

BULLETIN 55 A

Geologic Series

**The Peats of New Jersey  
And Their Utilization**

by

SELMAN A. WAKSMAN



**DEPARTMENT OF  
CONSERVATION AND DEVELOPMENT  
STATE OF NEW JERSEY**

CHARLES P. WILBER, Director and Chief of the  
Division of Forests and Parks

MEREDITH E. JOHNSON, Chief of the Division of  
Geology and Topography

IN COOPERATION WITH  
**AGRICULTURAL EXPERIMENT STATION,  
RUTGERS UNIVERSITY**

WILLIAM H. MARTIN, Director

Trenton, N. J.

1942

# The Peats of New Jersey And Their Utilization

---

PART A

NATURE AND ORIGIN OF PEAT. COMPOSITION AND  
UTILIZATION.

by

SELMAN A. WAKSMAN

Soil Microbiologist, N. J. Agricultural Experiment Station

*"Muck is the mother of the meal chest"*—

Old Scottish saying, quoted from Browne.

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

STATE OF NEW JERSEY

IN COOPERATION WITH THE NEW JERSEY

AGRICULTURAL EXPERIMENT STATION, RUTGERS UNIVERSITY

## BOARD OF CONSERVATION AND DEVELOPMENT

State House Annex, Trenton, N. J.

---

GEN. HENRY L. MOELLER, <i>President</i> .....	Millburn
ARTHUR J. COLLINS .....	Moorestown
WILLIAM C. COPE .....	Glen Ridge
HARRY A. DERBY .....	Montclair
MARTIN J. HOGENCAMP .....	Paterson
W. STEWART HOLLINGSHEAD .....	Riverton
CHARLES A. MEYER .....	Andover
OWEN WINSTON .....	Mendham (P. O. Gladstone)

## LETTER OF TRANSMITTAL

---

March 30, 1942.

MR. CHARLES P. WILBER, *Director,*  
*Department of Conservation and Development,*  
*Trenton, N. J.*

SIR:

Although given little publicity, the peat deposits of New Jersey constitute an important natural resource. The domestic demand for this type of material is normally supplied in large part from Germany and Scandinavia, but since those sources have been cut off there has been renewed interest in our local peat deposits. The report on peat written by Dr. Selman A. Waksman of the New Jersey Agricultural Experiment Station is therefore of timely aid in meeting the demand for detailed information which has arisen concerning these deposits. Part A, which follows, is a general description of the nature and origin of peat. Part B is now in preparation and will contain detailed descriptions of all the larger peat deposits and many of the smaller ones.

It gives me pleasure to acknowledge the generous cooperation of the New Jersey Agricultural Experiment Station in making this report available for publication as a bulletin in the Geologic Series of this Department's publications.

Respectfully yours,

MEREDITH E. JOHNSON,  
*State Geologist.*

## THE ORIGIN OF PEAT

When spring displayed her quickening powers  
Up sprung aquatic plants and flowers,  
So thick, the sun could scarcely trace  
His image in the liquid glass.  
Rearing its brilliant head between  
Broad floating leaves of glossy green  
The yellow water lily swum  
Upon the surface of the scum.  
Like serried groves of hostile spears  
The reeds uprais'd amidst the meers  
Their pointed heads of dusky brown  
By every passing breeze bow'd down.  
There rose the waterflag which decks  
Its golden leaf with purple specks,  
And water plantain to the view  
Appearing like the pictur'd yew.  
The bulrush overlook'd the rest  
With polish'd shaft and knotted crest  
And many more which to describe  
Would puzzle half the simpling tribe.  
Which when drear autumn nipt their bloom  
Sunk down into the watery tomb.

WILLIAM HARRISON,  
*The Fen Poet.*

Cited by Miller and Skertchly.

# PEATS AND THEIR UTILIZATION

## PART A.

### NATURE AND ORIGIN OF PEAT. COMPOSITION AND UTILIZATION.

SELMAN A. WAKSMAN

*New Jersey Agricultural Experiment Station, Rutgers University*

### PREFACE TO PART A<sup>1</sup>

---

Despite numerous books that have been written, in many languages, which deal with peat and despite the many scientific and agricultural societies in different countries dedicated to peat, this subject has received but limited consideration in this country. Very little attention is being paid to peat as a whole, and even in those scientific institutions where peat is receiving much consideration, as in the Florida, Michigan and Minnesota Experiment Stations, and in the Soils Division of the U. S. Department of Agriculture, attention is devoted primarily to the agricultural utilization of the peat.

Just a century ago (1842) Samuel L. Dana, the brilliant American agricultural chemist, published "A Muck Manual for Farmers," in which he elucidated the nature and utilization of peat. His ideas concerning the function of peat in plant nutrition, however, were rather limited. Under the influence of the great European chemists Berzelius and Mulder, Dana considered the organic constituents of peat and soil as the most important plant nutrients, "Geine," a term applied to the organic matter of the soil, was said to be "as essential to plants as is food to animals. . . . geine is the food of plants."

With the advance of our knowledge of soil processes and plant nutrition, resulting largely from the work of Boussingault in France, Lawes and Gilbert in England, and Liebig in Germany, the humus concept of plant nutrition was gradually replaced by the mineral theory. One of the outstanding representatives of this school in

---

<sup>1</sup> Assistance in the preparation of this material was furnished by the personnel of Work Projects Administration, Official Project No. OP 65-1-22-477.

America, Samuel W. Johnson, in 1859 published a series of lectures on peat and muck, in which he emphasized the potential value of peat for agriculture, not as a direct but as an indirect nutrient for plants, namely, as a source of nitrogen and as an agent for improving physical and chemical soil properties.

The major interest in peat was centered, at that time, however, upon its use as a fuel. This can be illustrated by the work of Hyde in 1866 (137) and of Leavitt in 1867 (170), followed by the monumental work of Shaler (266-269), as well as by numerous scientific and agricultural papers published in journals and by the various agricultural experiment stations, the U. S. Department of Agriculture, and the U. S. Bureau of Mines. In New Jersey, for example, the interest in peat dates back more than a century (253). Despite these studies, the utilization of peat did not make much progress in this direction, because the rapid and extensive use of coal and later of oil, as well as the large deposits of these materials available in this country, made the use of peat as a fuel superfluous. The latest and perhaps the most complete discussion of peat in the United States, from this point of view, is that of Soper and Osbon (279), published in 1922. It gradually became recognized that the most important uses to be made of peat in this country are for plant growth and for soil improvement.

The present work consists of two parts: Part A comprises a general survey of the nature and origin of peat; part B, a survey of the peat resources of New Jersey, carried out with funds supplied by the Work Projects Administration. Part A was prepared entirely by the writer with a certain amount of technical assistance from some of the workers on the W.P.A. project. The contribution made by the members of this project to part B, will be listed in detail in the preface to that part.

Opportunity is taken here to express appreciation to the W. P. A. administration of New Jersey, for assistance in the preparation of this monograph, and to the various members of the staff connected with this project, especially to Mr. C. A. Hickman and Miss A. Sadtler, for the preparation of the photographs and sketches. The author also wishes to express his appreciation to Herminie B. Kitchen for her painstaking work in the editing of this manuscript.

SELMAN A. WAKSMAN.

## CONTENTS

---

### PART A. NATURE AND ORIGIN OF PEAT. COMPOSITION AND UTILIZATION.

	PAGE
Introductory. The nature of peat, its formation and abundance.....	11
Chapter I. Terminology of peat and causes of confusion.....	16
Chapter II. Types of peat and systems of classification.....	25
Chapter III. Climatological, geological and botanical factors involved in peat formation .....	41
Chapter IV. Chemical composition of peats.....	57
Chapter V. Physical and physico-chemical properties of peats and peat soils .....	80
Chapter VI. Microbiology of peats. Peat formation and decomposition. Peat subsidence .....	90
Chapter VII. Utilization of peat for agricultural purposes.....	103
Chapter VIII. Industrial utilization of peat .....	131
Bibliography .....	140



## ILLUSTRATIONS

	PAGE
Fig. 1. Eight representative profiles from European and American peat bogs: I-IV, Swedish profiles (221); V, Maine profile (309a); VI-VIII, New Jersey profiles .....	19
2. Lowmoor bog (Echo Lake) in New Jersey .....	27
3. Forest peats in New Jersey: (a) Onga Hat cedar swamp; (b) Sleeper Creek bog .....	28
4. Floating mat of peat, Budd Lake, N. J. ....	31
5. Tidal marshes in New Jersey: (a) Bridgeton marsh; (b) Raritan River marsh .....	32
6. Effect of tidal marsh on cedar forest, Secaucus, N. J. ....	35
7. Pollen diagram of peat bogs in southern Sweden (221) .....	43
8. Typical pollen grains, spores and diatoms found in peat bogs: (1) <i>Fraxinus</i> , (2) <i>Quercus</i> , (3) <i>Betula</i> , (4) <i>Juglans</i> , (5) <i>Populus</i> , (6) <i>Corylus</i> , (7) <i>Alnus</i> , (8) <i>Salix</i> , (9) <i>Sagittaria</i> , (10) <i>Ulmus</i> , (11) <i>Juniperus virginiana</i> , (12) <i>Tilia</i> , (13) <i>Fagus</i> , (14) <i>Larix</i> , (15) <i>Thuja</i> , (16) <i>Carya</i> , (17) <i>Typha</i> , (18) <i>Acer</i> , (19) <i>Pinus strobus</i> , (20) <i>Abies balsamea</i> , (21) <i>Tsuga canadensis</i> , (22) Spores, (23) Diatoms .....	45
9. Three stages in the development of a highmoor peat bog, each of which may at present be an independent entity: 1. The lake or sedimentary stage. 2. The sedge and reed or lowmoor stage (it could also have been the forest stage). 3. The sphagnum or highmoor stage .....	47
10. Cross-section of peat accumulation along the plain of a fair-sized river .....	49
11. Diagrammatic section showing formation and structure of marine marshes (after Chapman, 42a) .....	51
12. The origin and structure of a marine marsh, showing forest peat layers .....	53
13. Influence of moisture upon the decomposition of peat, taken from the surface 30 cm. of the bog, during the early stages of decomposition, as shown by evolution of CO <sub>2</sub> and liberation of nitrogen in an available form (308) .....	94
14. Seasonal fluctuations in nitrate nitrogen and soil reaction in the top 4 inches of a lowmoor soil .....	95
15. Subsidence of peat soils in Florida—Okeelanta peat profile (47) ..	100
16. Cultivated lowmoor peat, Newton, N. J. ....	107
17. Utilization of peat bogs for cranberry growth, Indiantown bog, Weymouth, New Jersey .....	115
18. Handling of peat for fuel, County Sligo, Ireland .....	133

# THE PEATS OF NEW JERSEY AND THEIR UTILIZATION

## ABSTRACT

Part A comprises a survey of the development of our knowledge of the nature, origin, composition, classification and utilization of peats in this country and abroad. Attention is called to the confusion of terms used to designate peats and peat formations. The reasons for this confusion are examined in detail. An attempt is made to simplify the concept of peat as a whole, and of the various peat types as produced in different regions from different plants and under different topographic and environmental conditions. The botanical and chemical criteria for the classification of peats are examined critically and evaluated. The relationships between available nutrients, plant associations and peat formations are correlated. Four major and several minor types of peat are recognized.

The botanical and chemical composition of peats, as well as their physical and physico-chemical properties are examined from the point of view of the nature of peat and its utilization. The microbiology of peat bogs and the role of microorganisms in peat formation and peat decomposition are given special consideration. Finally the problems involved in the utilization of peat, for agricultural and industrial purposes are discussed from an historical and from an applied point of view.

---

## INTRODUCTORY

### THE NATURE OF PEAT, ITS FORMATION AND ABUNDANCE

Peat is formed, by winds and flowing streams, from plants growing under water or in a water-saturated state; it is also produced when plant and animal residues are brought into water basins and allowed to settle at the bottom. Under these conditions the decomposition of plant remains is inhibited or prevented. Saturation with water results in a limitation of the air supply, in acid conditions, and in a shortage of certain nutrients required by microorganisms. All these factors favor the formation and accumulation of the organic residues and their partly decomposed products.

Peat accumulates in bodies of water, usually designated as *bogs*, *marshes* or *swamps*, where the drainage is so hindered as to prevent rapid decomposition of the plant and animal residues that have been produced or deposited in the water. Peat formations are found throughout the world, especially in the temperate and in the colder zones, but also in the more humid semitropical and even tropical climates.

In a natural environment, peat may contain 80 to 96 per cent water. On a dry basis, the organic content of peat varies from less

than 50 to 99 per cent. When the dry portion of the peat includes as much as 80 per cent inorganic material, the area, if designated as a swamp, need not be considered as a true peat bog. It has actually been suggested (281) that only those formations that contain 50 per cent or more organic matter on a dry basis be designated as *peats*. At the last meeting of the Peat Section of the International Society of Soil Science, it was decided to recognize as peat bogs only those areas in which the depth of the organic matter layer, excluding the fresh surface plant residues, is at least 20 cm. for drained areas and 30 cm. for undrained land.

The nature and the origin of peat puzzled investigators for many years, during which numerous theories and hypotheses were proposed. An early American writer (170), for example, asserted that peat "is unquestionably of vegetable origin, and is the result of decomposition to a certain stage, modified or affected by the agency of air, water, temperature, time, and pressure. By some it was considered a bituminous deposit from the sea—the wreck of floating islands previous to the great convulsions which the earth underwent during the formation of the present continents and islands. By others it was even regarded as an organic substance in a state of vitality, and actually growing."

This definition, as well as numerous other concepts, which need not be dwelt upon here, served to confuse rather than to clarify the understanding of peat. In more recent times, it has been established that the fundamental factors which influence the formation of peat are functions of climate, soil, and water. These control the nature of the vegetation and the processes of decomposition. Peat-forming plants find favorable conditions for their development on poorly drained land, where rain water or drainage water may collect and stand permanently. This is enhanced by high humidity of the air, which prevents evaporation, by regular rainfall, and by a low temperature. Under these conditions, the decomposition processes are usually very slow, and the partly decomposed plant residues thus give rise to peat.

In the development of a peat bog, algae and other aquatic plants, as well as products of higher plants, such as pollen and leaves, and inorganic dusts, first accumulate. These slowly form the bottom layer of deep peat deposits. When the waters become shallow, as a result of the filling of the lake, or in shallower waters in general, the algal and pollen zone is followed by a zone of aquatic vegetation. This gradually leads to the growth of sedges and reeds, until the level of the bog has been raised to that of the surrounding country. Various

grasses and shrubs, as well as a variety of sphagnum mosses, will then appear. Coniferous trees develop later and are followed by deciduous trees. At that stage, the surface of the bog has risen above the water level with the result that decomposition processes are able to keep pace with the accumulation of the peat material. If the water level is then suddenly elevated, as by subsidence of the land, the growth of the trees may be stopped and lower plants which are more adapted to an aquatic environment reappear. A new period of peat accumulation begins and the whole plant association may become changed.

In a peat profile, one may find dark, well-decomposed layers, indicating a period of low water level or drought. The occurrence of several such layers indicates that similar conditions have occurred at different times during the period of the peat formation. The occurrence of a layer of poorly decomposed fibrous plant residues points to a period of prolonged precipitation and to a rise in water level. Since the lower strata of a peat profile are formed by plants growing below the water level, they are much more colloidal or macerated, and virtually free from fibrous or woody materials. The upper strata of the profile are produced by plants growing above the water level and are commonly highly fibrous in nature.

Several typical peat profiles are illustrated in Fig. 1.

The organic matter in peat bogs is not inert, but undergoes a process of slow anaerobic decomposition, accompanied by the evolution of various gases, such as carbon dioxide ( $\text{CO}_2$ ) and marsh gas ( $\text{CH}_4$ ). The deeper portions gradually become compact. All peats contain mineral matter which either accumulates from the decomposition of plant residues or which has been brought in by the flowing waters and streams, in solution or in suspension.

When a peat bog is drained and brought under cultivation, a highly organic black soil results. Though this is a form of peat, it is usually designated as *peat soil* and frequently as *muck*.

That the utilization of peats dates back many centuries is recognizable in the following quotation from the Natural History of Pliny (XVI, 1 Chauci), concerning various peoples who "mould mud with their hands and dry the mud in the wind rather than in the sun; this earth they burn to cook their food and warm their bodies benumbed by the cold." In countries where only limited coal supplies are available, as in Ireland, Russia, Sweden, Denmark, Holland, and Germany, various attempts have been made to utilize peat as a source of fuel.<sup>1</sup> In some countries, notably in Holland, England, and Ger-

<sup>1</sup> The second world war has forced many countries, notably Denmark, Sweden, and the U. S. S. R., again to resort to peat as an important if not a major source of fuel.

many, a shortage of land combined with an increasing population led to the development of peat bogs for agricultural purposes. It is natural, therefore, that those countries should show an intense interest in determining the nature and extent of the available peat. Committees of experts were appointed, comprising various peat boards, peat societies, and peat institutes. These led to the organization of many special peat experimental stations. The oldest of these is the Danish Heath Society, formed in 1862. This was soon followed by similar organizations in Germany, Sweden, Holland, Finland, Austria, Norway and Russia. Though they differed considerably in their nature and functions, they all had the same interest, the study of peat. Even in mountainous Switzerland, peat received considerable attention (106).

In Germany, a number of experimental fields were laid out and an experimental peat station was established in Bremen. A society for the promotion of peat utilization was founded. A special section for the study of peat was organized in the Technical University at Hanover, and a technical director was appointed for the German peat bog utilization society. Under the leadership of three directors, M. Fleischer, Br. Tacke, and Fr. Brüne, the Bremen station led in the contributions made to the knowledge of peat and its utilization. Bavaria founded the Royal Bog Utilization Institute in Munich and several peat utilization stations. Other sections of Germany also had their own peat societies. In Austria, a special peat experimental station was founded in Vienna, and various peat societies were organized and courses of instruction in peat were offered in several institutions.

In Sweden, an experimental peat institute was founded at Jönköping, with a staff of agronomists, chemists, and engineers. The Swedish Peat Reclamation Society, with Dr. H. von Feilitzen as president, established an experimental station at Flahult. Other societies were organized for the advancement of the Swedish peat industry. In Holland, more than 400 km. of main canals and about 1,000 km. of bog canals were built with a view to promoting the advancement of the peat industry. Hausding (128) pointed out that in the winning of peat in Holland about 10,000,000 cu. m. were cut out every year and the land was thereby gained for agricultural purposes. In Russia, peat exploitation for both industry and agriculture has reached a high state of development. A peat factory was erected at Redkino, in 1901. This was later developed into an experimental station, with many laboratories and a large staff. Several large institutes are devoted exclusively to the study and utilization of peat.

In most countries where peat utilization has made notable progress, the state has passed peat preservation laws which control the manner of utilizing not only the peat itself but also the resulting soil for agriculture or for forestry.

In this country no special institutions for the study of peat existed until two or three decades ago. An early American pioneer (37) wrote enthusiastically:

We may judge of the character of a nation by the amount and use of its muck heaps. They are the bases of enterprise; they spread gladness through the hearts of the dwellers in cities, as well as over the rural districts; they crown the hills with corn, and the valleys with waving grain; they clothe the fields with grass, and sprinkle the lawn with flowers. With them, we may reach almost any degree of civilization; without them, we should gradually relapse into the condition of those originally occupying these fair lands.

Two Federal agencies, the Bureau of Mines and the Bureau of Plant Industry, have made a survey of the occurrence and utilization of peat in the United States. The first Peat Experiment Station was established in 1925, at Belle Glade, Florida, thereby giving recognition to the importance of peat in agriculture.

Most of the calculations of the extent, nature, and value of the peats in the United States have been based upon generalizations. Davis (68) said, for example, that only 8 per cent of 139,855 square miles of swamp land in the United States, exclusive of Alaska, have peat deposits of good quality. Elliott (83) estimated that the areas of peat and other wet lands in the United States occupy 79,000,000 acres. In more recent reports (118), this figure has been raised to between 91 and 114 million acres. Minnesota, Michigan, North Carolina, and Texas were said to contain 4 to 6 million acres each; Louisiana was said to contain 10 millions, and Florida nearly 17 millions. Davis assumed an average depth of peat of 9 feet. On this basis, he calculated a yield of 200 tons of fuel peat per acre-foot. These and other calculations are of doubtful significance, since peat may never become an important source of fuel in this country. This fact, however, does not diminish the value of the peat-land resources of the United States, primarily for agriculture and for soil improvement. As such, they represent a tremendous source of potential national wealth.

One is safe, therefore, in concluding that although peat bogs will never become gold mines for their owners, they can be made just as remunerative as other industries, provided careful and businesslike methods are adopted for their development (128).

## CHAPTER I

## TERMINOLOGY OF PEAT AND CAUSES OF CONFUSION

The concept of peat formation was definitely established long ago. For example, it was recognized and clearly defined more than half a century ago by a prominent American geologist, N. S. Shaler (266-269), who wrote that "the formation of swamps (i. e., bogs) depends upon conditions which retain upon the surface a sufficient quantity of water to prevent the complete decay of the vegetable matter which may be accumulated upon it, as a result of the entire or partial death of the plants which occupied the district." That the exact nature of the peat material, however, was but little understood can be recognized from the following definition by an early American student (170): "Peat is the spongy substance found in almost every country, filling up cavities in the surface, and constituting what is termed bog; it varies in color from light brown to black, and in consistency from that of a bran paste to that of clay in the bank."

More recently a New Jersey geologist (213) improved considerably upon the foregoing definition, as follows:

Peat is a brownish to black deposit formed by the accumulation and slow decay of vegetable matter under water, in bogs and swamps. It may be in some cases, the incipient state in the formation of coal and a chemical gradation can be traced from peat to anthracite. Peat is often fibrous, though in some varieties but few fibres may be distinguished. The process (of peat formation) is one of slow oxidation out of contact with the air, in which the amount of carbon increases as the volatile elements like oxygen and hydrogen decrease.

The terminology for designating peats and peat formations has been greatly confused, for a number of reasons: Various types of peat differ in appearance and composition, as a result of differences in the peat-forming vegetation and in the particular conditions under which peat is formed. The fact that peat undergoes considerable decomposition on drainage which changes its appearance as well as its physical and chemical properties, gave rise to different conceptions of peat obtained at different stages of decomposition. The adaptation of terms used in one language to another resulted in much duplication and confusion; this was further aggravated by minor differences in the nature of the peat or in its utilization.

The ancients had much less difficulty, since the words *turba*, *turbs*, *turboe*, and *turfa* were used to designate peat as far back as the end

of the 12th century. The word *turbaria* was used to designate a peat bog; *turbagium* was recorded early in the 14th century, in connection with the right of digging peat. In commenting upon these early uses of peat, Leavitt points out that words of like significance occur frequently in the foundation charters of the monasteries in Germany, in conveying the right to dig peat.

To bring out the confusion which has been introduced in the definition and characterization of peat types, it is sufficient to direct attention to the terms most commonly employed. The following list is not exhaustive. Some of these terms are mere localisms. Others have been used largely for the purpose of emphasizing the differences in type of peat, its physical or chemical condition, and its utilization. Many are merely synonyms.

Peat	Bog	Lowland	Marshy
Muck	Moss bog	Moorland	Swampy
Moor	Peat bog	Peat land	Boggy
Moss	Green bog	Morass	Earthy
Bog muck	Low bog	Mire	Peaty
Swamp muck	Flat bog	Quagmire	Fibrous
Moss peat	High bog	Mere	Quaggy
Peat moss	Transition bog	Bog soil	Muddy
Creeping moss	Woody bog	Peat soil	Sloppy
Blanket moss	Climbing bog	Peaty soil	Squashy
Mull	Hanging bog	Swampy soil	Spongy
Peat mull	Quaking bog	Peat humus	Moory
Turf	Muskeg	Meadow peat	Turfy
Heather	Swamp	Forest peat	Moorish
Humus	Heath	Alpine peat	Fenny
Acid humus	Fen	Lake peat	Paludal
Mild humus	Carr	Dry peat	Pitchy
Mud	Lake swamp	Fuel peat	
Bog mud	River swamp	Spongy peat	
Mud peat	Fresh water swamp	Moorland peat	
Slime	Swamp moor	Hill peat	
Ooze	Marsh	Liver peat	
Sludge	Grass marsh	Sapropet	
	Marine marsh	Gyttja	
		Dy	
		Dopplerite	

In order to define the more important of these terms and to show their interrelationship and possible justification, it is important to trace their development. The disagreement and confusion in the use not only of the different terms, but even of any one of them, is due largely to the point of view taken. The geologist has been interested in peat because of its relation to the earth's crust and the role that it has played in the origin of coal. The geographer has emphasized the topographical aspect of peat, its location and relation to environment. The botanist has been concerned primarily with the plants growing on the surface of the bog or with the plants from which the



peat originated. The chemist in attempting to unravel the complex chemical nature of the peat material, has limited himself chiefly to the inorganic constituents, having found the organic substances far too complex. The physical chemist has paid attention to the colloidal nature of the peat as a whole, especially in connection with the water relations. The industrial chemist has been interested in peat largely as a source of fuel. The bacteriologist has paid to peat the least attention, since as an anaerobic system it is rather poor in the types of microorganisms that are found in ordinary field soils. The agriculturist has been interested either in the utilization of peat for the growth of cultivated crops or in the exploitation of the physical and chemical properties of peat for fertilizer and other purposes. The textbook writer, the dictionary compiler, and the popularizer have frequently confused all these concepts, with the result that the impression obtained from these definitions is frequently incorrect.

#### PEAT

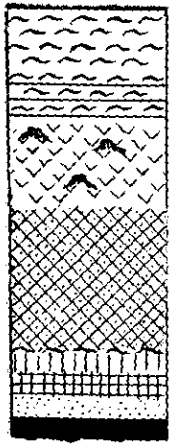
Both American and foreign investigators have erred in the same general direction; in attempting to emphasize the complexity of the peat material, they have often confused the concept of peat. It is sufficient to cite here several definitions by some of the more recent investigators of the subject.

According to a recent American student of peat (54, 55) :

Peat is the general name applied to the remains of plants which at one time formed an aquatic vegetation, or a marsh of coarse sedges or tall reeds, a bog of mosses and heaths, or a swamp of shrubs and trees. A peat deposit is, therefore, the result of the accumulation of many generations of plants from one or several groups of vegetation and in all cases contains at least one or more layers of different kinds of material. On that account the term "peat" is restricted in the meaning to a compact and well shrunken mass of organic material which accumulated in water or under conditions of a rising water level and varies in thickness from about 8 to 10 inches upward.

An outstanding European investigator (315) presented a definition which may be looked upon as a summary of the confused ideas that are still prevalent concerning the nature of peat :

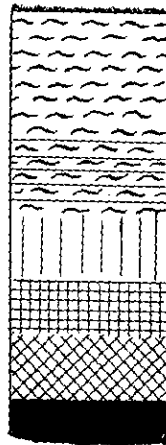
Peat is an organic mineral formed out of dead plants rich in cellulose, by a special process of ulmification or peat formation; it becomes colored brown to black when exposed to air; it is soft in its natural moist condition, and is very rich in water; its specific color depending on its content of ulmin. Peat consists largely of the elements carbon, hydrogen, oxygen, varying amounts of nitrogen, of sulfur and ash. Various animal residues are admixed, in the form of manures and chitin. On drying, peat shrinks quite considerably, changing into loose fragments or into hard, frequently fibrous clumps, breaking apart with the formation of sharp edges. The air dry substance of peat swells, the degree of swelling depending on the constituent plant residues, on the state and perhaps even the type of peat formation and on the pressure to which it was



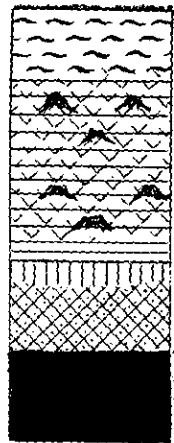
I



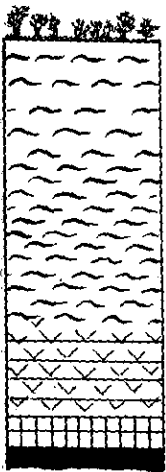
II



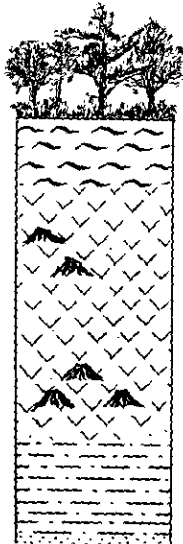
III



IV



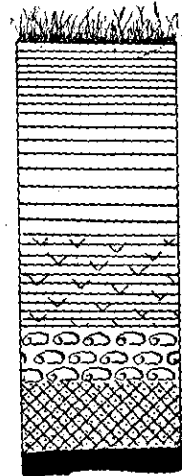
V



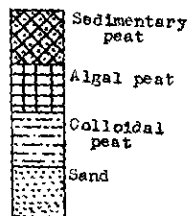
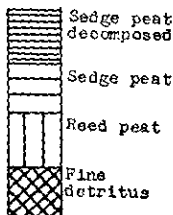
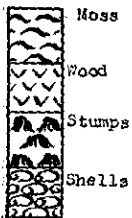
VI



VII



VIII



SURFACE VEGETATION

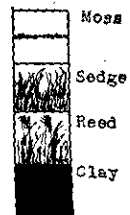


FIG. 1. Eight representative profiles from European and American peat bogs: I-IV. Swedish profiles (221); V. Maine profile (309a); VI-VIII. New Jersey profiles.

subjected during the continuous contact with water; it never gives a structural mass which would resemble soil even when fully softened. According to the degree of ulmification and the nature of peat formation, the plant residues from which peat has been formed are still recognized by the naked eye.

When one compares this conception of peat with that common in the middle of the last century, it appears that but little progress has been made. This is brought out in the following quotation from S. Johnson (145, 146):

The production of peat from fallen and decaying plants depends upon the presence of so much water as to cover or saturate the vegetable matters, and thereby hinder the full access of air. Saturation with water also has the effect to maintain the decaying matters at a low temperature, and by these two causes in combination, the process of decay is made to proceed with great slowness, and the solid products of such slow decay are compounds that themselves resist decay and hence they accumulate.

In recent years, however, considerable progress has been made in the understanding of the botanical and chemical nature of the various types of peat. Many bogs have been carefully investigated and the plant residues tabulated. It is now possible to correlate a certain type of peat with a definite association of plants which have given origin to it, as well as with a characteristic chemical composition (289). In order to elucidate this concept, it is sufficient to quote the definition given by Puchner (228):

Peat is a mass of dead plant residues, the decomposition of which took place very slowly due to a lack of sufficient oxygen and which has not been completed yet. The physics and chemistry of peat is partly the physics and chemistry of the plants from which peat originated and which may still be present in it in a slightly changed form.

The following definition, which takes into consideration the various factors involved in peat formation, is suggested by the author:

*Peat forms a layer of the earth's crust, largely organic in nature, which has originated in water basins and in a water-saturated condition as a result of incomplete decomposition of the plant constituents due to the prevailing anaerobic conditions. The nature of the peat depends upon the plant association which has given rise to it and which in turn has been controlled by the nature and amount of the mineral nutrients in the waters in which the plants were growing. The chemical composition of peat is influenced by the nature of the plants from which it has originated and by the moisture relations during and following its formation and accumulation.*

## MUCK

Similar, if not even greater, confusion exists in regard to some of the other terms that are commonly used to designate peat formations. The term *muck*, for instance, is defined in several dictionaries as follows:

Dung in a moist state; manure. Any kind of impure or decayed peat or black swamp earth especially when used as manure. Earth of any kind to be, or being, excavated.

Moist manure; decomposed vegetable matter mixed with animal dung; hence manure in general. Vegetable mold combined with earth; as swamp muck.

Dung in a moist state; a mass or heap of rotten vegetable matter.

In general, attempts to distinguish between the terms *muck* and *peat* have gone no further than to designate by *peat* a natural formation and by *muck* a cultivated peat (38, 33, 54, 279, 321). Some attempts have been made to base these differences upon actual chemical composition, that is, the material was called *peat* or *peat soil* when the ash content was less than 50 per cent, and *muck soil* when it contained more than 50 per cent ash or was in an advanced stage of decomposition (328). It has been said, for example (181), that:

The term *muck* refers to those soils which contain a high percentage of organic (vegetable) matter, in a well decomposed condition. *Peat* signifies the rawer organic soils. It is evident that there is no sharp line of demarcation. In general, the agricultural practices which are suited to *muck* are likewise adaptable to *peat* soil. For that reason the term *muck* may be considered to include both *mucks* and *peats*.

This confusion between the two important terms for designating peat is well recognized by a number of investigators. It is sufficient to cite from an American Experiment Station worker (6):

There are so many gradations between peat and a true muck that it is difficult to make any sharp distinction between them. They vary from coarse, fibrous, brown-colored material to fine-grained, dark-colored organic matter. When the process of decay has not proceeded to the extent that the cellular structure of the peat is destroyed, and portions of leaves, twigs and partially decayed wood are present, the deposit is properly designated as peat. As decomposition proceeds the more resistant parts of the plant residues are disintegrated and the color darkens. This is the transition stage from peat to muck. Further reduction of the organic residues to a mass of finely-divided organic matter, having no resemblance to the fibrous plant remains, and additions of mineral water washed from silt and clay upland soils, change it to a true muck. Many of the organic deposits do not contain sufficient mineral matter to be properly classed as muck. The mineral content of muck is 25 per cent or higher. That of peat is less, ranging from 5 to 15 per cent. There are, however, such decided differences in the physical condition, and their capacity to produce crops that, from an agricultural point of view, the peats which have been reclaimed for a number of years and changed considerably by cultivation, can be designated as muck.

Unfortunately, few had such a clear concept as the above.

## TURF

Several dictionaries and encyclopedias define *turf* as peat used or ready for use as fuel, though agreement on this concept is far from unanimous.

More than six decades ago, a British investigator (273) wrote that the word *peat* was quite unknown among the agricultural population of the fens:

The substance is called turf, and where thin, or so weathered as to be unfit for fuel, the term moor is applied. It is usual to speak of "moory land," "black land," or "fen" where the soil is peaty. The word "fen" has, however, come to be used merely in contradistinction to "highland," but it is an unsafe term to use in speaking to the labourers, for though among themselves they talk of "down the fen," it seems to be tacitly understood that to outsiders or inquirers "there are no fens now."

## PEAT-FORMING AREAS

Confusion in terminology similar to that of peats and peat-like materials exists in regard to the designation of areas in which peat is formed. This is true especially of the terms *bog*, *marsh*, *swamp*, and *moor*, all of which are used to designate undrained peat lands.

The term *bog*, for instance, has been modified often (168) on the basis of plant habitat (238, 239, 279). *Sphagnum bog* referred to any bog with a pronounced sphagnum-heath association, whereas the term *acid-bog* was used in a more general sense and corresponded to the moors (296):

... many of our so-called swamps, tamarack swamps, tamarack bogs, cedar bogs, cedar swamps, mixed bogs and so on, fall under the general category of circumneutral bogs, and specifically into either fens or fen-moors (168).

An attempt was made to differentiate between a *bog* and a *swamp*, as follows (200):

A bog may be defined as a fresh water swamp characterized, especially in the shrub stage, by an abundance of xerophytic plants. It might well be designated as a xerophytic swamp. This type of swamp, by reason of its unique vegetation, the ecological problems involved, and the economic value of the frequently underlying peat deposits, has probably received more attention at the hands of investigators than all other swamp types put together. In comparing the plant associations encountered in a lake-bog succession with those in an ordinary lake-swamp series, the first appreciable differences are perceived in the sedge stage, while the departure of the two types from one another becomes very pronounced in the shrub and tree stages.

Soper and Osbon (279) defined a swamp as:

... a low, flat area covered or saturated with water and overgrown by trees, with or without an undergrowth of shrubs. The surface may be overgrown by a thick mat of vegetation, consisting of small plants, a condition found in many of the swamps of New England, or as in some parts of Dismal Swamp,

Va., it may be covered with water and comparatively free from small plant growth. Swamps are sometimes named from the trees that predominate in them, as spruce swamp, cedar swamp, gum swamp, cypress swamp, etc. In swamps containing standing water the contribution of sphagnum moss and heath shrubs to the debris from which peat forms is small.

This and other attempts to differentiate between bogs and swamps, marshes and moors have failed, just as they have in differentiating between peat and muck.

Transeau (303) designated "bogs" as undrained swamps and "swamps" as partly drained bogs. A similarly confused definition was given by another botanist (225), namely, that:

A swamp is a feature of the topography where the water table is above the surface and the soil is inorganic or of a humus nature. A bog is a feature of the topography where the water table is at or near the surface and the soil is of organic origin (peat formed *in situ*).

It is hardly necessary to dwell further upon the confusing concepts in regard to other terms listed on page 17.

The process of peat formation or *paludification* also has been highly confused. On the one hand, it seems to be generally agreed that the transformation of plant material into peat is primarily microbiological in nature; on the other hand, some investigators still consider the process as entirely chemical in nature. Bersch has said (30), for example, that microorganisms are not active in the processes of peat formation, though he regards decomposition under aerobic conditions, which leads to a complete destruction of plant residues, as microbiological in nature. Peat formation and aerobic decomposition are thus looked upon by some as two distinctly different processes, the first of which leads to an accumulation of plant residues with a partial chemical transformation, whereas the second leads to a complete disintegration of the residues into their constituent elements or simple compounds ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ , ash). The incorrectness of this assumption will be brought out later. The difference between these two processes is merely one of degree and not of kind.

A much clearer, even if not fully clarifying, concept in regard to the formation of peat was given by Harshberger (126), who said:

Peat formation depends upon the slow and imperfect decay of the bog mosses and other plants associated with the plant remains. The imperfect decomposition in turn is dependent upon the presence of so much moisture that the excess of air is impeded, while the relatively low temperatures in the bog also hinder the process of decay. The compounds at first formed have antiseptic properties and these soon put an end to further bacterial activity, and the process of peat formation becomes a chemical one and extremely slow. The solid decomposition products are brown substances, partly soluble in water and imparting to it the color of strong tea and an acid reaction.

In addition to true peats, there are a number of soil or bog formations enriched with sand or clay which may be designated as *peaty* (anmoorige). These include the heath and heather soils and alluvial sedimentation along rivers and streams. The term *swampy* may be applied to areas covered with water all or part of the time, but in which no true peat is formed, i. e., when the material has less than 50 per cent organic matter or is less than one foot deep.

The sedimentary types frequently have been greatly confused, especially since certain specific terms were introduced for them (219), namely, *gyttja* and *dy*. In attempting to standardize these two terms (87), it has been suggested that *dy* (gel-mud) be considered as material formed by the precipitation of the colloidal material in lakes poor in plankton; *gyttja* (nekron-mud) as material formed by accumulation of plankton residues, and other lake, plant, and animal products. Often *dy* was used to designate well decomposed material, usually of sedge and reed origin. The term *gyttja* was often preceded by another qualifying term, namely, clay *gyttja*, shell-*gyttja*, algal *gyttja*, diatom-*gyttja*, etc. (73).

A system of hydrogeological terminology of peats, especially sedimentary types, also has been introduced (313). In it, recognition is accorded the type of deposition of the individual layers, the period of deposition, genetic origin, chemical and physical properties, and regional distribution.

#### CHAPTER SUMMARY

The terms used to designate peat types and natural formations where peat is produced have been, and still are, highly confused. The reasons for this are evident when we consider that various types of peat result from different forms of vegetation growing under different climatic conditions and in waters of varying chemical composition, that many designations have been adapted from the uses made of the peat, and that different terms to designate the same peat formation have been adopted from different languages. If all conditions are taken into consideration, only very few types of peat need be recognized and few terms employed.

## CHAPTER II

## TYPES OF PEAT AND SYSTEMS OF PEAT CLASSIFICATION

The existence of a number of peat types has long been recognized. These are determined largely by differences in the nature of the plants from which the peats have originated and by the extent of their decomposition. The practical utilization of various types of peats for agricultural, industrial, and other purposes is entirely dependent upon the proper recognition of the nature of these peats. Some of the common designations of peat types have been based upon the recognition that each of these types can be used only for specific purposes. Thus one finds *peat moss*, *fibrous peat*, *muck*, and *peat humus*. The first two are good for litter and other absorbing purposes; the last two are used for soil improvement, for the growth of special truck crops, or as fertilizer carriers.

*Classification of peats.* Various systems of peat classification have been proposed and used in different countries and periods. These systems were based on several factors: first, the nature of the plant association on the surface of the bog; second, the nature of the plant materials which gave origin to the peat as a whole or to certain predominant layers of the peat profile; third, the formation of the peat below or above the water level; fourth, the concentration of minerals in the waters entering the bogs; and fifth, the physical and mechanical properties of the peat; namely, sedimentary, colloidal, amorphous, and fibrous peats.

The chemical analyses, at least those that were commonly employed before 1920, did not yield sufficient information for the characterization of the different peats (261). The recognition of peat types based upon the plant associations found on the surface of the bogs was possible only in the case of virgin bogs; however, on drainage and cultivation, the surface vegetation can no longer be used as such a criterion. The water level at which the peat has been formed could not give a sufficient basis for peat differentiation since various gradations could thus be obtained.

Glaciation was a highly important factor in the origin and distribution of most of the peat deposits in North America and in Europe. During the glacial epoch, a succession of ice sheets spread southward from Canada over New England, New York, the northern parts of New Jersey and Pennsylvania. As these sheets melted away, they left irregular deposits of glacial drift consisting of clay or ground rock, boulders, sand and gravel, all of which had been transported by the



moving ice. Very often this drift blocked the stream valleys and gave rise to lakes. The scouring action of the moving ice on the solid rock produced many hollows, which formed ideal areas for peat accumulation (279). The action of the waves and streams, as well as coastal subsidence have also played prominent roles in the formation of peat deposits. The subsidence of the coast gave rise to the formation of landlocked lagoons and deltas. Here salt-marshes as well as fresh-water bogs were formed. In some cases salt-marsh peat overlies peat of fresh-water origin, thus pointing to several stages of coastal subsidence.

An early American geologist (266-269) proposed the following system of classification of peats:

A. Marine marshes:

1. Above meantide:
  - (a) grass marshes, (b) mangrove marshes.
2. Below meantide:
  - (a) mud banks, (b) eel grass areas.

B. Fresh water swamps:

1. River swamps:
  - (a) terrace swamps, (b) estuarine swamps.
2. Lake swamps:
  - (a) lake margins, (b) quaking bogs.
3. Upland swamps:
  - (a) wet woods, (b) climbing bogs.
4. Ablation swamps.

Much simpler systems than this have been proposed. These are based on the present common acceptance of the abundance of nutrients in the waters entering the bog, which thus influences the type of vegetation as the determining factor in the classification of peats. Nutrient-rich peats (eutrophic) are thus differentiated from nutrient-poor (mesotrophic) and nutrient-poorest peats (oligotrophic). Goodwin (113), for example, classifies peats as follows, using the term *mire* derived from the Swedish *myr*:

I. Topogenous mires, or fens:

1. eutrophic fen,
2. oligotrophic fen.

II. Ombrogenous mires:

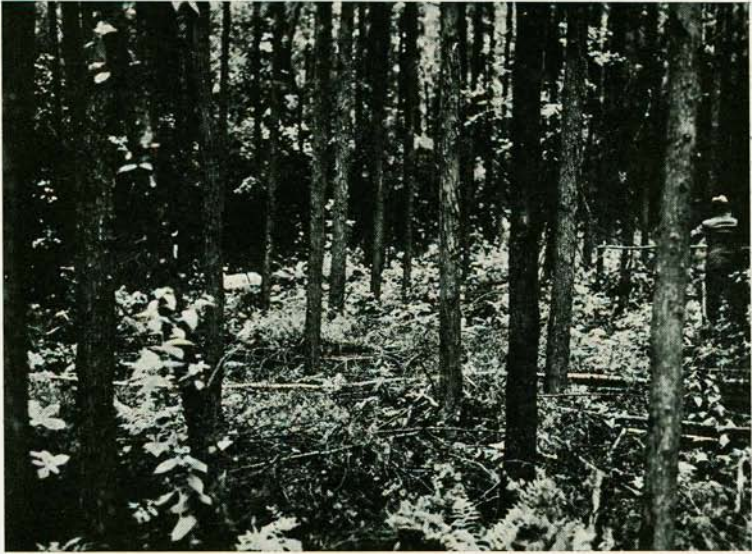
1. blanket bogs,
2. raised bogs.

In general, the major peat types recognized in the different countries depend chiefly upon the forms prevalent in each country. At present, four predominant types are recognized:

1. Upland or highmoor peat, also called bog peat, moor peat, moor, heath, sphagnum peat, moss peat, or true peat. The predominant



FIG. 2. Lowmoor bog (Echo lake) in New Jersey.



a.



b.

FIG. 3. Forest peats in New Jersey: (a) Onga Hat cedar swamp; (b) Sleeper Creek bog.

vegetation consists of various species of sphagnum mosses, such as *S. medium*, *S. recurvum*, and *S. balticum*, as well as *Calluna vulgaris*, *Pinus sylvestris*, *Cassandra calyculata*, *Ledum palustre*, *Andromeda polifolia*, *Eriophorum vaginatum*, *Rynchospora alba*, and *Scheuchzeria palustris*. These peats are formed in waters poor in mineral nutrients and containing little calcium; the waters originate either from atmospheric precipitation or from mineral-poor soils. Such peats may be formed on top of a lowmoor peat, a forest peat, or directly on sand, clay, or rock. This type of peat usually occurs in cold and moderate climates, with a high rainfall. Different types of sphagnum prefer different moisture conditions, *S. cuspidatum* growing in the moistest regions, and *S. medium* and *S. acutifolium* developing in less moist regions.

2. Lowmoor or lowland peat, frequently spoken of as marsh peat, muck, turf, fen, reed peat, sedge peat, or humus peat. The dominant and characteristic species of plants in this type of peat are the various sedges and reeds, and certain trees and shrubs, comprising species of *Carex*, *Phragmites*, *Cladium*, *Scirpus*, *Juncus*, *Equisetum*, *Hypnum*, *Alnus*, and *Betula*. Sphagnum plants are absent or occur only rarely. These peats develop chiefly in filled-in lakes and in river valleys; the bogs are fed by ground waters rich in mineral salts. This type is frequently divided into various subtypes based largely upon the predominant plants in the bog, such as carex peat, cladium peat, hypnum peat, phragmites peat, tule peat, or mixed formations. In England, this type of peat is commonly divided into (a) fen proper, where sedges and grasses predominate, and (b) carr, where the plant associations consist mainly of trees and shrubs (208).

3. Forest peat, often spoken of as swamp peat, or forest peat. The common vegetation consists of *Betula*, *Quercus*, *Alnus*, *Pinus*, *Picea*, *Juniper*, with an admixture of *Calluna*, *Oxycoccus*, *Salix*, *Andromeda*, *Carex basiocarpa*, and *Chalmagrostis lanceolata*. Various species of sphagnum (*S. recurvum* and *S. subicolor*) may produce a continuous carpet. These peats develop along the upper courses of rivers and may occur at the end of sphagnum bogs. They are fed partly by ground waters and partly by precipitation; the waters are less rich in minerals than those of the lowmoor peats.

4. Aquatic peat, often spoken of as sedimentary, macerated, colloidial, or mud peat, which are formed largely by algae and other aquatic plants and animals, with an admixture of spores, pollen, and particles of clay and sand. These peats are usually found in the lowest layers of the peat profile, although they may form independent bogs predominantly of this type.

In addition to these major types of peat, a number of minor types, as well as various transition or intermediate peats, are also found.

Among the minor types, one may include the heath-peatland formation, namely, the *Vaccinium-Calluna* association, which is incorrectly called peat, since it is more nearly a "raw humus" similar to "alpine humus," or humus produced at high altitudes. Certain peats may have been produced from others by physical or chemical action. This is true, for example, of dopplerite (301), which has been deposited from solution or has settled as a fluid in peat fissures, and which was believed to be leached from peat by alkaline solutions.

The foregoing system of classification of peat types has been variously modified, frequently by a mere change in the designations of the peats. Dachnowski (58-63) and others (125) spoke, for example, of the bog, marsh, swamp, and aquatic types of peat. Ogg (208) classified peat formation as heath, moor, and fen. The dominant plants in heathland are heather (*Calluna vulgaris*) and other members of the Ericaceae, as well as lichens and mosses. The sandy substratum is impoverished in mineral salts through leaching, and the humus and iron compounds which are carried down frequently form a hardpan below the surface. Moorland peat comprises several varieties which differ considerably in character and composition; they have in common a high acidity, a low content of mineral salts, and a relatively high moisture content. The moisture concerned in the formation of moorland peat is usually rain water or ground water, very poor in bases. Various species of sphagnum form the major constituents of this type of peat. The bog is usually highest in the center, sloping toward the edges, as a result of which this type of bog is usually designated as highmoor, a translation from the German "Hochmoor." It was also designated as humpmoor, which was considered to be a better English equivalent. Species of cotton grass (*Eriophorum vaginatum*) are abundant in this type of peat. The fens comprise the true lowmoor peats.

The differences in the botanical composition of various peats are accompanied by important differences in their organic and inorganic constituents, as well as in reaction and in abundance of nutrient elements.

*Stratification of peat.* The stratification of peat deposits is directly related to the changes in the wet and dry periods which accompany changes in climatic conditions during the various periods of the formation of the particular peat layers. A vertical cut of a peat profile commonly shows the following stratification (333):

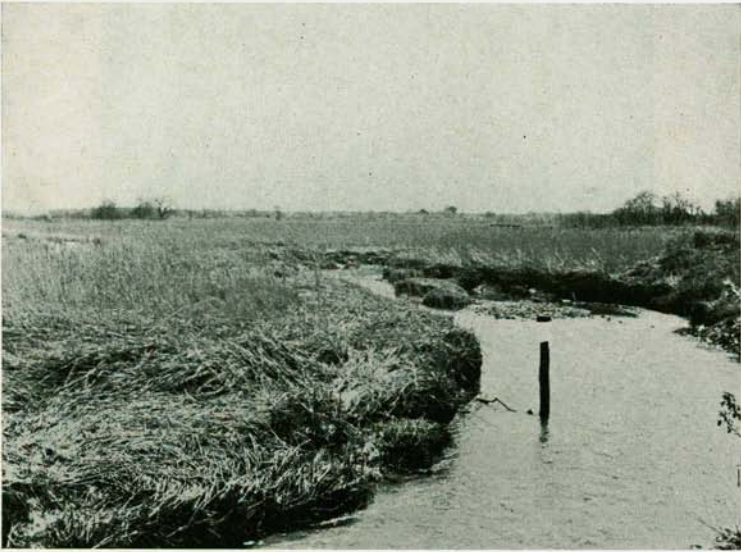


FIG. 4. Floating mat of peat, Budd Lake, N. J.





a.



b.

FIG. 5. Tidal marshes in New Jersey: (a) Bridgeton marsh; (b) Raritan river marsh.

(32)

## Surface

## Highmoor peat stage:

Heath-peatland,  
Sphagnum peat,  
Eriophorum-sphagnum peat.

## Transition peat stage:

Eriophorum peat,  
Scheuchzeria peat,  
Alder, eventually birchwood peat.

## Lowmoor peat stage:

Carex or hypnum peat,  
Phragmites peat,  
Liver peat (algae and other lower plants and animals),  
Mineral mud layer (diatoms, etc.)

## Bottom

As the peat continues to accumulate in a standing body of water such as a lake, the water becomes shallower. New species of plants gradually come in and supplant those which were found extensively in the deeper layers of water. If the water originally was shallow, the sedimentary layer of peat may be entirely lacking, the sedge and reed peat forming the deepest layer in the bog. In addition to sedges and reeds, other plants of the grass family, such as the cattails and rushes, frequently occur. The structure of this type of peat is usually fibrous, the leaves and roots of the sedges and reeds being easily recognizable, though the surface few inches of the profile may be well decomposed. The color of this type of peat varies from brown to brownish black, the darker color being characteristic of the more thoroughly decomposed material.

The sedges may play an important part in the development of the peat bog, since they may grow out from the rim of the lake to produce a mat on the surface of the water, which will thus form a "floating" or "quaking" bog. As this mat is built up, it usually sinks of its own weight and comes to rest on the bottom of the bog.

Among the lowmoor peats, the salt marshes are of particular interest. They have been formed in almost the same manner as the fresh-water peats, from which they differ, however, in character and utilization. Since few seed plants tolerate salt water, the number of plants found in these marshes is rather small. The most common types are the salt-marsh grasses, rushes, and sedges. The entire vegetation of some of the salt marshes consists of one dominant and two or three subordinate species of plants (279). In some of the



coastal bogs of New England, salt-marsh peat is underlain by peat of fresh-water origin, indicating the subsidence of that land along the Atlantic Coast. Bastin and Davis (20), in discussing the origin of certain peat deposits on the coast of Maine, pointed out that the salt-water peat, which was formed from the remains of plants similar to those now growing in these marshes, is 3 or more feet thick. According to these investigators:

The gradual subsidence of the coast line was thus recognized. The marshes gradually became filled with salt water, and peat was formed from the decay of salt-water plants and gradually deposited upon the fresh-water peat. It has been estimated from the thickness of the salt-water peat that the coast has been sinking at the rate of about a foot a century. As the fresh-water deposits are both underlain and overlain by salt-water peat in some places, it seems that a slight uplift of the coast preceded the present period of subsidence.

The moss peats, which give rise to built-up bogs, raised bogs, climbing bogs, or highmoors, are more characteristic of Europe than of the American continent, except for certain areas in eastern Canada and the northeastern and northwestern parts of the United States.

The forest peats are characterized as low, flat areas covered or saturated with water and overgrown by trees, with or without an undergrowth of shrubs. The surface may be covered with an abundant vegetation, consisting of small plants, or it may be covered with water and be comparatively free from small plant growth. These bogs are sometimes designated as swamps and in accordance with the predominating trees, also as spruce swamp, cedar swamp, gum swamp, and cypress swamp. The contributions of sphagnum moss and shrubs to the peat formation are comparatively small in bogs containing standing water (279).

In the aquatic types of peats the plant remains accumulate below the level of the water. The residues comprise structureless, soft fragments of plants, outer coats of cellular organisms, diatoms, algal filaments, and varying proportions of silt, laid down by wind and current. These peats may be further subdivided into three groups: 1. macerated peat (mud, sapropel, gyttja), consisting of spores, pollen grains, fragments of leaves and aquatic material, rootlets, chitinous and siliceous portions of skeletons, as well as various shells, with an admixture of clay, silt, and sand; accumulations of marl and diatomaceous material may also take place in these peats; 2. colloidal peat (liver peat), consisting of a gelatinous, plastic mass of organic residues, comprising spores, pollen, seeds of aquatic plants, animal excreta, algal filament, and precipitated plant substances; 3. dopplerite, comprising certain end products of decomposition combined with calcium or so-called calcium humate (104).



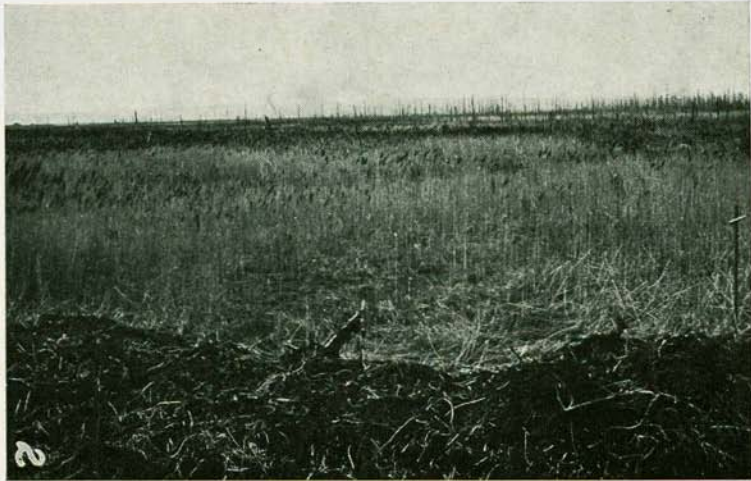


FIG. 6. Effect of tidal marsh on cedar forest. Secaucus, New Jersey.

The aquatic peats, deposited in water varying from 2 to more than 15 feet in depth, result from the remains of a variety of plants, such as pond weed, water plantain, and water lily, mixed with the sediment brought in by streams. This type of peat varies from coarsely macerated to finely divided material; the latter is often smooth to the touch and has the consistency of liver when wet. It varies in color from gray through green and brown to black. It is often intermingled with roots of sedges and reeds. The deep-water peat may be mixed with or underlain by white or gray marl. The latter is a nearly pure form of calcium carbonate deposited in large part by a few small plants of the algal family. These plants absorb the calcium from the water and deposit it in the form of an encompassing scale. When the plants die, the calcium accumulates to give rise to a marl deposit. Shells may also be present in the marl, but this is generally an indication that mollusks existed in the lake at the time that the marl was forming (70).

*Botanical characterization of peats.* Peats have often been characterized by their botanical composition, by the degree of their decomposition, and by their physical properties. One of the most successful of these systems is the one proposed by Von Post (220, 221), who asserts that, in every characterization of peat types, the following points must be considered:

1. Deposition of peat. It is important to determine whether the particular peat or layer of peat was formed in place or whether it was brought in by water and other agencies to the place where it is found. In the first case, so-called autochthonous or true peats are produced; in the second allochthonous peats, sedimentary formations, and gyttja.

2. The degree of humidity during the stage of formation of the peat deposits. It is essential to determine whether the peats were constantly or periodically covered with water, or whether the moisture necessary for the accumulation of the organic matter in the bog was obtained from a high water table.

3. The nutrients available to the plants growing in peat bogs. The abundance of such nutrients determines whether the peat formations are eutrophic, mesotrophic, or oligotrophic.

4. The nature of the decomposition processes. An insufficient recognition of these processes has resulted in a rather complex terminology. In terms of Von Post's concept, anaerobic decomposition in the bog, or the so-called process of putrefaction and fermentation, give sapropel products. When air is admitted in restricted quantities, a dy formation results, and under low porosity a raw humus is formed.

Complete aeration gives products of decay or moder. Sapropel can be recognized by the green color of the extract with alkalis, and dy by a brown color. This concept is rather confusing.

The peat-forming plant associations found in a bog may be looked upon as a direct result of the humidity and nutrient content of medium. These influence not only the botanical composition of the peat, but also its physical and chemical properties. The production of methane in certain peat layers indicates that decomposition is still taking place. Von Post suggested that not only the important macro- and micro-botanical properties of the peat but also its structural properties be defined. He designated the degree of decomposition by a scale of 10 degrees. The extent of decomposition or "huminosity" of the peat was expressed as H. Thus little-decomposed, fibrous, light-colored peat material was designated as H<sub>1</sub>, whereas well-decomposed, colloidal, deep brown material was H<sub>10</sub>. R was used to designate the presence of root fibers (scale of 0-3); V, wood residues (0-3); B, degree of moisture (0-3).

This system could be applied only to a region of uniform geological history and climate where peat formations vary widely in age, in plant composition, and in degree of decomposition. In more confined regions, as in the peat formations in Florida or New Jersey, where the geology is different or where it varies markedly, this system has only a very limited application, except for secondary characterizations of peat strata.

On the basis of these systems, peats may be classified into several formations and series:

I. *Autochthonous formations or true peats.* These result from the gradual accumulation of successive generations of plants *in situ*, in the presence of more or less permanent but concealed water. This type of peat is characteristic of the upper portions of bogs and upper strata of filled lakes (101). These peats can be subdivided into two groups, the lowmoor and the highmoor, depending upon the nutrients available during the growth of the plants which gave rise to these formations. In the first, the nitrogen is seldom less than 1 per cent, usually 2.0-2.5 or even 3 per cent; ash, 4 to more than 20 per cent; in the second, the nitrogen reaches 1.5 per cent only seldom and is usually less than 1 per cent, and the ash seldom exceeds 3 per cent, usually being 1 to 2 per cent.

1. *Lowmoor peat.* This series is frequently subdivided into three groups, on the basis of humidity gradations of the mother formations: (a) *limnic* (formed below the water), (b) *telmatic* (reed peat), and (c) *terrestrial*.

2. *Highmoor peat*. This series is also subdivided on the basis of humidity into several subgroups: (a) moss peat, the vegetation consisting of *Andromeda*, *Calluna* and other ericaceous plants, *Betula*, *S. angustifolium*, and *S. acutifolium*; (b) forest moss peat, with *Pinus*, *Picea*, *S. fuscum*, etc.

II. *Allochthonous peats or sedimentary formations*. These have a lacustrine character. They result from the gradual accumulation of wind-blown, drifted, and sedimentary plant residues in open, quiet bodies of water. These formations are found in deep permanent lakes and in the lower portions of bogs. They have been subdivided (220), as follows, into:

1. *Organogenic substances principally of the gyttja type*. These are subdivided into several groups: (a) profundal gyttja or clay gyttja, which is compact, more or less elastic, colored greenish, with a larger or smaller content of mineral mud, formed in the deeper parts of the lake; (b) littoral gyttja, compact, mostly granulated, of a brown or brownish-green color, formed largely of detritus of higher water plants as *Nymphaeaceae*, *Potamogeton*, as well as leaf residues; (c) algal gyttja, compact, very elastic, consisting mostly of *Myxophyceae*, reddish to reddish-brown in color; (d) calcium carbonate gyttja, which is merely a variation of the previous types, with a calcium-rich ground mass, of a whitish-yellow, reddish-brown-yellow, or greenish-yellow color, mollusk gyttja is a transition form, the calcium content of which is not sufficiently large to change the color of the material, but is sufficient to prevent the dissolution of the mollusk shells; this leads to the formation of a material composed chiefly of  $\text{CaCO}_3$ ; (e) floating peat, related to littoral gyttja, which is formed on the border and consists of pieces of wood, branches, seeds, leaves, etc.; floating sand and diatomaceous earth are the final culmination of these. In gyttja, the organic matter is rich in nitrogen (4-5 per cent) and in sulfur (1-2 per cent) and possesses a high calorific value.

2. *Organogenic substances principally of the dy type*. These are compact, usually inelastic, granular formations, of a chocolate-brown or dark-brown color, often greenish; a related type may be formed from sphagnum.

*Classification of peats for practical purposes*. Peats obtained from different bogs and placed on the market may be classified into four types:

1. Moss peat is yellowish brown and is fibrous. It is acid (pH 3.5-5.0) and low in nitrogen (about 1 per cent) and ash (1.5-3.0 per cent). Moss peat will absorb 6 to 15 times its weight of water. This type of peat is marketed in various degrees of fineness. The

coarser material is used for stable bedding and poultry litter, and the finer particles for horticultural purposes and for soil improvement. The marketable product usually contains 30 to 35 per cent water. Formerly, most of the peat of this type was imported from Europe, but there are now several large producers of moss peat in this country whose products are as good as any of those from abroad.

2. Sedge and reed peat is usually dark brown to black and is powdery when dry. It is less acid than peat moss (pH 4.5 to 6.5) and is high in nitrogen (2.0 to 3.5 per cent) and ash (5 to 30 per cent). When burned, it loses 70 to 95 per cent of its weight. The material will absorb three to six times its dry weight of water. The marketable product of this type of peat usually contains between 50 and 70 per cent water. Frequently, distinction is made between the raw and the cultivated products. The latter are black and granulated, as a result of aeration and decomposition. This type of product is widely used, either as such, or in the form of composts, for the improvement of lawn and garden soils.

3. Forest peat is brown and fluffy, but somewhat less fibrous than moss peat. It is acid (pH 3.8 to 5.5) and contains an abundance of fine particles of macerated wood. In chemical composition this peat stands midway between moss peat and sedge and reed peat, having a nitrogen content of 1.0 to 2.5 per cent and an ash content of 3 to 20 per cent. The product will absorb four to eight times its weight of water. Coarse material should be removed by screening, before being offered for sale. This type of peat is frequently used for mulching purposes.

4. Peat soil (also called peat loam, alluvial peat, sedimentary peat). This type of material comes from low-organic peat deposits. Peats ranging from 10 to 50 per cent organic matter, on a dry basis, fall in this class. This type of peat is useful in composts and in fortifying poor sandy and heavy clay soils.

#### CHAPTER SUMMARY

The confusion often arising in the classification of peat bogs and peat materials is due largely to the great variations in the nature of the peat, as a result of variations in the vegetation giving rise to the peat, in nature of the waters entering the bog, in zonation of the peat profile, and in degree of decomposition. Among the numerous criteria proposed for classifying peats, the botanical (plant association in the peat itself) and the chemical (pH, ash, and nitrogen) are the most logical and most convenient. Only four major and several minor types of peat need be recognized on the basis of these criteria.

## CHAPTER III

CLIMATOLOGICAL, GEOLOGICAL, AND BOTANICAL FACTORS  
INFLUENCING PEAT FORMATION

Among the primary factors which control the formation and nature of a peat bog, the climatic, geologic, and topographic occupy a prominent place. They determine the nature and abundance of the vegetation in the bog, which, in turn, controls the type of peat resulting. Peat bogs may be considered primarily as peat-forming plant associations. The character of the peat depends largely upon the nature of the plants and the extent of their decomposition. The plant associations are further influenced by the nature of the soil and the water in which they grow. Soils and waters rich in mineral elements, especially calcium, phosphorus, potassium, and nitrogen, give rise to a type of peat different from that formed in soils and waters poor in these nutrients. The influence of the mineral subsoil makes itself felt even after the plant covering has ceased to be in direct contact with this part of the soil. The peat stratum grows thicker year by year, each new generation of plants receiving some of its nourishment from the buried dead plant material underneath it, which in turn has been fed partly by the underlying layer. This supply of nutrients is not inexhaustible, however; the new plant associations use only a part of the nutrients existing in the lower layers, and therefore the peat bogs, in their process of growing upward, may change continually in the type of plant association. Peats are thus influenced directly by their vegetation, and indirectly, by the nutrient supply and environmental conditions.

*Climatological factors.* Peats began to form in the northern bogs of the United States immediately upon the retreat of the Wisconsin ice sheet, which took place sometime between 12,000 and 25,000 years ago. The available evidence from the plant and animal remains which are found buried in the peat bogs, especially those occurring near the bottom, may thus be from five to more than twenty thousand years old (318, 39).

The wind-carried dust fell into the bogs and gradually accumulated there. The most abundant remaining constituents of this dust are the pollen grains of the various plants. These have been preserved in an excellent condition, because their chitinous walls rendered them resistant to decomposition. By treatments with chemical reagents, the pollen grains can be separated from the rest of the peat and exam-



ined microscopically. The pollen of the various plants can thereby be recognized, and the dominant plant species typed. The numbers of pollen grains usually found in one gram of dry peat range from 50,000 to one million, the most important being those of trees. The nature of the forest vegetation which surrounded the peat bog, at the time of deposition of the particular peat layer, can thus be determined (87).

The various layers of peat can be analyzed for their pollen content and a record of the changes in the forest vegetation of the region obtained; the pollen can, therefore, serve as a measure of the climatic changes. Certain pine trees, for example, flourished in a dry but not very warm climate, whereas the alder grew best under moist and warmer conditions. Since peat deposits began to form in early post-glacial time, it is thus possible to obtain information regarding the changes in climate in a given region during the entire period of peat formation.

A study of the peat deposits of northwestern Europe brought out the fact that there have been seven climatic periods. These were grouped into three phases: (a) increasing warmth, (b) maximum warmth, and (c) decreasing warmth. The vegetation and the climatic changes were thus correlated with the various prehistoric periods, as determined by the archaeological remains found in these bogs (207).

As a result of a study of a number of peat bogs in Central Europe, the following periods of forest history were recognized (316, 335):

1. Subarctic or steppe period, comprising the late glaciers, with wide meadows and sporadic clumps of pine and birch trees.
2. Pre-boreal period, known as the pine period, with thin stands of pine forests; the birch trees gradually retreated and the heat-loving forests began to appear.
3. Boreal period. The post-glacial heat reached an optimum and resulted in the drying of the bogs, which became covered with fragmentary forests, composed chiefly of alder trees.
4. Atlantic period. In addition to the pine, there was always a thin forest of mixed oak, elm, and linden, and in some areas, of oak alone. In many places a spruce type was formed, beech and fir appearing toward the end of this period. The younger bog groups also began to appear.
5. Sub-boreal period. This appears as the pine-oak-elm-linden-beech period in some bogs. Pure beech predominated in the highlands. The eastern conifer and western deciduous regions now appeared. The frequent separation of the European

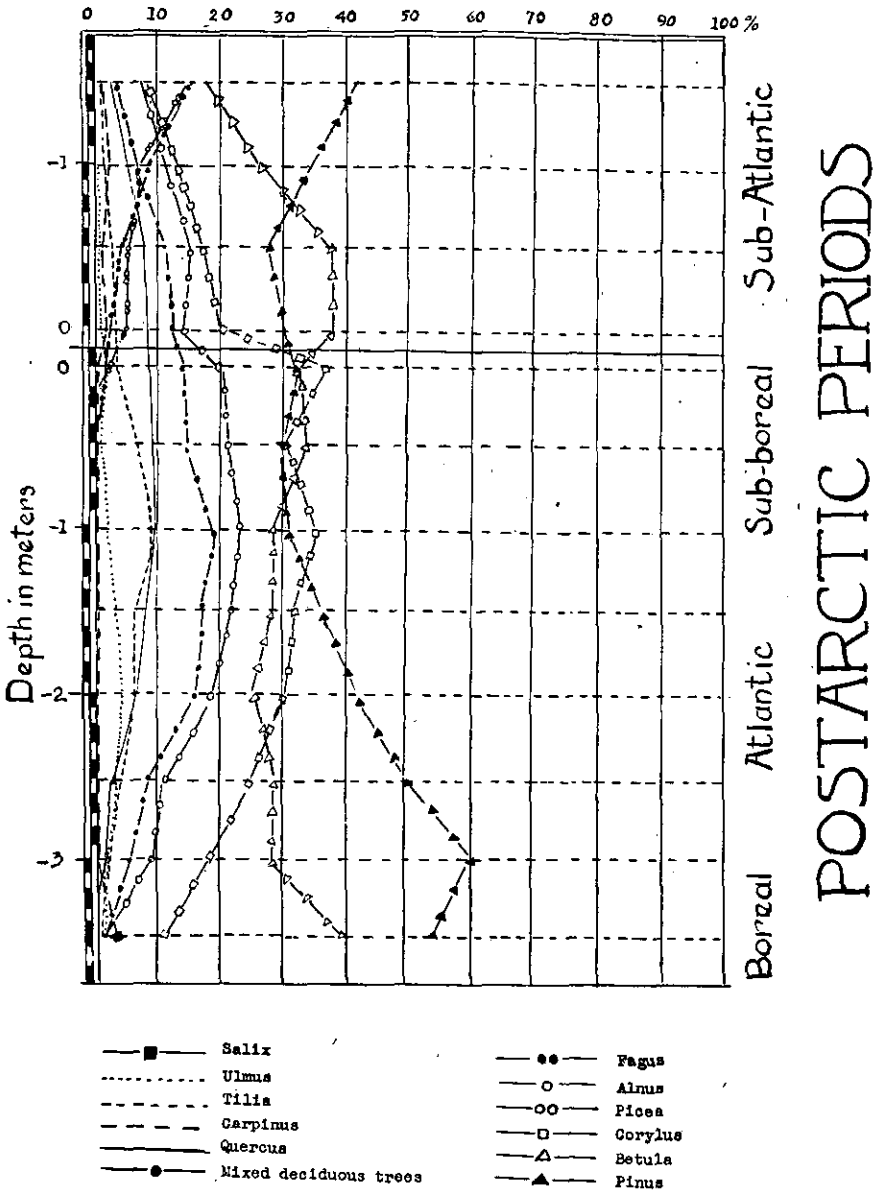


FIG. 7. Pollen diagram of peat bogs in Southern Sweden (221).

sphagnum peats into the upper pale layers and lower dark to brown layers corresponded to a change in climate in the sub-boreal period; the boundary was often designated as the "Grenzhorizont" (315).

6. Sub-atlantic and forest area. Conifers and oak again increased, and the beech retreated. Man appeared on the scene, accompanied by an increase of grass plants as farm and meadow lands took the place of the forests.

The European vegetation during the last four periods is illustrated in Fig. 7, by the pollen diagram reported for southern Sweden.

Various studies have been made (16, 73, 107, 263, 275, 306) of the glacial and post-glacial lake sediments and of bog sediments and peats in North America. No generally acceptable picture of the vegetational and climatic changes has yet been drawn, because of the large size of the region and the differences in climate and vegetation, which produced varied effects in the different parts of the region.

The forest flora in eastern North America was found to be more complex than that prevailing in western Europe, because many species of the Tertiary flora were exterminated in Europe during the Pleistocene glaciations, the Alps preventing the retreat of the flora southward. In North America, however, the members of this flora retreated before the ice to the south and southwest.

Smith (275) found that the pre-boreal period in North America was characterized by a rise in fir and later by a birch maximum between the spruce and the pine maxima. Peats were then formed only very slowly; the period is thus poorly represented in most of the peat profiles.

The boreal period was characterized by a pine maximum, followed by a decline in pine and a rise of deciduous trees. The climate became warmer and drier in the last part of this period. The peat profiles near the Atlantic Ocean show a maximum forest complexity and a lack of differentiation at the end of this period and the beginning of the succeeding period. An increase in species requiring greater humidity now took place, corresponding with the beginning of the Atlantic period in Europe.

The warmer, drier climate in North America, corresponding to the sub-boreal period of Europe was characterized by oak and oak-hickory forests. There was next a return to greater humidity, as shown by increasing spruce in the northern areas, thus corresponding to the sub-Atlantic period of Europe.

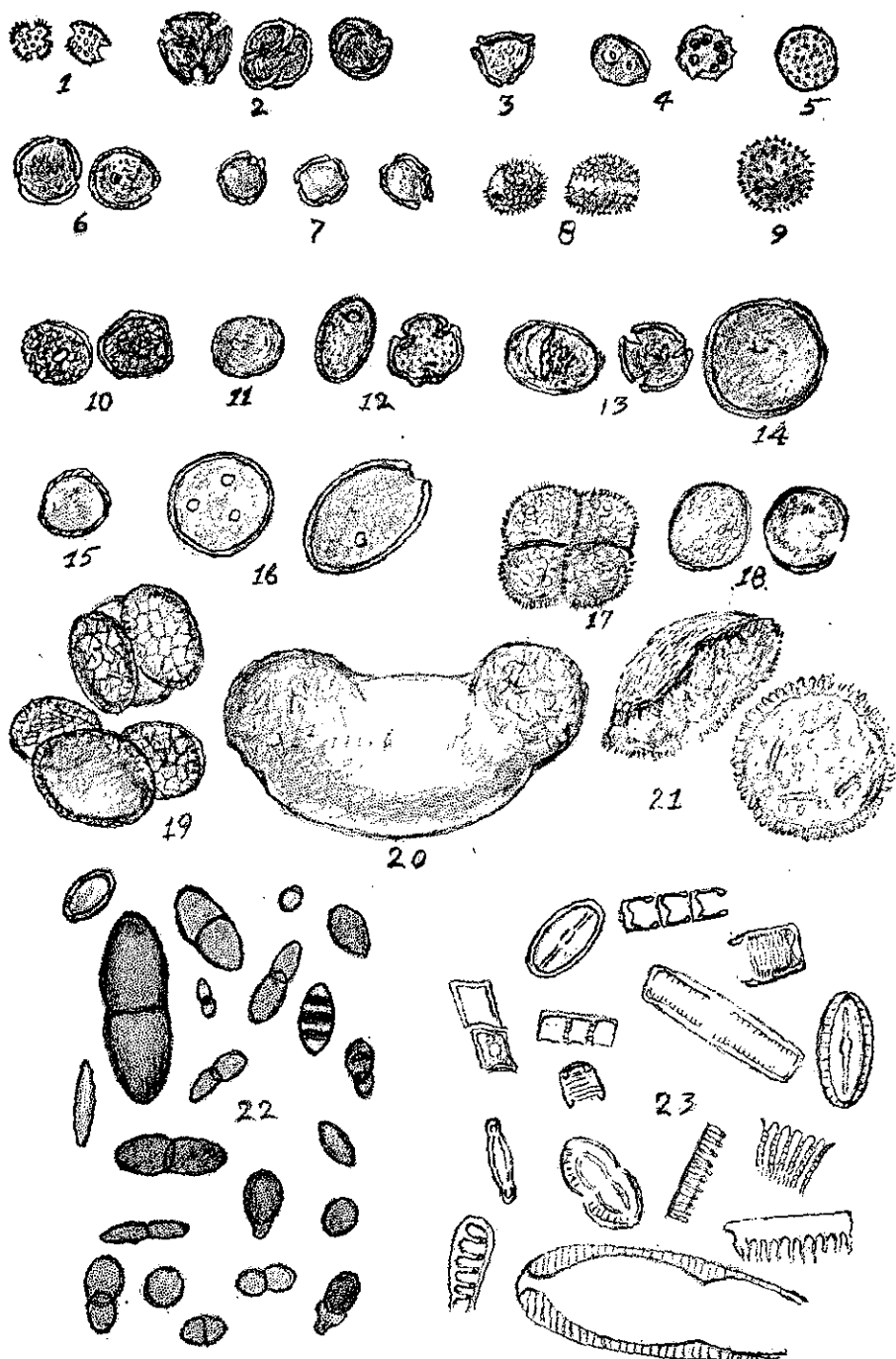


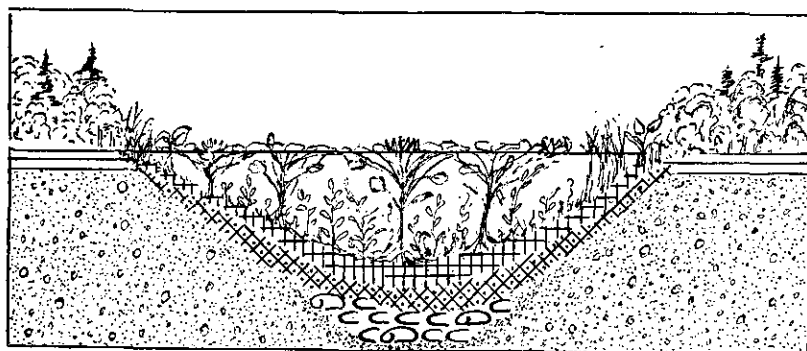
FIG. 8. Typical pollen grains, spores and diatoms found in peat bogs. 1. *Fraxinus*. 2. *Quercus*. 3. *Betula*. 4. *Juglans*. 5. *Populus*. 6. *Corylus*. 7. *Alnus*. 8. *Salix*. 9. *Sagittaria*. 10. *Ulmus*. 11. *Juniperus virginiana*. 12. *Tilia*. 13. *Fagus*. 14. *Larix*. 15. *Thuja*. 16. *Carya*. 17. *Typha*. 18. *Acer*. 19. *Pinus strobus*. 20. *Abies balsamea*. 21. *Tsuga canadensis*. 22. Spores. 23. Diatoms.

*Topographic factors.* On the basis of topography, three general types of peat deposits are commonly recognized: 1. the filled basin, or the accumulation of peat in lakes; 2. the built-up peats, giving rise to the highmoor or so-called climbing bogs, whereby peat is produced on flat or gently sloping moist surfaces not covered with water; and 3. a combination of the first two, in which the second type of peat is underlain by the first. The second type of peat bog is formed in areas where the drainage was interrupted and the soil became permanently saturated with water. Many of these bogs are underlain by colloidal or aquatic peats. The most extensive deposits of lake peats and of built-up peats are found in the Great Lakes and Atlantic Coast States; lowmoor peats predominate in the latter States. The highmoor or climbing bogs are found in the northern areas, largely in Maine (210).

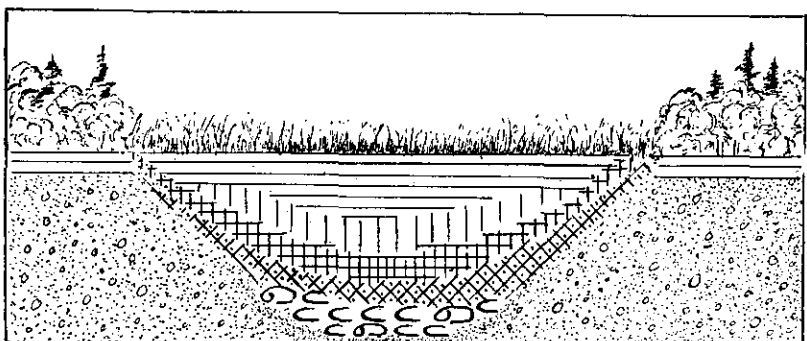
In the filling of a lake, transported materials, such as plant particles, spores, and pollen brought into the bog from the outside play an important part; certain remains of plants growing in the lake also contribute. Forsaith (101) found in the bottom of many lakes in Florida very deep peat deposits consisting of material chiefly of allochthonous origin. This consisted of the plankton of the lake together with large quantities of pollen of conifers and dicotyledons. As the lakes became filled, the remains of aquatic plants were added. In the lowest parts of the deposits, shells of diatoms intermingled with fine drifted particles of land plants and pollen. When the accumulated material reached the surface, the nature of the peat constituents exposed to the oxygen of the air and to the attacks of microorganisms became so changed that the original structure was lost. Only the upper 2-3 feet of the peat material, out of a total of 10 to 20 feet, however, were thus acted upon by microorganisms.

There is usually a certain definite correlation between the level of the water in the basin and the state of preservation as well as the botanical and chemical composition of the deposit. The deposits under open-water conditions consist mainly of aquatic plants and drift material of terrestrial origin. The upper levels, however, representing the filling of lake or estuary, consist almost entirely of deposits of plants grown in place.

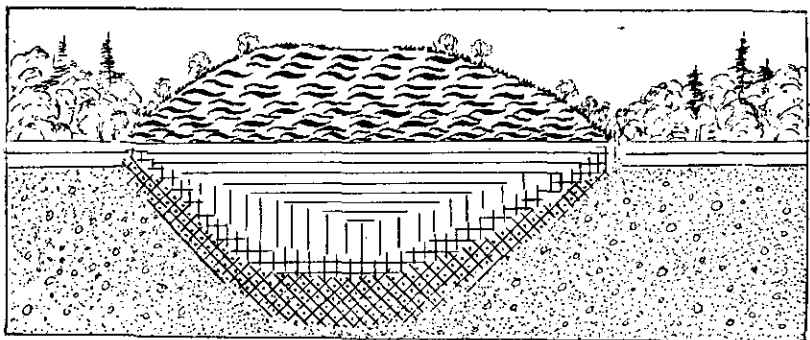
The lake deposits have been described by Potonié (222) as "sapropel." A marked distinction was recognized between this type of material and ordinary peat or soil humus. The former is produced from aquatic plants, in which a predominant role was ascribed to algae. Such deposits are rich in fat and in protein. Humus, however, is formed from land or bog plants, in which carbohydrates and



1.



2.



3.

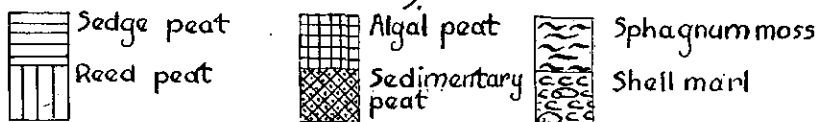


FIG. 9. Three stages in the development of a highmoor peat bog, each of which may at present be an independent entity. 1. The lake or sedimentary stage. 2. The sedge and reed or lowmoor stage (it could also have been the forest stage). 3. The sphagnum or highmoor stage.

lignins play a predominant role. According to Jeffrey (139), sapropel does not represent a stage of considerable decomposition of plant material, as originally was assumed; it is merely a form of sedimentation of finely divided material, consisting largely of spores of vascular cryptogams.

It has been established that aerobic microorganisms, which are chiefly concerned with the rapid decomposition of plant materials, are unable to grow at all or grow only to a limited extent beneath the surface of the water in a peat bog. The remarkable state of preservation of delicate plant and animal structures in the peat, under the level of low water, was explained by a total lack of microbial activities. These assumptions led to the conclusion that microorganisms could not have played any important role in the modification of the sedimentary material deposited beneath the surface of open water. This assumption is hardly justified, since a study of the chemical composition of this material will reveal important chemical changes.

The filling up of ancient lakes has taken place in a more or less regular manner, as illustrated in Fig. 9. The bottom of the bog usually consists largely of inorganic ooze, rich in silicates (clay) or carbonate (marl). Different layers of fine detritus, varying in organic matter content, are superimposed upon these. The inorganic constituents may vary considerably, depending upon the character of the surrounding country. If the shores and bottom of the lake are of a sandy nature and the surrounding area is broken by hills, much sand may be found in the bottom layers. On the other hand, if the land is level and densely forested, the flow of the streams is very slow and the material washed in from the shores is not so rich in inorganic constituents. The peat found in such regions may thus be more or less free from alluvial sediments. The calcareous remains of *Chara*, lime-rich silt, and shells of diatoms and of mollusks are frequently also found in the peat. The sedimentary material contains an abundance of pollen grains of deciduous and coniferous trees, spores of ferns and fungi, and a great deal of amorphous material. Imbedded in the amorphous material are woody and herbaceous plant fragments, strips of cutinized epidermis, and similar remains.

Autochthonous peats consist largely of more or less decomposed plant residues. They usually show a light brown fibrous or dark brown granular texture, depending upon the herbaceous or woody nature of the plants. If the material is more completely decomposed, by prolonged action by microorganisms, the plants may become structureless and amorphous.

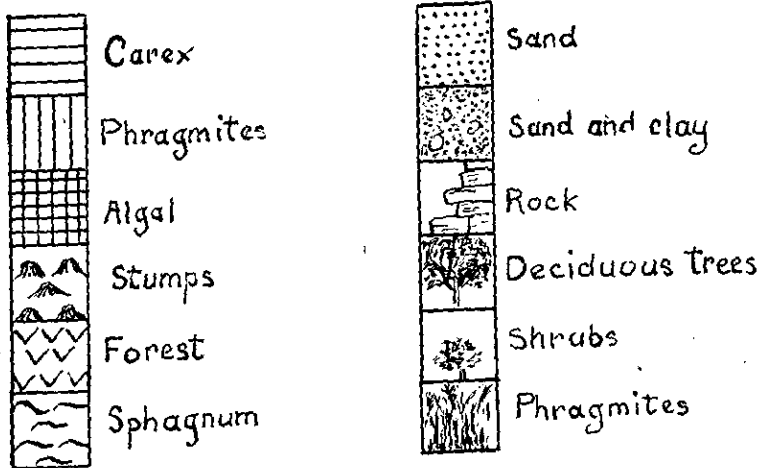
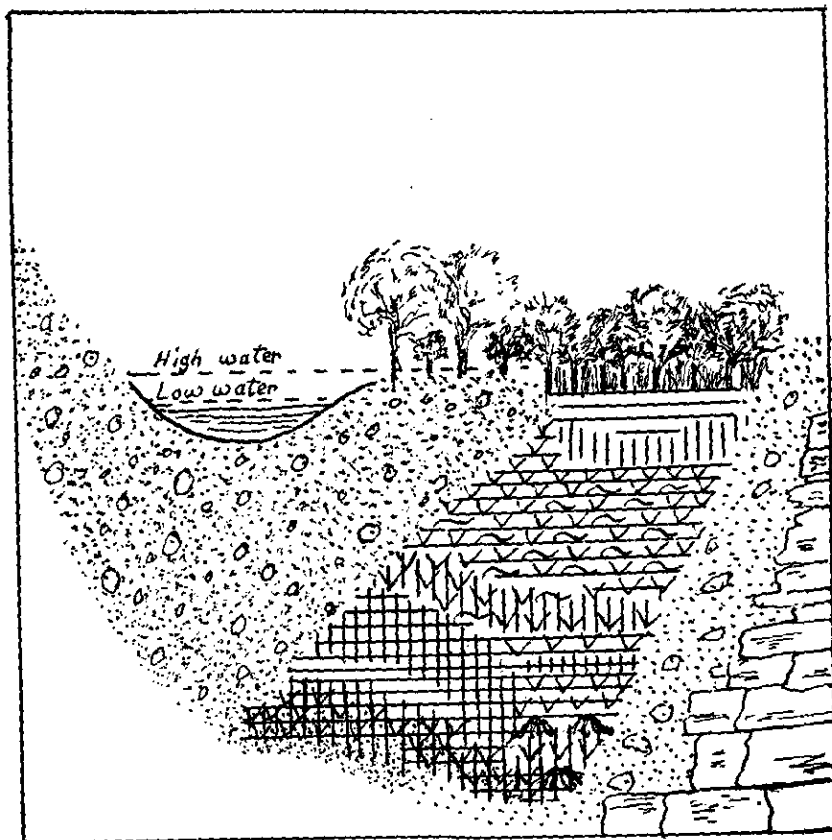


FIG. 10. Cross section of peat accumulation along the plain of a fair-sized river.



Some peat deposits in filled basins were greatly influenced by drought and drainage conditions, which resulted in marked changes in the growth and decomposition of the various plant associations. Changes in the surface water from alkaline to acid also influenced the composition of the vegetation.

In proceeding from the bottom upward, one can observe that fine-grained algal peat is usually found at the bottom of the filled-basin deposits. This is usually overlain by layers of reed and sedge peat. In shallow filled-basin deposits, the absence of algal peat, which is not uncommon, shows that the second plant association took root in the shallow water soon after the basin was formed and prevented the dominance of algae and other cryptogamic plants (210, 221). Auer (19) recognized three stratigraphic types of bog in Eastern Canada; namely, sphagnum peat bogs, or the ocean type; carex peat bogs, or the continental type; and a transition from ocean to continental, or combination of the two. He reported six distinct horizons in the raised bogs of the oceanic type; namely, fresh sphagnum, decomposed sphagnum, little-decomposed sphagnum, carex, organic ooze (sedimentary peat), and inorganic ooze (lake sediment).

*Plant associations in peat bogs.* Numerous studies have been made of plant associations and plant successions of peat bogs. No attempt will be made to review even a small part of the extensive literature published in the various countries. It is sufficient to say that the botanical composition of a bog influences markedly the chemical composition of the resulting peat (314). Attention will be paid primarily to the bogs along the northern part of the Atlantic coastline. Nichols (200-202) describes in detail the succession of plant societies in the peat bogs of this region. When one progresses from the deeper parts of a lake toward the shore, several zones, readily characterized by the dominant plants, are encountered. The four important zones are 1, the *Potamogeton* or pondweed; 2, the *Castalia-Nymphaea* or water-lily; 3, the *Scirpus* or bulrush, the *Pontederia* or pickerel-weed, and the *Typha* or cat-tail; and 4, the *Carex* or sedge. Others might be added. This sequence is said to be the same throughout the northern United States, although modifications frequently have been observed. The vertical succession of the vegetation which gave rise to a peat bog corresponds closely with that found in horizontal zonations. The pondweeds now growing in a given locality will later be succeeded, in turn, by water-lilies, pickerel-weed, and sedges and reeds. The depth of the water influences considerably the specific vegetation of group 3. The cat-tail, for example, grows best in water only a few inches deep; the pickerel-weed, on the other hand, thrives in water

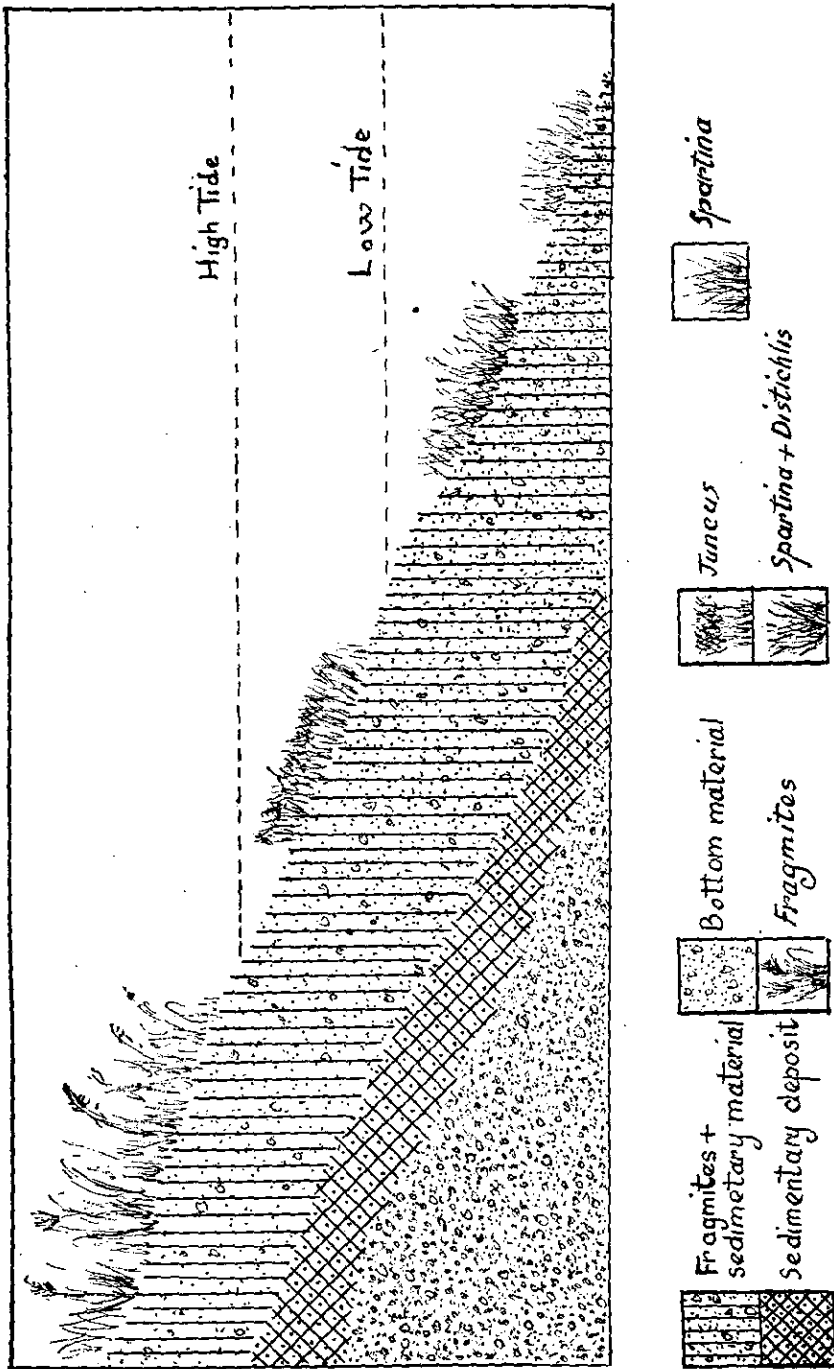


FIG. 11. Diagrammatic section showing formation and structure of marine marshes (after Chapman, 42a).

from 6 inches to nearly 2 feet deep; and the bulrush develops best in shallow water, can also grow in water which is more than 5 feet deep.

As soon as the bottom of a lake has been built up high enough to be exposed during a part of the year, aquatic plants begin to give way to land forms. The various stages in the above plant succession are frequently referred to as the *lake series*, whereas the later stages are spoken of as the *swamp series*. No sharp differentiation between the two, however, can be made. Although the various species of group 3 are characteristic of wet bogs, one may often observe within this zone, along the shore of a lake, a gradual transition from lake vegetation to swamp vegetation. This latter thus may be said to represent a transition zone from that of true lake vegetation to that of peat bogs. The first land plants to follow the lake vegetation are the sedges, which give the name to that stage of the development of a bog, and which subsequently give rise to the lowmoor peats.

The lowmoor peats also represent highly complex plant associations. Various hydrophytic plants, including *Glyceria canadensis*, *Iris versicolor*, *Lysimachia terrestris*, and *Scirpus cyperinus*, are found in the lower, wetter areas. *Aspidium thelypteris*, *Calamagrostis canadensis*, *Eupatorium purpureum*, *Verbena hastata*, and other shrubs are found in the higher and drier areas. Many of the sedges remain with the shrubs, though occupying a subordinate position. The most common shrubs in the open bogs are the alders (*Alnus rugosa* and *A. incana*). The lake-bog succession terminates in a bog forest, where the red maple (*Acer rubrum*) is usually present and may even predominate. It is accompanied by *Ulmus americana*, *Betula lutea*, and *Fraxinus nigra*, frequently also by the tamarack (*Larix laricina*) and the white cedar (*Chamaecyparis thyoides*) (200-202).

Those bogs that are produced by seepage or by spring waters have no true aquatic stage. The plant association in these bogs is dominated by sedges, rushes, and grasses, similar to the sedge stage of the lake-bog succession. Certain bogs, such as low meadows, are representative of the group of periodic-spring bog. The association here may be different from that of a permanent bog, the vegetation being grass-like with an admixture of other herbaceous plants. These bogs may be very wet in the winter and spring, but the surface layers may become relatively dry later in the season. The tree stage in periodic bogs exhibits marked differences from that dominant in permanent bogs. Some of the trees characteristic of the latter may also be found here, the red maple and elm being the predominant species.

In the built-up peat deposits, mosses and heath shrubs play a predominant role. The peat usually consists of the remains of only a

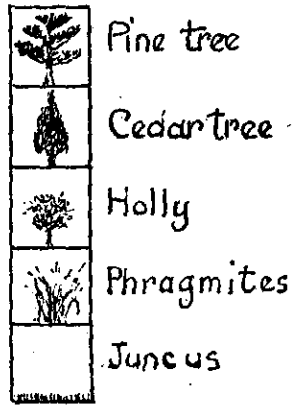
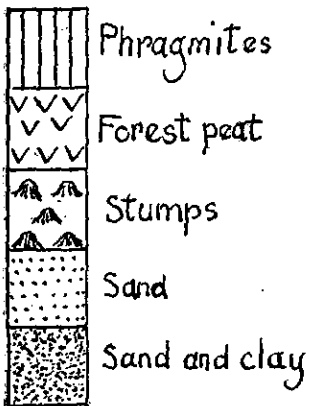
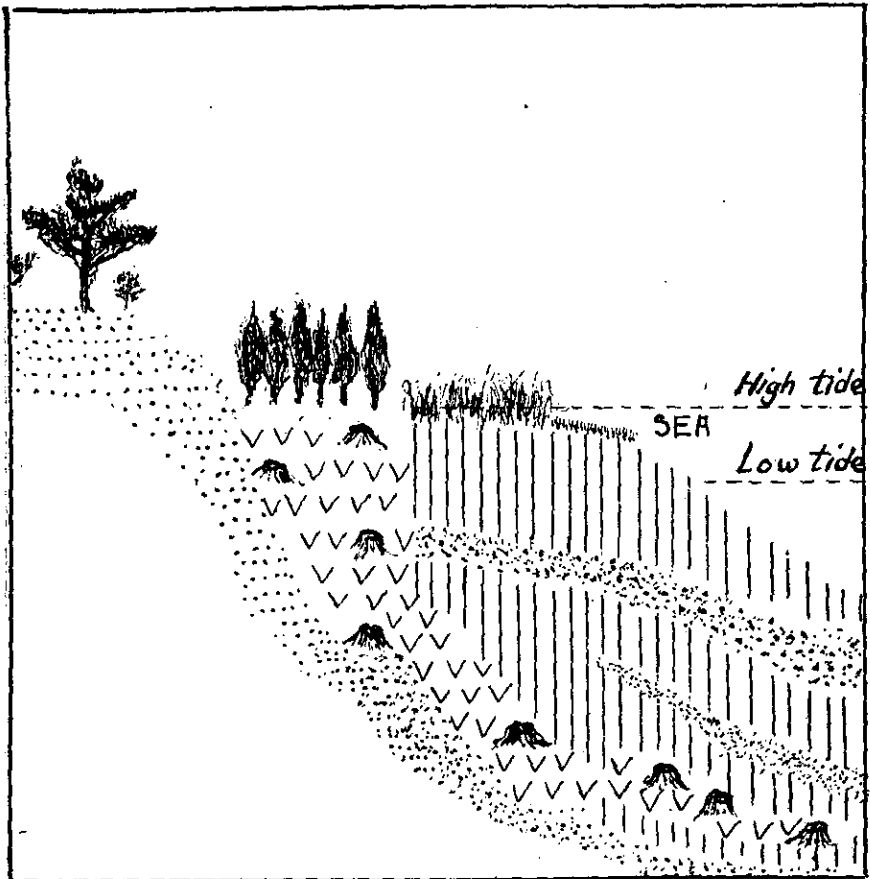


FIG. 12. The origin and structure of a marine marsh, showing forest peat layers.

few plant forms and is therefore relatively homogeneous. The peat may consist almost entirely of sphagnum in various stages of decomposition. Some of the built-up bogs are overgrown by plants of the same kind that formed the major part of the peat profile, indicating uniform climatic and topographic conditions for a long time. In some cases, however, the vegetation may be more advanced, heath shrubs and trees predominating (210).

The successions of plant societies in many of these bogs have been described by Nichols (200) as follows: The shrubs together with sphagnum tend to form elevated patches; sedges and sphagnum dominate the intervening lower ground; the spruces, usually 4-8 feet high, grow scattered among the shrubs. The shrubs of open bogs are divided into two groups:

Group I. *Andromeda glaucophylla*, *Chamaedaphne calyculata*, *Chiogenes hispidula*, *Gaultheria procumbens*, *Gaylussacia dumosa*, *Gaylussacia baccata*, *Kalmia angustifolia*, *Kalmia polifolia*, *Ledum groenlandicum*, *Vaccinium oxycoccus*.

Group II. *Alnus rugosa* (or *A. incana*), *Amelanchier oblongifolia*, *Ilex verticillata*, *Myrica caroliensis*, *Nemopanthus mucronata*, *Pyrus melanocarpa*, *Rhododendron viscosum*, *Rhus vernix*, *Vaccinium corymbosum*, *Viburnum cassinoides*.

The first group comprises the shrubs peculiar to bogs; those found in the second group are not strictly bog types. Some bogs may be free from sphagnum altogether. The sphagnum usually appears first as a superficial layer growing on the surface of the shrub or sedge mat; however, it soon develops so rapidly as to exert a profound influence on the character of the bog vegetation. Sphagnum plants grow upward in dense masses, commonly forming tussocks which may rise as high as two feet above the water level. Those plants which are unable to accommodate themselves to the change in environmental conditions are gradually eliminated.

Salt-marsh peat, though formed in a manner similar to fresh-water peat, differs considerably in character (331). The number of plant species found in salt-marshes is limited. In some of the coastal marshes of New England and New Jersey (45), salt-marsh peat is underlain by peat of fresh-water origin, indicating the subsidence of that portion of the Atlantic Coast (210, 49, 143).

*Nutrient relationships in peat formation.* Paul (214) has shown that the nutrient relationships of sphagnum plants vary greatly with the composition of the medium in which they grow. This was found (119, 121) to hold true not only of plant associations as a whole, but also for individual plant species. The concentration and especially

the amount of available mineral nutrients in the water is particularly important in this connection. Since highmoors contain the minimum amount of nutrients in an assimilable form (tables 8, 10, 13), sphagnum plants grown in these bogs also contain the minimum amount required for their metabolism and growth. Because of their anatomical structure, sphagnum plants are able to absorb the mere traces of nutrients present in solution, depending largely upon those coming from dust and rain water. This explains why the sphagnum plants and peat from highmoors of different regions vary but little in mineral composition. Forest and lowmoor peats show an entirely different relationship, since a much larger amount of nutrients is brought in by the waters feeding those bogs. There is, therefore, a considerably greater variation in the chemical composition of the same species of plants grown in different types of bog than of those grown in the same kind of peat but in different localities. Sphagnum plants from lowmoors are always rich in mineral nutrients, whereas highmoor sphagna are always poor. *S. platyphyllum*, for example grown in two different localities, contained 6.87 per cent crude ash in one case and 12.81 per cent in another; of this, 1.31 and 1.30 per cent was CaO, 0.35 and 0.53 per cent MgO, 0.95 and 0.63 per cent K<sub>2</sub>O, 0.26 and 0.18 per cent P<sub>2</sub>O<sub>5</sub>, 1.9 and 1.29 per cent nitrogen, respectively.

A detailed study of electrolyte content of peat water has been made by Weber (315), Kivinen (158), and others. The nature and the concentration of the mineral salts in the water, as well as the reaction of the water were shown to have an important influence upon the nature of the peat produced. This is brought out in tables 1 and 2, where the results of earlier and more recent analyses are given.

TABLE 1  
Chemical composition of peat waters (315)  
Milligrams per liter

Constituent	Highmoor peats *	Lowmoor peats	Transition peat
Ignition residue .....	23.8	141.9	73.2
Organic matter .....	149.2	170.5	73.7
Nitrogen .....	3.6	2.7	2.5
K <sub>2</sub> O .....	4.4	3.9	2.7
Na <sub>2</sub> O .....	4.5	8.0	6.2
CaO .....	1.6	58.7	22.7
MgO .....	0.6	9.2	3.9
Fe <sub>2</sub> O <sub>3</sub> —Al <sub>2</sub> O <sub>3</sub> .....	0.49	6.0	5.2
SO <sub>3</sub> .....	0.9	3.0	15.9
P <sub>2</sub> O <sub>5</sub> .....	0.6	1.3	1.0
Cl .....	12.3	11.3	6.6
SiO <sub>2</sub> .....	9.1	4.4	13.2

\* Averages of several analyses.

TABLE 2

*Chemical composition of the waters in different peat bogs (158)*

Milligrams per liter of water

Constituent	Highmoor peat	Lowmoor peat	Transition peat
Loss on ignition .....	97.0	246.3	85.0
Mineral residue .....	6.0	178.0	17.5
CaO .....	1.8	81.8	4.7
MgO .....	1.0	35.3	1.9
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub> .....	1.4	1.5	...
Cl .....	0.8	...	0.7
SiO <sub>2</sub> .....	1.0	5.0	2.7
pH .....	4.4	7.0	5.4

The flora of sphagnum bogs is widely recognized as being predominantly xerophytic; the plants characteristic of these bogs show such structural characters as one would expect in plants growing in dry places, in spite of the fact that the substratum in which they grow is wet. This was designated as "physiological drought" as distinguished from physical drought (237). Many theories have been advanced with a view to explaining the condition of physiological xerophytism prevalent in bogs. It has been variously ascribed to the acidity of the medium, to the low temperature prevailing in the bogs, to insufficient aeration, and to the accumulation of root excretions or of various toxic substances.

## CHAPTER IV

## CHEMICAL COMPOSITION OF PEATS

Although it has long been recognized that peat is primarily an organic substance, with varying amounts of mineral matter, knowledge of its chemistry remained rather confused, until the early part of this century. This was due partly to the great variation in composition between the different peats and partly to the misapprehensions concerning the chemical nature of the so-called "humic acids" (307) and their role in peat composition and peat formation. This confusion can best be expressed in the words of the great Swiss chemist, Früh (105), who believed that "the transformation products of plants which are characteristic of peat are the ulmic acids and ulmins, humic acids and humins, as well as the salts of these." In other words, peat was defined in terms of compounds little understood.

These and similar ideas dominated the attitude of the great majority of chemists and botanists interested in peat. The process of peat formation was usually designated as "humification," "ulmification," and "humification." The transformation of the various plant constituents which go to make up peat and the microorganisms concerned in these processes were completely disregarded. Whenever these activities were considered at all, they were limited to the so-called putrefactive processes which were said to take place in peat formation, as a result of the exclusion of air.

Weber (315) assumed, for example, that, in the presence of an excess of water, the cellulose molecule of the plant breaks up, giving, on the one hand, a small amount of carbon, hydrogen, and oxygen, and, on the other hand, a colloidal body which possesses the nature partly of an acid and partly of its salt. This residual molecule was designated as "ulmin." This "ulmin" was believed to become dark brown or black in the presence of air. It was said to form compounds with nitrogen and phosphorus (293). A part of the nitrogen was considered to exist in the form of amino acids and acid amides (265) and a part in the form of animal residues and excreta. Though "ulmin" could be brought into solution only by treatment with strong alkali solutions or with nitric acid, it was said to give rise to a group of compounds designated as "ulmic acids" which were soluble in alkalies (17, 206, 21, 122).

*Methods of analysis of peat.* Before the present century, the chemical analyses of peat as well as of peat-forming plants were limited,



in most cases, to the determination of dry organic matter, moisture, ash, and total nitrogen. In many instances, a detailed analysis of the various ash constituents of the peat was undertaken; this was true especially of calcium, magnesium, phosphorus, and potassium, and occasionally of sulfur and sodium. Comparatively little information was gained by such methods of analysis. This was recognized by Ziler and Wilk (333), who said that there are cases on record where the chemical analyses of the ash of a peat corresponded to that of a highmoor type whereas actually a lowmoor peat was analyzed, or *vice versa*. The study of the composition of the organic matter in the peat, which makes up 50 to 99 per cent of the total dry material in true peats, did not proceed further than the elementary analysis.

The first study of the organic chemistry of peat began with the separation of the ether- and alcohol-soluble fractions. Von Feilitzen and Tollens (89) introduced a new angle into this subject by determining also the pentosan and cellulose in the peat. In some cases, methods of analysis similar to those of the food chemist were employed. After an attempt to differentiate peat into digestible and undigestible fractions, the conclusion was reached (57) that this method "does not give sufficiently forceful illustration of the available organic compounds in plant remains now stored as layers of peat."

Within the last two decades, several methods have been developed for the separation of the organic complexes present in peat and the determination of their chemical nature. Particular attention was paid to the carbohydrates, especially the pentosans and cellulose, to the organic nitrogenous compounds, and to the group of fats and waxes (bitumens). Of particular interest is the proximate method of analysis of peat (309), which is based upon the separation of organic matter into several well-recognized fractions. By this method, the abundance of these constituents in the peat can be compared with that in plant materials; information can thus be gained not only in regard to the chemical composition of the peat but also of the processes involved in its formation from plant residues.

*Chemical composition of peats and peat-forming plants.* In view of the fact that peats are formed from plants decomposing largely under water or in a water-saturated state a knowledge of the chemistry of the peat involves a knowledge of the chemical composition of the plants which gave rise to the peat, the nature of the waters in which it has been formed and, in certain cases, the nature of the sedimentary or alluvial material brought in by the water (326).

TABLE 3

*Relative concentration of nutrients in different peats (119)*

Kilograms per hectare in upper 20 cm. of peat

	Typical highmoor peat	Transition peat with predominating highmoor character	Forest peat	Lowmoor peat
Postassium .....	130	111	159	343
Calcium .....	889	2,208	8,040	19,364
Phosphoric acid .....	490	413	1,101	1,288
Nitrogen .....	5,647	5,751	12,100	13,113

TABLE 4

*Concentration of nutrients in peats and peat-forming plants (332)*

Percentages of dry matter

Material	Nitrogen	Phosphoric acid	Potassium
Young sphagnum peat .....	0.64-0.74	0.03-0.04	0.02-0.03
Phragmites peat .....	2.29-3.23	0.09-0.28	0.04-0.19
Carex peat .....	2.94-2.47	0.14-0.20	0.05-0.06
Pollen peat .....	0.69-1.09	0.03-0.06	0.01-0.16
Liver mud .....	2.01-3.68	0.09-0.28	0.13-0.33
<i>Hylocomium squarosum</i> .....	1.27	0.44	0.87
<i>Calluna vulgaris</i> .....	1.04	0.23	0.51
<i>Sphagnum medium</i> .....	0.73	0.09	0.23

One cubic meter of peat containing 85-90 per cent water is usually considered to weigh 1,000 kilograms. Tacke (292) calculated that lowmoor peats contain, per 100 parts of dry material, 2.5 parts of nitrogen, 0.25  $P_2O_5$ , 2.5 CaO, and 0.10  $K_2O$ . The corresponding concentrations of these substances in highmoor or sphagnum peat was found to be 1.2, 0.1, 0.35, and 0.05. The concentration of the four important nutrients per hectare of peat land, to a depth of 20 cm., is reported in table 2. The concentration of these nutrients varies considerably not only in different peats, but also in different varieties of the same peat. This is brought out in table 3.

The organic chemical composition of different peats is given in tables 4 and 5, and the mineral composition is reported in tables 6 and 7. In order to compare the composition of peats with that of the plants from which peats are formed, the composition of a variety of plants is reported in table 8. The composition of peat bog waters is given in tables 1 and 9. The electric conductivity and refractive indexes of the water have also been measured (277).

TABLE 5  
*Chemical composition of several peats (92)*

Peat material	Average percentages of dry matter							
	Ether-soluble	Alcohol-soluble	Water-soluble	Hemi-cellulose	Cellulose	Lignin	Protein	Ash
Highmoor peat, Orono, Maine .....	2.83	4.96	6.41	24.6	15.4	17.98	5.25	3.13
Highmoor peat, Cherryfield, Maine .....	2.54	5.26	6.73	21.1	13.5	24.22	5.06	1.89
Heath-forest peat, North Carolina .....	4.04	7.06	3.28	4.5	2.9	54.66	8.38	9.07
Saw-grass peat, Florida .....	.57	1.97	2.82	6.9	3.3	56.72	21.56	9.99
Sedimentary peat, Florida...	.59	2.16	3.80	3.9	1.8	48.43	23.94	26.92
Saw-grass peat, Florida .....	.83	2.36	3.58	7.2	3.7	52.81	21.94	30.65
Woody-sedge peat, Washington .....	1.86	5.65	7.59	7.0	2.9	41.40	20.31	9.61

TABLE 6  
*Chemical composition of certain peats (157)*

Peat material	Average percentages of dry matter								Total
	Ether-soluble	Water-soluble	Alcohol-soluble	Hemi-cellulose	Cellulose	Lignin	Protein	Ash	
Amblystegium-Cyperaceae peat, cultivated...	2.76	2.77	5.35	12.38	....	46.00	15.15	4.96	89.73
Cyperaceae peat ...	4.73	2.98	5.10	12.32	5.44	41.78	14.72	4.95	92.02
Eutrophic-sphagnum peat...	1.31	3.23	3.37	12.99	3.97	32.28	15.55	15.77	88.47
Sphagnum peat ...	3.53	7.82	4.56	18.15	16.55	38.53	3.81	1.48	92.43
Forest-sphagnum peat, cultivated...	2.75	3.60	5.78	12.24	4.35	38.42	9.44	22.27	98.85
Sphagnum peat, dark .....	2.54	10.11	2.23	26.79	28.69	16.20	2.73	3.24	92.53

Among the various chemical components of peats, the mineral salts constituting the ash have received the greatest attention.

*Ash and its relation to the nitrogen content of peat.* The ash content of peat depends largely on the ash of the original plants from which the peat was formed and on the minerals in the waters coming into the bogs.

The sphagnum plants are very low in minerals. They (121) vary considerably in composition, depending upon the specific nature of the plant and the environmental conditions of growth. The composition of one species of sphagnum is distinctly different from that of another. On the other hand, *S. fuscum* and *S. medium* vary in composition depending upon the locality in which they are grown. Some sphagnum mosses can adjust themselves to certain pH optima (337). When the plants die and undergo decomposition, some of the minerals, especially the potassium and phosphorus, go into solution and are made available for new growth of young plants; other mineral constituents, especially the salts of calcium and magnesium, tend to remain in the dead plant. This is one of the reasons why peat formed from these plants is very poor in potassium and phosphorus. The waters coming into these bogs are chiefly of atmospheric origin and are also poor in mineral salts, which accounts further for the low ash content of sphagnum peat.

The lowmoor peats, especially the sedge and reed peats, and also the forest and sedimentary peats are considerably richer in ash, because the plants from which they are derived assimilate larger quantities of minerals, which remain in the plants, thus contributing to the ash content of the peat. The terrestrial waters brought into these bogs are also rich in minerals. In view of the fact that plants possess a luxury consumption of ash constituents, the plants growing in these bogs contain more ash than those growing in highmoors. Phragmites (reed) peat was found (333) to contain 10.5 to 14.6 per cent ash; carex (sedge) peat, 5.68 per cent ash; whereas the ash content of sphagnum peat is variously found to be between 1.93 to 3.92 per cent, and that of Eriophorum peat only 0.59 per cent.

The nitrogen content of reeds is usually given as 1.5 per cent, of Hypnum moss 1.4 per cent, of Sphagnum 1.1 per cent (varying from 0.63 to 1.46 per cent), and of Eriophorum 1.3 per cent. When the plant materials undergo decomposition, in the process of peat formation, the nitrogen content of the resulting peat increases, in many instances to more than twice that of the original plants. This is true only of lowmoor and forest peats. Highmoor peats, rich in Sphagnum and Eriophorum plants, show no increase in nitrogen content; a

TABLE 7  
*Chemical composition of ash in several peats (92)*

Location and description of peat	Average percentages												
	Soluble SiO <sub>2</sub>	Insoluble SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	CO <sub>2</sub>
Highmoor peat, Orono, Maine .....	7.79	33.12	4.59	13.63	0.50	3.68	17.92	7.48	5.59	1.18	0.92	0.20	4.88
Highmoor peat, Cherryfield, Maine ..	8.55	28.14	4.75	12.74	0.52	4.18	15.41	15.25	7.61	2.55	2.35	0.28	2.17
Heath-forest peat, North Carolina .....	8.08	58.27	3.20	10.75	1.26	1.49	6.18	5.31	4.46	0.66	0.59	0.03	0.36
Saw-grass peat, Florida .....	5.02	9.47	2.16	2.29	0.46	0.94	41.21	6.03	6.29	0.56	0.39	0.08	25.25
Sedimentary peat, Florida .....	16.85	16.40	8.18	7.09	0.81	1.02	21.52	6.47	16.25	0.43	0.35	0.03	4.34

decrease may even take place, as a result of the rapid decomposition of the nitrogenous compounds, leading to a loss of the nitrogen as ammonia, or of the slower decomposition of the nitrogen-free organic complexes, which cannot thus serve as readily available sources of energy for the microorganisms. The nitrogen that is made available from the decomposition of the nitrogenous complexes is not, therefore, reassimilated and changed into microbial cell substance. In reed peat, nitrogen increases from 1.5 to 3.4 per cent; sedge peat is often found to contain 4.16 to 4.50 per cent of the nitrogen in the organic matter, whereas moss peat contains only 0.6-0.8 per cent nitrogen.

The calcium content of highmoor peats varies considerably, the lowest amount being found in peats with a typical highmoor vegetation (121), such as *S. medium* and *S. rubellum*. In typical highmoor peats, the calcium content may be less than 0.5 per cent, as shown in table 2. For every 100 parts calcium, in such peats 635 parts nitrogen, 62 parts phosphoric acid, and 14.7 parts potassium were found. In peats with a calcium content of 0.5-1.0 per cent, the corresponding figures were 260 parts nitrogen, 18.7 parts phosphoric acid, and 5 parts potassium. Numerous highmoor peats formed on soil contain 1 per cent calcium, however, and numerous lowmoor peats have a calcium content that is more nearly characteristic of highmoor peats. According to Gully (121), one must discard the idea that calcium-poor peats must be considered as highmoor peats or that nitrogen-rich peats are lowmoor peats.

The botanical characterization of peat throws only limited light on the abundance of nutrient elements. Highmoor peat formation corresponds to a certain plant biological relationship and to the impoverishment of potassium in the soil. The ash of this type of peat contains much less potassium (0.36-1.41 per cent) than phosphoric acid (1.93-3.65 per cent) and calcium (3.57-19.23 per cent).

The less typical of the highmoor is the nature of the peat, the higher is the calcium content of the ash and the lower are the phosphoric acid and potassium contents. Forest peats are often designated as transition peats, since they stand midway, in the content of nutrients, between the highmoors and the lowmoors. Older peats gain in calcium but become poorer in nitrogen, potassium, and phosphoric acid (124).

The high calcium content of some of the lowmoor peats is due to the presence of this element in the base-exchange complex of the organic colloids resulting from the decomposition of the sedges, reeds, and other plants (246). The peat-forming plants are richer in phosphoric acid and potassium than the peat itself; this is true of the

other important mineral constituents as well. When the plant dies, the easily soluble salts, which are not in organic combination in the plant, especially the alkalis, are rapidly washed out; they are immediately reabsorbed by the growing plants and used for the building of new plant protoplasm. Because of the death of their predecessors, the plants growing in the bogs are thus able to use a large part of the nutrients required for their continued new growth.

The concentration of the inorganic compounds in peat is thus found to depend upon the nature of the peat, conditions of its formation, and processes of decomposition. Fleischer (99) reported that a typical moss peat contains 0.8 per cent nitrogen and 2.0 per cent ash; the latter includes 0.05 per cent phosphoric acid, 0.03 per cent potassium, and 0.25 per cent calcium. The corresponding concentrations of these elements in a lowmoor peat are 2.5 and 10, the latter including 0.25, 0.1, and 4.0 per cent of the three inorganic compounds or elements. The ash content of peat does not increase with the depth of the deposit, but is largely controlled by the nature of the profile and the abundance of sand, silt, and calcium carbonate in the waters (191, 31, 29, 333).

Accumulations of marl, calcium carbonate, and silicates, especially in the lower layers of lowmoor peat profiles, are common. Sedge and reed peat and sedimentary peats are likely to be rich in sulfur. The highmoor peats, however, contain only small amounts of sulfur. Both sulfur and phosphorus are present in peat principally in organic combinations. Some peats may have a high sulfur concentration, in the form of iron sulfide (marcasite), especially in areas that are fed by drainage waters rich in sulfate.

Other elements, such as molybdenum (186), may be occasionally found in peat. The presence of iron may become so important as to give rise to special accumulations known as *bog iron*. Kivinen (159) has shown, for example, that  $\text{FeCO}_3$  is widely distributed in the lowmoors in Finland, where it occurs near the surface or in the lower layers. It is gray and soapy in texture and rusts readily on exposure.

*Ether- and alcohol-soluble constituents of peat.* Organic compounds make up 50 to 99 per cent of the total solid constituents of peat. It is, therefore, natural to expect that the most important problems in regard to the nature, formation, accumulation, and decomposition of peats would be connected with their organic composition. The organic complexes include fats and waxes, cellulose and hemicelluloses, lignins and their derivatives, nitrogenous complexes, and a variety of other substances, simple and complex in composition. Not all of these have been studied to any extent, and only fragmentary information is available in regard to most of the others.



TABLE 8  
*Chemical composition of the profile layers of representative peat deposits of New York (328)*

Nature of peat layer	Depth inches	pH	C:N ratio in peat	Chemical constituents, percentages of dry matter					
				Ash	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Total nitrogen
Woody .....	0-6	4.8	21.01	11.96	3.56	1.79	4.94	0.51	2.33
Woody reed .....	6-12	5.0	29.72	8.11	1.28	0.68	4.52	0.49	2.11
Fibrous woody reed .....	12-24	5.2	27.29	17.66	8.10	2.63	4.47	0.58	1.82
Fibrous reed .....	26-36	5.3	28.74	7.31	0.42	0.76	4.55	0.49	1.86
Sedimentary .....	84-96	6.6	12.03	43.68	27.60	9.76	1.83	0.73	2.48
Woody .....	0-6	5.6	16.66	11.64	3.27	1.26	4.80	0.62	2.89
Sedimentary .....	12-18	5.6	22.50	12.51	1.93	1.06	6.85	0.83	2.19
Fibrous reed and sedge .....	30-36	5.7	17.35	12.89	0.65	0.43	6.20	0.61	2.88
Sedimentary .....	60-72	6.1	14.49	14.86	1.21	0.84	6.11	0.64	3.37
Woody .....	0-6	4.2	28.23	7.14	3.60	1.01	1.42	0.22	1.90
Sedimentary .....	6-14	4.4	55.91	7.09	4.50	0.94	0.98	0.13	1.04
Fibrous reed .....	14-24	4.4	29.33	4.77	1.53	0.88	1.35	0.18	1.94
Sedimentary .....	36-48	4.8	12.15	37.63	23.82	7.82	1.65	0.81	2.89
Fibrous reed and cat-tail .....	0-7	5.7	14.57	38.80	20.94	10.82	4.79	0.91	2.36
Sedimentary-fibrous reed and cat-tail.	7-12	5.8	14.81	41.42	19.32	9.65	4.60	0.82	2.25
Sedimentary-fibrous reed and sedge..	12-24	5.8	14.43	40.09	18.20	9.75	4.07	0.83	2.44
Sphagnum .....	4-12	3.8	33.25	6.40	3.81	0.88	0.92	0.18	1.51
Sedimentary reed and sedge .....	18-26	4.0	38.62	5.85	2.80	0.70	1.56	0.21	1.49
Fibrous reed .....	30-38	5.3	22.26	6.80	0.89	1.07	3.30	0.46	2.43
Fibrous reed and sedge .....	60-70	5.7	18.97	24.38	13.93	4.91	3.12	0.62	2.21

TABLE 9  
Composition of some natural plant materials which give origin to peat (309)

Plant material	Percentages of total dry matter							Total
	Ether-soluble	Cold and hot water soluble	Hemi-cellulose	Cellulose	Lignin (ash and nitrogen-free)	Protein	Ash	
Carex, upper growing portion...	2.54	12.56	18.36	28.20	21.08	7.08	3.30	93.12
Carex, rhizomes .....	1.66	3.18	20.86	11.78	41.74	14.62	4.56	98.40
Cladium, upper growing portion	1.14	6.87*	21.45†	28.31	29.09	7.19	3.89	97.94
Cladium, lower portion and roots .....	0.90	5.21*	20.75†	30.74	30.90	3.81	3.57	95.88
Hypnum .....	4.58	8.41	18.92	24.75	21.13	4.16	4.33	86.28
Sphagnum, upper growing portion .....	1.47	3.86*	30.82	21.13	6.97	5.88	3.18	73.31
Sphagnum, lower dead portion	1.60	1.56	24.50	15.88	19.15	1.86	19.92	84.47
Fallen needles of <i>Pinus strobus</i> (+12.57‡)	11.35	7.29	18.98	16.43	22.68	2.19	2.51	94.00
Fallen oak leaves .....	4.01	15.32	15.60	17.18	29.66	3.47	4.68	89.92

\*Cold water only. †Pentosans only. ‡Alcohol-soluble portion.

The fats, waxes, or the so-called bitumens have received most consideration. This group is frequently designated as the ether- and alcohol-soluble fraction. In view of the fact that different plants vary considerably in these constituents, it is essential to know the composition of the original plants, as compared with the same constituents in the resulting peats (tables 10-12).

Ether extracts from plants and plant residues, ethereal and fatty oils, oleoresins and resins, certain wax-like substances and nitrogenous fats. Alcohol extracts from plant materials, various waxes, tannins, resins, bitter substances, alkaloids, chlorophyll, certain pigments, and soluble carbohydrates. The wax extracted from peat with alcohol or benzol-alcohol can be divided into two or more fractions; some are dark brown, having the odor of beeswax, and soluble in ether; their melting point varies from 46 to 87.5° C.

Sedge and reed peats contain the lowest amounts of ether- and alcohol-soluble substances. Sphagnum peats are much richer in these constituents. Pollen peat is richest, since almost one-third of the organic matter in this type peat is made up of these fractions. As the age of the peat increases, the amount of ether- and alcohol-soluble substances also increases, at least for sphagnum peats, as shown by Zailer and Wilk (333):

Degree of decomposition of peat	Ether-soluble fraction	Alcohol-soluble fraction
	<i>per cent</i>	<i>per cent</i>
Undecomposed .....	1.16	2.98
Little decomposed .....	2.33	4.24
Well decomposed .....	4.22	5.50
Completely decomposed .....	5.58	11.16

Comparison of the ether- and alcohol-soluble fractions obtained from different peats cannot always be made very accurately, since some investigators extracted the peat with alcohol after ether, others extracted separate samples with the two solvents, and still others used benzol-alcohol and a variety of other solvents.

The following results were reported by Birk (31), on the basis of ash-free, dry organic matter in the peat:

Nature of peat	Ether-soluble fraction	Alcohol-soluble fraction
	<i>per cent</i>	<i>per cent</i>
Sphagnum and hypnum .....	1.0-2.0	.....
Young sphagnum .....	5.9-9.5	1.8-4.0
Old sphagnum .....	15.1-20.1	4.9-10.0
Forest .....	15.7	6.8
Sedimentary .....	18.5	8.6

TABLE 10  
*Chemical composition of a highmoor peat profile near Cherryfield, Maine (309)*

Depth of peat, cm.	Percentages of dry matter									
	Moisture content of original sample	Reaction, pH	Ether-soluble	Alcohol-soluble	Hemi-cellulose	Cellulose	Lignins	Protein	Ash	
1-8 .....	92.7	4.04	2.35	1.45	26.45	16.86	27.18	4.08	2.00	
8-20 .....	92.6	3.95	2.62	1.92	25.24	14.74	29.21	4.28	1.14	
20-30 .....	92.6	3.85	2.82	1.83	24.55	15.97	28.85	5.11	1.02	
30-46 .....	92.9	3.86	2.57	2.08	22.25	13.69	32.23	5.24	0.90	
46-61 .....	93.6	3.73	2.96	3.20	18.48	14.66	33.24	4.81	1.06	
183-214 .....	93.4	4.47	3.97	3.15	15.94	15.55	37.43	4.41	0.99	
460-480 .....	92.4	4.71	4.89	4.29	12.69	11.85	44.83	4.73	1.10	
550-580 .....	92.2	5.18	5.97	5.06	5.96	5.06	54.11	11.53	2.83	

TABLE 12  
 Chemical composition of Florida (Everglades) peat profile (309)  
 Percentages of dry matter

Peat formation	Depth of layer	Ash	Crude protein	Ether-soluble	Cold and hot water soluble	Alcohol-soluble	Hemi-cellulose	Cellulose	Lignin	Total
Surface layer .....	cm. 0-6.5	12.09	22.75	2.96	1.31	1.22	6.87	0.30	43.72	91.22
Upper fibrous layer ...	6.5-26	10.00	23.06	2.98	1.73	1.06	6.41	0.28	46.12	91.64
Typical saw-grass peat .....	26-40	6.86	22.25	3.16	1.60	1.31	8.04	0.43	44.90	88.55
Lower fibrous layer .	40-50	8.05	21.25	3.21	1.45	1.39	7.63	0.43	47.63	91.04
Sedimentary layer ....	50-62	59.60	9.00	2.97	1.07	0.45	2.19	...	19.33	94.61
Lower portion of sedimentary layer .	62-70	42.37	12.98	1.46	0.82	0.68	2.64	...	28.47	89.42
Lower fibrous layer .	110-120	15.14	20.38	1.58	0.84	1.23	4.30	...	48.44	91.91

Extensive studies on the bitumen content of peat have been made by Russian investigators. Stadnikoff (286, 287) reported that high-moor peats contain 3-7 per cent ether-soluble and 22.5-24.0 per cent alcohol-soluble material. Titow (302) found that 5.3 to 10.9 per cent of the peat was benzene ( $C_6H_6$ ); of this, 15-20 per cent was made up of high-molecular hydrocarbons (tri- and penta-tricontane); the saponifiable fraction was made up of acids (carboceric,  $C_{25}H_{50}O_2$ ) and esters with alcohols ( $C_{27}H_{56}O$ ); the resin fraction consisted of cyclic acids and esters (80).

*The nitrogenous constituents of peat.* The nitrogenous constituents were given but little consideration in the "humic acid" studies on peat, since they usually did not fit into the various hypothetical chemical formulas suggested for these acids. It was even believed by some that the nitrogen might exist in the peat almost entirely in the form of ammonia, or even that it could be absorbed from the atmosphere and bound in that form by the peat. It is true that ammonia in small quantities is produced in the decomposition of peat, but, it does not accumulate and is either consumed by the growing plants or by the microorganisms decomposing the carbohydrate constituents of the plants. In drained bogs the ammonia may be oxidized to nitrate.

The early assumptions that the nitrogen in peat is absorbed from the atmosphere by the "humic compounds" may be dismissed. This nitrogen is derived only from the plants from which peat has been formed. In the process of decomposition of the plant residues, the nitrogen is transformed, through the action of microorganisms, directly or indirectly, thereby becoming more closely bound.

The nitrogen in peat is almost entirely organic in nature. Although most of the chemical analyses of peat include the determination of total nitrogen, comparatively little is known concerning the nature of the organic nitrogenous compounds, and especially the forms in which these are present in the natural peat.

A part of the nitrogen is known to be in the form of protein and certain protein compounds and derivatives; on hydrolysis of peat, various amino acids, such as leucín, tyrosin, and iso-leucín, are produced (141, 142, 248, 250). Among the non-protein nitrogenous bodies found in peat are cytosine, xanthine, and hypoxanthine (262); the presence of pyridine, pyrimidine and purine compounds is also indicated.

The nature of most of the protein and of other nitrogen combinations in peat is still only imperfectly understood. Robinson (248, 250) has shown that only small quantities of amino acids and other amino compounds are present as such in peat, but on treatment with

mineral acids, they gradually increase in concentration. Only 26 per cent of the total nitrogen in peat, however, is in the form of protein that can be converted by hydrolysis into primary amino compounds, with the probable formation of amino acids; about 10 per cent of the nitrogen is accounted for as amides. Some nitrogen in peat, especially in the highmoor type (85), may be present in the form of ammonia. The comparatively high concentration of amides in peat proteins has also been established by Davies (67) and others.

Jodidi (141, 142) used a 47.5 per cent sulfuric acid solution for the extraction of nitrogen from peat. The treatment was continued for 28 to 72 hours, at boiling temperature, under a reflux condenser. Even as a result of such vigorous treatment, not more than 60 to 64 per cent of the total nitrogen was brought into solution. A 33 per cent solution of sulfuric acid extracted, in 28 hours, only 50 per cent of the nitrogen. The concentration of the acid and the length of extraction were found to be of importance. Boiling water alone extracted, in 16 hours, only 3.7 per cent nitrogen; this increased to 5.8 per cent when the peat was autoclaved for 10 hours. On repeated extraction with 33.3 per cent  $H_2SO_4$ , 43.23 per cent of the nitrogen was extracted during the first 10 hours, 10.01 per cent during the next 11 hours, 9.61 per cent in the next 29 hours, and 5.47 per cent during the fourth treatment for 32 hours, giving a total extraction of 68.32 per cent in the 82 hours. When calculated on the basis of total nitrogen in the peat, the products of hydrolysis consisted of 1.50 per cent ammonia, 16.02 per cent amide, 2.96 per cent diamino, and 39.05 per cent monoamino forms (189).

These results emphasize the fact that although a large part of the nitrogen in the peat is in the form of protein, this is not in a free state. Were such the case, it would be readily subject to decomposition by bacteria and fungi, but the fact is that only small amounts of the nitrogen are made available through decomposition even under favorable conditions of aeration and moisture. According to Potter and Snyder (224), 20.5 per cent of the nitrogen soluble in alkalis is of a non-protein nature; a 1 per cent HCl solution extracted only 0.67 per cent of the nitrogen. Sphagnum peats gave, on an average, 8.6 per cent of the total nitrogen in a 1 per cent acid solution; 65 per cent of that nitrogen was in the form of ammonia (116).

Morrow and Gortner (195) considered the insoluble part of the nitrogen in humus as "humic" nitrogen; nearly 50 per cent of the total nitrogen was found in this form. This humic nitrogen originates during the hydrolysis of the proteins and is derived largely from the tryptophane group (117). The presence of carbohydrates that gave rise to furfural causes an increase in this form of nitrogen.

An analysis of sphagnum peat brought out the significant fact that the portion which was soluble in NaOH and was not precipitated by HCl gave a nitrogen distribution approximating that of plant proteins. The nitrogen dissolved in dilute HCl, however, showed a distribution not due to protein material; the filtrate from the bases contained 65.4 per cent of the nitrogen as ammonia and amide nitrogen, and only 17.1 per cent amino nitrogen. The ammonia probably originated from the amides as a result of hydrolysis. The true humin nitrogen of protein origin remained in the residual material after hydrolysis. It varied from 22.9 to 28.3 per cent of the total nitrogen (195).

Chitin, partly of plant and partly of animal origin, was found (228) to be present in peat. It appears, however, that not all types of peat contain appreciable quantities of chitin (134).

It has been suggested (78) that peats be treated with mineral acids and alkalis, in order to make the nitrogen more available (78). At best, however, only a part of the total nitrogen may thus be affected even after prolonged treatment.

*Cellulose and hemicelluloses in peat.* The cellulose and pentosans found in peat are derived largely from the original plants. Von Feilitzen and Tollens (89) reported the presence of 15.4 per cent pentosan in *Calluna vulgaris*, 14.7 per cent in *Sphagnum cuspidatum*, and 11.4 per cent in fibrous peat. The pentosan content of the surface layer of sphagnum peat varied from 6.3 to 12.8 per cent, diminishing with depth, so that below 200 cm., there was only 2.7 to 5.9 per cent. The cellulose content of *S. cuspidatum* plants was 21.3 per cent, 15.2 per cent in sphagnum peat at a depth of 20-100 cm., and only 6.9 per cent in the same peat at a depth of 100-200 cm. Highmoor peat was shown (129) to contain true cellulose.

The presence of cellulose was believed (224, 74) to distinguish peat sharply from bituminous and brown coals. This difference could not be confirmed (284), however, for perfectly justifiable reasons, since many peats contain very little true cellulose, as shown in tables 11 and 12.

In addition to pentosans, peats contain a variety of other hemicelluloses, of both the polysaccharide and polyuronide types. These give, on hydrolysis with dilute inorganic acids, mannose, galactose, levulose, and pentoses. These amount to as much as 4.5-10.8 per cent of the humus. Zailer and Wilk (333) recorded a decrease of pentosan from 10.3 per cent, at the surface of the peat, to 5.1 per cent at 7.5 meters' depth.

Since the carbohydrates are low in carbon, and the waxy substances and the lignins contain a higher percentage of carbon, and since the



TABLE 11  
*Chemical composition of a lowmoor peat profile from Newton, N. J. (309)*  
 Percentages of dry matter

Depth of peat, cm.	Original moisture	Reaction pH	Ether-soluble	Water-soluble	Hemi-cellulose <sup>1</sup>	Lignin	Protein	Ash
12 .....	78.7	5.9	0.66	3.08	10.31	38.35	22.48	13.22
80 .....	86.6	6.3	1.10	1.24	8.95	50.33	18.72	10.13
160-180 .....	90.5	6.3	0.49	2.31	7.02	57.83	14.81	10.15
160 .....	86.2	6.7	0.78	1.14	7.51	42.10	19.81	15.00
Lake peat .....	88.1	6.8	0.67	0.81	12.14	33.25	19.38	24.87
Sedimentary layer .....	80.9	8.0	0.36	1.24	5.92	15.62	9.81	59.55

<sup>1</sup>No true cellulose in any of the layers.

last two are more resistant to decomposition, a reduction of the cellulose and pentosan content with increasing depth of peat is largely responsible for the gradual increase in total carbon of peat with increasing depth. In the decomposition of plant residues, the cellulose and hemicelluloses tend to disappear rapidly, especially under aerobic conditions. In the anaerobic peat bogs, certain hemicelluloses and even some cellulose may persist for a long time.

In view of the fact that both hemicelluloses and cellulose are hydrolyzed by concentrated inorganic acids, giving reducing sugars, methods have been devised for determining the total carbohydrate content of the peat by the use of such treatments (151). The treatment with 72 per cent sulfuric acid was found by Keppeler (153) to change all the cellulose and a large part of the pentosans and other hemicelluloses to reducing sugars; the determination of the latter was looked upon as a measure of the carbohydrate content of the peat. The part of the organic material unaffected by the acid may be considered to consist largely of lignin. It was suggested that this method be used for following the course of peat formation from the original plants. The reducing sugars found by this method in *Sphagnum cuspidatum* were 68.5 to 71.4 per cent, and in *S. medium*, 61.5 to 64.5 per cent. The pentoses can also be determined by distillation with 12 per cent hydrochloric acid. The difference between the total sugar and the pentoses gives the hexoses.

By determining the relation between the sugar formed on treating peat with acid to the sugar produced by similar treatment of the original plant material, an index of the degree of peat formation can be obtained. This calculation is based on the fact that the cellulose and hemicellulose disappear as plant residues decompose. The reducing power of the original sphagnum plants was taken as 68. The degree of decomposition of sphagnum peat was calculated from the following formula:

$$(100 - \frac{\text{total reduction} \times 100}{68})$$

Various coals with reductions of 0.82 to 5.04 per cent, gave a degree of decomposition equivalent to 98.8-92.6. Young peat with a total reduction of 34.7 to 57.3 per cent showed a degree of decomposition of 49.0 to 15.7. Young sphagnum peat was found to contain 14.7 per cent pentoses and 40.6 per cent hexoses. An old sphagnum peat contained 3.8 per cent pentose and 16 per cent hexose, and still another old peat contained 7.9 per cent pentose and 4.9 per cent hexoses.

By this method, it was possible to demonstrate that with an increase in depth of peat, there is a decrease in the total reducing power and, therefore, an increase in the degree of decomposition of the peat. The amount of residue left after treatment with concentrated sulfuric acid (the ash-free lignin, certain waxy materials, and some protein) was taken as an "index of peat formation." This index was comparable to the degree of decomposition.

Keppeler (153) was thus able to devise a very ingenious practical method for determining the chemical nature of peat and to use the data as a measure of the degree of decomposition of the peat. This was a mere beginning of a detailed chemical study of peat and of the processes taking place in peat formation. The method did not differentiate sufficiently between the hemicellulose fraction (exclusive of the pentosans) and the cellulose in the peat. It did not consider at all the important nitrogen complexes of the peat and their role in peat formation and transformation. The degree of decomposition was calculated by the use of a figure obtained in the reduction of sphagnum peat, which is inapplicable to other kinds of peat. Keppeler's method, therefore, did not find universal application.

The transformation of the carbohydrate constituents of trees in the process of peat formation can be studied by similar methods (231).

*Lignin in peat.* Hoppe-Seyler (133) was the first to direct attention to the role of lignin in the accumulation of organic matter in nature. It was soon found that various peats contain considerable quantities of material insoluble in concentrated solutions of mineral acids. The older the peat, the greater is this fraction. Since the methoxyl group is considered to be characteristic of the lignin molecule, its content in peat may be taken as an index of the lignin content. On this basis, an accumulation of lignin is found to take place in peat (table 13). The methoxyl content was found to increase with depth in highmoor peats and to decrease with depth in lowmoor peats. It was also found that in the formation of brown coal, the methoxyl content increases with age, to a certain point, beyond which it begins to decrease. The presence of 3.34 per cent methoxyl was reported (216) in peat, 0.24-0.79 per cent in brown coal, and none in anthracite coal.

Under the anaerobic conditions prevailing in peat bogs, lignin is more resistant to decomposition than are cellulose and some of the other plant constituents; hence, it accumulates. The fact that the methoxyl content of the lignin in peat and coal is always considerably lower than that of the lignin in plant materials (table 13) has been

explained by a partial loss of some of the methoxyl in the process of decomposition of the plant material (184). The relation of lignin to peat formation has received considerable attention in recent years (32, 285, 307).

TABLE 13

*Concentrations of methoxyl in different depths of peat profiles (96)*

Percentages of dry matter						
Nature of peat	Depth	Ash	Methoxyl content	Insoluble in concentrated HCl	Soluble in NaOH	Bitumen content
	<i>meters</i>					
	..	1.8	0.49	29.5	11.0	2.0
Highmoor ..	0.9	1.7	1.22	58.0	20.0	4.9
	1.8	1.8	1.67	72.5	35.0	7.7
Lowmoor ..	Increasing depth	7.1	2.97	74.5	...	5.3
	..	6.8	2.73	77.5	...	6.3
	..	6.6	1.66	84.5	..	12.2

*Systematic study of chemical composition of peat.* To be able to understand the chemical nature of peat as a whole, as well as to be able to follow the processes leading to the accumulation of large quantities of organic matter in the form of peat, it is, first of all, important to adopt a definite system of analysis. This can also be applied to the study of the composition of the plants from which the peat originated, and thus allow a comparison between the chemical composition of the plants and that of the resulting peat. The system can be only proximate.

Such a method, developed in our laboratories, is outlined here. By this method, the following seven groups of organic and inorganic constituents are recognized in peat:

1. Ether-soluble and alcohol-soluble fraction. Several 5-gm. portions of air-dry peat are extracted for 16-24 hours with sulfuric ether. The ether is removed and the soluble portion transferred to weighing bottles, which are dried at 105° C. and weighed. The soluble portion comprises the fats, waxes, and sterols. The residual peat portions are now extracted twice with 95 per cent alcohol, at boiling temperature, for 1 hour each. The two repeated extracts are combined, evaporated in weighed dishes or weighing bottles, and dried to con-

stant weight. This fraction comprises some of the waxes, resins, tannins, pigments, alcohol-soluble sugars, and amino acids. These two treatments are often replaced by benzol-alcohol.

2. *Water-soluble portion.* The peat treated with ether alone or with ether and alcohol is extracted for 24 hours with cold water. The extract is removed by filtration through paper and divided into three portions: one is evaporated to dryness to give the water-soluble organic matter and ash; one is used for the determination of total nitrogen; one is used for the determination of reducing sugar. The residual peat samples are next treated with water for 1 hour at boiling temperature. Soluble organic matter, ash, and total nitrogen are measured in the extract. Although fresh plant materials are rich in water-soluble substances, peat is rather poor in these constituents, since most of them are washed out in the process of decomposition and since peat is constantly in contact with water. For practical purposes, the determination of this group of constituents in peat may be dispensed with, unless very accurate results are wanted.

3. *The hemicellulose group.* The residual peat samples are extracted twice with 2 per cent hydrochloric acid at 100° C., for 5 hours under a reflux condenser. The digest is filtered through dried and weighed filter papers, and thoroughly washed with distilled water. The residue is dried at 70-100° C. and weighed. The combined filtrates and washings are used for analysis of the total reducing sugars. These can be reported as hemicellulose sugars, or when multiplied by 0.9, as total hemicellulose. Separate determinations of the pentosan in the untreated peat show that the amount of pentosan in peat is considerably less than the total hemicellulose, as determined by hydrolysis with dilute acids.

4. *Cellulose determination.* The residual material is weighed, and, if necessary, ground. Two 1-gm. portions are put into 250-cc. flasks and 10 cc. of 80 per cent sulfuric acid (by weight) is added to each flask. The acid is allowed to act in the cold, with occasional stirring. At the end of 2 hours, 150-cc. portions of distilled water are added to the flask, and the contents either boiled for 2 hours under a reflux condenser or autoclaved for 30 minutes at 15 lbs. pressure. The contents are then filtered through gooch crucibles or small dried and weighed filter papers, and washed thoroughly until free from acid. Aliquot portions of the filtrate are neutralized and used for sugar determinations. The amount of sugar found serves as a measure of the true cellulose content of the peat.

5. Lignin determination. The residual material left from the cellulose determinations is dried at 70° C. and weighed; two portions are used for ash determination and the others for total nitrogen. The total dry material, minus the ash and the protein (total nitrogen x 6.25) gives, on proper multiplication, the lignin content in the sample peat.

6. Nitrogen fractions of peat. To obtain a balance of the nitrogen fractions in peat, one can calculate: 1. the amount of nitrogen soluble in cold and hot water; 2. the nitrogen soluble in dilute acids; 3. the nitrogen soluble in concentrated acids; 4. the nitrogen of the lignin. These four fractions account for virtually all the nitrogen of the peat, except for a small part soluble in ether and alcohol, in the form of nitrogenous fats and certain amino acids. The total nitrogen, minus the water-soluble nitrogen, multiplied by 6.25 is reported as crude protein. Undoubtedly a large part of this nitrogen, however, is present in the peat in some other form than protein or protein derivatives.

7. Mineral constituents or ash. This fraction, comprising all the inorganic constituents of the peat, is determined by loss on ignition.

By means of this proximate system of analysis, it is possible to account for 90-95 per cent of the constituents of different plant materials and various types of peat. The highmoor peats are an exception, since they are rich in polyuronides, which are only partly accounted for in the hemicellulose group. Unless these polyuronides are taken into consideration, the resulting data for sphagnum plants and highmoor peats may not exceed 75-80 per cent of the total material.

## CHAPTER V

PHYSICAL AND PHYSICOCHEMICAL PROPERTIES OF PEATS AND  
PEAT SOILS

Because they are primarily organic in nature, peats and peat soils possess certain characteristic physical properties that distinguish them on the one hand from fresh or partly decomposed plant materials, and on the other from mineral soils. The mechanical structure of peats, their colloidal properties, and other physical and physicochemical characteristics are determined and controlled by the nature of the plants from which they have been formed, by environmental factors, especially nature of waters and temperature, and by other conditions which have contributed to their formation and decomposition. The water level of the bog, the rate of evaporation, conditions of drainage, rainfall, as well as dry vs. wet seasons, are particularly important in regulating the growth and type of peat produced and its physical and chemical properties (318-319).

*Water-absorbing capacity.* Among the various physical properties of peat, the high water-absorbing capacity is most significant. Different peats vary considerably in this respect, depending on their origin, degree of decomposition, and chemical composition. Low-moor peats absorb, on a dry basis, 400 to 800 per cent of water, whereas sphagnum peats are able to absorb as much as 800 to 1,600 per cent water (table 14); the moisture-holding capacity of the peats in a natural state may even be much higher (table 15). Because of this specific property, peat has found wide applications, chief among which are its uses in the improvement of the physical condition of the soil; as a litter in stables for the absorption of the urine; and in poultry houses. In the utilization of peat for increasing the water-holding capacity of sandy soils, the specific effect upon the amount of water available for plant growth must be considered. Despite the fact that peat increases the water content of mineral soils, it holds the water so tightly that plants may not be able to use it (165). Feustel and Byers (94), however, concluded that peats are superior to mixtures of peat with soil, both in their moisture-absorbing capacity and in their ability to retain the available moisture against evaporation. Of the various types, a well-decomposed sedge and reed peat gave the lowest rate of evaporation and a sphagnum peat the highest; partly decomposed sedge peat fell between. Moss peat transferred more readily its internal moisture in the surface of the peat by capil-

larity, where evaporation is most rapid. Reed peat, especially in a well-decomposed state, is more granular, and its structure is such that capillary continuity is broken; this type of peat, therefore, tends to have a damming effect on soil moisture immediately below the surface. The moisture contents of peats at the wilting point were found to be in the reverse order of magnitude to their respective evaporation rates. Soils treated with peat had a higher wilting point, which was proportional to the quantity of peat incorporated in the soil and to the amount of unavailable moisture held by the particular peat over and above that held by the soil before mixing.

TABLE 14

*Water absorption of different layers of peat from same bog (91)*

Depth of peat	Nature of plant material	Grams of water absorbed by 100 gm. of peat
<i>cm.</i>		
0-27	Well-decomposed heath and moss peat .....	890
27-43	Moss peat with some Eriophorum .....	1,390
43-61	Undecomposed moss peat .....	1,560
61-76	Well-decomposed heath and moss peat .....	820
76-91	Heath and moss peat residues .....	720
91-117	Well-decomposed heath and some undecomposed moss peat and Eriophorum .....	580
117-131	Well-decomposed sedge and reed peat .....	510
131-157	Well-decomposed sedge and reed peat .....	400

TABLE 15

*Physical properties of several peats (92)*

Nature and location	Apparent specific gravity of oven-dry peat	Moisture holding capacity	Maximum shrinkage	Reaction
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>pH</i>
Sphagnum peat of Orono, Maine .....	0.10	2,305	65	3.9
Sphagnum peat of Cherryfield, Maine .....	...	1,608	..	3.7
Heath—forest peat				
North Carolina .....	0.60	422	72	3.6
Sawgrass peat, Florida .....	0.50	805	74	6.3
Sedimentary peat, Florida .....	0.93	432	82	6.3
Sawgrass peat, Florida .....	0.63	594	76	5.8
Woody-sedge peat, Washington .....	...	617	..	4.8



Numerous methods, many of which give satisfactory results, have been proposed for determining the moisture content of peat. Among these are the vacuum method, the replacement methods, the loss of distillation (35), the desiccator method (167), and the use of special reagents (297).

*Wetting of peat.* Dry peat is not readily wetted by water. The heat of wetting in alcohol-water solutions increases with an increase in water content up to a ratio of water to alcohol of 4:1, where wetting ceases. Extraction with benzol-alcohol before drying does not change the resistance to wetting, since the wax and resin contents of peat are not the significant factors. After evacuation, however, dried peat can be wetted by water, the heat of wetting being 13.7 calories per gram of peat. The wetting resistance was found to be due to a strongly adsorbed air film, since the wetting resistance is not changed even after adsorption of water vapor to 32.7 per cent. Peat has, therefore, been termed an "aerophilic" material (42).

*Drying of peat.* When a peat bog is drained sufficiently so that the surface can bear heavy weights, the peat may still contain 80 to 90 per cent of water. Further drying is necessary to prepare a marketable product. For example, peat moss used for litter usually contains 30 to 35 per cent moisture, and in no case more than 40 per cent; when it is thoroughly air-dried, the amount of moisture may be reduced to 20 per cent. In a marketable state, peat used for soil improvement (sedge and reed or forest peat) may contain 60 to 65 per cent moisture. If this type of peat is dried to a much lower moisture content, it loses to a great extent its property of reabsorbing moisture readily.

Raw peat can be dried most economically in the air. In many cases, recourse is had to the use of artificial heat, or to compressing the peat after it has been taken out of the bog, but such methods have not proved economically successful.

Peat gives off water spontaneously at temperatures lower than 100° C. The nearer the temperature approaches 100° and the longer the heating, the more water is given off. Forcing of dry air through the peat helps drying greatly, especially below 80°. Dehydration of peat is also favored by application of pressure, though there does not appear to be any direct proportion between the amount of pressure and the degree of dehydration. Peat dried under 100° C. exhibits the same changes in colloidal properties as that dried under pressure above 100°. Peat dried for 4 hours at a moderate pressure under 100°, and then allowed to stand in free air at room temperature con-

tinues to dry much more rapidly than raw peat. Peat thoroughly frozen, likewise, dries more quickly and retains a better physical structure (80, 81); it is also more easily torn up and disintegrated. Peat frozen through has a greater water-absorptive capacity than non-frozen peat from the same bog (128). The improvement in the drying of peat probably depends upon the breaking up of the humus gels that hold water within the peat (211).

Considerable attention has also been paid to the use of various peat coagulants to assist in the drying of peat (285). Among these,  $\text{FeCl}_3$  and  $\text{CaCl}_2$  have received particular attention. Their practical significance is still open to question, except for very special uses.

*Peat as a colloidal system.* Since peat consists largely of organic bodies in a colloidal state, it possesses various properties which are characteristic of colloids. These may be summarized as follows: 1, the ability to form a stable emulsion with water; 2, the formation of a peat hydrosol from such an emulsion; 3, the swelling properties of peat; 4, the ability of peat to lose water; 5, the buffering properties of peat; 6, the coagulation of peat with bases of heavy metals as well as with salts.

High calcium peats form suspensions readily. The fibrous and more acid peats, however, do not form any emulsions in water. The particles in suspension are charged electronegatively and move in an electric field toward the positive pole at a speed of 0.000024 cm. per sec. Neutral and acid salts, as well as acids, coagulate the hydrosol formed from peat. Alkalies peptize the hydrosol. Calcium chloride is a good coagulant; the same is true of  $\text{Fe}^{++}$  and especially of  $\text{Fe}^{+++}$ , colloidal  $\text{Fe}_2\text{O}_3$  being most efficient. The filtration rate increases with an increase in concentration of the coagulating agent, but when this concentration reaches a certain maximum further increases in concentration may lead to a decrease in the rate of filtration (336).

The valency of the cation determines the capacity of the salts to coagulate the peat hydrosol. The following corresponding values have been obtained for the coagulation effect of Na, Mg, Al: 1, 14, 2700. The coagulated products show adsorption properties.

*Volume weight of peats.* It has been suggested that the determination of the air content of peat in a fresh condition is of greater value than the determination of the pore volumes (235). The swelling and shrinking of the organic colloids make the determination of the pore volume rather difficult. Seasonal variations are found in the water and air content of the peat. The degree of decomposition of peat soils

is influenced by the air content. The volume weights of a variety of peats are presented in table 16.

TABLE 16  
*Volume weight and chemical composition of various peats (292)*  
Kilograms per cubic meter

	Weight		Composition of raw peat			
	Raw peat	Anhydrous peat	Nitrogen	Lime	Phosphoric acid	Potash
Young sphagnum peat ...	952	83	0.56	0.3	0.04	0.08
Intermediate peat .....	1,000	155	1.64	0.8	0.07	0.06
Old sphagnum peat .....	1,010	111	1.27	0.4	0.05	0.06
Transition sphagnum and sedge peat .....	992	139	2.28	0.9	0.08	0.04
Transition forest peat ...	889	135	1.99	2.4	0.07	0.07
Reed peat .....	991	103	1.99	0.5	0.09	0.08
Sedimentary peat,						
(a) containing alluvial material .....	1,104	387	7.04	8.6	1.43	0.70
(b) without admixtures .....	1,072	154	2.01	0.9	0.12	...
Liver peat .....	1,060	181	3.56	2.1	0.20	0.90
Heather peat .....	691	499	4.09	0.8	0.75	0.45

*Absorption of bases.* Among the colloidal properties of peat, the absorption of bases and the buffering capacity, are next in importance to the ability to absorb water. The absorption of the cations  $\text{Ca}^{++}$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$ , as well as of the anion  $\text{PO}_4^{=}$ , by peats of different origin from solutions of different salts was found to take place in agreement with the absorption formula of Freundlich (198). The anion part of the absorbed Ca-salt had no influence on the degree of absorption of the calcium, with the exception of calcium phosphate, which was absorbed in large quantities by sphagnum peat. Potassium and ammonium are absorbed to a greater extent from the solutions of their salts by sedge and reed than by sphagnum peats. This difference in absorption may be explained by a higher content of calcium in the first type of peat. Consequently liming of sphagnum or highmoor peats has a favorable influence on the absorption properties for potassium and ammonium; the loss of these valuable ions in drainage waters is thereby reduced (198). When neutral salts are allowed to react with acid peats, the hydrogen in the peat is replaced by the cation of the salt, although not on an equivalent basis. There may be an increase either in the cation or in the anion of the salt solution, depending on the concentration and nature of the ions. The exchange may be in the nature of a Donnan equilibrium (27).

A comparison of the rate of absorption of different bases by acid peat showed (304) that  $\text{CaCO}_3$  was acted upon least rapidly, followed in ascending order by  $\text{CaO}$ ,  $\text{Na}_2\text{CO}_3$ , and  $\text{NaOH}$ . The effects of the hydroxide and carbonate of either base were similar at  $\text{pH} < 6.0$ , but at  $\text{pH} 7.0$  the hydroxides were more active. The rate of neutralization with  $\text{CaCO}_3$  increased with an increase in the initial  $\text{pH}$  value of the peat. This suggested a method for calculating the lime required for the neutralization of peat. The nature of the peats had considerable effect upon the change in  $\text{pH}$  per unit of calcium added. Changes in  $\text{pH}$  as a result of liming were partly correlated with the decomposition of the peat (277).

TABLE 17

*Relation of buffer capacity to soil reaction and to the ash and the lime content of peat (327)*

Ash and lime, in percentages of dry soil

Peat	Buffer capacity*	pH	Ash	CaO
39	2.30	3.8	5.84	soil 0.60
17	2.70	4.4	8.73	1.42
33	3.40	4.6	7.78	2.10
8	4.20	4.6	17.01	3.41
38	4.60	5.4	17.02	3.21
53	4.75	5.5	24.24	3.12
45	4.85	5.6	13.04	4.48
9	4.87	5.3	17.24	6.03
31	4.90	5.9	19.76	4.99
44	4.94	6.4	31.76	5.15
22	4.97	6.2	17.14	7.94
43	4.99	7.6	21.73	9.40

\* M.e. per 5 gm. soil from 5 m.e. of  $\text{HCl}$ .

A study of the absorption of ammonia and other bases by different types of peat revealed (175) the fact that sphagnum peats contain more absorbed ammonia than the sedge and reed peats. The upper layers of both types of peat were found to contain more absorbed ammonia than the lower layers. The calcium in the peat is present in the absorbed state and is easily replaced by sodium. The sphagnum peats give appreciable amounts of phosphorus when treated with  $\text{NaCl}$  solution; sedge and reed peats, however, give only traces of ammonia. The former peats are saturated with hydrogen and the latter with calcium. The ammonium-retaining and base-exchange capacities of peat are due to different and variable fractions of the total hydrogen present in the peat (91).

One hundred parts of peat (sphagnum) were reported (cited in 128) to be able to absorb 1.6 to 2.5 parts of ammonia, whereas the same weight of straw absorbed only 0.26 parts. In another experiment, 100 kilos of peat absorbed as much ammonia as 225 kilos of straw. This results in the removal of the bad odor in stables and privy closets in which this type of peat is used. Because of its ability to absorb urine and to retain the ammonia, the most valuable constituents of the manure, which would otherwise be lost by decomposition or evaporation, peat contributes to their preservation for agricultural use. König demonstrated as far back as 1882 (128) that the absorptive power of peat for ammonia is influenced markedly by the nature of the peat. The following results were reported, by the use of 20 gm. of dry peat and a solution of ammonium carbonate:

Nature of peat	Ash content of peat per cent	Nitrogen absorbed from solution per cent	Nitrogen absorbed by 100 parts of dry peat
Moss peat .....	2.2	73.6	1.55
Moss peat .....	2.5	65.3	1.37
Decomposed heath peat .....	6.9	47.7	1.00
Sedge and wood peat .....	22.0	39.8	0.84
Sedge and wood peat .....	37.5	32.1	0.68

The addition of peat to soil results in an increase in the buffer and absorption capacities of the soil (79,327). Sphagnum peats, because of their high acidity, low base content, and low degree of saturation have a high buffer capacity for bases and a low capacity for acids. On the other hand, the low acidity, the high base content, and the high degree of saturation of sedge and reed peats gives them a high buffer capacity for acids and a low capacity for bases. The transition peats usually fall between the above (15). The buffer capacity of peats and peat soils is thus closely related to their acidity, content of bases, especially calcium, and degree of saturation (152).

The base-exchange capacity of peat can be determined by treating it with 0.2N barium acetate solution. The material thus treated is leached twice with normal  $BaCl_2$  solution and washed free from chlorides. The barium held is replaced by ammonia, normal  $NH_4Cl$  solution being used, and the ammonia is determined in the filtrate (197). The absorbed barium may also be extracted with hydrochloric acid and determined gravimetrically as barium sulfate (91).

*Reaction of peats.* A number of methods have been used for determining the total and active acidity in peat. The original  $CaCO_3$  method of Tacke and Süchting (293) has been modified (259) by

the substitution of calcium bicarbonate solution. This is prepared by passing  $\text{CO}_2$  into a  $\text{CaCO}_3$  suspension until it becomes saturated. One gram of finely divided peat is added to 200 cc. of the  $\text{Ca}(\text{HCO}_3)_2$  solution containing 0.4 gm.  $\text{CaO}$ ; the flask is stoppered and shaken or allowed to stand with occasional stirring for 24 hours. The solution is filtered and titrated with 0.02N hydrochloric acid. The results are expressed in milligrams of  $\text{CaO}$  per gm. of air-dry peat. Increased fineness of grinding increases the reaction velocity and slightly increases the final value.

Most of the measurements of the reaction of peats and peat soils, however, are now carried out by the use of pH measurements. The relation between the pH of the peat and its buffer capacity is presented in table 17.

The development of acidity in peat soils was said to be associated with oxidation (215). Four main types of peats and peat soils have thus been differentiated on the basis of their pH values: 1, oxidizing peats having a pH of less than 3.8, with *Calluna vulgaris*, *Vaccinium myrtillus*, or *Molinia coerulea* as the dominant members of the vegetation; 2, reducing peats with an approximate pH of 5.5 to 4.4, with a mixed vegetation; 3, peats feebly oxidizing at times, having an approximate pH of 4.4 to 3.4, with mixed vegetation of the highmoor type; and 4, peats feebly oxidizing at times, below pH 3.4, with an *Eriophorum* vegetation. A change from pH 4.0 in the surface layer to near neutrality at the bottom is often observed (156, 164).

*Temperature relations in peat soils.* Peat bogs and peat soils show a drop in temperature from the surface downward, followed by a rise at the bottom. The latter is due to the more rapid heating of the mineral bottom from the periphery of the deposit (330). The movement of heat from the lower layers to the surface takes place more rapidly in a moist than in a dry peat soil, especially when the soil is compacted. The looser the surface layer of the soil, the greater is the danger from frosts.

The temperature changes in peat soils are described (251, 252) as follows:

During the night, the cooler air from the upper atmosphere is driven down over the peat area by the warmer currents rising from the adjacent mineral soils, since these give up their heat to the atmosphere much more rapidly than do peat soils under similar local weather conditions. Lower temperatures tend to occur during the night in the zones of the atmosphere lying next to the peat surface. The surface layer of peat gives up its heat to cooler air passing over it much more

rapidly than it can receive heat from the lower layers. This results often in untimely frosts on parts of the area where the water table lies well below the surface, even when those parts of the peat bog with the ground water level near the surface or adjacent areas of mineral soil are not touched by the frost at all.

Heat conductivity appears to be the predominant factor responsible for the difference in frost occurrence. Mineral soils are good conductors of heat, whereas organic soils are comparatively poor conductors. Mineral soils, therefore, allow the heat that has been accumulated at various depths during the day to travel to the surface at a greater speed than in the case of the peat soils. The result is that the surface of the mineral soils is kept at a higher temperature, while that of the peat soils is allowed to become excessively cold, even though their temperature at the lower depths is much higher than that of the mineral soils. The air above the mineral soils is warmed at a correspondingly greater degree than that above the organic soils, and on a night when not too heavy a frost occurs the mineral soils are able to prevent a frost, while on the peat soils frost occurs (36).

Dry peat is a poor conductor of heat; the more compacted is peat, the better it is able to conduct heat. Moist peat conducts heat better than dry peat; and the wetter it is the better heat conductor it becomes. The conductivity of moist or wet peat lies between that of water and that of dry peat (251).

Crops grown on peat soils are, therefore, much more subject to frost during the spring and summer months than those grown on mineral soils. The moisture content of the peat soil, its compactness, the state of the decomposition of the peat, its mineral content, and methods of fertilization, are of great importance in this connection.

The more decomposed a peat becomes, the less is the probability of frost danger. Old peat soils, therefore, are not so subject to frost as are those recently reclaimed. When the mineral content of the peat is high, the danger from frost is also less. If the surface of the peat is covered by a layer of sand or clay, the danger of summer frosts can thus be greatly decreased.

*Toxicity of bog water.* It has been pointed out previously that bog water has a certain injurious effect upon growing plants (236). It was at first suggested (160) that the toxicity of the bog water is due to the presence of chemical compounds which are harmful to the plants. This was based on the observation that water from a bog overflowing into adjacent meadows caused considerable damage.

Among the reasons which are commonly suggested to explain this injurious effect, two are of special interest: first, the water acts as a reducing agent, and second, the water contains chemical substances that are otherwise harmful to plant life. When exposed to the air, the moist peat takes up oxygen; on the surface is formed a hard crust which is impervious to the further absorption of oxygen. The humus compounds of the peat, by withdrawing oxygen from iron compounds, are believed to form salts which are destructive to vegetable life (275).

Rigg and Thompson (240), in a study of peat bogs around Puget Sound, found that the water from the bogs gave a precipitate on standing a few hours after saturation with electrolytes; it also gave a precipitate on standing a year or more without electrolytes. The filtrate that was obtained on precipitation with  $(\text{NH}_4)_2\text{SO}_4$ , was dialyzed until free from sulfates. It was found to be non-toxic to the root hairs of *Tradescantia* cuttings. Bog water, on the other hand, when dialyzed for the same length of time as the filtrate, was toxic to these root hairs. It was suggested that cultivation of the peat results in the oxidation of the toxic material to non-toxic compounds.

Livingston (173) found that stimulating substances are present in the water of bogs that are characterized by a specific type of vegetation; they are absent, however, from river swamps and large lakes. Bogs with a type of vegetation intermediate between that of the river swamp and true peat, contain a limited concentration of these substances, their amount being roughly proportional to the extent of the xerophilous character of the vegetation. The stimulating substances were believed to play an important role in preventing the growth in bogs of plants other than those of a xerophilous habit (48).

*The atmosphere of peat bogs.* Rigg and associates (241) made a study of the composition of the gases in peat bogs and in peat soils. They found that the difference between wet bogs and dry bogs is characterized by the gases dissolved in the waters of the bogs, wet bogs containing methane and greater concentrations of carbon dioxide. The methane replaces the nitrogen in solution, and consequently wet bogs contain smaller quantities of dissolved nitrogen. There was very little, if any, oxygen in the samples of bog water examined. This marked oxygen deficiency was believed to be a large factor in the inhibition of growth of non-bog plants in bogs.



## CHAPTER VI

## MICROBIOLOGY OF PEATS

## PEAT FORMATION AND DECOMPOSITION. PEAT SUBSIDENCE

Microorganisms play three distinct roles in the formation and decomposition of peat:

1. They bring about the first stages of the rapid breakdown of plant residues, which gradually results in their transformation into peat. Most of the organisms concerned in this process are aerobic in nature.

2. After they have been formed, the various layers or horizons of a peat bog do not remain undisturbed through the centuries. Gradual changes in the peat take place continuously, largely through microbiological action. The organisms involved in these processes are chiefly of the anaerobic types.

3. When a peat bog is drained and air is admitted, the peat begins to undergo decomposition. As a result, the complex organic compounds are broken down into simpler substances. This is accompanied by the liberation of the various constituent elements of the peat in forms available for plant growth. The organisms concerned in these processes are chiefly aerobic, although they may be quite distinct from those which are concerned in the first group of processes.

*Occurrence of microorganisms in peat.* Many chemists have questioned the occurrence of microorganisms in peat bogs. They believed that bogs are largely sterile and that the occasional occurrence of microorganisms is accidental. As late as 1912, a prominent peat student (30) emphasized, in the introduction to his book on peat, that "whereas it is generally accepted that the decomposition of plant residues in mineral soils is microbiological in nature, microorganisms play no role in peat formation." This was the point of view accepted by many chemists and geologists, who believed that the changes occurring during the formation of peat from plant materials are purely chemical in nature, involving processes of hydrolysis, oxidation, reduction, and condensation.

Even those who were willing to agree that the initial stages of peat formation from plant residues may be caused by microorganisms, persisted in their belief that once peat has been formed, it remains resistant to further change. An attempt was even made to clothe an insufficient understanding of the processes involved in peat formation

in such vague terms as "putrification," "humification," "liptobiolite formation," "rotting of waste materials," and "peatification," as if these were purely chemical processes, brought about by atmospheric agencies and not involving activities of microorganisms (233).

When a detailed study was undertaken of the microbiological population of peat bogs (12, 242, 44, 310, 26), the fact came to light that not only are microorganisms found in those bogs in very large numbers, at the surface, at different depths, and in different stages of bog development, but all the transformations taking place in the bog are characteristically microbiological in nature. It thus became recognized that peat formation is largely a microbiological process, which begins immediately after the death of the plants. The subsequent, even if slower, changes are of both a microbiological and a chemical nature.

In lowmoor peat bogs, the numbers of aerobic bacteria diminish gradually with depth, whereas the numbers of anaerobic bacteria increase. Fungi, as well as aerobic cellulose-decomposing and nitrifying bacteria, are found in lowmoor peat bogs at or just below the surface and tend to disappear at 75 to 90 cm. Actinomycetes are abundant at the surface of the lowmoor bog. They also diminish with depth, but not so rapidly as the fungi, and disappear completely at a depth of 120-150 cm. The rate of decomposition of peat, as measured by the evolution of  $\text{CO}_2$  and of other gases, is much slower than the decomposition of fresh plant residues (25, 166).

Among the various groups of microorganisms found in peat bogs, the occurrence of cellulose-decomposing bacteria, especially in lowmoor and in forest peats, is most characteristic. Their presence is associated with the decomposition of the cellulose in these bogs. The activities of the anaerobic bacteria in the lower layers result in the production from cellulose of various gases rich in methane and in hydrogen; in sulfur-containing bogs, hydrogen sulfide is another characteristic product of decomposition. Cellulose-decomposing bacteria also occur in highmoor peat bogs, though the acid reaction is not very favorable for the development of cellulose-decomposing bacteria. This fact and the fact that the carbohydrates of the sphagnum plants are highly resistant to decomposition, account for the very slow disintegration of these plants in the peat bog. Sphagnum plants with a relatively low nitrogen content (about 1 per cent of the dry weight) will liberate a part of this nitrogen as ammonia during decomposition. This is due largely to the inability of the microorganisms to attack readily the carbohydrates of the sphagnum and to build up cell protein from the ammonia. Furthermore, the lack of nitrifying bacteria prevents the oxidation of the ammonia to nitrate.

Thiessen and Strickler (300) found bacteria at all different depths of four peat profiles. Fungi were observed only in the upper strata. Actinomycetes were not found at all in one deposit and only in the upper strata of the other three. Nitrifying bacteria were absent in one deposit but were present at the surface of two others and to a depth of two and one-half feet in the fourth. Cellulose-decomposing bacteria were recorded for all deposits. Some of the bogs contained aerobic thermophilic bacteria at all depths, and anaerobic thermophiles down to two feet.

The behavior of the various known types of cellulose-decomposing microorganisms was believed (299) to be proof that their activity is limited to the very surface layers of the peat profile. Cellulose decomposition decreases in intensity under an excess of moisture and ceases in acid peats long before the cellulose has been eliminated. The addition of stable manure was found to increase the numbers of microorganisms as well as their activity in woody sedge peat. The addition of lime stimulated evolution of  $\text{CO}_2$  but had little effect on the numbers of organisms (305).

The presence of microorganisms in different peat layers, laid down many centuries ago, has thus been definitely established. These microorganisms, principally bacteria, have been shown to be chiefly responsible for the formation and transformation of peat (table 18).

*Processes of peat formation.* The processes of decomposition involved in the formation of peat by microorganisms from various plant materials, either grown in the bog or brought into it by wind and by water, can best be illustrated by comparing the chemical composition of various types of peat with the plants from which they originated. The data presented in tables 11 and 12 show that, in lowmoor peats, the cellulose has disappeared to a large extent, whereas the lignin, protein, and mineral constituents have greatly increased. In this respect, the processes of decomposition and synthesis are very similar to those taking place in composts and in soils. In highmoor peats, the cellulose and hemicelluloses have accumulated, whereas the nitrogen and minerals have not increased appreciably. This is due to the resistance of the carbohydrates to decomposition, either as a result of differences in the physical and chemical condition of these compounds in sphagnum plants or of the acid conditions prevailing in these bogs.

*The influence of drainage and aeration upon the decomposition of peats.* Peats in their natural environment are relatively poor in aerobic microorganisms and decompose only very slowly; however, when properly drained, with the humidity favorable and air accessible, the bacterial flora is greatly increased and decomposition is accel-

TABLE 18  
*Occurrence of microorganisms in a lowmoor peat profile (310)*  
 On basis of fresh peat material

Depth of sample	pH	Moisture content	Bacteria (aerobic and facultative aerobic and actinomycetes)	Actinomycetes	Fungi	Aerobic cellulose-decomposing bacteria*	Nitrifying bacteria*	Anaerobic bacteria
cm.		per cent		per cent				
Surface .....	5.9	61.1	6,000,000	90	105,000	++	+++	+
30 .....	6.0	72.5	350,000	40	250	+	++	++
45 .....	6.2	82.3	450,000	25	175	..	++	++
60 .....	6.3	87.5	40,000	20	150	..	+	++
75 .....	6.3	87.1	35,000	25	33	..	+	++
90 .....	6.4	80.8	20,000	15	....	..	..	++
120 .....	6.7	83.6	100,000	2	....	..	..	+++
150 .....	6.8	84.5	500,000	..	....	..	..	+++
165 .....	8.0	64.8	200,000	..	....	..	..	+++
Clay bottom								

\* + designates a few; ++ a fair number; +++ abundance of organisms; ++++ numerous; (about 25,000 or more colonies formed by 1 gm. of material).

erated. Under such conditions, peats change rapidly in composition, particularly in respect to organic substances. This is accompanied by the development of a wide variety of bacteria (182).

The process of decomposition in drained and aerated peat can be followed easily by measuring the rate of  $\text{CO}_2$  evolution and by the formation and accumulation of ammonia and nitrate. The relative moisture content of the peat has a marked influence upon the rate of its decomposition. This is brought out by the results of one experiment, where, under certain moisture conditions favorable for the activities of microorganisms, about 15 per cent of the total dry material of lowmoor peat was decomposed in 18 months. It was found that by controlling the moisture content, one can control, almost at will, the speed of decomposition of the peat. The optimum moisture for the aerobic decomposition of a lowmoor peat was shown to be 50 to 80 per cent, on the basis of the moist peat; above and below this range, the rate of decomposition rapidly diminished (Fig. 13).

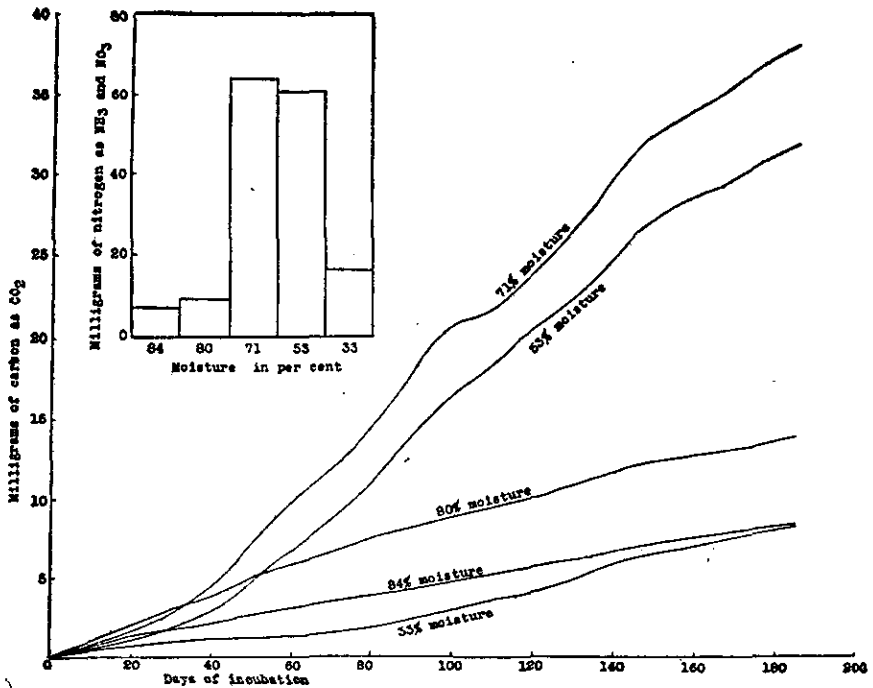


FIG. 13. Influence of moisture upon the decomposition of peat, taken from the surface 30 cm. of the bog, during the early stages of decomposition, as shown by evolution of  $\text{CO}_2$  and liberation of nitrogen in an available form (308).

The chemical changes observed to occur in the organic constituents of lowmoor peats as a result of decomposition, brought out the fact that the peat decomposed as a whole, none of the specific organic complexes disappearing more rapidly than others. The liberation of the carbon in the peat as  $\text{CO}_2$  was accompanied by a parallel transformation of the organic nitrogen to ammonia, with an average C:N ratio of 18:1, which was that of the peat itself. With the progress of decomposition, the peat constituents soluble in dilute alkali solutions also increased. Drying of peat, followed by re-moistening, greatly stimulated the rapidity of decomposition.

The subject of nitrification in peat soils has attracted considerable attention. The transition from the protein material to nitrate proceeds through the ammonia stage (295). Arnd (14) observed that in certain peats nitrification was a very slow process and that nitrifying organisms were very few in number. Upon the addition of lime to an acid peat, nitrification was greatly stimulated, although it was not possible to correlate the degree of nitrification with the amount of lime added or with the pH value of the peat (271, 329). The seasonal fluctuations of the nitrate content and of the reaction in a lowmoor peat soil is brought out in figure 14.

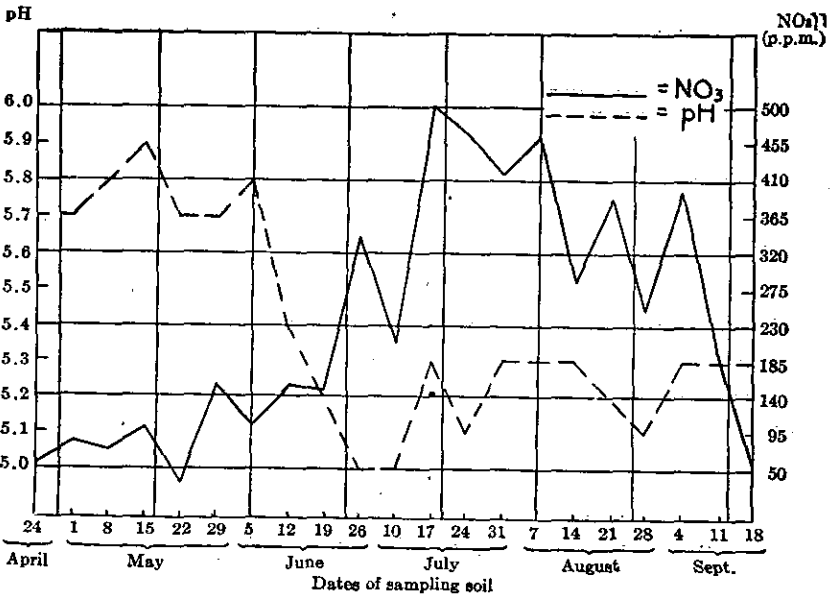


FIG. 14. Seasonal fluctuations in nitrate nitrogen and soil reaction in the surface 4 inches of a lowmoor soil (329).

Valmari (307) found the largest amount of ammonia produced in peats with a water content of 70 to 80 per cent of their total water-retaining power; the optimum amount of moisture for nitrate accumulation was about 10 per cent lower than that for ammonia formation. The presence of bases favored the process of nitrification. The addition of potash and phosphate had a favorable effect. Willis (325) studied the effect of lime upon a lowmoor peat containing 52.8 per cent volatile matter and having an initial pH of 3.6. The nitrates in the unlimed portion of the peat increased from 28 to 114 parts per million; where lime was added, they increased on the average, to 205 parts per million of the moisture-free peat. Nitrate nitrogen was found (329) to accumulate rather rapidly in a newly cleared bog but to a somewhat less extent in a peat that had been under cultivation 20 or more years (172).

The addition of stable manure to peat has a favorable effect (88) upon decomposition and nitrification; this is believed to be due to the inoculation of the peat with the bacteria of the manure. Any practice that results in excessive nitrification, however, has been found to be undesirable. A study of unproductive peat soils indicated (322) that in some instances excessive quantities of nitrate may be responsible for poor crop growth. Alternate wetting and drying of the peat results in an excessive concentration of the salts at the surface of the soil (329).

Peat may prove to be an ideal medium for denitrifying organisms; resulting in a rapid destruction of the nitrate (243, 13, 14). Unsuitable conditions of drainage and acidity will inhibit the process of nitrification. Shallow layers of peat placed under unfavorable moisture conditions were found to lose nitrogen. The conclusion was reached that, under field conditions, losses of nitrogen cannot be completely prevented.

The addition of stable manure to peat soils initiates a great many processes, some of which may be chemical and others biological in nature (278). The microorganisms already present in the peat as well as those artificially introduced with the manure are believed to be responsible for the numerous changes in the physical nature and chemical composition of the peat. In one experiment, when manure was added to peat placed in a series of cylinders, the indigenous microflora of the peat, as well as the added flora, developed rapidly. The latter rather than the former were shown to be largely responsible for the greater part of the decomposition processes in the peat thus treated. This treatment resulted in a marked increase in the fertility of the peat. Raw peat treated with composts tended to maintain its

TABLE 19  
*Influence of moisture and added nitrogen upon microbiological activities in lowmoor peat (308)*  
 On the basis of 20 gm. of dry peat

Moisture content per cent	Nitrogen added*	CO <sub>2</sub> given off				NH <sub>3</sub> -N mgm.	NO <sub>3</sub> -N mgm.	Total nitrogen mgm.
		2 days mgm. C.	8 days mgm. C.	12 days mgm. C.	20 days mgm. C.			
Natural peat <sup>1</sup> .....	-	14.8	34.5	46.8	64.3	0.3	11.3	11.6
Natural peat <sup>2</sup> .....	+	16.8	37.9	50.9	68.7	0.3	22.2	22.5
200 <sup>3</sup> .....	-	8.3	23.1	35.0	54.4	7.9	1.5	9.4
200 .....	+	9.0	24.3	36.1	54.5	17.5	1.7	19.2
300 .....	-	6.6	20.6	31.0	48.9	8.2	0.8	9.0
300 .....	+	8.2	23.8	34.7	51.6	18.4	1.0	19.4
450 .....	-	3.4	13.9	20.2	32.2	9.1	0.9	10.0
450 .....	+	3.4	14.9	23.3	36.4	20.6	0.9	21.5

\* 10 mgm. of nitrogen added in the form of ammonium sulfate.

<sup>1</sup> Fresh peat containing 67 per cent moisture.

<sup>2</sup> Peat previously air-dried, then adjusted to 200, 300, and 450 per cent moisture.



TABLE 20.  
*Influence of moisture upon the rapidity of decomposition of lowmoor peat (308)*  
 On basis of 20 gm. of dry peat

Treatment of peat	Moisture content	CO <sub>2</sub> liberated in 21 days	Nitrogen liberated in 21 days		
			NH <sub>3</sub> -N	NO <sub>3</sub> -N	Total N
Untreated, 60 gm. ....	per cent 66.6	mgm: C 164	mgm: 1.6	mgm: 8.2	mgm: 9.8
Air-dried,* 23 gm., + 20 cc. water .....	53.5	115.1	25.1	3.8	28.9
Air-dried,* 23 gm., + 37 cc. water <sup>†</sup> .....	66.7	41.9	9.6	5.6	15.2
Air-dry peat, 11.5 gm., + 30 gm. moist peat .....	51.8	109.4	22.4	4.2	26.6

\* Only 15 per cent moisture left.

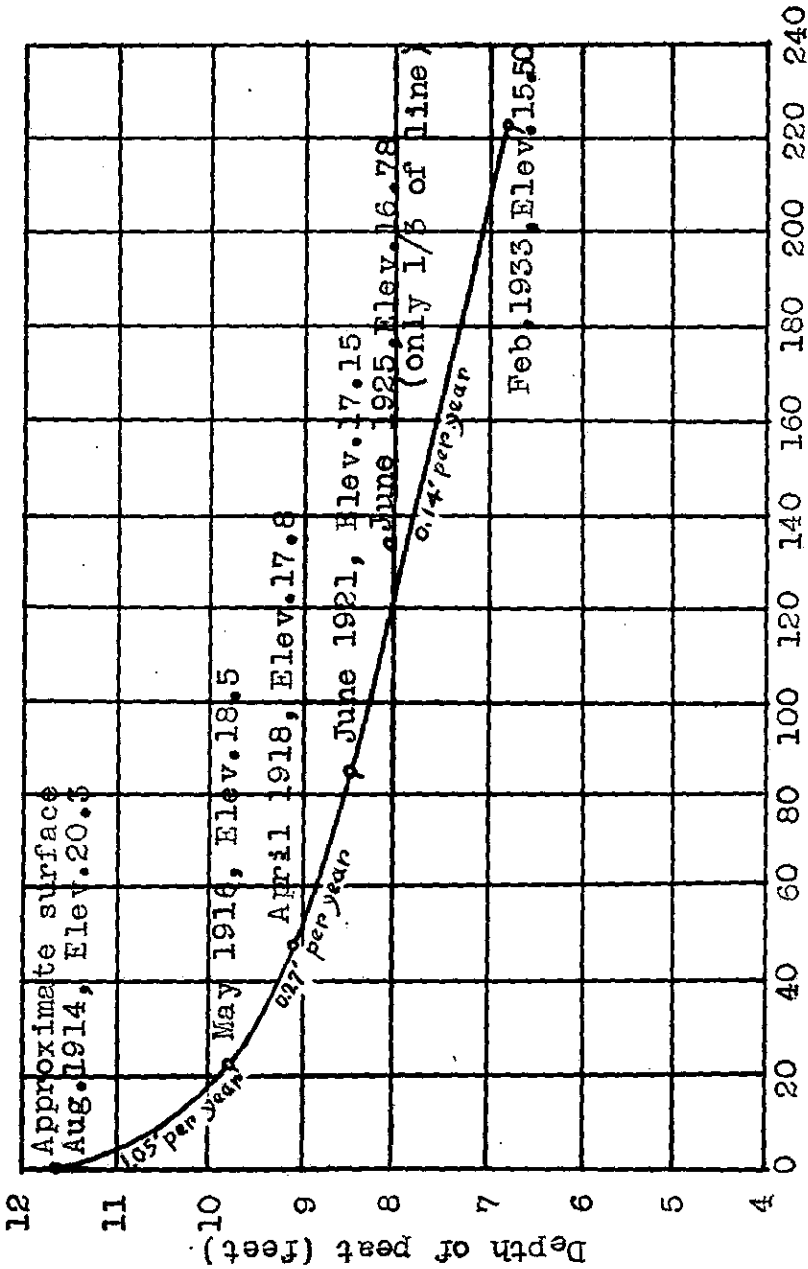
<sup>†</sup> Saturated with water, not well absorbed; anaerobic environment.

fertility during many years of continuous cropping. That the effect thus produced by the manure was partly due to improved aeration was demonstrated by the fact that the incorporation of sand in the peat also increased the biological activity as well as the crop response. In order to increase the rate of decomposition of the peat, it has been variously treated with acids and alkalies at various temperatures. A number of peat preparations have thus been produced and placed on the market, on the basis of their greater reactivity. Many of these preparations have been enriched in available nitrogen by a process designated as ammoniation, or with phosphorus and potash, or with all three nutrient elements. In view of the low concentration in most peats of the so-called trace elements, small amounts of Cu, Mn, Zn, and others, have often been added (76, 77).

Spontaneous ignition and self-heating of peat may be classified among the phenomena associated with peat decomposition. These processes take place when peat is partly dried and placed in heaps for later use. The cellulose content of the peat does not appear to influence these processes; however, the pectins and other hemicelluloses seem to be, at least partly, responsible. This process depends largely upon the physical and microbiological condition of the heap, together with a combination of certain chemical factors, such as the amount of iron combined with the organic substances (162). It is now generally assumed that the oxidation processes in a heap of partly dried peat are initiated by bacteria, with the result that a rise in temperature takes place. This is followed by chemical changes in the state of certain elements or compounds present in the peat or produced during decomposition, which finally lead to spontaneous heating (123).

*Subsidence of peat.* When a peat bog is partly or fully drained, two groups of processes set in: (a) the physical shrinkage of the peat, due to greater compactness (fig. 15), and (b) aerobic decomposition of some of the organic constituents, favored by improved aeration. As a result of these two reactions, the organic colloids which make up the major part of the peat, undergo a considerable amount of shrinkage. This results in an increase in the rate of subsidence of the peat.

The subsidence of peat in the Fenland in Great Britain is one of the oldest records available. In 1848, a graduated iron column was sunk into the peat bog down to the underlying clay, so that the top of the column was level with the surface of the bog. In 1870, a subsidence of 7 feet and 8 inches was recorded, and in 1875 of 7 feet and 9 inches. Pumps were then installed to remove the excess water, a



Months since drainage  
 FIG. 15. Subsidence of peat soils in Florida.—Okeelanta peat profile (47).

procedure necessitated by the extensive subsidence. The lowering of the water table resulted in a further drop of 3 inches in one year. In 1913, or 65 years after the insertion of the column, the total subsidence was found to be 10 feet. Since the initial depth of the peat in the Fenland was 18 feet, the mean annual compression for the total period was 2.2 per cent; this ranged from 93 inches in 27 years, with an 18-foot column of peat, to 24 inches in 38 years, with an initial peat layer only 10 feet deep (273).

Careful studies of the subsidence of peats have been made in a number of States in this country. Records of twenty-two reclaimed peat areas in southern Louisiana and Florida (209), ranging in depth from a few inches to 16 feet, indicated an average subsidence of approximately 18 inches during 8 years. Tests made with fresh, undrained Louisiana peat showed shrinkages of about 60 per cent as a result of drying. When the peat was resaturated with water, even for a long time, only 70 per cent of the original volume was recovered. As the density of the surface peat layer increased, there was an increasing check to aeration and subsidence.

Certain peats in Oregon, with an initial depth of 7 feet, were also found to shrink 18 inches in 10 years, as a result of drainage and cultivation. In some cases, following drainage, the subsidence was approximately two feet in 20 years; approximately one inch of fresh peat was turned up at each subsequent plowing (226).

Subsidence of peat is greatest during the first years following drainage, the total amount of subsidence depending on the depth of the drainage canals, as well as on the depth and composition of the peat. The shrinkage upon drying is due primarily to the organic colloids. The process is partly irreversible, since the colloidal state is not fully recovered even upon long contact of the dry peat with water. In the drying of peat blocks for industrial use, shrinkage may reduce the size of the block to less than one-fourth the original volume (110).

In designing drainage systems, vertical shrinkage of the order of 33 per cent has been suggested (226). Thoroughness of subdrainage of the peat has various effects upon the resulting soil; it increases, for example, the tendency to and the intensity of frost at the surface. Dryness of the peat surface increases the danger of frost, especially when other conditions are favorable for it (252).

Erosion by wind or water may also cause losses of peat. The rate of peat decomposition can be controlled by adjusting the water table, thus controlling the moisture, temperature, and aeration of the peat. It can be influenced further by modifying the reaction and nutrients required by microorganisms in the decomposition of the peat.

In a study of the subsidence of peat soils in Florida, Clayton (46, 47) found that the rate of subsidence appeared to be proportional to the depth of the deposit above the permanent water table, or to the total depth in those cases where the water table is below the bottom of the deposit. Peat areas near Okeelanta in the upper Everglades and at Fellsmere, Indian River City, were selected for this study. The amount of subsidence was found to depend more on the depth of the peat layer above the water table than on the total depth of the peat in the deposit. In the more compact peat formations, such as the "custard apple" belt adjacent to Lake Okeechobee, the subsidence was less than that in the more fibrous saw-grass peat, farther from the lake. This is due to the higher mineral content and greater density of the "custard apple" soil. Immediately following drainage, the rate of subsidence is highest; it decreases with time. It was suggested that if peat fires are prevented, the rate of subsidence may be reduced very materially. The losses due to biological and chemical oxidation may be largely offset by the addition of the fibrous portion of root systems of the growing plants. Cultivation accounted for only a small part of the total subsidence. The total subsidence reported for the Florida peats was about 1.0 to 1.5 inches annually, following drainage. When the water table was high (18 inches below the surface), the annual subsidence was reduced to 0.8 inch.

Some work has also been done on the subsidence of peats in New Jersey. Smock (276) reported in 1892 that the drainage of peat bogs resulted in a long-continued shrinkage or subsidence of the land, the actual amount varying with the depth and character of the peat formation. The following approximate subsidences were noted: Hackensack Meadows, during 1869 to 1887, 3 to 3.5 feet; Cohansey Creek, Cumberland County, peat 2.5 to 3 feet; Mays Landing peat, about 1 foot; the greatest subsidence, that of a Salem peat, 3.5 to 4.5 feet. It was suggested in that report that "in planning drainage works this tendency to subsidence must be fully appreciated as, if long continued, the ditches become more and more ineffective, and thereafter the water can only be removed by pumping. Failure to discern the shrinkage of marsh soils has caused many to believe that the tides rise higher than in former years, but there is no evidence that such is the case."

## CHAPTER VII

## UTILIZATION OF PEAT FOR AGRICULTURAL PURPOSES

The major uses of peats and peat lands throughout the world, and especially in the United States, are connected with agriculture. This includes their use as (a) a soil for the growth of field and garden crops, (b) a source of organic matter for soil improvement, (c) a supplement or carrier in the preparation of certain fertilizer materials, (d) an organic material in the preparation of composts, and (e) a litter in stables.

The reclamation of peat lands and their utilization for crop production probably offers the greatest possibilities in this country. Since most of the peats in the United States have a fairly high nitrogen content (1.5-3.0 per cent), they form one of the most extensive sources of this essential element, which can be gradually converted into plant food at a sufficiently low price to be economically justifiable.

The great agricultural potentialities of the peat lands in the United States were realized nearly a century ago by one of the early American students of peat, Brown (37), who wrote:

Some 40 years ago, these boggy or swampy lands were regarded as nearly worthless for anything except the meagre timber, or fuel which might be obtained from them in winter, or the scanty and coarse herbage they afforded to cattle during the summer drought. Such is the change in their value that, where, at the period named, they would scarcely command \$5 an acre, they now bring from \$30 to \$100; and, in the neighborhood of villages located on plain or sandy lands, where they afford the greatest benefit in gardening, they are worth \$500 an acre, provided the muck is of good quality, and the deposit deep and of convenient access. Indeed, it is often said by persons about to purchase farms, that they would not enter upon such as are not supplied with meadow muck; for, where it abounds, and a good barn-cellar exists, thrift and prosperity are always certain.

Brown also recognized the value of peat for soil improvement, thereby making possible more intensive cultivation of crops on less land. Peat was believed to be most suitable for restoring the exhausted lands to fertility:

It possesses the wonderful power of *tempering* all other soils and bringing them into activity, sometimes by its attractions from the atmosphere, or by yielding up its own virtues to the roots which freely traverse it and again by the mechanical influences it exerts upon the whole mass where it is introduced. When, therefore, muck is applied to stiff, clayey lands, it still produces those desired results which enable the farmer to cultivate them with pleasure and profit.

Peat has long served for improving mineral soils in other countries also, as shown for the Fen country in England (190), where peat has been used with very great advantage as a manure upon the light sandy lands. Peat was known to supply nitrogen to the soil in such a way as to be available for the nutrition of the plants. When peat was thoroughly mixed with a poor soil, it was found to decompose; a part of the nitrogen was believed to escape into the air, but a part was said to be gradually converted into ammonia, which in turn was changed to nitrate. This method of improving light sandy lands was considered as valuable and inexpensive. Black, thoroughly decomposed, friable peat from a deposit that had been drained, aerated, and cultivated for several seasons, was found to be suitable not only for the growth of crops, but also as an agent for improving the physical condition of the soil. Acid sphagnum peat thus is used for improving beds for the growth of rhododendrons, azaleas, orchids, blueberries, and other plants that require an acid soil and are able to use nitrogen in an organic form. Attempts have been made to utilize peat as an ingredient of commercial fertilizers.

The early use of peat in the preparation of composts is illustrated by the following quotation from Brown:

. . . next to a compost of muck and barn manures, a mixture of muck and ashes is the most common, and by experienced persons is considered the most profitable. If muck were always dug and exposed to the action of frost, sun and rain, and overhauled two or three times in the course of the year, its application would be safe at any time; but, as this is not always the case, some regard must be had as to its condition, when it is to be incorporated with the soil.

It is evident from Brown's comments that, even a century ago, it was not considered safe to take fresh peat directly from the bog, place it on the field, and plough it under. Its effects were believed to be so unfavorable "as to prejudice the farmer entirely against its use."

The use of peat as an absorbent of urine, as well as of the gaseous constituents of the manure in stables, was recommended at an early date in this country by Brown, who predicted:

The time may come when people in the large cities will look upon muck as one of the most valuable agents in Nature, to preserve health, by absorbing the foul gases which are always generated there, and rendering them innocuous. To the farmer, in his barns, styes, sinks, reservoirs, and cellars, it can scarcely be dispensed with and leave a hope of profitable farming. He covers his steaming heaps with it, and their exhalations are arrested and stored up by this wonderful substance ready to be given up again to the plants which he desires should be nourished and perfected by it. Sprinkled on the floors of cattle or horse-stalls, it readily absorbs the musty odor, and leaves the atmosphere elastic and pure.

Peat was also said to have antiseptic properties, since it was believed to prevent cholera and fever, by absorbing "all those noxious malaria which are so prevalent during the warm season. It is really the abater of every nuisance."

Great progress has since been made in the utilization of peat in agriculture. In many countries, peat farming forms a highly specialized branch of agriculture, served by special Experiment Stations and other research organizations, with problems all of their own.

*Systems of reclamation of peat for agricultural purposes.* The utilization of peat lands for the growth of crops was summarized recently by Harmer (125). This subject has a long and complicated history. Various systems have been employed in different countries and for different peats. Of these, some were found to be very useful and others failed sooner or later. The *fen*, the *burning*, and the *Rimpau* methods were once widely applied.

The *fen* method of peat cultivation was first developed in Holland in the 16th century and later was utilized also in Northern Germany. An early New Jersey geologist (276) suggested its use in this country.

The method, which was limited to highmoor peat areas close to cities, consisted in removing the surface layer of the peat, using the underlying layer of well-decomposed material for fuel, then adding the previously removed upper layer to the subsoil, and working it in with the latter. Frequently a compost of stable manure and city refuse was also added to the mixture of soil and surface peat.

The preparation of the soil was carried out as follows: After the lower layer had been removed from a part of a bog, the excavation was filled with the surface layer of poorly decomposed peat removed from an adjacent tract. A layer of four or five inches of sand, taken from the bottom of the canal, was added to the surface of the peat material and well worked into the latter. A heavy dressing of a compost was then added. The sand served to compact the loose mass of vegetable material and to improve its moisture supply; the compost supplied the plant nutrients essential for crop production and resulted in the production of an active mass of microbial cell substance which acted as a binder between the organic and the inorganic soil particles (4).

The *burning* method of treating peat was developed in the seventeenth century, in Holland and elsewhere in Europe. Like the *fen* method, it found special application in the reclamation of highmoor peats. The surface layer of the peat was burned off and the ashes



produced were mixed with the lower layers, which were then cropped. This method proved of little benefit after a few yearly burnings and was later discarded. Anderson (8), in his book published in 1794, condemned the prevailing practice of burning peat. On the other hand, he recognized the importance of liming acid peats, of avoiding over-drainage, and of rolling peats. Aiton (2) approved of these ideas in 1811. He found liming, combined with a covering of clay or the use of manure or both, to be the prevailing practices in Scotland.

The *Rimpau* method of peat cultivation was developed in Germany in the middle of the last century. It differed somewhat from the fen method, the sand being applied as a layer over the peat and cultivation being confined to the sand layer. Phosphate and potash fertilizers were added. This method proved very successful on the lowmoor peats of southern Germany, which are high in lime, but proved to be a failure in the highmoors of northern Germany.

Modern systems of reclaiming peat lands are summarized as follows by Ogg (207, 208) :

1. *Removal of peat.* This is followed by (a) cultivation of the land as such; (b) warping the land, in other words, flooding it with mud-bearing water until a sufficiently thick deposit of silt and clay is obtained; (c) deposition of refuse on the land; or (d) the Dutch "dalgrond" system, in which it is required by law that the surface 2 feet of peat be laid aside, later placed on the bottom of the bog and mixed with the subsoil.

2. *Cultivation of the surface of the peat.* This is done by (a) burning the peat, followed by special crops such as buckwheat, rye, and oats; (b) manuring the peat heavily, sanding or claying the surface; (c) using special cultivation machinery. The general practice in most European countries is to drain the land, cultivate the surface by means of a special peat-cultivator, and apply lime and fertilizers as required.

It has been suggested (321) that five major factors may determine whether or not it would pay to drain and farm peat land: 1, the clearing and breaking of land; 2, the cost of drainage; 3, the chemical nature of the peat; 4, the danger of frost during the growing season, and 5, the relative acreage of peat land and mineral soil on the farm.

In the development of a peat area for agricultural purposes, it is first necessary to clear the land. The trees and shrubs are removed, their shallow root systems making this process rather simple. Mosses and thick grass may be burned. The ash from the shallow surface

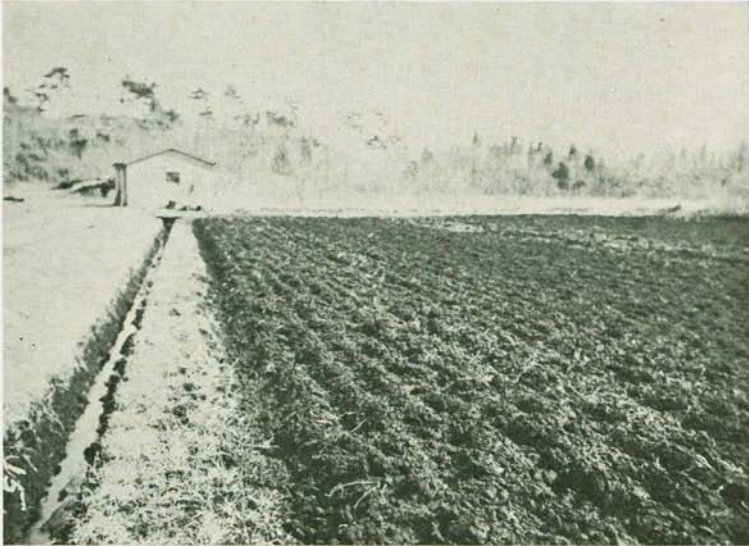


FIG. 16. Cultivated lowmoor peat, Newton, N. J.

burning increases greatly the productivity of the peat lands, especially during the first few years and especially in the case of forest and highmoor peats. Care must be taken to avoid the burning of grass during the hot summer months, since this may lead to the burning of the peat itself, especially if the water table is low.

The bog is then drained, by digging first large main ditches requiring the uses of a dredge. Ditches thus made around the edge of a bog may reduce the moisture content of the peat sufficiently to enable the growing of crops without further drainage. Tile is used for deep drainage, in most cases both ditches and tile being necessary. This is determined by the depth of the bog and the nature of the mineral subsurface. When the bog is shallow and the peat is not more than 3 feet deep and is underlain by sand, small open ditches may be sufficient to drain the bog for the growth of most crops. With a clay subsoil, the lateral ditches must be closer together to provide thorough drainage.

Crops grown on poorly drained peats are likely to suffer during dry summers from lack of water, because the roots develop in the surface layer. This layer may dry out readily, thus injuring the root systems. The lowering of the water table actually increases the amount of water available to the plants during the latter part of the season, since it favors a deeper root system (320).

That the climate controls to a large extent the depth to which the water must be lowered, has been shown by Alway (4), who emphasized that in regions of heavy rainfall the water level can be lowered much more than in regions of scant or medium rainfall. In regions with a cool climate, the water table should be kept from 20 to 40 inches below the surface. The control of the water table to suit the requirements of the special crops, notably truck crops, is a much sounder economic policy than for general farming (251).

Certain crops, such as onions, are sensitive to extremes of soil moisture. Too high water levels will result in a delay in the "bottoming" of the onion and will result in a large proportion of "thick-necks." A too low water table will give a poor stand and slow growth in dry weather. A shallower water table, about two and one-half to three feet below the surface, during the summer months has, therefore, been recommended (4). When the peat becomes too dry, dams fitted with boards or flood gates in the outlet ditches may be used, so that the water can be readily brought to the desired elevation.

Cabbage gave good results when the water was held three feet below the surface. Corn gave the best growth of plants on the 4-foot level and best ear formation on the 5-foot level. Rapid growth, how-

ever, made them knobby and irregular. Early varieties of potatoes gave the best yield with water held 3 to 4 feet below the surface, whereas later varieties produced more heavily on deeper levels (84).

Among the many specific problems involved in the use of peat soils for crop production, are those of the managements of different types of peat, the "rawness" of newly broken peat soils, and the "coldness" of peat soils, as compared with adjacent mineral soils.

Certain types of peat, such as the finely divided sedimentary or lake peats, may be difficult to control, although they may become productive when properly treated (127, 53). On drying, these peats tend to shrink, producing cracks, whereas on continued cultivation, they may form fine dusts which easily blow away. Certain types of peat may be impervious, resulting in a water-logged soil for several days after heavy rains, even when properly drained (181).

Unproductivity of peat soils may be due to a lack of one or more nutrient elements or it may be caused by the presence of certain toxic bodies. The lowest layer of the peat and the surface layer of the underlying mineral soil may contain substances such as sulfate and sulfuric acid, which are highly toxic to plants. These are rendered harmless by addition of lime. Even when a peat is well supplied with lime in the surface layers, it may contain toxic substances below. These ordinarily occur not only in undrained bogs, but may appear after drainage, as a result of the oxidation of the original iron sulfide or iron pyrites. In contact with the oxygen of the air, these form iron sulfate and sulfuric acid, both of which are soluble in water and become toxic. When these are mixed with lime, calcium sulfate is produced (4).

Peat soils are generally recognized as more susceptible to frosts than the mineral soils bordering them. In a study of the peat soils in the Everglades region in Florida, it was found that the frost risk increases as one recedes from the lake toward the interior of the bogs. Proved crop types and rotations which will reduce to a minimum the possible damage from frost during the winter months have been recommended (3).

Large areas of tidal marshes may be reclaimed for farming purposes, when the need for land and for agricultural products justify the expenses involved in drainage and reclamation. Until cheaper and more easily drained mineral soils are completely occupied or exhausted, many areas of these peat lands will remain undrained and unutilized. Upon reclamation, these soils frequently prove to be of higher value than the more easily managed mineral soils; their cultivation under intensive methods of agriculture may produce far greater profits per acre (33).

*Use of peat for crop production*

Peats have been used in Europe, for many years, for the growth of crops (100, 264). The first attempts to use peat lands in the United States for the growth of crops were made in the older agricultural districts of the East, especially in the States of New York and New Jersey. Some of the peat bogs in these States have been converted into some of the most productive farm lands. They are usually spoken of as muck lands, marsh lands, and locally as "black acres."

Peat soils of the lowmoor type usually require applications of phosphorus and potassium fertilizers, in order to yield a good crop (table 21). When shallow peats are underlain with clay, the need for potassium or for stable manure is manifest during the first few years after drainage. The need may disappear, as a result of the gradual mixing with the subsoil which contains a large quantity of potassium. In time, a need for phosphorus and nitrogen may develop. A complete fertilizer, such as stable manure, when available, may prove to be most helpful (320).

TABLE 21  
Rates of application of fertilizers to peat soil (30,4)

	Lowmoor bog	Highmoor bog
Pounds per acre		
First year of cultivation (potatoes)		
Lime (CaO) .....	None	1,800-3,500
Phosphoric acid <sup>P</sup> (P <sub>2</sub> O <sub>5</sub> ) .....	110-180	180- 270
Potash (K <sub>2</sub> O) .....	110-180	180- 270
Nitrogen .....	None	45- 70
Second year (potatoes on lowmoor and meadow on highmoor bog)		
Lime .....	None	None
Phosphoric acid .....	55- 70	110-160
Potash .....	110-125	110-125
Nitrogen .....	None	30- 55
Third year (winter rye on second and meadow on the first)		
Lime .....	None	None
Phosphoric acid .....	25-55	110-125
Potash .....	55-70	90-110
Nitrogen .....	None	40- 55
Fourth year (oats or meadow on second and meadow on the first)		
Lime .....	None	700
Phosphoric acid .....	Replacement	Replacement
Potash .....	Replacement	Replacement
Nitrogen .....	None	40-55

According to Hopkins (132), if a peat soil has only one to three feet of peat and is underlain with sand or sand resting on rock, or if the peat itself is very deep, the land is usually very deficient in potassium. Since lowmoor peat is rich in nitrogen and is somewhat better supplied with phosphorus, fertile soils may result from such bogs. It may be unnecessary to grow clover or to apply phosphorus to such soils for many years, the most profitable crop being corn, unless some rotation should become necessary. As a 4-year average on two plots, phosphate alone gave a yield of 2.0 and 12.0 bushels of corn, potash alone gave 43 and 39.9 bushels, and phosphate and potash gave 45.8 and 41.2 bushels.

The peat soils in the State of Michigan became famous for the onions grown on them (125, 250). This crop can be grown almost continuously on the same field for many years without appreciable decrease in yield. The very strongly acid peat soils (pH 4.5 or less) do not produce satisfactory crops until the reaction has been corrected by the application of lime.

Newly cleared peat soils may prove to be unproductive for certain vegetable crops. This may be due to an unfavorable soil reaction, especially in highmoor and forest peats. Before the peat is cleared, in preparation for cultivation, the reaction of the soil and the nature of the subsoil should be determined. If there is no lime-bearing material below the peat, it may be necessary to apply lime when the bog is cleared and subsequently every few years. If the initial reaction is about pH 4.0, as much as eight tons of lime per acre may be required in the first application. Shallow peat deposits which have an underlying marl must also be treated with care, since the highly alkaline condition thus created is difficult to correct, even with sulfur, unless used in large quantities.

The optimum reaction for the growth of vegetables is not the same on different types of peat. It is, therefore, impossible to designate any particular reaction of peat soils as an optimum for a given crop. This optimum may vary considerably, because of differences in the chemical composition of the peats, and in the rate and nature of the decomposition processes (294).

The application of sulfur to alkaline peats was found to benefit particularly certain crops, such as onions. The amount of sulfur required depends on the degree of alkalinity of the peat and on its depth (125). If the peat is originally high in lime and has been recently burned, proper drainage and use of certain crops, such as sugar beets, mangels, cabbage, and carrots, are recommended. Most alkaline peats require an initial application of from 250 to 1,000

pounds of sulfur. Even slightly acid peats, however, may often be benefited by a small application of sulfur, such as 100 to 200 pounds per acre (125).

Very often, copper sulfate has to be applied to peat soils, in order to yield good crops, as shown by experiments carried out in Europe, as well as at the Michigan and Florida Experiment Stations (181, 125, 3). The benefits from the use of copper are more evident in hot dry seasons than in a cool wet season, and are greater on a well drained peat than on poorly drained peats. Usually an initial application at the rate of 50 pounds per acre will be sufficient to benefit a crop. In following years, an annual application of 25 to 50 pounds per acre may be made until a total of 150 to 200 pounds has been applied. Alkaline peats may also benefit from the addition of 100 to 200 pounds per acre of manganese sulfate (23, 125).

Peat soil may become highly productive when properly fertilized. On the better drained and more acid peats, a greater proportion of potash is needed in the mixture, whereas on the poorer drained and the alkaline peats, somewhat more phosphate is required. Nitrogen gives an early-sown crop grown on an old peat a good start and results in a more rapid growth. Nitrogen is, however, not often required on well-drained new peats (125). Alway (4) divided the low-acid or high-lime peats into (a) those that do not require any addition of fertilizer, (b) those that require only phosphate, (c) those that need potash, and (d) those that need both phosphate and potash.

On well-decomposed peats, the growing of green manure crops for plowing under tends to decrease the blowing of the peat, the addition of fresh organic matter to the soil acting as a binder upon the peat particles. The crop is also likely to benefit considerably from this treatment. A seeding of oats will protect the soil from drifting during the winter months, when the peat is to be left fallow after early fall plowing and it will not interfere with the cropping in the spring. Sudan grass and soybeans are also excellent green manure crops (125).

A peat bog may gradually be transformed into a pasture without cultivation or even seeding. The application of farmyard manure is advisable in preference to mineral fertilizers. Lundblad (179) suggested that manure contains many germinating seeds; the protection by the manure of young shoots against frost and drought especially when spread on the surface in early spring, is also of importance.

The palatability and the nutritive value of hay from peat lands have received much attention, especially since nutrition deficiencies have frequently been attributed to such hay. A "licking disease" of

cattle has been observed in certain areas where the hay from peat meadows was fed to calves (29, 100). It was said to be so serious in some cases that the raising of calves was impossible. The disease manifested itself chiefly in the form of a tendency to gnaw and lick various indigestible objects, such as mortar, stones, and wood (5). Despite these local reactions, Bersch (30) concluded that the hay from peat meadows is, in general, just as palatable and nutritious as that from meadows on mineral soils; no difference which would cause the peat-grown hay to have a lower value than other hay (217) was found.

Among the various special crops grown on peat soils, the blueberry and cranberry occupy a unique position.

Coville (51-52) found that the blueberry requires an acid soil and that it grows luxuriantly in a mixture of peat and sand; nitrates may be present only in low concentrations, if at all. The ability of this plant to grow under these conditions is due to a fungus associated with its roots. The fungus is said to take up organic nitrogen from peat, delivering it to the plant in an available form. The establishment of a blueberry-growing industry depended upon the utilization of sandy, acid peats, especially those found in the pine barrens of New Jersey and in similar areas.

The cranberry is another acid-loving plant. It also has a mycorrhiza fungus similar to that of the blueberry, which is probably also of importance in the growth of this plant. The soils used for cranberry culture have such an excess of moisture and acidity that in comparatively few instances would they be suitable for general agricultural crops. The cranberry crop in the States of Massachusetts and New Jersey are among the most important crops of small fruits grown. Only a small part of the available land has thus far been utilized for this purpose (24).

The top layer of soil for cranberry culture is usually an acid forest peat, which varies in thickness from a fraction of an inch to 20 feet. It is usually underlain by sand of varying degrees of thickness, and finally by a hardpan impervious to water. When mixed with the sand, the peat gradually decomposes, giving the sand a black appearance, and giving rise to a type of soil usually designated as Savannah land. Many cranberry soils contain a considerable percentage of iron oxide, which may result in an iron-ore bottom (24).

Many peat lands have been utilized for reforestation. This presents certain special problems, due to acidity, to lack of drainage, and to lack of aeration which would favor the development of a proper root system. The following simplified procedure has been used:





FIG. 17. Utilization of peat bogs for cranberry growth. Indiantown bog, Weymouth, New Jersey.

Blocks of peat, 14 inches square and 5-8 inches thick, are removed from the ditches, dug 30 feet apart, and placed inverted in rows, 5-6 feet apart. After the peat has been allowed to dry out for a month or more, the block is slit and tilted, and a tree seedling inserted in the slit with its roots spread out in the underside of the peat, in the aerated layer of the partly decomposed plant growth (258). The problem of rooting of plants in peat soil can be improved by mixing the peat with mineral soil (298).

*Peat as a fertilizer and soil improver*

Aside from its value as a soil for the growth of agricultural crops, peat finds extensive use for raising the fertility of impoverished mineral soils, for improving their texture, and for increasing their moisture-holding capacity.

The value of peat to impoverished soils has long been recognized. In his "Muck Manual," first published a century ago (1843), Dana (66) thus emphasized this possibility: "Peat is, among manures consisting chiefly of geine, what bone-dust is among manures consisting of animal matter. Peat is highly concentrated vegetable food. When the state in which this food exists is examined, it is found not only partly cooked but seasoned."

Johnson (145, 146) had a much clearer concept of the natures and uses of peat. In his "Essays on Peat, Muck, and Commercial Manures," he emphasized the characteristic properties of peat "which made it favorable for soil improvement, as its remarkable power of absorbing and retaining water, both as a liquid and as a vapor; its power of absorbing ammonia; its effect in promoting the disintegration and solution of mineral ingredients of the soil, and its influence on the temperature of the soil." He also emphasized the properties of peat as a direct fertilizer, especially the organic matter of the peat and its nitrogen. Because of these, peat is a valuable addition for improving the texture of the soil.

TABLE 22  
*Influence of sedge and reed peat on the growth of tobacco plants in the greenhouse (291)*

Peat added, per cent	Green weight of 2 plants	Relative weights of plants
	<i>oz.</i>	
None	3.88	100
12.5	5.26	137
25 <sup>1</sup>	4.88	126
25	6.00	152
50	8.38	216

<sup>1</sup> No nutrients added.

The use of peat for soil improvement and the fertilizing properties of peat have attracted considerable attention (180, 147). The addition of peat to heavy clay soils was found to exert a highly favorable effect. For the growth of strawberries and for flower gardens, one-third peat was mixed with the top four inches of soil; when used on a large scale, as much as five tons of peat per acre has been applied together with manure and fertilizer. According to Laurie (169), acid types of peat are valuable for the propagation of cuttings when mixed with equal parts of sand. The less acid peats are valuable sources of organic matter and are good substitutes for leaf-mold and manure; they are valuable for growing bulbs and potted plants; they can be used as mulches in flower and in shrub gardens, and for lawn establishment and improvement.

Wide differences in the rate of decomposition of peat have been observed (180). The most active materials were, in many instances, those taken from the surface of the peat deposit. It was suggested even by early workers (146), however, that in order to avoid any injurious effects, peat must first be composted before its application to the soil. It was emphasized that when applied to mineral soil, peat should be weathered for some time "in order to destroy its antiseptic qualities and break down its gummy texture."

Numerous chemical analyses have been reported of peats to be used as fertilizer materials (272). In general, the term *fertilizer*, when applied to peat, is definitely a misnomer, since it cannot compare in effectiveness upon plant growth with inorganic fertilizers or with organic manures, such as dried blood, tankage, fish, or cottonseed meal (307).

Different types of peat vary not only in chemical composition but also in their effectiveness upon the soil and the plant. It was reported (175), for example, that on sandy loam soils, moss peat serves as a good source of nitrogen during the first year of application. Afterward, this type of peat may not have so good an effect. Lowmoor peat, on the other hand, does not give so good a response during the first year, but afterward the increase in yield becomes more marked as the nitrogen gradually becomes available. Only in the third year (177, 91) does the phosphorus become available to some extent.

Peat has also been used as a filler in commercial fertilizers (98) and for mixing with dried blood. This use of peat was considered to be legitimate, for it enabled the manufacturers to produce a fertilizer of superior mechanical condition. Unfortunately, the manufacturer is tempted to include the peat nitrogen in his guarantee of available nutrients; thus the same price is paid for this nitrogen as

for high-grade organic nitrogen. Under these conditions, the use of peat as a filler is objectionable. On examination of 30 samples of peat from Connecticut, Johnson (146) found a variation in nitrogen content from 0.4 to 2.9 per cent, with an average of 1.5 per cent. As the nitrogen of peat applied to the soil is only slowly available, its value as a source of food for plants is rather limited. Storer (288) asserted that, in spite of its inertness, peat nitrogen may be made to contribute to the support of crops and that it has, therefore, considerable value.

In recent years, greater emphasis has been laid on the utilization of peat for soil improvement than as a direct fertilizer. Sedge and reed peats were found (282, 283) to result in a marked improvement in the physical properties of soil for plant growth. They persisted much longer in the soil than the organic matter produced from stable manure. In a season of normal rainfall, and even with more precipitation, treatment of sandy soil with lowmoor peat considerably increased the moisture content of the soil and thereby gave considerable increases in yield (203). In a dry season, however, the addition of peat resulted in only small increases in yield, because the increase in the available water was too small, in relation to the requirements, to bring about marked effects.

Marketable peat for soil improvement can be produced by several methods. The bog is first drained and cleared of trees and brush. The land may then be cultivated. This results in the decomposition of the cellulose and affords a means for determining the agricultural value of the peat material. After the upper layer has been plowed and harrowed, the peat is excavated to a depth of 2 or 3 feet and left in rows on the surface of the bog. When the moisture has been reduced to about 60 to 66 per cent, by air-drying, the material is scraped, loaded into cars, and hauled to a pile. The peat may then be bagged and shipped. All attempts to use heated rotary driers in order to lower the moisture content of the peat to 10 or 20 per cent have failed, since the water-absorbing properties of the peat were thereby considerably reduced.

Another method for harvesting peat is the so-called "hydropeat" process. It is suitable for those bogs where drainage is too costly and where there is an excess of water, due to an adjoining lake or stream. The peat is well macerated with the water and pumped upon a platform. The excess water drains off readily and the peat is allowed to dry by exposure to atmospheric agencies.

Among the numerous experiments designed to study the effects of peat for soil improvement, the following may be cited. These

have been carried out in Connecticut (291), a New Jersey sedge and reed being used on tobacco as the test crop.

Greenhouse tests were first made to determine the quantity of peat that would be required and would prove most profitable. The peat was added to sand in pots, in proportions of 12.5, 25, and 50 per cent by volume. Each pot received 0.25 gm. of  $\text{CaCO}_3$  and a nutrient solution consisting of urea, sodium acid phosphate, potassium carbonate, magnesium sulfate, and traces of boron and iron. Enough water was added to provide suitable moisture. One plant was set in each pot and allowed to grow for about 75 days. The results are given in table 22. The addition of peat had a highly favorable effect upon plant growth, even in the presence of mineral nutrients. The conclusion was reached that the increased yield of plants is due to the fact that the peat either contains some available plant nutrients or increases the availability of those present. The benefit was most pronounced with 50 per cent peat.

In a second series of experiments, the peat was added in concentrations of 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30 per cent by volume. To each of a series of 2-gallon pots a nutrient solution, containing, per liter, 0.2 gm. ammonium nitrate, 1.0 gm. calcium nitrate, 2.4 gm. di-potassium phosphate, 1 gm. magnesium sulfate, 0.005 gm. ferric citrate, and traces of boron and manganese, was added. One tobacco plant was set in each pot. Gradual increases of peat, up to 21 per cent, gave corresponding increases in the size of the plants. These were harvested after two months, and the dry weights are reported in table 23.

TABLE 23

*Influence of varying quantities of sedge and reed peat upon the growth of tobacco plants in sand medium (291)*

Per cent peat by volume	Approximate per cent of peat by weight	Weights of	
		whole plant	Weight of leaves
		oz.	oz.
..	..	1.35	0.43
3	0.7	2.50	0.55
6	1.4	3.30	0.63
9	2.1	3.25	0.65
12	2.8	3.25	0.73
15	3.5	3.45	0.75
18	4.2	3.00	0.73
21	4.9	4.20	0.83
24	5.6	4.20	0.80
27	6.3	3.85	0.80
30	7.0	3.80	0.83

*The use of peat for composts*

With the gradual reduction in the supply of available horse manure, because of the replacement of the horse by the automobile and tractor, the possible value of peat for organic composts to take the place of stable manure came into consideration. Further, with the realization of the importance of humus in maintaining a good mechanical condition of the soil, the use of peat for soil improvement, either as a direct application or as a compost with stable manure or with soil, also began to receive much attention. Although deleterious effects have sometimes resulted from growing plants soon after the application of fresh peat-moss litter manure, such losses have not been observed when the peat manure has been composted for a time.

Weiss (317) drew attention to an experiment carried out in 1815, which consisted of mixing peat and manure in heaps, with the result that rich composts were produced. Another interesting application of the composting procedure was pointed out by one of the early students of New Jersey soils, Kitchell (157), in 1855:

Shell marl, either alone or composted with peat and muck, may be advantageously used in large quantities on clayey, sandy and loamy soils. The principal object in composting it with peat and muck is, at the same time, to add organic matter to the soil. If the soil contains already a sufficient quantity of organic matter in an active or proper state, it may be applied alone. Its mechanical action on many soils, particularly on hardpan, or clayey soils, rendering them more pulverulent and open, is of great importance.

It has been recognized in recent years that the most convenient way of utilizing peat-moss litter is to form compost heaps (54, 56, 72). Piles are made in the open, usually in the shade; they consist of alternate layers of peat-moss litter, manure and soil, frequently with additions of mineral fertilizers, especially phosphates. Other types of peat composts can be prepared by the use of sewage or sewage sludge, fish scraps, and molasses. Peat-moss litter manure was found to give excellent results when used as a top dressing on golf greens (72). Composts incorporating peat are also widely used as substitutes for leaf composts and are employed as a dressing for certain types of grassland (22).

Manure, soil, lime, and rock phosphate are commonly added to the peat as supplementary materials. The chemical nature of the particular peat, its reaction, and the conditions of composting are highly important in this connection, because they influence the materials to be used and the manner of composting (174, 183, 278).

Mixture of peat with rock phosphate results in the solubilization of some of the insoluble phosphorus (227, 199, 256, 278). The use

It was further determined whether lowmoor peat was able to prevent or reduce leaching. A series of pots were filled to a height of 2 inches with pure sand, on top of which was placed a 2-inch layer of the peat. A mixture of sand and soil in the proportion of one to two, was then added. Six control pots had a 4-inch layer of sand at the bottom covered by the sand-soil mixture. One tobacco plant set in each pot was treated with a nutrient solution. The results of analysis of the bottom sand demonstrated that the peat decreased the leaching of the nutrients to an extent of 50 per cent.

#### *Fertilizer from peat*

Extensive study has been made to produce a fertilizer from peat by adding to it various nutrient elements (292, 187, 94). Either simple mixtures were used or attempts were made to incorporate the chemicals into the peat in a more drastic manner. The addition of anhydrous ammonia to peat, in a closed bomb at 25° to 300° C. and a pressure of 100-300 atmospheres, gave ammoniated products, with varying nitrogen contents, namely, 4-6 per cent at 50° C., 10.5-13 per cent at 180° C., and 14-21 per cent at 300°. Unfortunately, a large part of the nitrogen was thereby rendered unavailable (71). Dragunov (76) found that when peats were freed from absorbed bases, the total nitrogen could be increased to 6 per cent. Ammoniation was said to make the nitrogen of the peat more readily hydrolyzable. Plot tests showed that the ammoniated peat was superior to mineral nitrogen and had a better residual action. Humophosphates were obtained by acidifying the alkaline extracts of peat with  $H_3PO_4$ , then ammoniating. These preparations were found to contain 5.7 per cent nitrogen and 22-26 per cent total  $P_2O_5$ , most of which was water-soluble. Nitrohumates were obtained by treating peat with nitrates and ammonia (311). Low-ash peats, which would include the sphagnum peat types, were usually found best for the purpose (178).

By chlorinating the peat before treatment with ammonia, the solubility of the organic matter was increased (77). The formation of 75-90 per cent of water-soluble constituents in ammoniated peat involves the production of ammonium salts of carboxylic acid, which are transformed on continued heating, giving rise to  $CO_2$ . In the presence of an excess of ammonia, the  $CO_2$  is converted to urea and, by dehydration, gives rise to other amides. This transformation of the ammonium salts prevents loss of ammonia upon storage (135, 255).

of such a mixture in alkali soils gave increased crop yields (140). Logvinova (176) found that phosphate-peat mixtures produced more lasting effects upon the soil, increasing the yield of clover much more than phosphate alone. The exchange of the hydrogen ion in the base-unsaturated acid peat for the calcium ion in the phosphate took place apparently just as soon as the two were mixed. Lowmoor peat which is not so unsaturated with bases as highmoor peat, did not give as good results when mixed with phosphates. Poorly decomposed peats composted with fertilizer, lime, and a small amount of manure, were valuable for their effect upon the growth of rye grass and tomatoes (180). This type of compost was superior in its action to the same materials without preliminary composting. A satisfactory mixture, consisting of 7.5 pounds of ammonium sulfate, 15 pounds superphosphate, 5 pounds potassium sulfate, 10 pounds of lime, and 20 pounds horse manure, was added per cubic yard of peat.

The addition of lime to acid peats, such as sphagnum and forest types, is essential for proper composting. This can be demonstrated by the fact that the losses on composting of a sphagnum peat increased from 8.7 per cent of dry weight when no lime was added, to 29.4 per cent when  $\text{CaCO}_3$  was introduced. This increased decomposition of the peat was accompanied by a reduction in the cellulose and hemicelluloses and by an increase in the lignin and protein. After prolonged composting, however, the protein content began to decrease, as a result of its gradual decomposition (161).

Katzmann (150) neutralized the acid reaction of acid peat with  $\text{CaCO}_3$ , and inoculated the mixture with stable manure. Calcium cyanide was added as a nutrient, corresponding to 0.7 per cent of the dry matter content. After four months the product had better action in field experiments than natural manure. The loss of nitrogen amounted to 12 per cent, that of  $\text{P}_2\text{O}_5$  to 3.1 per cent, and that of  $\text{K}_2\text{O}$  to 2.1 per cent.

#### *Use of peat as an absorbent, in stables and poultry houses*

The use of peat as a litter in stables for bedding purposes has found extensive application in this country and in Europe, where it has been used for over a century (218, 128). "Peat litter" was the term used for this material, as distinguished from "peat mull," a powdery product obtained when the sphagnum peat is removed from the bog, dried, and sifted. Peat mull has been used in privy closets, for purifying and deodorizing sewage, as an insulating material, for addition to molasses meal for packing and for various horticultural purposes (108, 148, 261, 333). The peat best suited both as a litter and as a mull is light, incompletely decomposed material, of a fibrous nature and con-



sisting chiefly of sphagnum moss, cotton-grass or *Eriophorum*, and other vegetable fibers, such as are found in the various horizons of highmoor or sphagnum bogs. This type of peat also occurs sometimes in thin layers in the black or brown lowmoor bogs and fens. The chief sources of peat moss suitable for peat litter were, up until the recent war, the highmoor bogs of Northeastern and Northwestern Germany, Holland, Sweden, Russia, to a lesser extent Scotland, Finland, and Denmark, as well as the northeastern and northwestern parts of the United States and Canada.

The absorbing power of peat litter usually ranges from 1,200 to 1,500 per cent, though a good peat litter may have an absorbing power even lower than 800 per cent. The determining circumstances for the use of various grades of peat materials as litters are chiefly the demand and market price. The water-absorbing capacity of other different litters available to the farmer are considerably smaller than those of peat. Cereal straw, for example, has a water-absorbing capacity of 200 to 350 per cent, and sawdust of 360 to 500 per cent.

The litter is spread in the stables to a depth of 10 to 20 cm. and, until the animals have become accustomed to it, covered with some straw. For every square meter of the stable floor 9 kilograms of peat are required. The manure is removed from the stables once or twice a day; the fully saturated litter is also removed and replaced by 1 to 2 kilos of fresh litter per animal. The full bedding should be removed when the air of the stable has become saturated with smells, when the animals show a disinclination to lie down, or when they wet their coats in doing so. A bed thus prepared lasts 2 to 4 weeks. Urine channels in the stalls are filled with peat litter to prevent the liquid from flowing away; when absorbed by the peat, this makes an excellent manure (128).

It has been said that the hoofs of the animals standing in this bedding attain a high degree of flexibility and soundness, which can only be compared with the condition of pasturing animals. Their stamping in the stalls is noiseless, because of the softness and resiliency of the moss as a litter. The temperature in the stables is somewhat lower than that in stables where straw or other forms of litter are used, since the peat litter prevents the rapid heating of the manure due to decomposition. Peat litter tends to keep the atmosphere of the stables odorless by preventing the formation of ammonia. By keeping down unpleasant gases, peat litter is said to reduce the susceptibility of animals to diseases of the eyes, lungs, and hoofs. It also adds to the value of the stable manure, by preventing its rapid decomposition.

In poultry houses where the peat moss is placed on the floors, diseases are said to be far less frequent. The birds scratch the material searching for food, thereby keeping themselves clean. The droppings are soon worked up into the litter, and the resultant chicken manure becomes enriched in available nitrogenous materials.

Fresh peat manure has found favor with market gardeners, since it is very similar in action to straw manure. It is even claimed that better crops of beets and other vegetables were obtained on land treated with peat manure than on land receiving straw manure. Peat manure was believed to be especially beneficial for rapid-growing crops. Favorable results were reported from Russia, where an increase of 8 per cent in the yield in cereals and 25 per cent in root crops resulted from applications of peat manure (10, 11).

Peat moss was found to be a very effective material for the conservation of the nutrient elements in the animal excreta and urine. There is also said to be less loss by composting of peat manure mixtures than of straw manures, thereby making peat manure richer in fertilizer elements, as shown in table 24.

It has been estimated that 100 kilos of peat litter are required per annum for every 100 kilos live weight of animal in stables. Draught animals, which do not spend all the time in the stable, require less. A horse requires about 75 to 90 kilos of sphagnum peat litter a month; sedge and reed peat, if used at all, is required in much larger amounts, sometimes up to 200 kilos (128).

Not only peat moss but also certain other forms of fibrous peat may be used as stable litter; they absorb the nitrogen-rich urine, most of which is ordinarily wasted. As an effective deodorizer and disinfectant, peats are usually superior to lime and ashes, and even to some of the more expensive disinfectants. They are a nearly ideal material for use in earth closets and other receptacles which receive moist waste organic matter. As early as 1867 every farmer in this country knew the efficacy of peat as a disinfectant and deodorizer (170).

Certain types of peat may be used in the construction of filters to purify sewage effluent. Small peat filters were found to be good in conjunction with the usual household septic tanks where an effluent is desirably free from objectionable smells. Larger plants are used together with screens and sandtraps. The final product may be used as fertilizer. One of the special properties of peat which recommend it for this purpose is the lack of odor and flies (1).

TABLE 24  
*Conservation of manure constituents by various forms of bedding (111)*

Bedding	Percentage of dry matter						
	Dry matter in manure	Fresh manure			Dry manure		
		Total nitrogen	Ammonia nitrogen	Phosphoric acid	Total nitrogen	Ammonia nitrogen	Phosphoric acid
Straw .....	15.9	0.23	0.02	0.15	1.43	0.13	0.95
Peat .....	14.3	0.33	0.07	0.15	2.27	0.45	1.06
Peat + straw .....	17.0	0.33	0.05	0.17	1.94	0.28	1.01

*The use of peat in greenhouses and for other horticultural purposes*

In a finely shredded condition, peat, especially acid peat, has found numerous applications in horticulture. The distinction between acid and non-acid peat is so fundamental and so important horticulturally that the non-acid peat is commonly spoken of as "muck," in order to distinguish it from the acid peat which is referred to as "true peat" (52). Peat is used as a medium for germinating seeds, to start cuttings, to transplant and grow evergreens and shrubs, and to propagate orchids. As a mulch, acid peat protects plants and soil against the effects of alternate freezing and thawing and keeps down weeds.

The use of different forms of peat in greenhouses, on lawns, and on golf courses is becoming more general every year. Peat is used as a source of organic material and as an ingredient for top-dressing of soil. Favorable results have been obtained when one-fourth to one-half of the total volume of the soil has consisted of peat, manure or fertilizer being added to supply the required plant nutrients.

When peat alone was used as a medium for growing greenhouse crops, unsatisfactory results were obtained as compared to the ordinary mixture or compost of soil and manure. The addition of some stable manure to peat resulted in a marked increase in the amount of growth made by plants. In some cases, this medium proved superior to ordinary soil composts. Peat used as a mulch over the surface of the soil or incorporated into the soil gave increases in growth of most greenhouse crops. Applications of nitrogen and phosphate proved beneficial to many crops.

For many plants, peat was found to be a favorable medium for root formation. It has, therefore, been used for rooting hardwood and softwood cuttings. Strawberry runners also root readily in peat. Hitchcock (130) found that plant cuttings could be classified, as follows, according to the readiness with which they rooted in peat moss or in sand: 1. those that rooted readily in peat moss but poorly in sand; 2. those that rooted readily in sand but poorly in peat moss, and 3. those that rooted readily in either peat moss or sand. The fact that, with certain few exceptions, cuttings from all three groups rooted readily in a mixture composed of equal proportions of peat moss and sand indicated that this mixture is superior to sand as a general medium in which to root cuttings. Although the pH value of the soil is an important factor in determining the type of rooting response of some varieties of cuttings, it is not the only limiting factor. The critical acid value, at which injury to the cuttings listed in group 2

occurred, was found to lie between pH 3.6 and 4.1. Whether peat moss was used in a natural state, neutralized, or mixed with sand, a more rapid rate of root growth occurred in a medium containing only sand. Good rooting occurred for most varieties of cuttings over an acid range of pH 4.5-7.0. Laurie (169) also found that the majority of the hardwood and softwood cuttings rooted best in a mixture of sphagnum peat and sand. The use of disintegrated peat in seedbeds has also yielded good results.

Peat has also found extensive application in forest nurseries. Material having a pH of 5.5 or less was found to be most desirable, especially for raising coniferous stock. When the pH is 6.0-7.9, it may be satisfactory for hardwood nurseries, but undesirable for nurseries raising coniferous seedlings, because of the danger of damping-off and other infectious diseases. Peat having a reaction higher than pH 7.0 was unsatisfactory because of the danger of diseases and direct toxicity of the alkali-reacting substances. The use of colloidal or sedimentary peat in forest nurseries was said to be inadvisable, as it tended to cement the soil particles.

An admixture of peat to potting soils has frequently been found to promote a good texture and has proved useful for certain special plants. Peat is the principal constituent of most bulb composts. All ericaceous plants grow readily in peat or in a peat-sand mixture; the latter is commonly used for growing azaleas and rhododendrons. The texture of decomposed peat and its ability to maintain a uniform humidity for a long time make it especially useful.

#### *Use of peat as a top dressing for golf courses*

Mixtures of equal parts by volume of clay and poorly decomposed moss peat or sedge and reed peat applied to golf courses, showed, even at the end of one year, pronounced increases in the loss on ignition, moisture content, and maximum water-holding capacity of soil. The mixtures containing the more thoroughly decomposed peats retained more water than did the others. The addition of 50 per cent by volume of peat to the top 4 inches of a heavy clay soil caused a marked increase in soil acidity, as compared with soil receiving inorganic fertilizer but no peat. Often a deleterious effect was observed as a result of addition of peat, the grass appearing yellow and unthrifty. This effect, which was overcome by the addition of large amounts of nitrogen fertilizer, was believed to be due to no toxic action of the peat itself (194).

*Use of peat as a carrier of bacteria*

Numerous attempts have been made by Bottomley (34), various Russian investigators, and others to inoculate peat with nitrogen-fixing bacteria. This resulted in a variety of preparations designated as "Humogen," "Azotogen," etc. Extensive claims have been made that these are able to fertilize the soil, enrich it, and increase its nitrogen supply. These claims have not been substantiated. A repetition of these experiments (43, 257) indicated that the value of "Humogen" as a fertilizer was negligible. The theory that a vitamin-like substance called "auximone" is abundant in peat, thereby stimulating plant growth, has not been definitely established.

Peat is used successfully, however, as a carrier of legume bacteria. For this purpose sedge and reed peat are usually employed. If forest peat is used, the acidity must be carefully neutralized by means of lime. The peat cannot be sterilized by heat since substances are thus formed which become injurious to the bacteria added. The specific organisms are usually grown in liquid media, and the cultures containing a definite number of living cells are added to the peat which has previously been dried. These cultures, therefore, are not pure, since they carry a number of fungi and other microorganisms remaining in the peat. It is claimed that the legume bacteria are thus able to survive for a much longer period of time than ordinary liquid or agar cultures of these organisms.

*The use of peat in stock and poultry feed*

Certain types of peat have been used both in this country and abroad for preparing stock and poultry feed. The peat is air-dried and partly heated to bring about some carbonization; it is then screened and reduced to a powder containing about 10 per cent of moisture. The uncrystallized residues obtained in the refining of sugar are then mixed with the peat. A food is thus prepared which may be given to cattle and other livestock without causing gastric disorders. It is claimed that the peat also stimulates digestion, that it contributes some protein to the food, and that it is an excellent substitute for charcoal. Several peat preparations, obtained from moss and from sedge and reed peat have been used in certain European countries as a base for stock feed, though this use has tended to diminish.

Peat has often been used as an admixture, usually fraudulent, of concentrated foods in this country. This is brought out by the fact that various references are found in the earlier literature on the chemical analyses of foodstuffs.

To determine the possible value of an admixture of peat to cattle feed, an early New Jersey chemist, Street (290), utilized the well-known fact that pentosans are generally present in peat. Von Feilitzen and F. Tollens (89) analyzed fifteen samples of peat which were shown to contain from 2.65 to 12.75 per cent of pentosans, the peat samples taken from the upper and less decomposed horizons of the peat profile containing the highest amounts of pentosan. Seven samples of peat, differing widely in nature and mechanical condition, gave a pentosan content of 1.57 to 8.74 per cent, with an average of 3.81 per cent.

#### *Use of peat as a packing material*

Because of thin light weight, high moisture-absorbing capacity, and resistance to decomposition, peats, especially the moss types, form excellent packing materials (147). They have long been used for packing eggs, fruit, and vegetables. Since dry peat is a poor conductor of heat, it has also found application in ice houses and as a packing for water pipes. Fibrous peat, usually moss peat, and also little-disintegrated sedge and reed peat have been employed. Peat moss is also utilized extensively for packing and shipping flowers, shrubs, and various other plants.

#### *Peat as a carrier of toxic agents*

A number of peat preparations possessing fungicidal or insecticidal effects have also been made (82). Various arsenical and other substances are incorporated in the peat. In view of the fact that peat soils are apt to suffer from a lack of copper (3), this element may also be incorporated (196).

## CHAPTER VIII

## INDUSTRIAL UTILIZATION OF PEAT

As compared with its utilization for the growth of crops and for other agricultural purposes, peat has found, especially in this country, only limited industrial application (204). In this respect, peat has had a rather varied history. Most of the industrial processes were usually based either upon the calorific value of peat as a fuel or upon its cellulose content, for use as a fiber. The high nitrogen content of certain peats, and the water- and base-absorbing capacity of others, also led to their exploitation for certain specific purposes (9).

The greatest limitation to the utilization of most of these processes has been the cost of removing the high water content of the natural peat. The products had to justify this expense. In addition, the ash content of many peats also limited their extensive use as a fuel.

*Use of peat for fuel*

The earliest and most extensive use made of peat for industrial purposes as well as in the home has been as a fuel. This usage dates back to the beginnings of known history. At the time of the conquest of western Europe by the Romans, the Latin commentators spoke of the miserable condition of some of the people living in those regions (69). Peat has also been used for fuel in various sections of Northern and Eastern Europe, notably in Ireland, Holland, Germany and Russia (192, 244), as well as in parts of France and Austria. The disappearance of the forests at a comparatively early period in the history of Europe, while agriculture was the most important industry, led to the widespread use of peat fuel, especially by the poorer classes of people.

Probably in no other country have peat deposits been used so systematically and extensively as in Holland. Much capital was invested. The peat bogs have been drained by means of a series of canals, which served simultaneously as ship canals. The peat is dug, dried, and pressed into bricks. These bricks are loaded on flat-bottom boats and hauled over the canals to cities. On their return trips, the boats are loaded with street or other city refuse, much of which is delivered free to the boats. This material is used as fertilizer. By this method, a large part of Holland not only can obtain cheap fuel, but large peat bogs are thereby turned into profitable agricultural soils.



Only a few sporadic attempts have been made in the United States to use peats as sources of fuel. The early settlers of Massachusetts brought with them the Old World practice. An early American student of peat (170), speaking of its use as a fuel, quotes Prof. Emmons as follows:

There is one consideration which commends itself to the philanthropist of all our large cities; viz., the introduction of peat as a fuel to supply the necessities of the poor. It is believed that much suffering may be prevented and much comfort promoted by the use of peat in all places where fuel is expensive, as in New York and Albany. A careful examination, therefore, of places favorable to the production of this substance is a matter of some considerable importance, as it is the next best substitute for the more expensive article, coal; and anything for fuel which will save a further destruction of the forests, both in New York and the New England States, is worthy of adoption, from more considerations than one. We have in this homely substance of peat, an invaluable article, of which prejudice alone can prevent a general use.

In a country where wood was plentiful and could be had for the cutting, peat as a fuel could hardly compete. It is said that on Martha's Vineyard and on Nantucket Island, the descendants of the Indians still use peat for fuel because of the lack of other cheap fuels. In New Jersey, according to Cook (50), peat was "long used in Chatham Township, Morris County, and to a smaller extent in many other places." Various attempts have been made to manufacture peat fuel by means of machinery in New Jersey, as at Belleville, in Essex County, and at Allendale, in Bergen County. A plant was also projected at Beaverton, Morris County. The industry did not flourish, however, either in New Jersey or in New England (213).

Unlike the true coals, peat has a high oxygen content, varying from 30 to 40 per cent; its carbon content ranges from 50 to 60 per cent, on an ash-free basis, and the hydrogen content, from 5.5 to over 6 per cent. Nitrogen is found in varying amounts and may be unusually high. This becomes important when the fuel is considered from the standpoint of its value for the generation of a producer gas, for the production of power, and for the production of peat coke. Phosphorus and sulfur occur to a limited extent in all peat bogs. These elements usually vary from 0.03 to 0.09 per cent for the former, and from 0.22 to 1.0 per cent for the latter. High sulfur contents, however, are not very common.

One of the reasons for the failure of peat as a fuel has been the difficulty of converting the raw peat into a hard fuel that will not crumble on burning. Peat fuel suitable for commercial purposes has been produced only by the use of complicated and expensive machinery. A number of methods have been described and patented for the preparation of peat for fuel, so as to render it transportable and effi-

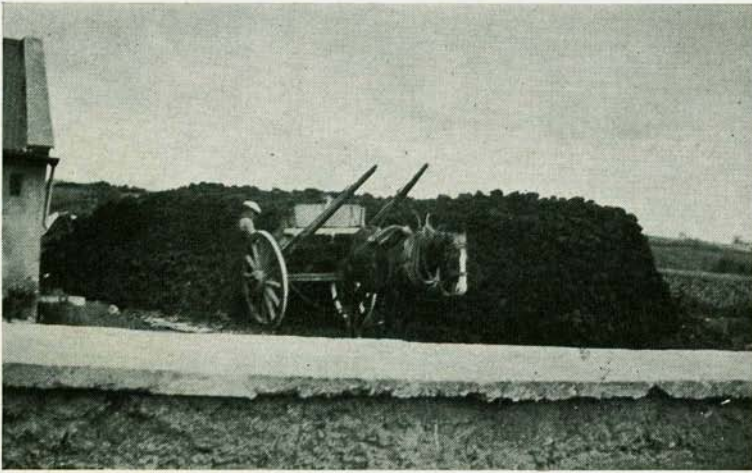


FIG. 18. Handling of peat for fuel, County Sligo, Ireland.

cient as a source of energy (338, 339, 245). Davis (69) outlined the following methods of production of fuel from peat: The blocks are cut by hand, by means of special spades when required for domestic use. Machine peat is a more compact and efficient fuel. It is made by macerating the peat and pressing it into molds; it is then dried by spreading the blocks on the ground, exposed to sun or wind. It may also be ground by a specially constructed mill similar to that used in grinding clay for making bricks; the peat is ground and molded into bricks in a wet state as it comes from the beds; on exposure to the air and sun, the bricks dry. This type of peat contains from 20 to 25 per cent moisture and has about 65 per cent of the fuel value of the same weight of bituminous coal when burned in stoves or under boilers. Peat briquets are compact and burn more slowly and persistently. The peat may also be powdered and then briquetted by the use of a binder or in a mixture with coal or lignite.

In an undrained bog, peat contains about 90 per cent water, which must be reduced to at least 30 per cent before the product can be used as a fuel. When a deposit is thoroughly drained, the water content of the peat is thereby reduced to 80 per cent or less, though it cannot be reduced to much below 70 per cent without drying in the open air or in a heated chamber. Artificial drying of peat, in order to remove all the excess moisture, requires the expenditure of a large amount of heat in comparison with that obtainable from the fuel prepared by this method. Peat fuel is, therefore, best prepared during the warm seasons of the year, when natural drying is possible.

In calorific value, a ton of machine peat is equal to about 1.3 tons of wood, 0.66 ton of bituminous coal, and 0.6 ton of anthracite. Comparative calorific values of peat and other fuels were reported by Davis (69) as follows:

	British thermal units
Wood .....	5,760
Hand-cut peat, air-dried .....	6,840
Machine-cut peat, air-dried .....	7,290
Lignite .....	7,500
Bituminous coal .....	11,000
Anthracite .....	14,000

Although peat fuel may not be extensively produced in the United States as long as there is an abundant supply of coal, it has great potential value as a source of heat and power and may be utilized to conserve coal and wood. During economic and industrial crises, it may be used locally, in some States, to prevent a shortage of fuel. Although many extravagant claims concerning the fuel value of peat

have been made, its inferiority to coal was early recognized. Much money has been spent fruitlessly in this country in trying to produce some form of peat fuel equal to coal in heating value (193).

#### *Charcoal from peat*

According to Davis (69), a crude process of making charcoal from peat was in use in several European countries early in the eighteenth century, especially in districts where wood was scarce. The charcoal burners of Europe made a circular dome-shaped heap of peat by piling cut bricks around a pole, at the base of which a small quantity of dry fuel was placed to start combustion. A flue-like space, through which the dry fuel was ignited and air was admitted, led to the outside of the heap. A small space around the central pole formed a chimney for gas and smoke, and various inlets for air were made through the sides of the structure. The peat was covered with a layer of brush, outside of which was placed a layer of soil varying in thickness from about one foot, at the bottom, to half as much at the top. After the fire was started, the chimney opening in the top of the heap was closed, and the supply of air regulated to prevent too much combustion. When the coking was complete, all openings were closed with moist soil, the fire was allowed to die out, and the mass was allowed to cool thoroughly before the heap was opened. The yield of charcoal obtained by this method was from 30 to 40 per cent of the original dry weight of the peat. The economic and technical aspects of coking of peat have been examined in detail by Wielandt (323).

Numerous processes have been developed for the utilization of peat for industrial purpose. It is sufficient to mention the manufacture of active carbon (7, 334, 255, 270) and the carbonization of peat combined with the production of cyanide (112). The low ash content of sphagnum peats made possible their utilization in certain blast furnaces as reducing agents, in place of coal or coke.

#### *Distillation of peat*

The products of carbonization of peat comprise various condensable gases, tar oils, charcoal, and a liquor containing methyl alcohol, acetic acid, acetone, ammonia, and other compounds. At lower temperatures, the charcoal is the main product; at higher temperatures, the gas becomes an important product (18, 28, 154, 234, 75, 149, 97). The type of gas producer used for this purpose depends upon the particular by-products which are to be recovered. When peat is distilled in a vacuum, the yield of gaseous and liquid products is reduced and that of tar increased (205, 138, 234, 103).

Attempts have been made to utilize peat for distillation purposes, 25-30 gallons of oil being obtained at 150°-360° C. from 1 ton of dry peat. Ammonium sulfate is obtained as a by-product, the amount depending on the nitrogen content of the peat. Peat has also been utilized in the production of illuminating gas, fuel gas, and in by-product gas-producing plants, as the Mond and Frank-Caro processes.

According to Keppeler (154), the gas from peats, especially of the sphagnum type, has a slightly higher calorific value than the producer-gas from coal. Its uniformity of composition and its freedom from sulfur render it suitable for metallurgical processes. Peat yielded good results in a revolving producer when gasified with coal. In the process of carbonization of peat, drying takes place up to 100° C.; from 100° to 200° C., more water is split off and CO<sub>2</sub> is evolved; above 200° C., the process becomes strongly exothermic; at 350° to 480° C., the CO<sub>2</sub> gives place to combustible gases. The resulting coke possesses a low ignition temperature and a high reactivity.

Neutral oils from a tar distilled from sphagnum peat up to 360° C. have been studied in Russia (302) and found to consist of mixtures of aliphatic and aromatic hydrocarbons and ketones. Aliphatic compounds were both saturated and unsaturated, the latter of the C<sub>n</sub>H<sub>2n-2</sub> type and evidently substituted alkenes. Ketones boiling at less than 170° C. were saturated aliphatic compounds and formed fatty acids from peat; those boiling at higher temperatures were cyclic types (229, 287).

#### *Use of peat for fabrics and paper*

Numerous uses have been made of peat for the production of paper, woven fabrics, mattresses, antiseptic dressings, artificial wood, special furniture, and house-insulating material. Peat has also been used for preparation of dye stuffs, for mud baths, and for a variety of other purposes. Most of these have only a local application, but may give rise to important developments.

Common grades of paper and cartons can be obtained from the surface layer of peat. Peat steamed or cooked with NaOH was found to give stronger paper than the crude product; peat cooked with H<sub>2</sub>O produced a stock lighter in color. The substitution of peat for waste stock or mechanical pulp results in somewhat lower mechanical properties of paper. In one process peat was cooked about two hours at a maximum pressure of two atmospheres with 3.5 per cent NaOH (247). In another process, peat is torn into fiber, mixed with about one third of its quantity of a preparation formed from rag clippings, freed from surplus water, treated with rosin and alum, and formed into sheets (254, 136).

Attempts to produce better grades of paper from peat have given negative results. By reworking the peat in the cold it has been possible to obtain somewhat better results. By treating it with chlorine, followed by  $\text{Ca}(\text{OH})_2$ , a product was obtained which could be bleached with  $\text{Ca}(\text{ClO})_2$  and give a suitable material for low-grade newsprint. Various wrapping papers, wall paper, paper board and cartons have also been prepared from peat of the highmoor or moss type (332).

#### *Use of peat for building and insulation*

Dry peat is a poor conductor of heat, which makes it a useful insulating material. It may be treated with a 5 per cent  $\text{LiCl}$  solution or with other dilute aqueous solutions of halide salts of an alkali metal or of ammonium, to render the product resistant to  $\text{H}_2\text{O}$  and to fire. Boric or phosphoric acid salts also may be used as fire-proofing agents (324).

#### *Use of peat as a catalyst*

Various products are manufactured from peat to give certain catalytically active substances. This is true of a carbonized product for conversion of phenol to hydrocarbons in city gas (205).

#### *Preparation of bitumens from peat*

Probably in no country has the industrial utilization of peat reached such a high state of development as in Russia. To the long list of applications, some of which have already been referred to, must be added that of extraction from certain types of peat of certain waxy substances designated by the collective name, "bitumens." Various peats are extracted with  $\text{C}_6\text{H}_6$ - $\text{EtOH}$  solutions; a yield of 8.0 to 20 per cent bitumen, depending on the organic matter in the peat, is obtained. By extraction with alcohol-ether solution, this bitumen can be separated into crystallizable wax and insoluble amorphous resin in the proportion of 45 parts of the former to 55 of the latter. The resins are easily polymerized by heating to  $180^\circ$ , and are rendered insoluble in  $\text{CS}_2$  and  $\text{C}_6\text{H}_6$  and  $\text{Cl}_2$ . Comparative distillation of the peat and bitumens indicates that in the initial stages of destructive distillation of peat, polymerization of the resins is involved (287, 302, 230, 19, 18, 338, 162).

*Use of peat for fermentation purposes*

Various attempts have been made to utilize peat for fermentation purposes. Only carbohydrates need be considered here, since the other constituents are hardly attacked by the anaerobic organisms (185).

*Use of peat for tanning purposes*

The so-called humic acid constituents of peat can be converted into a synthetic tanning material by oxidation. Peat has also been used as a reducing agent for  $K_2CR_2O_7$  in the preparation of one-bath tanning liquors. The resulting extract is said to have better tanning properties than glucose-prepared liquors, and it is much cheaper. Leather tanned with peat-reduced liquors resembles those which are tanned by the two-bath process. The dichromates are reduced in the presence of copper sulfate as a catalyst. The quantity of peat necessary to reduce dichromates is such that the ratio of humic acid to the dichromate is 1:2. Only those peats that have a low ash content and a high "humic acid" content, of not less than 50 per cent, can be utilized for this purpose (188).

## BIBLIOGRAPHY

- (1) Acklin, O., and Camenisch, A. Sewage purification by means of peat (filters). *Tech. Hyg.* 3: 45-49, 1934. (*Chem. Abs.* 28: 4510, 1934.)
- (2) Aiton, W. A treatise on the Origin, Qualities and Cultivation of Moss Earth. 1811.
- (3) Allison, R. V., Bryan, O. C., and Hunter, J. H. The stimulation of plant response on the raw peat soils of the Florida Everglades through the use of copper sulphate and other chemicals. *Fla. Agr. Exp. Sta. Bul.* 190, 1927.
- (4) Alway, F. J. Agricultural value and reclamation of Minnesota peat soils. *Minn. Agr. Exp. Sta. Bul.* 188, 1920.
- (5) Alway, F. J., Shaw, W. M., and Methley, W. J. Phosphoric-acid content of crops grown upon peat soils as an index of the fertilization received or required. *Jour. Agr. Res.* 33: 701-740, 1926.
- (6) Ames, J. W. Peat and muck soils. *Ohio Agr. Exp. Sta. Mo. Bul.* 4: 161-165, 1919.
- (7) Anasov, V., and Gagen, O. Active charcoal from peat. *Izv. Saratovsk. Obshch. Iestestvov.* 2: 81-89, 1928. (*Chem. Abs.* 24: 2551, 1930.)
- (8) Anderson, J. A practical treatise on peat moss. London, 1794.
- (9) Anonymous. Holland, the use of peat in. *Electrotech. Rund.* 30: 220, 1913; *Jour. Amer. Peat Soc.* 6: 177, 1913.
- (10) Anrep, A. Investigation of the peat-bogs and peat industry of Canada. *Canada Dept. Mines, Bul.* 351, 1915.
- (11) Anrep, A. Peat bogs for the manufacture of peat litter and peat mull in S. W. British Columbia. *Canada Geol. Survey. Rpt.* 1927: 53-61, 1928.
- (12) Arnd, Th. Beiträge zur Kenntnis der Mikrobiologie unkultivierter und kultivierter Hochmoore. *Centbl. Bakt.* (II) 45: 554-574, 1916.
- (13) Arnd, Th. Über schädliche Stickstoffumsetzungen in Hochmoorböden als Folge der Wirkung starker Kalkgaben. *Landw. Jahrb.* 47: 371-442, 1914; 49: 191-213, 1916.
- (14) Arnd, Th. Über die Entstehungsweise salpeter-und salpetrigsäurer Salze in Moorböden. *Landw. Jahrb.* 51: 297-328, 1918.
- (15) Arnd, Th., Siemers, W., and Hoffmann, W. Zur Kenntnis des Puffervermögens der Moorböden. *Ztschr. Pflanzenernähr. Düngung u. Bodenk.* (A) 19: 334-342, 1931.
- (16) Artist, R. C. Pollen spectrum studies on the Anoka sand plain in Minnesota. *Ecol. Monog.* 9: 493-535, 1939.
- (17) Aschan, O. Humocerinsäure, ein Bestandteil im Torf. *Torfwirtschaft.* 2: 1-9, 1921. (*Brennstoff-Chem.* 2: 316, 1921.)
- (18) Aschan, O. Distillation and extraction of peat. *Tek. Fören. Finland* 54: 285-288, 1934; 55: 31-35, 1935. (*Chem. Abs.* 29: 1230, 3493, 1935.)
- (19) Auer, V. Peat bogs of Southeastern Canada. *Canada Geol. Survey Mem.* 162: 1-32, 1930; *Handb. Moork.* 7: 141-223, 1933.
- (20) Bastin, E. S., and Davis, C. A. The peat deposits of Maine. *U. S. Geol. Survey Bul.* 376: 1-27, 1909.
- (21) Baumann, A., and Gully, E. Untersuchungen über die Humussäuren. II. Die freien Humussäure des Hochmoores. *Mitt. K. Bayern. Moorkult.* 4: 31-156, 1910.
- (22) Baur, A. J. Effect of composting on the chemical and biological changes in peat and in wheat straw. *Jour. Amer. Soc. Agron.* 26: 820-830, 1934.
- (23) Beckenback, J. R. A fertility program for celery production on Everglades organic soils. *Fla. Agr. Exp. Sta. Bul.* 333, 1939.
- (24) Beckwith, C. S. Cranberry growing in New Jersey. *N. J. Agr. Exp. Sta. Cir.* 144, 1922.
- (25) Bedford, R. H. The decomposition of peat measured by carbon dioxide evolved. *Sci. Agr.* 9: 522-532, 1929.



- (26) Begak, D. A., and Bielikova, N. M. Abundance and distribution of microorganisms in highmoor peat bogs. *Trudi Instorfa* 14: 44-78, 1934.
- (27) Behrens, W. U., and Robertson, I. M. Der Ionenumtausch in Torf. *Ztschr. Pflanzenernähr. Düngung. u. Bodenk.* (A) 23: 50-57, 1931.
- (28) Belani, — Gas generation from peat by low-temperature carbonization. *Erdöl u. Teer*. 10: 193-194, 1934. (*Chem. Abs.* 28: 7478, 1934.)
- (29) Bersch, W. Die Moore Oesterreichs. Eine botanisch-chemische Studie. *Ztschr. Moorkult. u. Torfverwert.* 5: 175-196, 343-374, 429-473, 1907.
- (30) Bersch, W. Handbuch der Moorkultur, Ed. 2. W. Frick, Wien u. Leipzig, 1912.
- (31) Birk, C. Das tote Moor am steinbuder Meer. *Arb. Lab. Tech. Moorverwert. Hochsch. Hann.* 1: 1-102, 1914.
- (32) Bone, W. A., Parsons, L. G. B., Sapiro, R. H., and Groocock, C. M. Researches on the chemistry of coal: VIII. The development of benzenoid constitution in the lignin—peat series. *Proc. Roy. Soc. [London]* (A) 148: 492-522, 1935.
- (33) Bonsteel, J. A. Soils of the eastern United States: XL. Marsh and swamp. *U. S. Department of Agriculture Bur. Soils Civ.* 69: 2-12, 1912.
- (34) Bottomley, W. B. Some accessory factors in plant growth and nutrition. *Proc. Roy. Soc. [London]* (B) 88: 237-247, 1914; 89: 102, 481, 1917; 91: 83, 1919; *Ann. Bot.* 34: 345-352, 1920.
- (35) Bouyoucos, G. A method for determining combined water and organic matter in soils. *Soil Sci.* 34: 259-267, 1932.
- (36) Bouyoucos, G., and McCool, M. M. A study of the causes of frost occurrence in muck soils. *Soil Sci.* 14: 383-389, 1922.
- (37) Brown, S. Fertilizer—on the value and uses of swamp muck. *U. S. Patent Off. Rpt. Agr.* 1856: 182-198, 1856.
- (38) Browne, D. J. The Field Book of Manures; or, the American Muck Book. A. O. Moore, New York, 1858.
- (39) Brüne, Fr. Studien über den Einfluss des Klimas auf das Gedeihen von Moorwiesen und Moorweiden. Berlin, 1907.
- (40) Bülow, K. V. Allgemeine Moorgeologie. Borntraeger, Berlin, 1929.
- (41) Carslaw, R. McG., and Graves, P. E. Farm organization of the black fens of the Isle of Ely. *Jour. Roy. Agr. Soc. England* 98: 35-52, 1937.
- (42) Chapek, M. V. The physico-chemical phenomenon of the wetting resistance of peat to water. *Kolloid Ztschr.* 66: 91-95, 1934. (*Chem. Abs.* 28: 1906, 1934.)
- (42a) Chapman, V. J. Studies in salt marsh ecology. *Jour. Ecol.* 26: 144-179, 1938; 27: 160-201, 1939; 28: 118-152, 1940.
- (43) Chittenden, F. J. Reports on experiments with bacterized peat or humogen. *Jour. Roy. Hort. Soc.* 41: 305-326, 1915.
- (44) Christensen, H. R. Mikrobiologische Untersuchungen von Hoch—und Niederungsmoortorf. *Centbl. Bakt.* (II) 37: 414-431, 1913.
- (45) Chrysler, M. A. The ecological plant geography of Maryland; Coastal Zone; Western shore district. The plant life of Maryland. *Md. Weather Serv.* 3: 149-219, 1910.
- (46) Clayton, B. S. Subsidence of peat soils in Florida. *U. S. Department of Agriculture Bur. Agr. Engin. Bul.* 1070, 1936.
- (47) Clayton, B. S. Subsidence of Florida peat soil. *Trans. Sixth Comm. Internatl. Soc. Soil Sci. [Zürich]* B: 340-343, 1937.
- (48) Clements, F. E. Aeration and air content. The role of oxygen in root activity. *Carnegie Inst. Wash. Pub.* 315, 1921.
- (49) Cook, G. H. On a subsidence of the land on the sea-coast of New Jersey and Long Island. *Amer. Jour. Sci. Arts* 74: 341-354, 1857.
- (50) Cook, G. H. Peat and muck deposits. *Ann. Rpt. N. J. State Geol.* 1866, 1878, 1879, 1880.
- (51) Coville, F. V. The agricultural utilization of acid lands by means of acid-tolerant crops. *U. S. Department of Agriculture Bul.* 6: 1-13, 1913.
- (52) Coville, F. V. The agricultural use of acid peats. *Jour. Amer. Peat Soc.* 18: 5-7, 1925.

- (53) Crandall, F. K., and Odland, T. E. Substituting fertilizers, green manure and peat for stable manure in the growing of vegetables. *R. I. Agr. Exp. Sta. Bul.* 234: 5-53, 1932.
- (54) Dachnowski, A. P. Quality and value of important types of peat material. *U. S. Department of Agriculture Bur. Plant Indus. Bul.* 802: 1-40, 1919.
- (55) Dachnowski, A. P. Peat deposits in the United States and their classification. *Soil Sci.* 10: 453-465, 1920.
- (56) Dachnowski, A. P. Preparation of peat composts. *U. S. Department of Agriculture Bur. Plant Indus. Cir.* 252, 1922.
- (57) Dachnowski, A. P. The chemical examination of various peat materials by means of foodstuff analyses. *Jour. Agr. Res.* 29: 69-83, 1924.
- (58) Dachnowski, A. P. The stratigraphic study of peat deposits. *Soil Sci.* 17: 107-133, 1924.
- (59) Dachnowski, A. P. Factors and problems in the selection of peat lands for different uses. *U. S. Agr. Bul.* 1419, 1926.
- (60) Dachnowski, A. P. Profiles of peat deposits in New England. *Jour. Ecol.* 7: 120-135, 1926.
- (61) Dachnowski-Stokes, A. P. Moss peat, its uses and distribution in the United States. *U. S. Department of Agriculture Cir.* 167, 1931.
- (62) Dachnowski-Stokes, A. P. Classification of peat soils. *Jour. Wash. Acad. Sci.* 22: 50-59, 1932.
- (63) Dachnowski-Stokes, A. P. Peat deposits in United States of America. *Handb. Moork.* 7: 1-140, 1933.
- (64) Dachnowski-Stokes, A. P. Essentials of a general system of classifying organic soils. *Trans. 3rd Internatl. Cong. Soil Sci. [Oxford]* 1: 416-418, 1935.
- (65) Dachnowski-Stokes, A. P. Structural characteristics of peat and muck. *Soil Sci.* 50: 389-399, 1940.
- (66) Dana, S. L. A Muck Manual for Farmers, Ed. 4. C. M. Saxton & Co., New York, 1856.
- (67) Davies, W. L. The proteins of different types of peat soils. *Jour. Agr. Sci.* 18: 682-690, 1928.
- (68) Davis, C. A. Peat resources of the United States, exclusive of Alaska. *U. S. Geol. Survey Bul.* 394: 62-69, 1909.
- (69) Davis, C. A. The uses of peat for fuel and other purposes. *U. S. Dept. Int., Bur. Mines Bul.* 16: 7-203, 1911.
- (70) Davis, C. A. Origin and formation of peat. *U. S. Dept. Int., Bur. Mines Bul.* 38, 1913.
- (71) Davis, R. O. E., Miller, R. R., and Scholl, W. Nitrification of ammoniated peat and other nitrogen carriers. *Jour. Amer. Soc. Agron.* 27: 729-737, 1935.
- (72) Dawson, R. B. Compost; its preparation and use. *Jour. Bd. Greenk. Res.* 1: 130, 1930.
- (73) Deevey, E. S. Studies on Connecticut lake sediments: I. A post-glacial climatic chronology for southern New England. *Amer. Jour. Sci.* 237: 691-724, 1939.
- (74) Donath, E., and Lissner, A. Zur Frage der Entstehung der Kohlen. *Brennstoff-Chem.* 3: 231-237, 1922; *Braunkohle* 27: 257-264, 1928.
- (75) Donnelly, J. T., and Reilly, J. Studies on peat: III. Low-temperature carbonization of peat. *Sci. Proc. Roy. Dublin Soc.* 19: 365-376, 1930.
- (76) Dragunov, S. S. Organo-mineral fertilizers from peat. *Ztschr. Pflanzenernähr., Düngung, u. Bodenk.* (A) 30: 199-208, 1933.
- (77) Dragunov, S. S. New ways of use and production of organic mineral fertilizers. *Trans. VI Mendeleev Cong. Theor. Appl. Chem.* 1932, 2 (2): 54-61, 63-64, 1935. (*Chem. Abs.* 30: 4971, 1936.)
- (78) Dragunov, S. S., and Bakhtina, E. F. Löslichkeit der Huminsäuren und die Stickstoff-Formen in verschiedenen Torfarten. *Ztschr. Pflanzenernähr., Düngung u. Bodenk.* (A) 34: 89-100, 1934.
- (79) Druzhinin, D. V. The role of peat in increasing the absorption capacity and buffer properties of soils. *Udobrenie i Urozhai* 2: 645-650, 1930. (*Chem. Abs.* 25: 3114, 1931.)

- (80) Dumanski, A. Sur les propriétés colloïdales de la tourbe. *Bul. Soc. Chim. France* 41: 166-185, 1927.
- (81) Dumanski, A., and Chapek, M. Colloid-chemical investigations of peat. *Colloid. Jour. (U. S. S. R.)* 2: 95-112, 1936. (*Chem. Abs.* 30: 6533, 1936.)
- (82) Dycherhoff, E. Use of peat in plant cultivation. Brit. Pat. 394, 654, June 19, 1933. (*Chem. Abs.* 27: 5882, 1933.)
- (83) Elliot, C. G. Swamp lands of the United States. Senate Document No. 443. 60th Congress, 1st Session. 1908.
- (84) Elliott, G. R. B. Cultivation of crops on peat or muck land. *Jour. Amer. Peat Soc.* 18: 25-35, 1925.
- (85) Ellis, J. C. B., and Morison, C. G. T. The ammoniacal nitrogen of peat and humus soils: II. *Jour. Agr. Sci.* 18: 346-349, 1928.
- (86) Erdtman, G. New methods in pollen analysis. *Svensk. Bot. Tidskr.* 30: 154-164, 1936.
- (87) Faegri, K., and Gaml, H. Entwicklung und Verheinitlichung der Signaturen für Sediment und Torfarten. *Geol. För. Stockholm Förhandl.* 1937; *New Phytol.* 37: 329-332, 1938.
- (88) Feilitzen, H. von. Über die Zusammensetzung des Torfes verschiedener Herkunft und Art. *Jour. Landw.* 46: 9-16, 1898.
- (89) Feilitzen, H. von, and Tollens, B. Über den Gehalt des Torfes an Pentosan und anderen Kohlenhydraten. *Jour. Landw.* 46: 17-22, 1898.
- (90) Feustel, I. C. Nature and use of organic amendments. *U. S. Department of Agriculture Yearbook* 1938: 462-468, 1938.
- (91) Feustel, I. C. The acidic properties of peat and muck. *U. S. Department of Agriculture Tech. Bul.* 690, 1939.
- (92) Feustel, I. C., and Byers, H. G. The physical and chemical characteristics of certain American peat profiles. *U. S. Department of Agriculture Tech. Bul.* 214, 1930.
- (93) Feustel, I. C., and Byers, H. G. The decomposition of hydrolytic peat products including ammoniated peat. *U. S. Department of Agriculture Tech. Bul.* 389, 1933.
- (94) Feustel, I. C., and Byers, H. G. The comparative moisture-absorbing and moisture-retaining capacities of peat and soil mixtures. *U. S. Department of Agriculture Tech. Bul.* 532, 1936.
- (95) Fischer, Fr. Was lehrt die Chemie über die Entstehung und die chemische Struktur der Kohle. *Naturwiss. en schaften* 9: 958-965, 1921; *Brennstoff-Chem.* 2: 37-45, 1921; 3: 65-72, 1922.
- (96) Fischer, Fr., Schrader, H., and Freidrich, D. Über den Methoxylgehalt vermodernder Pflanzenstoffe. *Gesam. Abhandl. Kennt. Kohle.* 5: (1920) 530-540, 1922.
- (97) Fischer, F., and Sustmann, H. Gasdruckverschmelzung von rheinischen Braunkohlenbriketts, von Vehlener Torf, von Fichtenholzsägemehl und von Steinkohlenteerpech. *Brennstoff-Chem.* 15: 387-389, 1934.
- (98) Fleig, O. Fertilizer containing peat. U. S. Pat. 2, 038, 994. (*Chem. Abs.* 30: 4266, 1936.)
- (99) Fleischer, M. Die Eigenschaften des Hochmoorbodens als landwirtschaftliches Kulturmedium. *Landw. Jahrb.* 20: 374-954, 1891.
- (100) Fleischer, M. Die Moorbesiedlung in Vergangenheit und Zukunft; ein Ratgeber für Siedler, Besiedlungsbehörden und andere Besiedlungsunternehmer. Berlin, 1920.
- (101) Forsaith, C. C. A report on some allochthonous peat deposits of Florida. *Bot. Gaz.* 62: 32-52, 1916; 63: 190-208, 1917.
- (102) Fowler, G. Fenland waterways past and present. *Cambridge Antiquar. Soc. Commun.* 33, 1933.
- (103) Foxwell, G. E. The use of peat in gas manufacture. *Gas World* 105: 176-177, 1936. (*Chem. Abs.* 30: 7309, 1936.)
- (104) Francis, W., and Tidswell, F. V. The mode of occurrence of dopplerite: an unusual constituent of peat. *Fuel in Sci. and Pract.* 6: 516-525, 1927. (*Chem. Abs.* 22: 562, 1928.)
- (105) Früh, J. J. Über Torf und Dopplerite. Eine mineralogische Studie. Zürich, 1883; *Ber. Schweiz. Bot. Gesell.* 1: 62-79, 1891.

- (106) Früh, J., and Schrötter, C. Die Moore der Schweiz mit besonderer Berücksichtigung der gesamten Moorfrage. Bern, 1904.
- (107) Fuller, G. D. Interglacial and postglacial vegetation of Illinois. *Trans. Ill. State Acad. Sci.* 32: 5-15, 1939.
- (108) Fürst. Die Torfstreu und ihre Bedeutung für Stadt und Land. Berlin, 1892.
- (109) Geikie, A. Text Book of Geology, Ed. 4. New York, 1903.
- (110) Gissing, F. T. Peat Industry Reference Book. C. Griffin & Co., London, 1920.
- (111) Gliemeroth, G. Der Einfluss von Stroh und Torfstreu auf die Düngwirkung des Stallmistes. *Jour. Landw.* 86: 234-247, 1939.
- (112) Goldschmidt, R. The utilization of peat. *Chim. et Indus. [Paris]* Spec. No.: 269-271, 1927. (*Chem. Abs.* 21: 3443, 1927.)
- (113) Goodwin, H. *Chronica Bot.* 6: 11, 1941.
- (114) Goodwin, H., and Clifford, M. H. Studies on the post glacial history of British vegetation. *Phil. Trans. Roy. Soc. [London]* 229: 323-406, 1938.
- (115) Gorbenko, V. Zur Frage der Bestimmung von Torfzerlegungs grade. *Izv. Nauch. Eksper. Torf. Inst., Moskau. (Mitt. Wiss. Exp. Torfst., Moskau)* 2: 104-121, 1922.
- (116) Gortner, R. A. The organic matter of the soil: I. Some data on humus, humus carbon, and humus nitrogen. *Soil Sci.* 2: 395-442, 1916.
- (117) Gortner, R. A., and Bliss, M. J. On the origin of the humin formed by the acid hydrolysis of proteins. *Jour. Amer. Chem. Soc.* 37: 1630-1636; 39: 2477-2501, 1917; 42: 821-827, 1920; *Jour. Biol. Chem.* 26: 177-204, 1915.
- (118) Gray, L. C., et al. The utilization of our lands for crops, pasture and forests, *U. S. Department of Agriculture Yearbook* 1923: 415-506, 1924.
- (119) Gully, E. Über die Beziehungen zwischen Vegetation, chemischer Zusammensetzung und Dungebedürfnis der Moores. *Mitt. K. Bayern. Moorkult.* 3: 1-38, 1909.
- (120) Gully, E. Die Nitritzerstorungs und Nitribildungsvermögen der Moorboden. *Landw. Jahrb. Bayern.* 6: 1-81, 1911.
- (121) Gully, E. Untersuchungen über die Humussäuren. III. Die Chemische Zusammensetzung und das Basenabsorptionsvermögen der Sphagnen, die Abhängigkeit derselben vom Standorte und die Bedeutung der einzelnen Nährstoffe bei der Bildung von Hochmoor. *Mitt. K. Bayern. Moorkult.* 5: 1-84, 1913.
- (122) Gully, E. Die Humussäuren im Lichte neuzeitlicher Forschungsergebnisse. *Internat. Mitt. Bodenk.* 5: 232-247, 1915.
- (123) Haldane, J. S., and Makgill, R. H. The spontaneous oxidation of coal and other organic substances. *Jour. Soc. Chem. Indus.* 53 T: 359-367, 1934.
- (124) Hammer, H. E. The chemical composition of Florida Everglades peat soils, with special reference to their inorganic constituents. *Soil Sci.* 28: 1-11, 1929.
- (125) Harmer, P. M. The muck soils of Michigan, their management and uses. *Mich. Agr. Exp. Sta. Sp. Bul.* 314, 1941; *Ext. Bul.* 123, 1932.
- (126) Harshberger, J. W. Bogs, their nature and origin. *Plant World* 12: 34-41, 53-61, 1909.
- (127) Hartwell, B. L., and Crandall, F. K. The substitution of stable manure by fertilizers, green manure and peat. *R. I. Agr. Exp. Sta. Bul.* 216, 1928.
- (128) Hausding, A. A handbook on the Winning and Utilization of Peat. (Translated by Hugh Ryan.) London, 1921.
- (129) Hess, K., and Komarewsky, W. Über Isolierung und Nachweis von Cellulose in Torf. *Ztschr. Angew. Chem.* 41: 541-542, 1928.
- (130) Hitchcock, A. E. Effect of peat moss and sand on rooting response of cuttings. *Bot. Gaz.* 86: 121-148, 1928.
- (131) Hoering, P. Moornutzung und Torfverwertung mit besonderer Berücksichtigung der Trockendestillation. Berlin, 1915.

- (132) Hopkins, C. G., Readhimer, J. E., and Fisher, O. S. Peaty swamp lands; sand and "alkali" soils. *Ill. Agr. Exp. Sta. Bul.* 157, 1912; *Soil Rpt.* 13, 1916.
- (133) Hoppe-Seyler, F. Über Huminsubstanzen, ihre Entstehung und ihre Eigenschaften. *Ztschr. Physiol. Chem.* 13: 66-121, 1889.
- (134) Höveler, W. Ueber die Verwertung des Humus bei der Ernährung der chlorophyllführenden Pflanzen. *Jahrb. Wiss. Bot.* 24: 283-316, 1892.
- (135) Howard, L. B., Pmck, L. A., and Hilbert, G. E. Ammoniated peat, mechanism of formation of water soluble nitrogenous constituents. *Indus. and Engin. Chem.* 27: 1508-1509, 1935.
- (136) Hoyer, F. Peat as raw paper material. *Kunststoffe* 18: 255-259, 1928. (*Chem. Abs.* 24: 1216, 1930.)
- (137) Hyde, J. B. Treatment and Uses of Peat and Peaty Material. Ballière Bros., New York, 1866.
- (138) Ivanov, B. I. The thermal decomposition of peat and its constituents. *Fuel* 14: 43-50, 86-92, 1935. (*Chem. Abs.* 29: 4156, 1935.)
- (139) Jeffrey, E. C. The origin and organization of coal. *Mem. Amer. Acad. Arts and Sci.* 15: 1924.
- (140) Jessen, W., and Lesch, W. Ueber den Einfluss von Kieselsäure, Torf und Humus auf die Löslichkeit und Aufnahme der Phosphorsäure. *Ztschr. Pflanzenernähr., Düngung. u. Bodenk.* (A) 17: 48-60, 1930.
- (141) Jodidi, S. L. Organic nitrogenous compounds in peat soils. *Mich. Agr. Exp. Sta. Tech. Bul.* 4, 1909.
- (142) Jodidi, S. L. The chemical nature of the organic nitrogen in the soil. *Jour. Amer. Chem. Soc.* 33: 1226-1241, 1911.
- (143) Johnson, D. W. The New England Acadian Shoreline. New York, 1925.
- (145) Johnson, S. W. Essays on Peat, Muck and Commercial Manures. Brown and Gross, Hartford, 1859.
- (146) Johnson, S. W. Peat and Its Uses, as Fertilizer and Fuel. Orange Judd & Co., New York, 1866.
- (147) Johnstone, K. G. The use of peat in horticulture. *Jour. Min. Agr. [Gr. Brit.]* 32: 474-481, 1931.
- (148) Junger, — Die Torfstreu in ihrer Bedeutung für die Landwirtschaft und Stadtereinigung. Berlin, 1890.
- (149) Karl, W., and Jacobs, I. H. Low-temperature distillation of brown coal, peat or similar materials, U. S. Pat. 1,721,997. (*Chem. Abs.* 23: 4557, 1929.)
- (150) Katzman, L. Manufacture of artificial manure from peat. *Mezőgazdasági Kutatószk* 3: 334-348, 1930. (*Chem. Abs.* 25: 2800, 1931.)
- (151) Kauko, Y. Hydrolysis of peat and lichens by dilute hydrochloric acid. *Ann. Acad. Sci. Fennicæ (A)* 26: 3-13, 1927. (*Chem. Abs.* 21: 2665, 1927.)
- (152) Kazakov, E. Acidity and degree of saturation of moorland soils. *Arb. Meliorat. Vers. Sta. Leningrad* 5, 1930 (*Chem. Abs.* 26: 236, 1930).
- (153) Keppeler, G. Bestimmung des Verrotungsgrades von Moor- und Torfproben. *Jour. Landw.* 68: 43-70, 1920.
- (154) Keppeler, G. Gasification and carbonization of peat. *Stahl u. Eisen* 46: 631-635, 742-750, 1926 (*Chem. Abs.* 21: 1698, 1927).
- (155) Kitchell, W. Geological Survey of the State of New Jersey for the year 1855. True American Office, Trenton, 1856.
- (156) Kivinen, E. The reaction of sphagnum fuscum peats. *Soil Res.* 3: 196-201, 1933.
- (157) Kivinen, E. Über die organische Zusammensetzung der Torfarten und einiger Torfkonstituenten. *Cent. Agr. Exp. Sta. Finland* 36, 1934.
- (158) Kivinen, E. Über Elektrolytgehalt und Reaktion der Moorwässer. *Cent. Agr. Exp. Sta. Finland* 38, 1935.
- (159) Kivinen, E. Zur Kenntnis der Eisenkarbonatvorkommisse in den Mooren Finnlands. *Bodenk. u. Pflanzenernähr.* 45: 96-104, 1936.
- (160) Klein, — Injurious effect of peat water on meadows. *Biedermann's Zentbl.* 1880: 168-171. (*Jour. Chem. Soc. [London]* 38: 738, 1880.)
- (161) Kondratiev, E. V., and Kutniév, S. K. Changes of the chemical composition of peat in self-heating. *Khim. Tverdogo Topliva* 6: 107-113; 403-408, 1935. (*Chem. Abs.* 29: 7614, 1935.)

- (162) Kounhoff, F. The decomposition of limed and unlimed peat. *Trans. Sci. Inst. Fert. (Moskau)* 104: 121-127, 1933. (*Chem. Abs.* 28: 4518, 1934.)
- (163) König, J., and Rump, E. *Chemie und Struktur der Pflanzenmembran.* Springer, Berlin, 1914.
- (164) Kotilainen, M. J. Untersuchungen über die Beziehungen zwischen der Pflanzendecke der Moore und der Beschaffenheit, besonders der Reaktion des Torfboden. *Wiss. Veröffentl. Finnisch. Moorkulturver.* 7, 1928.
- (165) Krüger, C. Über die Wirkung der Bemoorung von Sandboden. *Biedermann's Zentbl.* 42: 651-652, 1913.
- (166) Kurbatov, I. M. Determination of the degree of decomposition of peat. *Torfwesen* 11-12: 27, 1931. (*Chem. Abs.* 28: 4155, 1934.)
- (167) Kurnatov, N. W., and Pospelova, N. A. Tensimetric analysis of peat. *Jour. Appl. Chem. (U. S. S. R.)* 4: 969-982, 1931. (*Chem. Abs.* 26: 3358, 1932.)
- (168) Kurz, H. Influence of sphagnum and other mosses on bog reactions. *Ecology* 9: 56-69, 1928.
- (169) Laurie, A. The use of peat in the greenhouse. *Mich. Agr. Exp. Sta. Spec. Bul.* 194, 1930.
- (170) Leavitt, T. H. Facts about peat. *Manufacturers Hand Book*, Ed. 3. Lee & Shepard, Boston, 1867.
- (171) Lipman, C. B., and Wanck, M. E. The availability of nitrogen in peat. *Soil Sci.* 18: 311-316, 1924.
- (172) Lipman, J. G. The stuff of life. *Indus. and Engin. Chem.* 27: 103-110, 1935.
- (173) Livingston, B. E. Physical properties of bog water. *Bot. Gaz.* 37: 383-385, 1904.
- (174) Logvinova, Z. V. Peat compost as a fertilizer. *Trans. Sci. Inst. Fert. [Moskau]* 32, 1926.
- (175) Logvinova, Z. V. Peat as a source of nitrogen. *Trans. Sci. Inst. Fert. [Moskau]* 56: 1-66, 1929.
- (176) Logvinova, Z. V. The influence of peat on the utilization of phosphoric acid from phosphates. *Udobrenie i Urozahi* 1929: 211-216. (*Chem. Abs.* 24: 1925, 1930.)
- (177) Logvinova, Z. V. The utilization of peat in agriculture. *Trans. Sci. Inst. Fert. [Moskau]* 104: 61-90, 1933.
- (178) Logvinova, Z. V., and Ivanov, A. G. The effectiveness of organomineral fertilizers. *Rpts. Sci. Inst. Fert. and Insectofungicides, Leningrad. Third. Internat. Cong. Soil Sci. [Oxford]* 1935: 67-82.
- (179) Lundblad, K. Transformation of a Scirpus-Carex bog to grassland without soil cultivation or seedling. *Svenska Mosskulturför. Tidsk.* 51: (1) 45-66, 1937.
- (180) McCool, M. M. Value of peats for mineral soil improvement. *Contrib. Boyce Thompson Inst.* 4: 245-255, 257-271, 1932.
- (181) McCool, M. M., and Harmer, P. M. The muck soils of Michigan. *Mich. Agr. Exp. Sta. Spec. Bul.* 136, 1925.
- (182) Makrinov, I. A. The biochemistry and biodynamics of the decomposition of peat. *Arkhh. Biol. Nauk.* 30: 169-180, 293-302. (*Chem. Abs.* 24: 4375, 5788, 1930.)
- (183) Makrinov, I. A. The decomposition of peat under aerobic conditions. *Centbl. Bakt. (II)* 89: 201-209, 1933.
- (184) Marcusson, J. Torfzusammensetzung und Lignintheorie. *Ztschr. Angew. Chem.* 35: 339, 1925. (*Biedermann's Zentbl.* 54: 386-388, 1925.)
- (185) Melin, E., Norrbin, S., and Odén, S. Methane fermentation of peat. *Ingen. Vetensk. Handl.* 53: 1-42, 1926. (*Chem. Abs.* 22: 1028, 1928.)
- (186) Meulen, ter, H. Distribution of molybdenum in nature. *Rec. Trav. Chim. Pays-Bas.* 50: 491-504, 1931 (*Chem. Abs.* 25: 3882, 1931).
- (187) Meyer, L. Die Düngewirkung von Nettolin, einer technisch aus Hochmoortorf hergestellten neuen Humusdünger. *Ztschr. Pflanzenernähr., Düngung., u. Bodenk. (B)* 12: 262-281, 1933.
- (188) Michailenk-Malenko. One-bath tanning extracts from peat. *Vestnik Kozhevennoi. Prom. i Torgovli* 31, 1928 (*Chem. Abs.* 23: 5347, 1929).

- (189) Miller, E. J., and Robinson, C. S. Studies on the acid amide fraction of the nitrogen of peat. *Soil Sci.* 11: 457-467, 1921.
- (190) Miller, S. H., and Skertchly, S. B. J. The Fenland Past and Present. Longmans Green, London, 1878.
- (191) Minssen, H. Beiträge zur Kenntnis typischer Torfarten. *Landw. Jahrb.* 44: 269-330, 1913.
- (192) Monkhouse, A. Peat burning in U. S. S. R. power stations. *Steam Engin.* 4: 427-428, 437, 1935 (*Chem. Abs.* 29: 7045, 1935).
- (193) Monnier, Le F. Peat as fuel. *Chaleur Indus.* 9: 54-62, 1928. (*Chem. Abs.* 23: 2014, 1929.)
- (194) Monteith, J., Jr., and Welton, K. Use of peat and other organic materials on golf courses. *U. S. Golf. Assoc. Bul.* 13: 90-110, 1933.
- (195) Morrow, C. A., and Gortner, R. The organic matter of the soil: V. A study of the nitrogen distribution in different soil types. *Soil Sci.* 3: 297-331, 1917; Morrow, C. A., Thesis. Univ. Minn., 1918.
- (196) Mulder, E. G. Sur l'influence due cuivre sur la croissance des micro-organismes. *Ann. Ferment.* (IV) 9: 513-533, 1938.
- (197) Muller, J. F. Some observations on base exchange in organic materials. *Soil Sci.* 35: 229-237, 1933.
- (198) Musierowicz, A. The adsorptive properties of peats in the light of the adsorption formula of Freundlich. *Roczn. Nauk Rolnicz. i. Lesynch.* 21: 129-152, 1928.
- (199) Myslakowski, K. Effect of peat on the utilization of phosphorite by millet. *Roczn. Nauk Rolnicz. i. Lesynch.* 23: 101-109, 1930.
- (200) Nichols, G. E. The vegetation of Connecticut; IV. Plant societies in lowlands. *Bul. Torrey Bot. Club* 42: 169-217, 1915, 47:—1920.
- (201) Nichols, G. E. The vegetation of northern Cape Breton Island, Nova Scotia. *Conn. Acad. Arts and Sci. Trans.* 22, 1918.
- (202) Nichols, G. E. Raised bogs in Eastern Maine. *The Geog. Rev.* 7: 159-167, 1919.
- (203) Nyström, E. Torfboden als Bodenverbesserungsmittel auf humusarmem Sandboden. *Svensk. Mosskult. Tidskr.* 44: 85-117, 1930.
- (204) Odell, W. W., and Hood, O. P. Possibilities for the commercial utilization of peat. *U. S. Dept. Int., Bur. Mines Bul.* 253, 1926.
- (205) Odell, W. W., and Siebel, C. W. Absorbent-catalyzer material from peat. *U. S. Pat.* 1,768,963, 1930.
- (206) Oden, S. Die Huminsäuren. *Kolloidchem. Beihefte* 11: 75-260, 1919.
- (207) Ogg, W. G. Reclamation of peat land in northern Europe. *Scot. Jour. Agr.* 12: 5-20, 1929.
- (208) Ogg, W. G. Peat. *Chem. and Indus.* 58: 375-379, 1939.
- (209) Okey, C. W. The subsidence of muck and peat soils in southern Louisiana and Florida. *Proc. Amer. Soc. Civ. Engin.* 43: 637, 1917.
- (210) Osbon, C. C. Classification and formation of peat and related deposits. *Jour. Amer. Peat Soc.* 14: 37-44, 1921.
- (211) Ostwald, W., and Wolf, A. The dispersoid chemistry of peat: V. The dehydration of peat at temperatures under 100°. *Kolloid. Ztschr.* 43: 336-345, 1927.
- (212) Otto, J. H. Forest succession of the southern limits of early Wisconsin glaciation as indicated by a pollen spectrum from Bacon's swamp, Marion County, Indiana. *Butler Univ. Bot. Studies* 4: 93-116, 1938.
- (213) Parmelee, C. W., and McCourt, W. E. A report on the peat deposits of northern New Jersey. *Geol. Survey N. J. Ann. Rpt. State Geol.* 1905: 223-313, 1905.
- (214) Paul, N. Die Kalkenfeindlichkeit der Sphagnen und ihre Ursache. *Mitt. I. K. B., Moorkulturanst. Stuttgart.* 2, 1908.
- (215) Pearsall, W. H. The soil complex in relation to plant communities. III. Moorlands and bogs. *Jour. Ecology* 26: 298-315, 1938.
- (216) Pictet, A., and Gaultis, M. Sur la lignine et ses relations avec la houille. *Helvetica Chim. Acta.* 6: 627-640, 1923.
- (217) Poijärvi, I. Comparison of the productive value of hays on mineral and peat soils. *Valtion Maatalousk. Julkaisu. [Finland]* 13, 1927.
- (218) Popp, M. Probenahme und Untersuchung von Torfstreu. *Ztschr. Pflanzenernähr., Düngung u. Bodenkn.* (A) 32: 182-184, 1933.

- (219) Post, H. v. Studier öfver nutidens koprogena jordbildningar, Gyttja, Dy, torf och mylla. *K. Svenska Vetensk. Akad. Handl.* 4 (1), 1862.
- (220) Post, L. v. Das genetische System der organogenen Bildungen Schwedens. *Mem. Nomenclature Classification Sols. Internatl. Soil Sci. Cong. [Helsingfors]* 1924: 287-304, 1924.
- (221) Post, L. v. Einige Aufgaben der regionalen Moorforschung. *Sveriges Geol. Undersökn. C*: 335, 337, 1926.
- (222) Potonié, H. Die Entstehung der Steinkohle. Borntraeger, Berlin, 1920.
- (223) Potonié, R., and Benade, W. The cellulose determination, a fundamental criterion in the differentiation of peat, brown coal and bituminous coal. *Braunkohle* 28: 335-340, 1929.
- (224) Potter, R. S., and Snyder, R. S. Amino-acid nitrogen of soil and the chemical groups of amino-acids in the hydrolyzed soil and their humic acids. *Jour. Amer. Chem. Soc.* 37: 2219-2227, 1915.
- (225) Potzger, J. E. A notable case of bog formation. *Amer. Midland Nat.* 15: 567-580, 1934.
- (226) Powers, W. L. Subsidence and durability of peaty lands. *Agr. Engin.* 13: 71-72, 1932.
- (227) Priyanishnikov, D. N. The value of peat as a material for the preparation of composts and peat manure. *Trans. Sci. Inst. Fert. [Moscow]* 34: 72-75, 1927.
- (228) Puchner, E. Der Torf. Stuttgart, 1920.
- (229) Rakovski, V. E., and Ioffe, P. M. The composition of peat gas-producer and low-temperature carbonization tars. *Khim. Tverdogo Topliva* 2: 93-107, 1931. (*Chem. Abs.* 27: 1484, 1933.)
- (230) Rakowski, E. W., and Edelstein, N. G. Die Torfbitumina: I. Fettsäuren. *Brennstoff-Chem.* 13: 46-49, 1932.
- (231) Rakowski, E. V., and Visotskaya, V. A. Changes in fiber in a peat bog. *Khim. Tverdogo Topliva* 2: 80-92, 1931. (*Chem. Abs.* 27: 1846, 1933.)
- (232) Ramtann, E. Einteilung und Bau der Moore. Beziehungen zwischen klima und dem Aufbau der Moore. *Ztschr. Deut. Geol. Gesell.* 62: 129-142, 1910.
- (233) Regny, P. V. de. Chemical transformations caused by the decomposition of vegetable wastes. *Indust. Min.* 5: 21, 1931. (*Chem. Abs.* 25: 2671-2672, 1931.)
- (234) Reilly, J., and Pyne, G. Peat: I. Thermal decomposition of peat under reduced pressure. *Sci. Proc. Roy. Dublin Soc.* 18: 329-341, 383-388, 1926.
- (235) Reincke, R. Über den Luftgehalt des Niedermoorbodens. *Ztschr. Pflanzenernähr. Düngung. u. Bodenk. (A)* 20: 217-232, 1931.
- (236) Rigg, G. B. A summary of bog theories. *Plant World* 19: 310-325, 1916.
- (237) Rigg, G. B. The toxicity of bog water. *Science* 43: 602, 1916.
- (238) Rigg, G. B. Comparisons of the development of some sphagnum bogs of the Atlantic coast, the interior and the Pacific coast. *Amer. Jour. Bot.* 27: 1-14, 1940.
- (239) Rigg, G. B. The development of sphagnum bogs in North America. *Bot. Rev.* 6: 666-693, 1940.
- (240) Rigg, G. B., and Thompson, T. G. Colloidal properties of bog water. *Bot. Gaz.* 68: 367-379, 1919.
- (241) Rigg, G. B., Thompson, T. G., Lorah, J. R., and Williams, K. T. Dissolved gases in waters of some Puget Sound bogs. *Bot. Gaz.* 84: 264-278, 1929.
- (242) Ritter, G. A. Beiträge zur Kenntnis der niederen pflanzlichen Organismen, besonders der Bakterien, von Hoch- und Niedermoores, in floristischer, morphologischer und physiologischer Beziehung. *Centbl. Bakt. (II)* 34: 577-666, 1912.
- (243) Ritter, G. A. Merkwürdigkeiten bezüglich der Salpeterbildung und des Salpetergehaltes im Moorboden. *Internatl. Mitt. Bodenk.* 2: 411-428, 1912.
- (244) Rivkina, K. I. Briquets of peat dust and iron ore. *Metall. and Chem. Engin.* 10: 34-38, 1935. (*Chem. Abs.* 29: 7042, 1935.)



- (245) Roberts, J. Mature and immature fuels. *Jour. Inst. Fuel* 7: 228-230, 1934. (*Chem. Abs.* 28: 7467, 1934.)
- (246) Robertson, I. M. Peat mosses: III. Composition of peat and the liming and fertilizing of peat soils. *Scot. Jour. Agr.* 16: 327-335, 1933.
- (247) Robinov, M. Y. Use of turf (peat) in the production of paper and carton. *Inst. Bumazh. Cellulose Prom.* 3: 81-104, 1932. (*Chem. Abs.* 28: 5664, 1934.)
- (248) Robinson, C. S. Organic nitrogenous compounds in peat soils: II. *Mich. Agr. Exp. Sta. Tech. Bul.* 7, 1911.
- (249) Robinson, C. S. Utilization of muck lands. *Mich. Agr. Exp. Sta. Bul.* 273, 1914.
- (250) Robinson, C. S., and Miller, E. J. Organic nitrogenous compounds in peat soils: III. *Mich. Agr. Exp. Sta. Tech. Bul.* 35, 1917.
- (251) Roe, N. B. Productivity of peat soil as influenced by the height of the ground water table. *Proc. First Internatl. Cong. Soil Sci.* 3: 637-661, 1928.
- (252) Roe, N. B., Neal, J. H., Colby, B. R., and Colby, B. C. Temperature of peat soil relative to summer frost control. *Agr. Engin.* 12: 93-98, 1931.
- (253) Rogers, H. D. Geology of the State of New Jersey for the year 1840. *Report of State Geologist.* C. Sherman & Co., Philadelphia, 1840.
- (254) Roth, C. C. Paper manufacture from peat. U. S. Pat. 1,721,974, July 23. (*Chem. Abs.* 23: 4573, 1929.)
- (255) Roux, A. C. Commercial treatment of peat. *Chim. et indus.* [Paris] Spec. No. 309-313, Sept., 1926. (*Chem. Abs.* 21: 641, 1927.)
- (256) Rozanov, S. N. Decomposition of crude phosphates by peat and the influence of neutral salts on this process. *Jour. Landw. Wiss.* [Moscow] 3: 751, 1926. (*Chem. Abs.* 24: 4576, 1930.)
- (257) Russell, E. J. Report on humogen. *Jour. Bd. Agr.* [London] 24: 11-20, 1917.
- (258) Ryle, G. B. Afforestation on peat or bog land. *Quar. Jour. Forestry* 27: 114-121, 1934.
- (259) Sauer, E., and Steinmetz, H. J. Ein Neues Verfahren zur Bestimmung der Gesamtsäure in Torf. *Kolloid Ztschr.* 53: 218-224, 1930.
- (260) Schneider, W., and Schellenberg, A. Über das Verhalten des Torfes gegen verschiedene für cellulose charakteristische Lösungsmittel. *Gesam. Abhandl. Kenntnis Kohle*, 5 (1920): 37-43, 1922.
- (261) Schreiber, H. Moorkunde nach dem gegenwertigen Stande des Wissens auf Grund 30 jähriger Erfahrung. P. Pare, Berlin, 1927.
- (262) Schreiner, O., and Shorey, E. C. The isolation of harmful organic substances from soils. *U. S. Dept. Agr. Bur. Soils Bul.* 53, 1909.
- (263) Sears, P. B. Postglacial climate in eastern North America. *Ecology* 13: 1-6, 1932.
- (264) Seelhorst, C. Handbuch der Moorkultur. Berlin, 1914.
- (265) Sestini, F. Der die Humusäure im Erdreich und Torf begleitende Stickstoffgehalt. *Landw. -Vers. Sta.* 51: 153-158, 1899.
- (266) Shaler, N. S. Preliminary report on sea coast swamps of the eastern United States. *U. S. Geol. Survey Ann. Rpt.* 6: 353-398, 1885.
- (267) Shaler, N. S. Tide marshes of the United States. *U. S. Department of Agriculture Spec. Rpt.* 7: 259, 1885.
- (268) Shaler, N. S. Fluvial swamps of New England. *Amer. Jour. Sci.* 33: 210-221, 1887.
- (269) Shaler, N. S. General account of the fresh water morasses of the U. S. *Geol. Survey Ann. Rpt.* 10: 255-339, 1890.
- (270) Shikata, M., and Naganuma, S. Active carbons from tundra peat produced in Karafuto: I. The comparison of the raw materials for active carbon. *Jour. Agr. Chem. Soc. Japan* 11: 988-996.
- (271) Shunk, I. V. Microbiological activities in the soil of an upland bog in eastern North Carolina. *Soil Sci.* 27: 283-303, 1929.
- (272) Shutt, F. T. Mucks, peats and miscellaneous fertilizer materials. *Canada Dept. Agr. Rpt. Dominion Chem.* 1926-27: p. 32-46.
- (273) Skertchley, S. B. J. The geology of the fenland. *Mem. Geol. Survey England and Wales*, pp. 145-151, 172-174. London, 1877.

- (274) Skopintzew, B. Über Entfärbung von gefärbten Naturwässern und wässrigen auszug aus Boden und Torf. *Ztschr. analyt. Chem.* 86: 219-235, 1931.
- (275) Smith, P. Correlations of pollen profiles from glaciated eastern North America. *Amer. Jour. Sci.* 238: 597-601, 1940.
- (276) Smock, J. C. Reclamation of tide marshlands. *Ann. Rpt. N. J. State Geol.* 1892: 16-19, 331-353, 1893.
- (277) Smorodintzev, I. A., and Adova, A. N. Effect of the pH of the reservoir on the acid base balance of peat. *Bul. Soc. Chim. Biol.* 13: 943-949, 1931. (*Chem. Abs.* 26: 3605, 1932.)
- (278) Snyder, R. M., and Wyant, Z. A. Studies on the biological decomposition of peat. *Mich. Agr. Exp. Sta. Tech. Bul.* 129, 1932.
- (279) Soper, E. K., and Osbon, C. C. The occurrence and use of peat in the United States. *U. S. Geol. Survey Bul.* 728, 1922.
- (280) Souci, S. W. Die Chemie des Moores. Emke, Stuttgart, 1938.
- (281) Spirhanzl, J. Zur Frage der Einteilung und Untersuchung der Moore in der Tschechoslovakischen Republik. *Trans. Sixth Comm. Internat. Soc. Soil Sci. [Zürich]* B: 281-285, 1937.
- (282) Sprague, H. B., and Marrero, J. F. The effect of various sources of organic matter on the properties of soils as determined by physical measurements and plant growth. *Soil Sci.* 32: 35-49, 1931.
- (283) Sprague, H. B., and Marrero, J. F. Further studies on the value of various types of organic matter for improving the physical condition of soils for plant growth. *Soil Sci.* 34: 197-208, 1932.
- (284) Springer, U., and Abele, G. Beiträge zur Abgrenzung der Begriffe Torf und Braunkohle. *Brennstoff-Chem.* 8: 117-120, 1927.
- (285) Stadnikoff, G. Neuere Torfchemie. Steinkopf, Dresden, 1930.
- (286) Stadnikoff, G., and Baryschewa, A. Über die Zusammensetzung von Torfbildnern und Torfarten: I. *Brennstoff-Chem.* 11: 21-23, 169-171, 1930.
- (287) Stadnikoff, G., and Titov, N. Untersuchungen über den Torfteer. *Brennstoff-Chem.* 9: 325-326, 957-958, 1928.
- (288) Storer, F. H. Agriculture in Some of Its Relations to Chemistry. New York, 1897.
- (289) Strache, H., and Lant, R. Entstehung und chemisches Verhalten der Kohlen und ihrer Bestandteile, Untersuchung der Kohlen. Kohlenchemie. Akad. Verlagsgesell., Leipzig, 1924.
- (290) Street, J. P. The detection of peat in commercial fertilizers. *U. S. Department of Agriculture Bur. Chem. Bul.* 105: 83-85, 1907.
- (291) Swanback, T. R. Hyper-humus. *Conn. Agr. Exp. Sta. 53rd Rpt.* 24: 220-227, 1929.
- (292) Tacke, B. I. Torf als Dünger und Bodenverbesserungsmittel. *Ztschr. Pflanzenernähr. Düngung. u. Bodenk.* (B) 12: 1-11, 1933.
- (293) Tacke, B., and Süchting, H. Über Humussäuren. *Landw. Jahrb.* 41: 717-754, 1911.
- (294) Tait, G. M., and Knott, J. E. Correcting the unproductiveness of acid and alkaline muck soils for the growing of vegetable crops. *N. Y. (Cornell) Agr. Exp. Sta. Bul.* 572: 1933.
- (295) Takushkin, I. V. Formation of nitrates from peat nitrogen. *Izv. Moskov. Selsk. Khoz. Inst.* 19: 400, 1913.
- (296) Tansley, A. G. Types of British Vegetation. Cambridge Univ. Press, 1911.
- (297) Taubmann, A. Über die Wasserbestimmung in Brennmaterialien mit Hilfe von Magnesiummethyljodid. *Ztschr. analyt. Chem.* 74: 161-167, 1928.
- (298) Thatcher, K. M. The effect of peat on the transpiration and growth of certain plants. *Jour. Ecol.* 9: 39-59, 1922.
- (299) Thaysen, A. C. Microbiological origin of peat. *Fuel* 9: 560-563, 1930.
- (300) Thiessen, R., and Strickler, H. S. Distribution of microorganisms in four peat deposits. *U. S. Dept. Int., Bur. Mines Coop. Bul.* 61, 1934.
- (301) Tideswell, F. V., and Wheeler, R. V. On dopplerite. Studies in the composition of coal. *Jour. Chem. Soc. Trans.* 121: 2345-2362, 1922.
- (302) Titow, N. Die leichten Neutralöle des Torfteers. *Brennstoff-Chem.* 13: 306-308, 1932.

- (303) Transeau, E. N. The bogs and bog flora of the Hudson River valley. *Bot. Gaz.* 40: 351-375, 418-448, 1905; 41: 17-42, 1906.
- (304) Turoila, P. Effect of calcium carbonate and of sulfuric acid on the acidity of various peats. *Wiss. Veröffentlich. Finnisch. Moorkulturver.* 8, 1928. (*Chem. Abs.* 24: 5092, 1928.)
- (305) Vandecaveye, S. C. Effects of stable manure and certain fertilizers on the microbiological activities in virgin peat. *Soil Sci.* 33: 279-299, 1932.
- (306) Voss, J. Postglacial migration of forests in Illinois, Wisconsin, and Minnesota. *Bot. Gaz.* 96: 3-43, 1934.
- (307) Waksman, S. A. Humus. Williams & Wilkins Co., Baltimore, 2d Ed. 1938.
- (308) Waksman, S. A., and Purvis, E. R. The influence of moisture upon the rapidity of decomposition of lowmoor peat. *Soil Sci.* 34: 323-336, 1932.
- (309) Waksman, S. A., and Stevens, K. R. Contribution to the chemical composition of peat: I-IV. *Soil Sci.* 26: 113-137, 239-252, 1928; 27: 271-281, 389-398, 1929.
- (310) Waksman, W. A., and Stevens, K. R. Contribution to the chemical composition of peat: V. The role of microorganisms in peat formation and decomposition. *Soil Sci.* 28: 315-340, 1929; 34: 95-113, 1932.
- (311) Walton, G. P., and Gardiner, R. F. Fertilizer material from peat. U. S. Pat. 1,858,230, May 10. (*Chem. Abs.* 26: 3866, 1932.)
- (312) Waren, H. Untersuchungen über die botanische Entwicklung der Moore mit Berücksichtigung der chemischen Zusammensetzung des Torfes. *Wiss. Veröffentlich. Finnisch. Moorkulturver.* 5, 1924.
- (313) Wasmund, E. Zur Nomenklatur der subaquatischen Sedimente. *Geol. Meere u. Binnengen.* 2: 444-448, 1938.
- (314) Waterman, W. G. Ecological problems from the sphagnum bogs of Illinois. *Ecology* 7: 255-272, 1926.
- (315) Weber, C. A. Über Torf, Humus und Moor. *Abhandl. Naturw. Ver. Bremen* 17: 465-484, 1903.
- (316) Weber, C. A. Was lehrt der Aufbau der Moore Norddeutschlands über den Wechsel des Klimas in postglazialer Zeit? *Ztschr. Deut. Geol. Gesell.* 62: 143-162, 1911.
- (317) Weiss, F. E. Directions for preparing manure from peat. *Jour. Bd. Agr. [London]* 23: 481-484, 1916.
- (318) White, D. Some needed peat investigations. *Jour. Amer. Peat Soc.* 17: 45-56, 1924.
- (319) White, D., Thiessen, R., and Davis. — The origin of coal. *U. S. Dept. Int., Bur. Mines Bul.* 38: 1-390, 1913.
- (320) Whitson, A. R., Albert, A. R., and Zeasman, O. R. Fertilizers and crops for marsh soils. *Wis. Agr. Exp. Sta. Bul.* 392, 1927.
- (321) Whitson, A. R., and Ullsperger, H. W. Farming marsh soils. *Wis. Agr. Exp. Sta. Bul.* 309: 1-32, 1919.
- (322) Wiancko, A. T. Unproductive peat or muck soils. *Ind. Agr. Exp. Sta. Ann. Rpt.* 26: 58-61, 1913.
- (323) Wielandt, W. Marshland utilization and peat coking. *Angew. Chem.* 48: 632-636, 1935. (*Chem. Abs.* 29: 5251; 30: 840, 1936.)
- (324) Wilkening, I. G. Building and insulating products from peat. *Brit. Pat.* 244, 716, Dec. 17, 1924. (*Chem. Abs.* 21: 311, 1927.)
- (325) Willis, L. G. Some potential changes induced by liming suspensions of a peat soil. *N. C. Agr. Exp. Sta. Tech. Bul.* 47, 1934.
- (326) Wilson, B. D., Eames, A. J., and Staker, E. V. Genesis and composition of peat deposits. *N. Y. (Cornell) Agr. Exp. Sta. Mem.* 188: 3-13, 1936.
- (327) Wilson, B. D., and Plice, M. J. Buffer capacity of peat. *N. Y. (Cornell) Agr. Exp. Sta. Mem.* 146: 1-11, 1933.
- (328) Wilson, B. D., and Staker, E. V. The chemical composition of the muck soils of New York. *N. Y. (Cornell) Agr. Exp. Sta. Bul.* 537: 1-26, 1932.
- (329) Wilson, B. D., and Townsend, G. R. Some nitrogen relationships in muck soils, *N. Y. (Cornell) Agr. Exp. Sta. Mem.* 137: 1-14, 1931.

- (330) Wilson, L. R. A temperature study of a Wisconsin peat bog. *Ecology* 20: 432-433, 1939.
- (331) Yapp, R. H., Johns, D., and Jones, O. T. The salt marshes of the Dovey estuary. *Jour. Ecol.* 4: 27-42, 1916; 5: 65-103, 1917.
- (332) Yushkov, N. U. Problem of turf in the paper industry. *Bumazhnaya Prom.* 11: 42-47, 1932. (*Chem. Abs.* 26: 5417, 1932.)
- (333) Zailer, V., and Wilk, L. Über den Einfluss der Pflanzenkonstituenten auf die physikalischen und chemischen Eigenschaften des Torfs. *Ztschr. Moorkult. u. Torfverwert.* 5: 40-64, 111-128, 197-260, 1907; 9: 153-168, 1911.
- (334) Zaturskii, M. Carbon from peat. Russ. Pat. 39,065, Oct. 31, 1934. (*Chem. Abs.* 30: 3624, 1936.)
- (335) Zeiller, H. Untersuchungen an Mooren in Gebiet des mittleren Mainlaufs. *Ztschr. Bot.* 34: 1-63, 1939.
- (336) Zhukov, I. I., Kremlevo, E. A., and Tikhomirov, A. V. Colloidal and chemical properties of peat. *Zhur. Prikladnoi Khim.* 2: 257-266, 1929. (*Chem. Abs.* 23: 4552, 1929.)
- (337) Ziegenspeck, H. In wie weit sind die Sphagnen und andere Moose befähigt im Leben ihre Umgebung auf ein bestimmtes pH-Optimum einzustellen. *Bot. Arch.* 38: 1-15, 1937.
- (338) Zweig, W. Natural bitumens, with special reference to bituminous shale. *Petroleum Ztschr.* 24: 243-246, 1928. (*Chem. Abs.* 22: 3771, 1928.)
- (339) Zweig, W., and Kossendey, F. Untersuchungen über die chemische Zusammensetzung eines norddeutscher Schiefertorfes. *Brennstoff-Chem.* 15: 69-71, 1934.

## SUBJECT INDEX

	PAGE
Absorbent, peat as .....	123-126
Absorption of bases .....	84-86
Acid bog .....	22
Aeration of peat .....	92
Agricultural utilization of peat .....	103-130
Algal peat .....	47
Allochthonous peats .....	39
Alpine humus .....	17, 30
Ammonia in peat .....	96
Ammonification of peat .....	121
Aquatic peat .....	29, 30, 34, 37
Ash in peat .....	62-65, 79
Atmosphere of bogs .....	89
Autochthonous peats .....	38, 48
Bacteria in peat .....	91, 92, 93
Bacterial carrier, peat as .....	129
Base-exchange of peat .....	86
Bedding, peat as .....	123-126
Bitumens from peat .....	58, 71, 138
Blueberry culture .....	114, 115
Bog .....	11, 17, 22, 23, 26, 30
Bog iron .....	65
Botanical composition .....	37-39, 50-54
Buffer capacity of peat .....	85, 86
Calcium in peat .....	64, 65
Catalyst, peat as .....	138
Cellulose in peat .....	58, 73-76, 78, 91
Charcoal from peat .....	136
Chemical composition of peat .....	55-56, 57-79
Chitin in peat .....	73
Classification of peats .....	25-30, 38, 39-40
Climate, effect of .....	41-44
Colloidal peat .....	34
Colloidal state of peat .....	83
Composts of peat .....	122-123
Copper, addition to peat .....	113, 130
Cranberry culture .....	114
Distillation of peat .....	136-137
Decomposition of peat .....	37, 48, 68, 92-99, 101, 118
Definition of peat .....	11, 12, 16, 18-20
Denitrifying organisms in peat .....	96
Dopplerite .....	17, 34
Drainage, effect of .....	92, 101
Drying of peat .....	82-83
Dy .....	17, 24, 39
Ether and alcohol soluble constituents in peat .....	65-71, 77
Fabrics from peat .....	137
Feed, use of peat as .....	129-130
Fen .....	17, 22, 26, 29, 30
Fen method of reclamation .....	105
Fermentation of peat .....	139
Fertilization of peat .....	111-113
Fertilizer from peat .....	117, 118, 121
Fibrous peat .....	25

	PAGE
Formation of peat .....	11-13, 23, 24, 92
Forest peat .....	28, 29, 34, 40
Fuel, peat as .....	131-136
Gyttja .....	17, 24, 34, 39
Heath .....	17, 26, 30, 33
Heather .....	17, 26, 30
Heat conductivity of peat .....	88
Hemicelluloses in peat .....	73-76, 78
Highmoor .....	26, 30, 33, 34, 38, 39, 46, 47, 64, 111
Horticultural utilization of peat .....	127-128
"Humic acids" in peat .....	57
"Huminosity" of peat .....	38
Humus, peat .....	17, 25, 30, 46
Hydropeat .....	119
Industrial utilization of peat .....	131-139
Insulation material, peat as .....	138
Lignin .....	76-77, 79
Litter .....	123-126
Lowmoor .....	27, 29, 33, 38, 40, 46, 52, 55, 62, 74, 91, 107, 111
Liver peat .....	17, 34
Macerated peat .....	34
Marl .....	48, 65
Marsh .....	11, 17, 22, 26, 29, 30, 32, 51, 53
Methoxyl in peat .....	77
Microbiology of peats .....	48, 90-102
Mire .....	17, 26
Moisture-holding capacity of peat .....	80
Moor .....	17, 22, 26, 30
Moss peat .....	17, 25, 34, 39, 126, 130
Muck .....	13, 17, 21, 25, 29, 127
Mull .....	17, 123-124
Nitrogen in peat .....	62, 71-73, 79
Nitrification of peat .....	95, 96
Nutrients in peat .....	54-56, 59, 64
Occurrence of peat .....	15
Packing material, peat as .....	130
Paludification .....	23
Paper from peat .....	137-138
Peat soil .....	13, 24, 40, 110, 111-114
Pentosans in peat .....	58, 73
Plant associations .....	50-54
Pollen in peat .....	43, 45, 46, 68
Profiles, peat .....	13, 19, 30
Proximate analysis of peat .....	77-79
Raw humus .....	30
Reaction of peat .....	86-87
Reclamation of peat .....	105-110
Rimpau method of peat reclamation .....	106
Salt marshes .....	33-34, 53, 54
Sapropel .....	17, 34, 38, 46, 48
Sedge and reed peat .....	29, 33, 40, 47, 68, 84, 117, 119, 120
Sedimentary peat .....	24, 29, 39, 40, 47
Shell marl .....	47
Sphagnum bog .....	22
Sphagnum peat .....	26, 33, 47, 55, 56, 73, 84
Spontaneous ignition of peat .....	99
Societies for peat study .....	14-15
Soil improvement by use of peat .....	103-104, 119-121
Stable manure, effect of, on peat .....	96
Stratification of peat .....	30-37
Subsidence of peat .....	99-102
Swamp .....	11, 17, 22, 23, 26, 30, 34, 52

SUBJECT INDEX

155

	PAGE
Tanning agent, peat as .....	139
Temperature of peat .....	87-88
Terminology of peat .....	16-24
Tidal marsh .....	32, 35, 110
Top dressing, peat as .....	128
Topography, effect of .....	46-50
Toxicity of bog water .....	88-89
Turf .....	17, 22, 29
Types of peat .....	25-30
Upland peat .....	26
Volume weight of peat .....	83-84
Water-absorbing capacity of peat .....	80-82
Waters, in peat, composition of .....	55-56, 88-89
Wetting of peat .....	82

