10,500 years ago on the basis of radiocarbon dates from marine shells in the Champlain Sea deposits. According to Chapman (1937), a portion of the upper marine shoreline in the Champlain Lowland stands at an elevation

of approximately 90 meters near Shelburne Falls, Vermont, a few miles south of Burlington and about 16 kilometers (10 miles) south of the bog. East of Burlington, in the vicinity of Fort Ethan Allen, a marine shoreline extending northward along the base of the hills northeast of Colchester, has been identified at 108 meters (355 feet) (Chapman, 1937). This location is about 8 kilometers (5 miles) east of the bog. As the bog is nearly at lake level today, the Champlain Sea episode had to be finished before the bog began forming.

The pollen assemblage for zone B suggests a climate that was warm and dry. High oak percentages in the zone with sustained pine percentages suggests a gradual warming of the climate along with the replacement of spruce and fir by deciduous trees such as maple, elm, beech, hickory, and basswood. The oak maximum in the zone could be a function of lower precipitation, higher temperature, or both. An increase in moisture beginning late in the zone and continuing through C-1 is suggested by the increasing percentages of hemlock, the decrease in pine, the rise in beech and elm, and the presence of maple and birch.

Non-arboreal types are present in zone B with grass reaching a maximum at the upper boundary. Published pollen diagrams from New England do not include as large a grass maximum for this zone. Sedge pollen is usually found increasing at the base of the B zone and reaching a maximum in the A-4 zone. Only traces of sedge pollen are found in the basal B zone sediments of this bog. This suggests that the grass maximum represents a local situation

peculiar to this bog area and is a successional stage in the development of the Colchester Bog rather than any kind of regional pattern.

During C-1, hemlock reaches a maximum and pine decreases. Beech and elm show increases. Maple, birch and basswood probably grew in association with hemlock, beech, and elm. Grass decreases and is replaced by Osmunda which is replaced by monolete endospores at the upper limit of zone C-1. Fluctuations of this type are not recorded in published pollen diagrams and as stated above suggest successional stages in the bog's development. This pollen assemblage may indicate a climate which is warmer and moister than the B zone.

Zone C-2 by its definition and usage includes records which are interpreted to indicate this zone records the warmest portion of postglacial time. This is inferred from the hemlock minimum, the high pine and the predominately deciduous aspect of the pollen diagram. Elm and beech show slight increases with birch, oak, hickory, maple and basswood present.

The pollen assemblages of zone C-3 suggest a cooler and moister climate than zone C-2. Spruce and fir return and increase near the surface and hemlock is abundant although declining toward the surface. Pine percentages are steady but decline at the surface and birch increases slightly. A ragweed maximum at the surface can be interpreted as indicative of farming activity in the region.

CHAPTER V

LILY PAD POND BOG

1. Georgraphic Setting and Description.

Lily Pad Pond Bog is in Chittenden County, in the town of Winooski, on the area formerly occupied by the Ethan Allen Air Force Base. Much of the property now belong to the University of Vermont in Burlington. However, as the Vermont National Guard retains training sites, in use during summer months, permission for access to the bog should be obtained. At other times, when the gates are open, travel within the area is not restricted.

The geographic coordinates of the Lily Pad Pond Bog are latitude 44° 31' N, longitude 73° 10' W, as shown on the Milton, Vermont, 15 minute USGS topographic quadrangle map. On the topographic map the bog is shown only as a pond, designated Lily Pad Pond. The aerial photograph (Figure 13) and ground reconnaissance quickly establish that a floating mat is surrounded entirely by water. The area is poorly drained as the bog-pond is within a depression on a nearly level sand plain. The surface of the bog mat is very weak and the peat deposit is 10 meters or more deep. When the bog sediments were sampled (June, 1968), the water table was at or near the surface of the peat. The bog is approximately 98 meters (320 feet) above mean sea level and occupies about



Figure 13. Aerial photograph of Lily Pad Pond Bog (indicated by arrow) and vicinity in vertical aerial photograph by U. S. Department of Agriculture, here reproduced at 1:31,500.

2 hectares (5 acres). The bog is located in the Vermont Lowland portion of the Champlain Lowland (as previously described for the Colchester Bog, Chapter IV). It is about 70 meters (225 feet) above the level of present-day Lake Champlain which is 28 meters above mean sea level. The area (Vermont Lowland) was covered by waters of glacial Lake Champlain and the Champlain Sea before the present lake. Bedrock geological studied indicate the bog area is underlain by rocks of massive dolomite and irregularly shaped masses of white quartz and chert. The bedrock belongs to the Claredon Springs Formation of upper Cambrian age (Stone and Dennis, 1964).

2. Modern Vegetation of the Bog and Neighboring Area.

Regionally, Lily Pad Pond Bog is in the same vegetation zones as previously described for the Colchester Bog (Chapter IV), i.e., the Hemlock-White Pine Northern-Hardwoods Forest of Nichols (1935) and Braun (1950), the Broadleaf and Needleleaf Forests-Northern Hardwoods of Kuchler (1965), and further defined by Westveld et al. (1956) as the Transition Hardwoods-White Pine-Hemlock zone.

The landscape immediately surrounding and including the bog is very similar to the forest type described by Westveld et al. (1956). The vegetation surrounding the bog has been disturbed by the activities of the Air Force Base and the National Guard in building roads, bunkers, ammunition dumps, and such structures. The mat of this bog is primarily of sedges in contrast to the predominately Sphagnum mats of the previously described bogs. Sphagnum is present but occurs only in hummocky patches. Figure

14 shows a view of the bog surface. Table 12 lists those plants common to the bog area.

3. Sediment Stratigraphy.

One core was recovered from the Lily Pad Pond Bog in the area of maximum thickness of the peat deposit. Transect lines were set up and probes for depth were made to locate this point. Figure 15 shows the transect lines, location of the probe points, depths found, and the sampling point. Two probes of the deposit reached 11 meters (39 feet). The point where the transect lines intersect was chosen as the sampling point.

Depth determinations were limited to the area of the bog mat as shown in Figure 15, as the more marginal portions are unsafe to walk on. It is possible the deepest point in the peat deposit has not yet been found as much of the southwestern portion of the bog mat was not probed because the mat was so unstable.

The total length of the core recovered is 10.10 meters. Samples were taken for determination of sediment sequence and pollen analysis. The stratigraphy, pH (at selected intervals), and color (Munsell) were determined in the field using moist samples. These data are summarized in Table 13.

Disintegrated peat occurs from a few centimeters below the surface to 6.50 meters. This material is very decomposed and little of the plant material has recognizable structure. From 6.50 to 9.90 meters, the sediment is an amorphous allochthonous peat. The bottom 0.2 meters of the core is composed of mostly inorganic silty material with little organic remains mixed in.



Figure 14. Lily Pad Pond Bog. The bog mat in the foreground is predominately sedges, rushes and a few grasses with meadowsweet and willows.

Table 12. Plants occurring on the bog surface (*) and in woodland and pioneer herb communities (+) on sandy soils surrounding Lily Pad Pond Bog, Chittenden County, Vermont. Observations by the author June, 1968.

Scientific Name	Common Name
Trees	
Acer rubrum *+	Red maple
Betula populifolia *+	Gray birch
Pinus rigida +	Pitch pine
Pinus strobus +	White pine
Populus deltoides +	Cottonwood
Quercus rubra +	Red Oak
Salix spp. *+	Willow
Shrubs and Herbs	
Carex diandra *	Sedge
Eleocharis palustris *	Spike rush
Eupatorium perfoliatum *	White boneset
Fragaria virginiana +	Wild strawberry
Galium trifidum *	Bedstraw
Glyceria pallida *	Pale manna grass
Juncus filiformis *	Bog rush
Melilotus alba +	White sweet clover
Onoclea sensibilis *	Sensitive fern
Potentilla anserina +	Cinquefoil
Scirpus acutus *	Bullrush
Spiraea latifolia *	Meadowsweet
Typha latifolia *	Cattail
Moss	
Sphagnum spp. *	Sphagnum moss

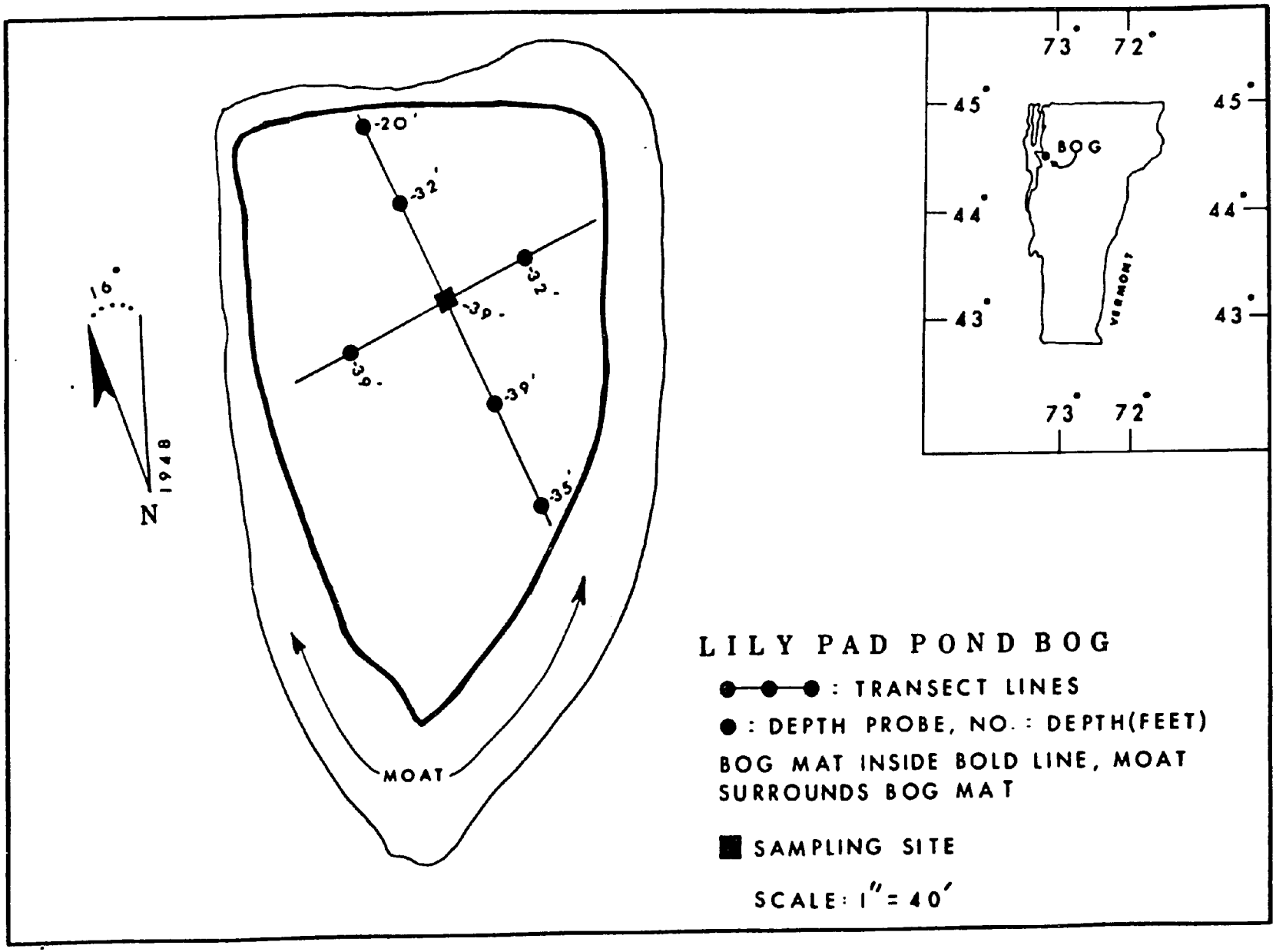

Figure 15. Sketch map of Lily Pad Pond Bog showing transect lines, depth probes, and sampling site.

Table 13. Description of the sediment profile for core taken from Lily Pad Pond Bog, Chittenden County, Vermont.

Depth (m.)	Profile Description	pH	Munsell Color[1]
0 - .35	Black amorphous peat, not sticky, not plastic	5.8 at .10 m.	5YR 2/1
.35 - 1.80	Dark reddish brown amorphous peat	6.4 at 1.50 m.	5YR 2/2
1.80 - 5.50	Dark brown to gray brown amorphous peat, slightly sticky, not plastic	6.8 at 2.50 m. 6.4 at 3.50 m. 6.8 at 4.60 m.	10YR 2/2 10YR 3/2
5.50 - 6.50	Very dark gray brown amorphous peat, slightly sticky, not plastic, rubbery	6.6 at 6.50 m.	2.5Y 3/2
6.50 - 9.90	Dark olive gray sedimentary peat, structureless, slightly sticky, not plastic, rubbery	6.8 at 8.50 m. 7.0 at 9.30 m.	5Y 3/2

Table 13. Continued.

Depth (m.)	Profile Description	pH	Munsell Color
9.90 - 10.10	Dark greenish gray silt, slightly sticky, not plastic, at 10.10 m. effervesces with dilute HCl		5GY 4/1

1. Colors were determined on moist samples using the standard Munsell color chart.

4. Pollen Stratigraphy.

The percentage pollen diagram for the Lily Pad Pond Bog is presented in Figure 16. The method used to calculate the percentages for this diagram is the same described for the Colchester Bog, Chapter IV.

To simplify the discussion of the pollen diagram, the same procedure has been followed as previously described in Chapter III. Each of the zones is characterized below; a more detailed discussion of each zone for the Lily Pad Pond Bog follows the characterization.

Zone A.	Spruce and fir maximum, low pine and deciduous trees, maxima for sedge, grass, alder, and ragweed.
Zone B.	Declining spruce and fir, pine maximum, increase in deciduous trees, decrease in NAP.
Zone C-1.	Pine minimum, hemlock maximum, presence of oak, beech, elm, and maple.
Zone C-2.	Pine maximum, hemlock minimum, slight increase in birch, hickory and basswood.
Zone C-3.	Return of spruce and fir, presence of pine, hemlock, oak, hickory, and elm. Maxima of alder at .20 meters, maxima of sedge and ragweed at the surface.

Zone A (10.10 - 9.75 meters). This zone in the Lily Pad Pond Bog is characterized by a high percentage of spruce with a

Figure 16. Percentage pollen diagram for the Lily Pad Pond Bog. Arboreal pollen percentages based on total tree pollen. Non-arboreal percentages based on total pollen and spores of vascular plants.

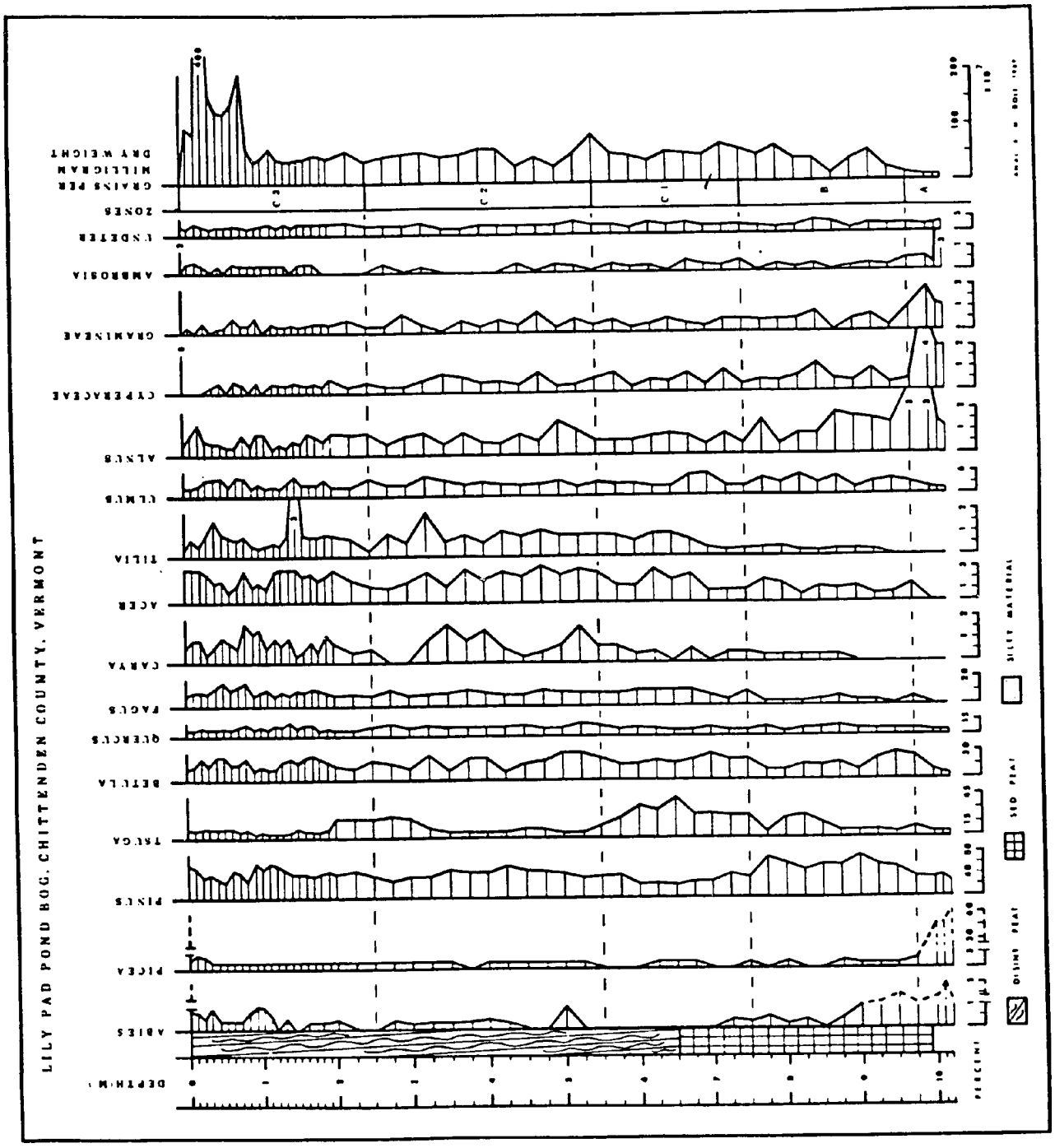
LILY PAD POND BOG, CHITTENDEN COUNTY, VERMONT
GRAINS PER MILLIGRAM DRY WEIGHT
ZONES
C-3
C-2
C-1
B
A
ABIES
PICEA
PINUS
TSUGA
BETULA
QUERCUS
FAGUS
CARYA
ACER
TILIA
ULMUS
ALNUS
CYPERACEAE
GRAMINEAE
AMBROSIA
CHENOPODIACEAE
DEPTH IN M
SILTY MATERIAL
SEDGE PEAT
WOODY PEAT

Figure 16.

maximum of over 60 percent. Fir reaches a maximum of 5 percent and decreases to 1 percent at the A/B zone boundary. Pine and hemlock are present at 35 and 3 percent respectively. A birch maximum occurs at 9.50 meters. Oak and elm percentages are low. Beech and maple, not present in the lowermost samples, first occur at 9.50 meters. The non-arboreal elements of alder, sedge, grass and ragweed show maxima in the zone and decline slightly at the 10.10 meter level. At the A/B zone boundary, pine is increasing, spruce and fir are decreasing and the deciduous tree elements are increasing.

Zone B (9.75 - 7.50 meters). The B zone, in the Lily Pad Pond Bog diagram, is distinguished by high pine percentages with a maximum of 70 percent. Hemlock percentages are low from 9.75 to 8.75 meters and rise to 20 percent at the zone boundary. Fir decreases rapidly and spruce is present in small quantities. Birch reaches a maximum at 9.50 meters. The deciduous tree percentages of oak, beech, hickory, maple, and elm become more frequent. Basswood appears for the first time at 9.25 meters. The non-arboreal types, alder, sedge, grass, and ragweed are decreasing. The B/C-1 boundary is marked by a decrease in pine, an increase in hemlock, and a slight increase in birch and beech.

Zone C-1 (7.50 to 5.50 meters). In this zone deciduous tree pollen begins to dominate for the first time in the Lily Pad Pond Bog diagram. There is a minimum of pine, and spruce and fir show low percentages. Hemlock reaches a maximum. Percentages of oak, birch, beech, hickory, and elm are constant with maple and

basswood increasing slightly. Alder, grass, and sedge are present. Ragweed pollen is present but no found at each sample interval in this zone. The upper limit of the zone is marked by decreasing hemlock and increasing pine with increases in birch, hickory, and maple.

Zone C-2 (5.50 - 2.50 meters). This zone, in Lily Pad Pond Bog, is characterized by a pine maximum and a hemlock minimum. Oak, beech, maple, and elm are present with percentages relatively constant throughout the zone. Birch and hickory show slight increases and basswood shows a peak at 3.25 meters. Alder, grass, and sedge are present in small quantities. Ragweed is present but inconsistent.

Zone C-3 (2.50 - 0 meters). Spruce and fir show increases. Pine percentages are constant with a slight increase at the surface. Hemlock increases at 2.00 meters and then declines steadily to 5 percent at the surface. Birch, oak, beech, and elm are present. Hickory has a slight maximum at 1.00 and maple at 1.50 meters. Alder, sedge and ragweed show maxima at the surface. Grass pollen occurs irregularly in the zone and usually less than 1 percent.

Table 14 lists the taxa not included on the pollen diagram for Lily Pad Pond Bog.

5. Discussion.

The pollen diagram for the Lily Pad Pond Bog is similar to that of the Colchester Bog. The most notable feature of the Lily Pad Pong Bog diagram is the presence of a portion of the A zone which is missing from the Colchester Bog but found in the Bugbee Bog.

Table 14. Taxa not included on the pollen diagram for Lily Pad Pond Bog. The number of grains counted follow each taxon.

Sample Level (m.)	Taxa[1]
0.00	Lar.-2, Jug.-1, Frax.-1; Cor.-1, Nys.-1, Ile.-1, Com.-2, Art.-1, Lyc.-6, Osu.-1, Moe.-3, Eri.-1
.10	Jug.-2, Frax.-3, Nys.-3, Ile.-2, Art.-1, Nup.-1, Lyc.-1
.20	Frax.-1, Nys.-1, Ile.-1, Lyc.-1, Eri.-2
.30	Jug.-2, Frax.-2, Nys.-2, Ile.-1, Eri.-1, Chen.-Am.-1
.40	Jug.-3, Frax.-2, Nys.-1, Car.-Ost.-1, Ile.-2, Eri.-1, Nup.-2, Osu.-1, Sph.-1
.50	Jug.-1, Frax.-2, Nys.-1, Car.-Ost.-1, Eri.-3
.60	Jug.-4, Frax.-1, Nys.-1, Ile.-2, Cary.-1, Com.-1, Nup.-2, Lyc.-1
.70	Frax.-2, Nys.-3, Ile.-2, Eri.-2, Chen.-Am.-2
.80	Jug.-2, Nys.-1, Eri.-2, Cary.-1
.90	Lar.-1, Nys.-1, Eri.-2, Lyc.-1
1.00	Jug.-3, Nys.-1, Eric.-2, Chen.-Am.-1, Nup.-2, Lyc.-1, Moe.-3
1.10	Jug.-2, Nys.-4, Cor.-1, Com.-2
1.20	Jug.-5, Moe.-1

Table 14. Continued.

Sample Level (m.)	Taxa
1.30	Frax.-2, Nys.-1, Ile.-1, Com.-1, Moe.-1
1.40	Jug.-2, Eri.-1, Art.-1, Nym.-3, Lyc.-2, Osu.-1, Sph.-1
1.50	Jug.-1, Nys.-4, Ile.-1, Nup.-1, Lyc.-2, Osu.-1
1.60	Jug.-4, Nys.-2, Cor.-1, Chen.-Am.-2, Moe.-1
1.70	Frax.-2, Nys.-2, Ile.-1, Eri.-1, Com.-1, Nup.-1, Moe.-1
1.80	Frax.-2, Nys.-2, Eri.-3, Chen.-Am.-1, Com.-1, Nup.-1
1.90	Jug.-1, Frax.-2, Nys.-3, Eri.-3, Chen.-Am.-1, Cary.-1, Com.-2, Moe.-1
2.00	Jug.-2, Nys.-1, Eri.-4, Ile.-2, Com.-1, Lyc.-4, Moe.-1
2.25	Jug.-2, Frax.-1, Eri.-2, Ile.-1, Chen.-Am.-1, Com.-1, Moe.-3
2.50	Lar.-1, Jug.-3, Frax.-2, Ile.-1, Lyc.-3, Moe.-5
2.75	Jug.-1, Eri.-2, Chen.-Am.-2, Com.-2, Nup.-1, Lyc.-1, Osu.-2, Moe.-1
3.00	Jug.-1, Nys.-2, Eri.-3, Ile.-2, Chen.-Am.-1, Cary.-1, Com.-1, Nup.-1, Moe.-1
3.25	Nug.-2, Eri.-2, Ile.-1, Chen.-Am.-1

Table 14. Continued.

Sample Level (m.)	Taxa
3.50	Jug.-3, Frax.-1, Eri.-3, Sph.-1
3.75	Jug.-1, Frax.-3, Com.-1
4.00	Jug.-3, Frax.-1, Eri.-3, Chen.-Am.-3, Cary.-1, Com.-1
4.25	Lar.-1, Jug.-3, Eri.-3, Chen.-Am.-2, Cary.-2, Com.-3, Lyc.-1, Osu.-1, Moe.-1
4.50	Lar.-2, Jug.-2, Eri.-3, Chen.-Am.-1, Cary.-2, Com.-4, Lyc.-2, Osu.-2, Moe.-2
4.75	Jug.-2, Sal.-1, Eric.-3, Chen.-Am.-1, Cary.-1, Nup.-2
5.00	Lar.-1, Jug.-1, Ile.-1, Com.-1
5.25	Lar.-2, Eri.-3, Chen.-Am.-1, Cary.-1, Com.-2, Lyc.-1, Moe.-1
5.50	Jug.-2, Eri.-3, Chen.-Am.-2, Cary.-1, Com.-3, Moe.-1
5.75	Lar.-1, Jug.-1, Eri.-5, Chen.-Am.-1, Cary.-1, Com.-3, Nup.-3, Lyc.-1, Moe.-1
6.00	Lar.-1, Eri.-5, Chen.-Am.-2, Cary.-2, Com.-4, Moe.-2
6.25	Frax.-2, Eri.-5, Ile.-5, Chen.-Am.-2, Com.-3, Nup.-1, Moe.-2
6.50	Lar.-2, Frax.-2, Eri.-4, Ile.-1, Chen.-Am.-2, Cary.-1, Com.-3, Nup.-2, Lyco.-1, Moe.-1

Table 14. Continued.

Sample Level (m.)	Taxa
6.75	Lar.-1, Eri.-5, Ile.-1, Chen.-Am.-1, Com.-3, Nup.-1, Moe.-1
7.00	Frax.-1, Eri.-4, Ile.-1, Chen.-Am.-1, Com.-1, Art.-1, Moe.-1
7.25	Lar.-1, Eri.-4, Chen.-Am.-2, Com.-3, Nup.-1, Osu.-1, Moe.-3
7.50	Eri.-4, Chen.-Am.-3, Cary.-2, Com.-5, Nup.-1, Osu.-1, Moe.-1
7.75	Lar.-1, Jug.-1, Eri.-1, Lyc.-2, Moe.-1
8.00	Lar.-2, Eri.-3, Chen.-Am.-2, Cary.-3, Com.-4, Art.-1, Typ.-2, Lyc.-1, Moe.-1
8.25	Eri.-4, Chen.-Am.-2, Com.-4, Art.-2, Lyc.-1, Osu.-1, Moe.-1
8.50	Lar.-1, Jug.-2, Frax.-1, Eri.-2, Chen.-Am.-3, Art.-2, Lyc.-3, Moe.-2
8.75	Lar.-1, Jug.-1, Art.-1, Lyc.-2, Moe.-4
9.00	Car.-Ost.-4, Cor.-1, Nup.-1, Lyc.-2, Moe.-16
9.25	Lar.-2, Jug.-1, Eri.-3, Ile.-1, Chen.-Am.-2, Com.-4, Lyc.-1, Moe.-2
9.50	Lar.-9, Sal.-1, Chen.-Am.-1, Com.-1, Lyc.-9, Moe.-7
9.75	Lar.-13, Sal.-2, Eri.-2, Chen.-Am.-1, Com.-1, Art.-1, Lyc.-35, Moe.-4

Table 14. Continued.

Sample Level (m.)	Taxa
10.00	Sal.-8, Eri.-1, Chen.-Am.-1, Cary.-1, Com.-1, Art.-2, Lyc.-1, Osu.-1, Moe.-3, Sel.-2
10.05	Lar.-3, Jug.-1, Sal.-2, Eri.-2, Chen.-Am.-1, Com.-3, Art.-5, Lyc.-6, Moe.-1, Sel.-2, Sph.-1
10.10	Sal.-11, Eri.-1, Chen.-Am.-1, Cary.-1, Umb.-1, Com.-6, Art.-25, Sel.-1

1. Lar.= Larix, Jug.= Juglans, Frax.= Fraxinus, Cor.= Corylus, Nys.= Nyssa, Ile.= Ilex, Com.= Compositae (other than Ambrosia and Artemisia), Art.= Artemisia, Lyc.= Lycopodium, Osu.= Osmunda, Moe.= Monolete Endospore, Eri.=Ericaceae Nup.= Nuphar, Chen.-Am.= Chenopodiaceae-Amaranthaceae, Car.-Ost.= Carpinus-Ostrya, Sph. = Sphagnum, Cary.= Caryophyllaceae, Sal.= Salix, Typ.= Typha, Sel.= Selaginella, Umb. = Umbelliferae

As this bog is only about 13 kilometers (8 miles) east of the Colchester Bog, the presence of the A zone suggests it began forming at an earlier time. As discussed in Chapter IV, this area was covered by the Champlain Sea episode of glacial Lake Champlain. Four stages of subsidence of the Champlain Sea are recognized by Chapman (1937). Only three of these stages have been recorded in Vermont. Listed below are the stages from youngest to oldest and the highest elevations mapped for them.

Stage	Elevation of Marine Shoreline
Plattsburg Stage	120 feet, South Hero, Vt. 159 feet, Swanton Junction, Vt.
Burlington Stage	300 feet, Moors Fork, N. Y. 172 feet, Burlington, Vt. on Starr Farm Road 170 feet, St. Albans, Vt.
Port Kent Stage	350 feet, Covey Hill, N. Y. 225 feet, Burlington, Vt. 260 feet, West Milton, Vt. 320 feet, Highgate Center, Vt.
Beekmantown Stage	425 feet, Moors Fork, N. Y.

As the Lily Pad Pond Bog, at present, is approximately 98 meters above mean sea level, it seems likely that the bog could have started to form during the Port Kent Stage and certainly before the Burlington Stage. If the inundation of marine waters into the Champlain Lowland occurred at 11,300 years ago (Broecker and Farrand, 1963) and was short-lived, this bog could have begun to form shortly after 11,000 years ago. The subsidence stages of the Champlain Sea are not radiocarbon dated, thus any time sequence assigned to them is purely speculative.

The B, C-1, C-2, and C-3 zones and their accompanying pollen assemblages are similar to those of the Colchester Bog and the same general interpretations are drawn from them. Further correlation of the data derived from the three bogs in this study will be found in the concluding chapter.

One notable exception to the similarity of the Lily Pad Pond Bog diagram to that of the Colchester Bog is the absence of a grass-Osmunda-monolete endospore sequence early in postglacial time. Their absence in the Lily Pad Pond Bog further suggests their presence is a local phenomenon and probably related to successional sequences in the bog's development.

CHAPTER VI

FOSSIL POLLEN AND SPORE DENSITY IN THE BOG SEDIMENTS

The density of fossil pollen and spores in the bog sediments analyzed in this study has been calculated. Profiles, shown in Figures 7, 12, 16, summarize the density of fossil pollen and spores per milligram dry weight of sediment.

Constructing pollen diagrams on a percentage basis and using the percentages of the various genera as equivalent to their representation in the vegetation may not be totally valid. Thus, the determination of the number of fossil grains per milligram dry weight has been computed in an attempt to reflect more accurately the relationship between the kinds of grains found in the sediments. Iversen (1960), working in Denmark, suggests that differential rates of migration, succession, and human influence also be considered in explaining postglacial vegetational sequences. Davis (1963), after studying the relation between pollen preservation in an area of 20 sq. km. in Vermont and pollen from surface samples from Brownington Pond, concluded that the postglacial zone, Zone B, one of the most consistent stratigraphic features of northeastern American diagrams is a methodological artifact.

Recently, many workers are attempting to show recognizable and consistent relationships between pollen percentages and regional vegetation. Lichti-Federovich and Ritchie (1965) suggest that a

geographical study of the modern pollen rain is the most useful approach to interpretation of pollen diagrams in our present state of knowledge. Davis (1967a) has compared late-glacial pollen assemblages with pollen assemblages now being deposited in regions of tundra, northern prairie-forest parkland, and boreal parkland for the northeastern United States and eastern and central Canada. She concludes that the resemblance of many of the late-glacial pollen assemblages to modern pollen being deposited in these regions today is sufficient to suggest that the late-glacial vegetation of New England resembled the modern vegetation of central Canada. These data point to the fact that although percentage pollen diagrams may not reflect the vegetational unit producing the pollen as accurately as one might hope, many of the broad conclusions concerning these vegetational units and their changes in time in a given region are reasonable.

Pollen diagrams are now being constructed using grains per milliliter of sediment, grains per milligram dry weight, and grains deposited per $cm.^2$ per year rather than percent in order to reflect more accurately the vegetational unit producing the pollen. Davis (1967b) ultimately retracted her negation of the postglacial pine period. Using radiocarbon dates to establish sedimentation rates for late- and postglacial time in Rogers Lake, Connecticut, she was able to determine the number of grains deposited per $cm.^2$ per year. The pollen diagram based on these data clearly showed a postglacial pine period.

1. Density of Fossil Pollen and Spores in the Colchester Bog.

Figure 17 is the pollen diagram for the Colchester Bog, based on the number of grains per milligram dry weight. The method for determining the number of grains per milligram has been described in Chapter II. In general, the trends of the genera are similar to those for the percentage diagram. The most striking difference is the apparent absence of the B pollen zone. This in an artifact created in constructing the diagram. Figure 12, Chapter IV, shows that the grains per milligram increases rapidly between 5.00 and 4.75 meters from 85 to 1,315. In order to plot the curve for pine and the other genera on a reasonable scale and due to the rapid drop in grain concentration in the lowermost five sample intervals, the density of pine is not clearly reflected. Below is shown the actual number of grains per milligram plotted for the tree genera for these five lowermost sample intervals. Pine is the most frequent type.

Sample level (m.)	Abies	Picea	Pinus	Tsuga	Betula	Quercus	Fagus	Carya	Acer	Salix	Tilia	Ulmus
5.00	-	.3	30	4	3.6	6.5	.6	-	1.1	1.4	.5	2.1
5.10	.1	.2	25	4.1	3.5	4.7	1.0	.2	.16	1.0	-	1.1
5.20	.3	.2	40	8.3	6.7	4.3	1.1	-	.5	.9	.6	1.9
5.30	.1	.1	17	3.1	3.7	3.2	.5	-	.3	.7	.1	.7
5.40	.3	-	35	3.3	4.1	1.8	.3	-	.1	.2	.3	1.7

Figure 17. Pollen diagram for the Colchester Bog plotted on the basis of the number of grains per milligram dry weight.

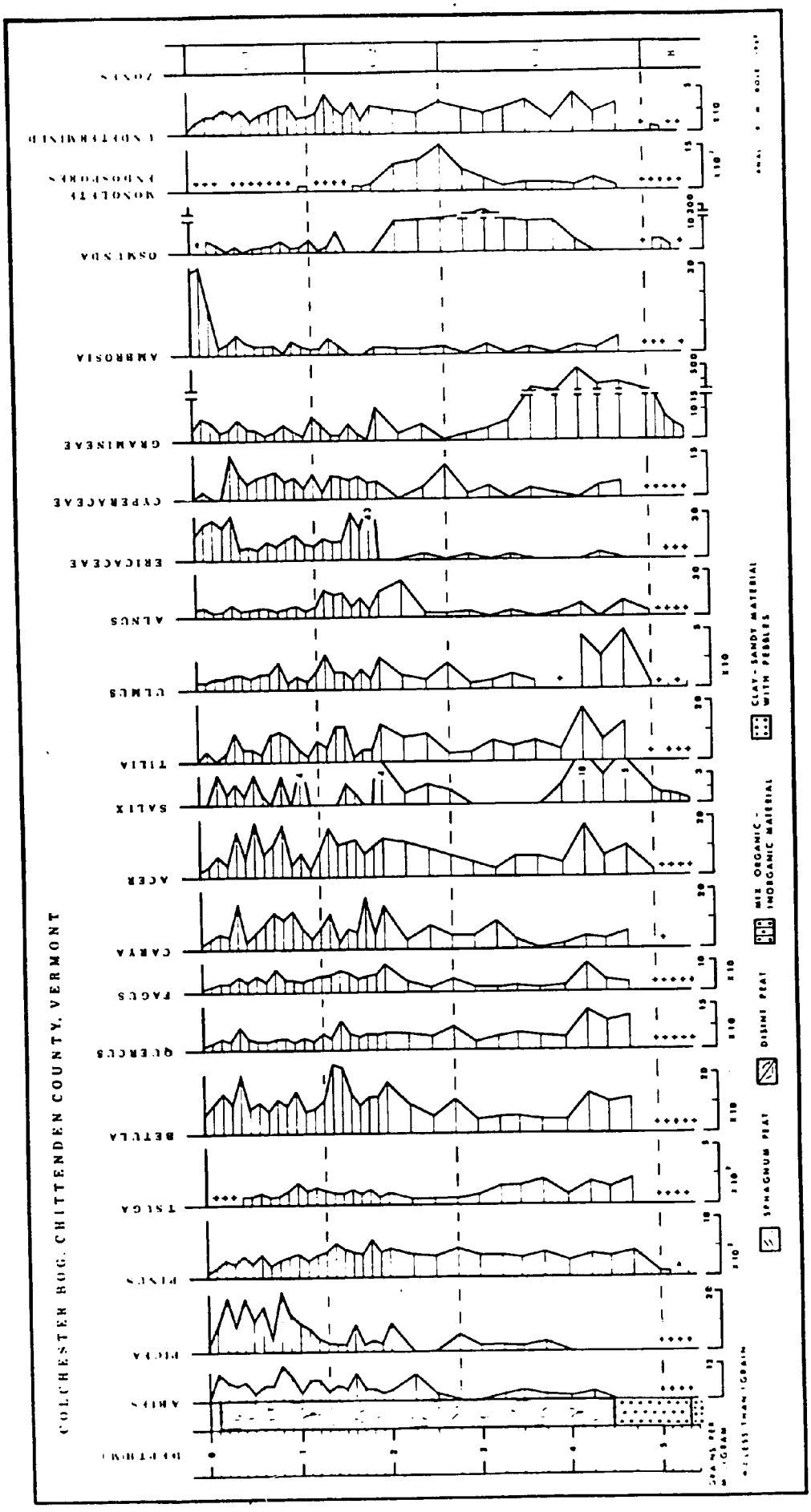
COLCHESTER BOG, CHITTENDEN COUNTY, VERMONT
ZONES
ARBOREAL POLLEN
NONARBOREAL POLLEN
ARTEMISIA
AMBROSIA
GRAMINEAE
CYPERACEAE
ERICACEAE
ALNUS
ULMUS
TILIA
SALIX
ACER
CARYA
FAGUS
QUERCUS
BETULA
TSUGA
PINUS
PICEA
ABIES
DEPTH(M)
CLAY - SANDY MATERIAL WITH PEBBLES
MIX ORGANIC - INORGANIC MATERIAL
DISINI PEAT
SPHAGNUM PEAT

Figure 17.

A comparison of the individual genera plotted on a percentage basis versus a grains per milligram dry weight basis, indicates the latter is more sensitive to changes in grain density. Birch plotted on a percentage basis (Figure 12) is nearly constant throughout the core. This, compared to birch plotted on a density basis, shows the density curve to be much more sensitive to grain density. Comparisons, in this way, to other genera show similar trends; some, however, are very similar whether plotted on percent or density basis as pine and hemlock.

Total grain density in the B zone in the Colchester Bog is low from 42 to 90 grains. At the B/C-1 zone boundary, the density of grains increases rapidly to more than 1,300. In the C-1 zone, the density of grains ranges from 1,315 to 1,771 grains per milligram. At the C-1/C-2 zone boundary is the maximum density of grains for this core of 2,688 grains per milligram. In the C-2 zone, the number of grains per milligram decreases to an average rate of about 1,100, ranging from 1,752 to a low of 783. The C-3 zone has the lowest density of grains in the core varying from 461 to 931 except at the surface where the number of grains is 1,576.

2. Density of Fossil Pollen and Spores for the Bugbee Bog.

Figure 7, Chapter III, shows the number of grains per milligram dry weight plotted stratigraphically. The density of grains is low in the A zone and at the A/B zone boundary the density increases rapidly from 720 to 1,876 grains per milligram. The B zone records the greatest grain density in the core at level 7.00 meters of 17,600 grains per milligram. The density then decreases

to 2,580 at level 6.25 meters which marks the B/C-1 zone boundary. Except for an increase at 6.00 meters to 7,800 grains, the density reamins rather uniform until level 1.75 meters. From 1.75 to 2.00, the concentration drops from 2,150 to 550 and continues to decrease to the surface. At the surface, there are only 130 grains per milligram dry weight.

Comparing the fluctuations of grain density with the radiocarbon dates for the Bugbee Bog, these data indicate that the grain density rose steeply from about 11,030 years ago reaching a maximum in the middle of the B zone about 9,500 years ago. Subsequently, the density dropped to a rather constant rate with minor exceptions for the last 7,000 years.

3. Density of Fossil Pollen and Spores in the Lily Pad Pond Bog.

A summary curve of the density of grains per milligram dry weight in the Lily Pad Pond Bog is shown in Figure 15, Chapter V. The density of grains in the A zone is very low, from 30 to 123 grains per milligram. At the A/B zone boundary, the density rapidly increases from 123 to 1,162 grains. In the B zone, the density of grains varies from 1,162 to 6,421 with an average density of about 4,000 grains per milligram. This constant density of nearly 4,000 grains per milligram is found in the C-1 and C-2 zones and remains into the lower part of the C-3 zone. At level 0.80 meters, the density increases rapidly from 6,207 to 20,246 and reaches a maximum of 40,000 grains per milligram at 0.30 meters. The density then decreases rapidly to 9,782 at 0.10 meters and to 397 grains per milligram at the surface.

4. Discussion.

The density data derived from this study indicate that in the three bogs the density is low in the lowermost sediments. The density then increases rapidly at the A/B zone boundary for the Bugbee Bog and Lily Pad Pond Bog and at the B/C-1 zone boundary for the Colchester Bog. The maximum density for the Bugbee Bog is in the B zone, for the Colchester Bog at the C-1/C-2 zone boundary and for the Lily Pad Pond Bog in the upper part of the C-3 zone.

The very low density of grains, in the lowermost sediments of the Colchester Bog, may be due to the dilution of grain density by the lake waters which covered the bog in its initial stages of development. In the B zone, which is dominated by pine (a prolific producer of pollen), it would be reasonable to expect the grain density to increase especially in the middle of the zone. Further, in the B zone, as defined for the Colchester Bog, many kinds of deciduous trees are present which are also contributing grains to the pollen rain in the region around the bog. These data suggest that lake water may have covered the bog area until late in the B zone when the lake receded below the bog surface since the density of grains increases markedly at the B/C-1 zone boundary. With the bog area now occupied by only a small body of water, the dilution effect on grain density would be greatly reduced.

It is also possible that during the high water stages in early B zone time the prevailing winds off the lake, which today are primarily from the west, would continually remove the grains suspended in the air and further contribute to the dilution effect.

Both Bugbee Bog and Lily Pad Pond Bog show marked grain density increases at the A/B zone boundary which would be expected as pine increases in numbers along with the first occurrences of deciduous trees. Probably the grain dilution theory suggested for the Colchester Bog did not influence the density of grains in the Lily Pad Pond and Bugbee Bogs since the vegetation to produce the grains was not well developed in the A zone contrasted to the B zone.

Once the grain density reached a maximum, the density then falls to a rather constant level until the intervals near the surface, when the density drops again. This is the general situation for the Bugbee and Colchester Bogs. The Lily Pad Pond Bog does not fit this description as the maximum grain density is attained in the upper meter. This seems anomalous as I would expect grain density to decrease near the surface as conditions for grain preservation are poorer than in sediments below one meter.

From these data, I would suggest the density of fossil grains will be low in the A zone, increase markedly in the B zone and perhaps early C-1, and then reach a rather constant density until the upper meter and then decrease again to the surface. The Lily Pad Pond Bog density data does not fit this theory and I suggest is the exception rather than the rule. However, there is as yet no established density pattern in sediments for peat bogs.

The pollen diagram, Figure 17, constructed on the basis of grains per milligram dry weight rather than percent is probably more sensitive to changes in density for those kinds of plants

which produce little pollen. The producers of great quantities of pollen grains, such as pine, show much the same curve whether plotted on a basis of percent or density.

CHAPTER VII

CONCLUSIONS

The pollen diagrams from the three study sites in north central Vermont permit reconstruction in considerable detail of the later, late-glacial and postglacial vegetation for this region. Two of the pollen diagrams, those of Bugbee Bog and Lily Pad Pond Bog, yield evidence for spruce-fir forests in Vermont during the last part of the late-glacial. With spruce and fir, in less lesser numbers were pine, hemlock, birch, but there was very little representation of other deciduous tree types. From the pollen found, at least oak and elm had already begun to become established in both areas, probably in small numbers. Non-arboreal pollen types indicate the presence of alder, sedges, and grass.

This pollen assemblage, reflected by the pollen counted, is readily correlated with similar assemblages in Vermont at Brownington Pond (Davis, 1965), about 110 kilometers (70 miles) north of the study sties, and at Pownell Bog (Whitehead and Bentley, 1963), about 258 kilometers (160 miles) south of the study sites. According to the Eastern North American pollen zone system, this pollen assemblage belongs in the zone A-4. The A zone is used to represent a portion of late-glacial time, usually greater than 10,000 years ago (Davis, 1965), and has been separated into four sub-zones A-4, A-3, A-2 and A-1, from early

to late. Only the A-4 is believed to be represented in these diagrams. Deevey (1951) in northern Maine, near Presque Isle, recognized zones A-3, A-2, A-1 and invented zones L-3, L-2, L-1 to denote time earlier than A when the spectra were dominated primarily by non-arboreal pollen, especially herbs. Davis (1958) identified the three A zones in central Massachusetts and added a fourth (A-4) to denote a secondary spruce maximum prior to the Post Glacial Pine Period. Further, she identified the L zones now designed T zones following Leopold (1956). The change from L to T presumably was done to denote the tundra-like vegetation which was now being found with some regularity. Krauss and Kent (1944), working in southeastern New Hampshire, recognized the upper A zone, presumably A-4, in one of the bogs they studied.

Both Lily Pad Pond Bog and Bugbee Bog pollen diagrams show this A-4 zone and both may represent essentially the same time interval even though the bogs are on opposite sides of the State. From the present evidence, the Bugbee Bog probably was not covered by the waters of glacial Lake Hitchcock. No shorelines identified with this glacial lake are at an altitude higher than 210 meters (695 feet) at the nearest localities reported (Stewart, 1961), 80 to 95 kilometers (50 to 60 miles) south of the Bugbee Bog area. It is probable that the glacial lake covered surfaces now higher than 210 meters in the vicinity of St. Johnsbury, including the bog, prior to isostatic uplift in the wake of the withdrawing ice. As there are no data on shorelines in the St. Johnsbury area, we can only estimate the extent of

glacial Lake Hitchcock. However, it seems probable it was never higher than 240 meters (800 feet) in the vicinity of Bugbee Bog and St. Johnsbury. At present, the bog is at an elevation of 398 meters (1,300 feet). Therefore, glacial Lake Hitchcock did not delay or interrupt bog development, although its presence might have influenced the character of the local climate and vegetation. As radiocarbon date on the lower sediments of the Bugbee Bog is 11,030 ± 200 years B.P. the last glacial ice must have receded from the area by this time. As the glacial ice receded north from Middletown, Connecticut, glacial Lake Hitchcock formed in front of the ice, the lake reached its maximum extent about 13,000 years ago (Schafer and Hartshorn, 1965). The rapid lowering of the lake and the abandonment of the southern end is dated at 10,650 and 10,710 years ago (Schafer and Hartshorn, 1965). These data indicate glacial Lake Hitchcock lasted for about 2,300 years. The radiocarbon date of about 11,030 years for the early sediment in Bugbee Bog indicates it began forming while the ice occupied valleys in the vicinity. Further, this evidence indicates the ice receded quite rapidly. Antevs (1922) studied the varved bottom deposits of the lake in great detail. He examined the overlapping varves from the morainic dam at Middletown, Connecticut, northward to St. Johnsbury, a distance of 298 kilometers (185 miles) excepting a gap in the varve record near Claremont in southwestern New Hampshire. The time interval occupied by the recession of the ice as determined from the varves was 4,100 years. This is in direct conflict with the radiocarbon chronology

which shows the ice front receded from Connecticut to St. Johnsbury in about 2,300 years.

The varves terminate at St. Johnsbury. This termination has been interpreted to indicate either a pause or a readvance of the ice (Shafer and Hartshorn, 1965). At the present time an inference as to the stade of the Wisconsinan represented by this pause is conjecture. MacClintock and Terasmae's work (1960) at Covey Hill, near the Quebec border at Moors, New York, shows Valders ice did not reach New England. The geologic evidence, the pollen data from a bog at Covey Gap, and Terasmae's pollen data and radiocarbon date at the St. Germain Bog (1960), indicate ice retreat from Covey Hill must have occurred before the Champlain Sea episode, and the till at Covey Hill is judged to be Port Huron (Mankato) in age. This till, called the Fort Covington, has a northwest till fabric orientation. The surface till in the Burlington, Vermont, area has a northwest fabric. Stewart and MacClintock (1964) report surface tills in the Sleepers River Valley, three miles northwest of St. Johnsbury, with northwest fabric. They suggest that the Burlington and Fort Covington Tills were deposited during the same glaciation since no evidence has yet been found of till older than Wisconsinan in these areas. The readvance of ice at St. Johnsbury, then, may be of Mankato age. Mankato (Port Huron) is, in the type area(s), due to a readvance. Flint (1957) has also suggested that this pause may be of Mankato age. Such data as these make it likely that the Bugbee Bog came into being before about 11,030 years ago and that the

Lily Pad Pond Bog may have been initiated at about the same time. This assumes that the early stages of the Champlain Sea which covered Lily Pad Pond Bog receded rapidly after initial inundation at 11,300 years ago.

The A/B zone boundary at the Bugbee Bog is at about 10,200 years ago. The A-3/A-4 zone boundary in southern New England falls between 10,300 (corrected) and 10,800 years ago (Davis, 1965; Davis and Deevey, 1964). It is assumed by most workers that the A/B zone boundary is between 9 and 10,000 years ago. Using Figure 8, Chapter III, the A/B zone boundary, at 10,200 years ago, occurs earlier in time than would be expected in northern New England. The determination of the boundary between these two zones has been made using the pollen assemblage found in conjunction with other published pollen diagrams for New England. Its placement is critical when attempting to assign a time to this boundary. It is my conviction that the boundary is placed in accordance with other published findings. If the A-3/A-4 zone boundary is at 10,300 to 10,800 years ago and the B zone is from 9,500 to 7,500 years ago in southern New England, then these events should occur later in time in northern New England. The radiocarbon chronology for the Bugbee Bog shows that these events occurred at nearly the same time in both southern and northern New England, and that the Postglacial Pine Period began about 10,200 years ago in northeastern Vermont.

The climate of the latter part of the late-glacial in north central Vermont is inferred from the pollen assemblage to

have been cool. Climatically, A-4 represents cooler and perhaps moister conditions than those of the present, if it is valid to compare the extensive coniferous forests growing under such conditions in eastern Canada today. The lack of significant percentages of deciduous tree pollen is also suggestive of a cooler climate during this period.

The postglacial sequence in New England is based on the pollen zones B, C-1, C-2, and C-3, recognized by Deevey (1939) in Connecticut 30 years ago. These zones are recognized in all three of the pollen diagrams in this study.

The B zone begins the postglacial time and is characterized as the Postglacial Pine Period. Pine is clearly the dominant tree in the pollen assemblage for this zone. Pollen diagrams in eastern North America consistently show this most conspicuous stratigraphic feature. Thus, it seems probable that early in postglacial time north central Vermont had a vegetation in which pine was the dominant tree. Along with pine, broadleaf deciduous tree genera become more common in the B zone. At both Bugbee and Lily Pad Pond Bogs, beech appears in the B zone along with birch, oak, and elm. Oak is present to 15 percent in the Colchester Bog diagram, 3 percent at Lily Pad Pond Bog, and 1 percent at Bugbee Bog.

This pollen assemblage suggests a climate for the B zone which is warmer than the A zone and perhaps dryer. Whitehead and Bentley (1963) suggest that the presence of oak in the B zone may indicate the climate is becoming more moist.

According to the radiocarbon dates for the Bugbee Bog, the B zone, as delimited, began about 10,200 years ago and lasted until 7,800 years ago, a period of 2,400 years. Davis (1965) indicates that the B zone in southern New England occurred between 9,500 and 7,500 years ago. The Bugbee Bog radiocarbon chronology, with the pollen zones as I have placed them, show this event occurred earlier and ended earlier in northern New England than this similar event in southern New England. It is reasonable that the time span for the B zone at Bugbee Bog would be similar to that for the Lily Pad Pond Bog. The Colchester Bog pollen diagram, lacking the A zone and perhaps some of the B zone, probably began forming after the last stageof the Champlain Sea had subsided. I would suggest the Colchester Bog did not begin to deposit organic matter until 9,500 or 9,000 years ago, in view of the pollen record in the B zone. With the exception of hickory, the deciduous tree kinds identified in the B zone in the Colchester Bog are well represented. Pine percentages are high and at 5.40 meters, the percentage is still increasing. This suggests that at 5.40 meter level may mark the mid-point of the pine zone.

The C zones are characterized by hemlock, pine, and deciduous tree pollen in north central Vermont. These zones were originally defined and characterized as C-1, oak and hemlock; C-2, oak and hickory; and C-3 oak and chestnut by Deevey (1939) in southern Connecticut. These zones are recognized in the pollen diagrams in this study even though the pollen diagram criteria are very different from those relating to the C zones in Connecticut.

Zone C-1, in this study, is characterized by a hemlock maximum and a pine minimum with the presence of oak, beech, and birch. The oak maximum found in southern New England for C-1 is not characteristic for C-1 in northern New England. Thus, the postglacial vegetation for north central Vermont changes from the condition in which pine is the dominant tree to that in which hemlock dominates in conjunction with the deciduous trees, oak, beech, and birch. Other deciduous tree genera (maple, elm, hickory, and basswood) are present in small amounts.

The pollen assemblage for zone C-1 suggests a climate that is warm and moist, at least moister than zone B according to the presence of hemlock and the increase in the importance of deciduous trees in addition to birch and oak. Deevey and Flint (1957) believe the beginning of the C-1 zone marks the beginning of an interval in post-glacial time when prevailing temperatures were higher than they are today. They have called this the Hypsithermal Interval, reviving a term proposed earlier but overlooked.

The radiocarbon dates on Bugbee Bog sediments show the C-1 zone began about 7,800 years ago and lasted until about 3,800 years ago. In southern New England the age of transition between zones C-1 and C-2 is established at 5,000 years ago (Davis, 1965). The radiocarbon data in this study indicate the duration of C-1 time is 4,000 years in north central Vermont. The duration in southern New England is 2,500 years, from 7,500 to 5,000 years ago.

Zone C-2, as defined in this study, is characterized by a hemlock minimum and high pine (except in the Bugbee Bog diagram where pine percentages remain lower than would be expected), with the presence of oak, beech and hickory. The hickory maximum which characterizes the C-2 in southern Connecticut is not found in the pollen diagrams from this study or in other published pollen diagrams for northern New England. However, a distinctive hemlock minimum occurs in Vermont diagrams that has been associated with the C-2 zone in north and central New England (Krauss and Kent, 1944; Davis, 1958, 1965; Whitehead and Bentley, 1963; Deevey, 1951). Oak, which also shows a maximum in southern New England diagrams, does not show a distinctive maximum in this zone for the bogs in this study. Only in the Bugbee Bog diagram does oak show an increase suggestive of a maximum. An oak maximum was identified for C-2 in Maine diagrams (Deevey, 1951) and by Whitehead and Bentley (1963) in southwestern Vermont. However, in northern Vermont, north of the sites in this study no oak maximum was found (Davis, 1965). This information indicates that the oak maximum for the C-2 zone in northern Vermont is not always identified. Deevey (1951) suggested that the hickory maximum absent in northern Maine diagrams, is replaced by a rise in pine, and presumably equivalent climatically to that of hickory since the northern Maine study site is north of the natural range of hickory. The Bugbee Bog diagram pine percentages do not show a rise in C-2 but remain constant at about 20 percent while oak rises from 5 to 10 percent. This may suggest that a least in the Bugbee Bog area conditions were not favorable for an increase in pine in C-2 time as might be expected.

Thus, the postglacial vegetation for north central Vermont during C-2 time is represented by a minimum of hemlock, an increase in pine (except at Bugbee Bog), and the presence of oak, hickory, beech, maple, and elm.

The pollen assemblage for the C-2 zone in north central Vermont suggests a climate that may be warmer, and perhaps the warmest in postglacial time. Because of the predominance of oak and hickory in southern Connecticut diagrams, Deevey (1939) concluded that the climate for C-2 must have been the warmest and driest in postglacial time. However, due to the lack of a significant oak and hickory maximum, other genera in the pollen assemblage suggest the climate was at least warmer and drier than the modern climate. Davis (1965) presented the pollen diagram for Brownington Pond, in northern Vermont, on a percentage basis and then corrected it by using modern day vegetation percentages gained by detailed vegetation mapping of a 20 sq. km. area around the pond and modern pollen rain percentages from bottom surface samples. She concludes the corrected diagram implies that the hemlock minimum is a real feature of the diagram that is caused by a significant decrease in the frequency of hemlock to a level similar to its abundance in the forest. However, she questions (p. 387) the significance of the climatic change implied by palynologists to indicate extreme warmth, "since the environmental factors influencing hemlock are not understood, few ecologists have supposed that its abundance at the present time is a function of climate." The end of the C-2 zone is also taken to mark the end of the Hypsithermal Interval.

Interpolating from the radiocarbon dates on this section, the C-2 zone for the Bugbee Bog began about 3,800 years ago and ended at about 1,600 years ago. I assume a similar time span for this zone for the Colchester and Lily Pad Pond Bogs. The transition, then, between C-2 and C-3 at Bugbee Bog is at 1,600 years ago. This transition, in southern New England is placed at 1,800 years ago based on radiocarbon dates at Barnstable Marsh, Massachusetts (Butler, 1959). This transition in both southern and northern New England are in close agreement. Further, I assume a similar date for this transition at the other sites in this study.

The C-3 zone pollen assemblage records the vegetation for north central Vermont for about the last 1,600 years. Spruce and fir return as hemlock gradually decreases in importance. Pine is present and its percentages indicate it is common. The deciduous tree genera remain at about the same level of abundance and no one dominates. Essentially, the vegetation implied is mixed conifer-hardwood forest.

The climate for the C-3 zone is thought to be cool, that is, not as warm as C-2. The return of spruce and fir and the decline of hemlock, with no pine maximum, are the indicators that suggest this shift in climate.

Ragweed pollen increases in percentage near and at the surface in the pollen diagrams from each bog. This increase is taken to indicate the influence of man on the vegetation since ragweed pollen increases have been associated with the result of forest clearance, cultivation, and field abandonment by European settl . Davis (1965) suggests that increases in red maple,

spruce, and fir in the upper 2 meters is also related to human influence, such as forest clearance, rather than the influence of climate. The Bugbee Bog diagram shows a maximum in ragweed pollen at the .10 m. interval and then the percentage decreases slightly at the surface. This suggests that the land originally cleared for agricultural use is being allowed to revert to forest. In the Bugbee Bog vicinity today, especially near Danville and St. Johnsbury, farming activity is on a rapid decline, particularly the use of fields for pasture for dairy. The Lily Pad Pond Bog diagram indicates a similar situation concerning the ragweed interpretation. In the Colchester diagram the ragweed maximum is at the surface. The area around Lily Pad Pond Bog, principally the town of Winooski, has very little if any farming activity remaining. However, in the Colchester Bog vicinity, much farming activity is still present, particularly as the land is quite fertile for market gardening.

Below is the sequence of vegetational history for north central Vermont as determined by pollen analysis from this study, correlated with the pollen zones, and assigned relative climate designations as inferred from the pollen assemblages.

Zones	Pollen Assemblage	Climate
C-3	Spruce and fir return; presence of pine, hemlock, oak, and birch	Cool
C-2	Hemlock minimum; high pine, presence of oak, beech, and hickory	Warm and dry
C-1	Hemlock maximum, pine minimum; presence of oak, beech, and birch	Warm and moist

Zone	Pollen Assemblage	Climate
B	Pine maximum	Warm and dry
A-4	Spruce and fir maximum low pine, rising NAP	Cool

Table 15 shows the correlation of the radiocarbon dates, pollen zones, and pollen assemblages for the three bogs in this study. I have used the radiocarbon dates for the Bugbee Bog to correlate similar events for the Colchester and Lily Pad Pond Bogs as I suggest these occurred at about the same time across the north centralpart of the State.

This study has reconstructed the vegetational history for north central Vermont from about 11,000 years ago to the present. Further, pollen zones have been assigned to characteristic pollen assemblages in order to attempt to correlate these data with published pollen analyses in Vermont and New England. The sequence of pollen zones and assemblages fit, in general, the published findings in Vermont and New England. A radiocarbon chronology has been established for one of the bogs in this study, the Bugbee Bog. Based on the radiocarbon chronology for the Bugbee Bog and the placement of the pollen zones determined in this study, the pollen zone chronology for north central Vermont is earlier in postglacial time than for the assigned chronology for southern New England. The only exception to this is the C-2/C-3 zone boundary which is at about the same assigned time interval. I also suggest that the same assigned time sequence for the pollen zones is applicable to the Colchester and Lily Pad Pond Bogs even though they are on the other side of the State, 120 kilometers

Table 15. Correlation of radiocarbon dates, pollen zones, and pollen assemblages for the three bogs in this study.

Absolute time scale x 10^3 yrs.	Pollen Zones	Colchester Bog, at Lake Champlain, alt. 100 feet	Lily Pad Pond Bog, 8 miles east of Lake Champlain, alt. 320 feet	Bugbee Bog, 15 miles west of Connecticut River, alt. 1,300 feet	^{14}C dates for Bugbee Bog
0	C-3	Ragweed, Return spruce and fir; presence pine, oak, beech	Return spruce and fir; presence pine, hemlock, elm; max.-ragweed .2 m.	Ragweed, Return spruce and fir; presence pine, oak, beech	180 ± 80
1					
2	C-2	Hemlock min.; high pine, oak, beech, max. monolete fern spores	Hemlock min.; pine max. slight incr. in birch, hickory, basswood	Hemlock min.; max. oak, birch, beech, sedge, monolete fern spores	2,130 ± 100
3					
4	C-1	Hemlock max.; pine decr.; rising oak, birch; grass max.	Hemlock max.; pine min., presence oak, beech, elm, maple	Hemlock max.; pine low, rising birch, oak, beech	3,940 ± 120
5					
6					6,450 ± 150
7					
8					

Table 15. Continued.

Absolute time scale x 10^3 yrs	Pollen Zones	Colchester Bog, at Lake Champlain, alt. 100 feet	Lily Pad Pond Bog, 8 miles east of Lake Champlain alt. 320 feet	Bugbee Bog, 15 miles west of Connecticut River, alt. 1,300 feet	^{14}C dates for Bugbee Bog
9	B	Pine maximum	Pine maximum; decr. spruce and fir	Pine maximum; decr. spruce and fir	
10	A-4	Absent	Spruce and fir max.	Spruce and fir max.	
11		Champlain Sea over bog site			11,030 ± 200
12				Glacial Lake Hitchcock in vicinity	

(75 miles) to the west. The pollen assemblages identified for each of the bogs is quite similar and are easily correlated with each other.

A climatic sequence is suggested for the generalized pollen assemblages identified. No detailed ecological studies of the indicator general used in deducing this sequence has been carried out for this study. This suggested sequence is deduced by using other published data for New England.

The density of fossil grains calculated for this study indicates the grain density is low in the A-4 zone, reaches a maximum density either in the B zone or at the B/C-1 zone boundary, and then assumes a rather constant density in the C-1, C-2 and the C-3 zones. The Lily Pad Pond Bog is an exception to this as the maximum density is reached near the surface. The pollen diagram constructed on density data shows a greater sensitivity for the genera which produce small numbers of grains. The curves for genera which produce large amounts of pollen, such as pine, are very similar to the curves based on percent.

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