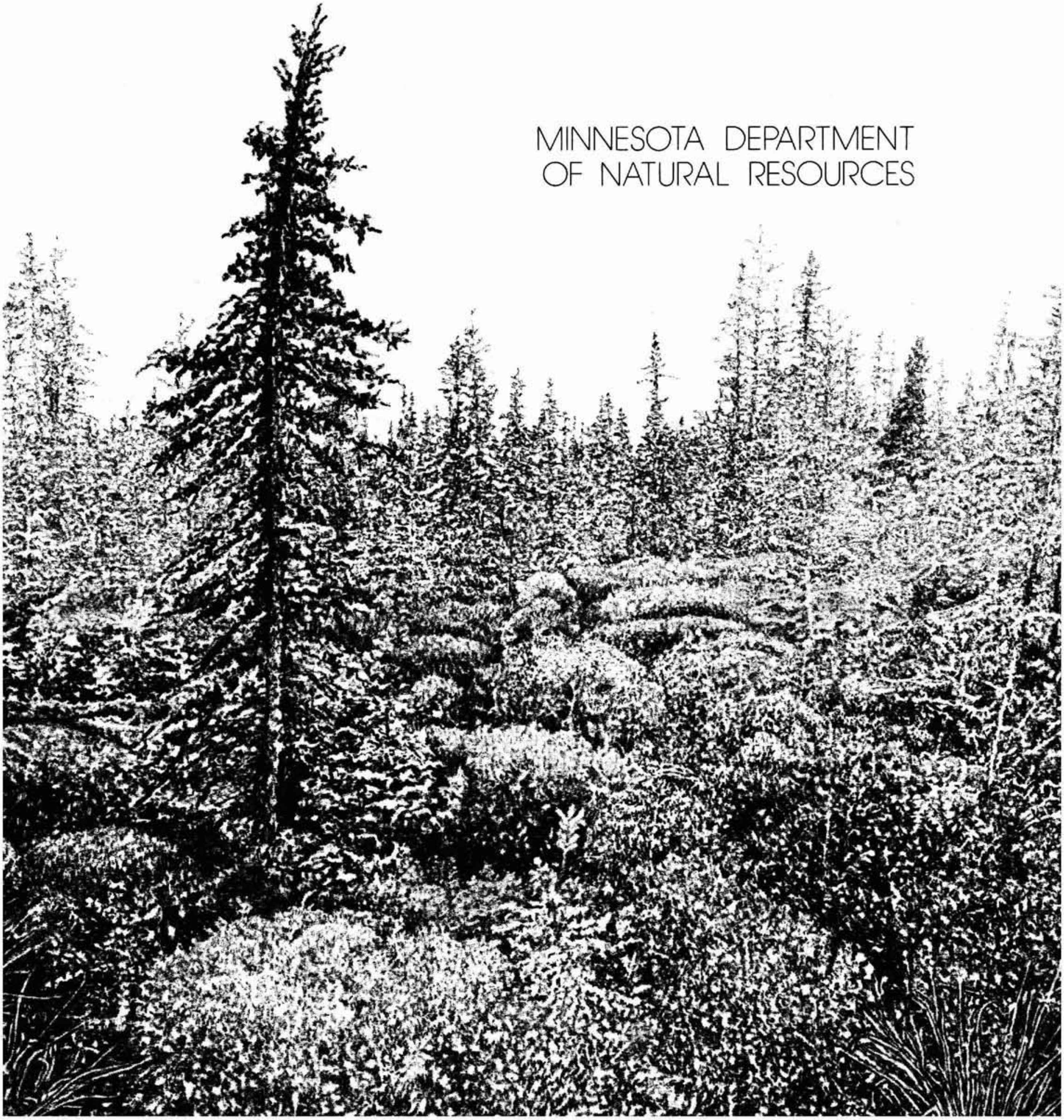
INVENTORY OF PEAT RESOURCES

AN AREA OF BELTRAMI AND LAKE OF THE WOODS COUNTIES, MINNESOTA

MINNESOTA DEPARTMENT
OF NATURAL RESOURCES



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prepared by the

Minnesota Department of Natural Resources
Division of Minerals

Peat Inventory Project
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This report is on deposit at
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INTRODUCTION

This report presents the findings of the Minnesota Peat Inventory Project's (MPIP) reconnaissance-level survey of an area of Beltrami and Lake of the Woods counties (fig. 1). Peatlands cover about 314,000 hectares (775,000 acres) of this area and constitute about 12 percent of the state's total peat resource.

The survey identifies the location and amount of fuel-grade and horticultural peat in the two county area. Funding for this project was provided by the State Legislature and by a grant from the U.S. Department of Energy and the Gas Research Institute. This report is the fourth in a series of publications that assess the peat resources in Minnesota.

The report consists of (1) a text that provides a general discussion of peatlands and describes the field and laboratory procedures of this peatland survey and (2) a map of the peat resources in the surveyed area.

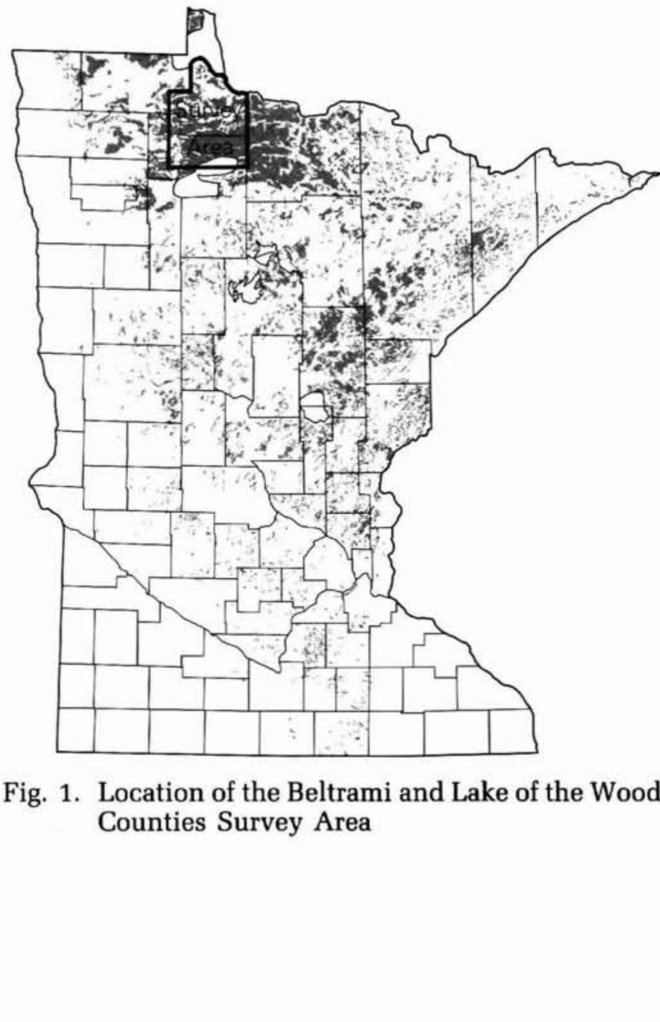

Fig. 1. Location of the Beltrami and Lake of the Woods Counties Survey Area

INTRODUCTION TO PEATLANDS

PEATLAND FORMATION

Requirements for Peat Formation

Peat is organic matter, in varying stages of decomposition, that accumulates over time under water-saturated conditions. Peat deposits contain plant remains from trees, shrubs, sedges, grasses, forbs, and mosses. Peat formation is dependent upon the interrelationship of geologic, topographic, climatic, and biotic factors (Heinselman 1963) and only occurs when the rate of production of organic material exceeds the rate of decomposition.

Peatlands are found throughout the world wherever the combination of environmental factors allows for peat accumulation. The most typical areas for peatland formation are the boreal and arctic regions of the northern hemisphere, but peatlands also can be found in the tropics and the subtropics (Moore and Bellamy 1974). The optimum areas for peatland formation have cool, humid climates and are poorly drained. Peat accumulates in these areas because the saturated conditions limit the amount of oxygen present, which in turn restricts the number of aerobic microorganisms that are available to digest the plant remains.

Peatland Formation Processes

There are two major processes of peatland formation: lakefill and paludification. Lakefill is the filling in of lakes and ponds by vegetation (fig. 2). Following the creation of a lake, limnic sediments, composed of aquatic plant and animal debris, begin to accumulate on the bottom. Plants, such as sedges, mosses, and ericaceous shrubs, become established along the lake margins and eventually die. These plant remains accumulate as peat because of the anaerobic conditions and form a medium on which other plants can grow (fig. 2, INITIAL STAGE). The accumulating peat and the living plants form a floating mat that slowly extends into the center of the lake (fig. 2, INTERMEDIATE STAGE). The water space between the floating mat and the limnic sediments is slowly replaced by peat as plants die and the plant debris accumulates (Tarnocai 1978) (fig. 2, COMPLETELY-FILLED STAGE).

Paludification, also called swamping, is the process of peatland formation and expansion caused by a gradual raising of the water table due to peat accumulation (Heinselman 1963) (fig. 3). It occurs on level or gently sloping terrain where the water table is close to the surface, creating conditions favorable to the growth of plants adapted to a wet environment. Plant debris gradually accumulates as peat, which further impedes drainage. The water table rises, and the peatland expands as the plants migrate from the original site of peat accumulation (fig. 3, INITIAL STAGE). Under constant climatic conditions, this cyclical process continues and makes peatland expansion upslope possible. Paludification can ultimately result in a continuous blanket of peat over the regional landscape, regardless of the underlying topography (fig. 3, EXPANSION STAGE).

The invasion of sphagnum moss species occurs as the peat build-up continues and the surface vegetation becomes increasingly isolated from the influence of the ground water. A cap of sphagnum moss peat may eventually accumulate on the previous peat deposition.

CLASSIFICATION

Peat Classification

Numerous peat classification systems exist, each designed for specific purposes. The systems range from classification of the resource for soil scientists to classification for the horticultural peat industry. Most peat scientists adopt a combination of classification systems

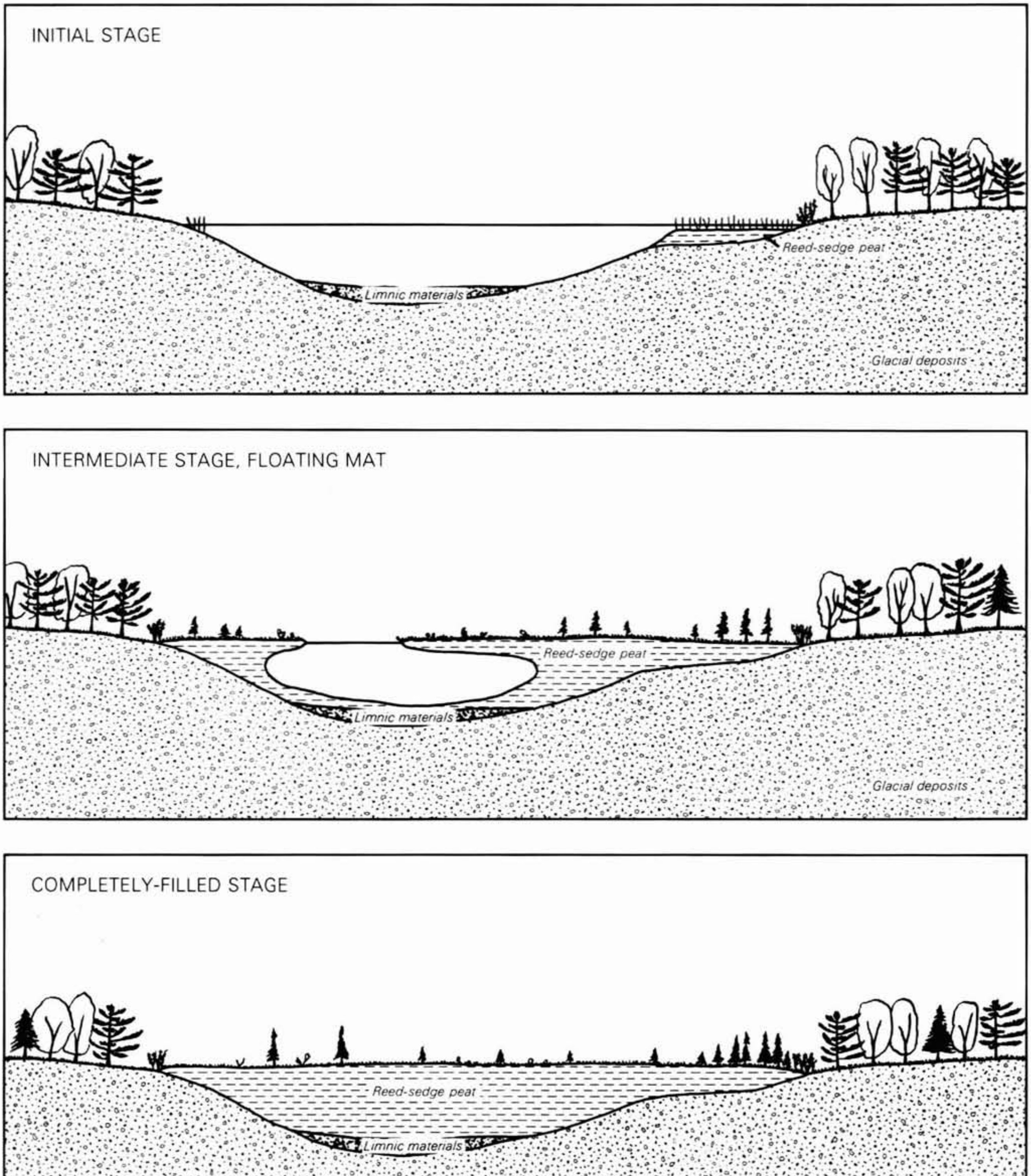

Fig. 2. Lakefill Process of Peatland Formation

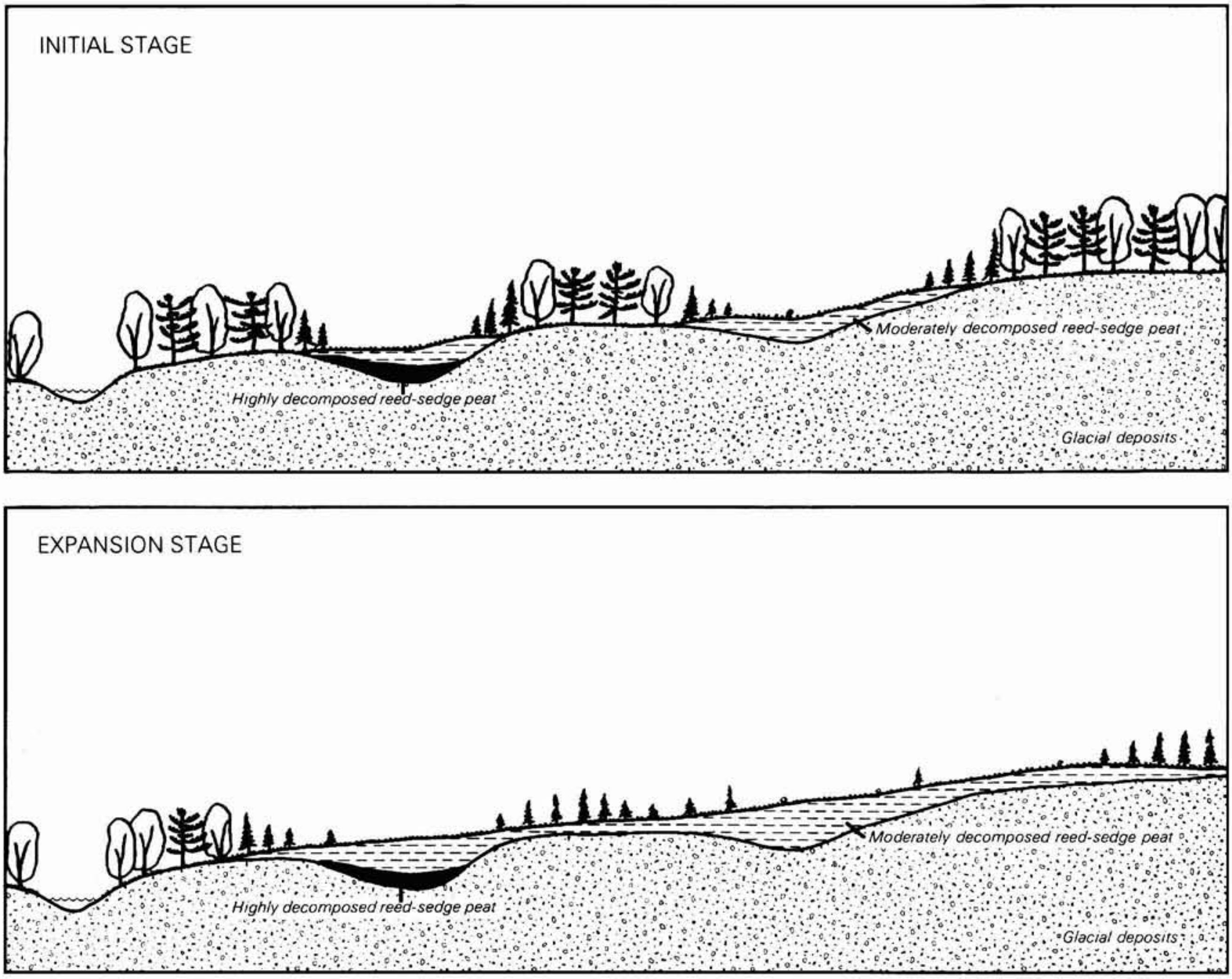

Fig. 3. Paludification Process of Peatland Formation

that incorporates criteria that pertain both to the degree of decomposition and to the botanical origin of the organic materials.

In the United States, systems developed by the Swedish scientist von Post, the U.S.D.A. Soil Conservation Service (SCS), and the International Peat Society (IPS) are widely used. In the 1920s, von Post developed a classification scheme to assess the degree of decomposition of undisturbed peat (Puustjarvi and Robertson 1975). It is a ten-point scale based on a visual examination of the physical properties of a peat sample. The peat is classified by squeezing a small sample in a clenched fist and observing (1) the amount and the turbidity of the water that is released, (2) the amount of peat that is extruded between the fingers, and (3) the nature of the plant residues. The scale ranges from H1 for undecomposed peat to H10 for completely decomposed peat (Table 1).

The Soil Conservation Service (1975) classifies organic soil (peat) by the degree of decomposition and by the botanical origin of the peat material. Two parameters, rubbed fiber content and the solubility of the organic soil materials in chemical solution, determine the degree of decomposition, which is used to classify peat into three types. Fibric soil materials are the least decomposed of the three types. The botanical origin of the relatively undecomposed plant fiber can be readily identified. Sapric soil materials are the most decomposed of the three types, and the origin of the plant material generally cannot be identified by a visual inspection. Hemic soil materials are intermediate in the degree of decomposition; usually, the botanical origin of the fibers can be identified.

In 1976, the International Peat Society, in an effort to standardize peat classification systems worldwide, published its classification proposal (Table 2). It collapsed

TABLE 1

MODIFIED VERSION OF THE VON POST SCALE FOR ASSESSING THE DEGREE OF DECOMPOSITION OF FRESH PEAT

Degree of decomposition	*Nature of water expressed on squeezing*	*Proportion of peat extruded between fingers*	*Nature of plant residues*	*Description*
H1	Clear, colourless	None	Unaltered, fibrous, elastic	Undecomposed
H2	Almost clear, yellow-brown	None	Almost unaltered	Almost undecomposed
H3	Slight turbid, brown	None	Most remains easily identifiable	Very slightly decomposed
H4	Turbid, brown	None	Most remains identifiable	Slightly decomposed
H5	Strongly turbid, contains a little peat in suspension	Very little	Bulk of remains difficult to identify	Moderately well decomposed
H6	Muddy, much peat in suspension	One third	Bulk of remains unidentifiable	Well decomposed
H7	Strongly muddy	One half	Relatively few remains identifiable	Strongly decomposed
H8	Thick mud, little free water	Two thirds	Only resistant roots, fibres and bark, etc., identifiable	Very strongly decomposed
H9	No free water	Almost all	Practically no identifiable remains	Almost completely decomposed
H10	No free water	All	Completely amorphous	Completely decomposed

SOURCE: Puustjarvi and Robertson, Peat in Horticulture.

the ten-point von Post system into three categories: R1 includes H1-H3, R2 includes H4-H6, and R3 includes H7-H10. The proposal also classified peat by its botanical origin. The groups include (1) moss peat, composed mainly of plant remains derived from sphagnum and other mosses; (2) herbaceous peat, composed mainly of plant remains derived from sedges, reeds, grasses, and related species; (3) wood peat, composed of plant remains from trees and shrubs; and (4) mixed groups.

Peatland Classification

Scientists classify peatlands by a number of criteria, including water chemistry, vegetation, and landforms. A brief explanation of three classifications follows.

Peatlands can be divided into two types, ombrotrophic and minerotrophic, based on the source of their water and nutrients (Sjors 1963). Ombrotrophic peatlands receive water and nutrients solely from precipitation. Their waters are acidic and nutrient poor. Minerotrophic peatlands also receive water and nutrients from precipitation, but in addition they are influenced by water that has percolated through mineral soils. Their waters are usually slightly acidic or circumneutral and are rich in nutrients.

Bogs, fens, and swamps are the general vegetation types associated with these two peatland types. Bogs are ombrotrophic peatlands that support a low diversity of species because of the extremely acidic and nutrient-poor conditions (pH less than 4.2 and Ca^{2+} concentration between 0.5 and 2.1 mg/l [Glaser, et al. 1979, Sjors 1963]). Bogs have a nearly continuous sphagnum moss carpet (Glaser, et al. 1979; Heinselman 1970), which increases the acidic conditions and further limits the species diversity on these peatlands. Bogs are often dominated by stunted black spruce in stands of varying densities, but they may also be unforested (open bog). The understory is composed of ericaceous shrubs, such as leatherleaf and Labrador tea; sedges; and cotton grass.

Fens and swamps are the two vegetation types that occur on minerotrophic peatlands. Because of the nutrient-rich conditions (pH 4 to pH 7 and Ca^{2+} of 2 mg/l [Glaser, et al. 1979, Sjors 1963]), both fens and swamps support a high species diversity. Although the species found in fens and swamps can include any of the species

TABLE 2

IPS Three-Grade Scale of Peat Decomposition

Scale grade	*Percent of fibers*	*Structure and look of the peat bulk*	*Presence and look of humus*	*Amount and look of water*
R1 Weakly decomposed peats	>70%	Spongy or fibrous, built of plant residues tied with one another. For separation tearing off the plant residues is required. Easily recognizable plant residues (well preserved). Elastic, compact.	Not visible or occurs in little amounts as a dispersed dark mass, saturating and coloring plant residues.	Great amount of water, which can be easily pressed out and pours as a streamlet. Almost totally pure or slightly brownish. May contain dark humus spots.
R2 Medium decomposed peats	70-40%	Amorphous-fibrous, grass and moss peats contain numerous plant residues of various size; woody peats are more friable due to the presence of wood residues in amorphous humus. When pressed in fingers, transforms into an amorphous, plastic mass.	Distinctly discernible against which plant residues are visible. Humus can be pressed out between fingers of the clenched fist but not more than 1/3 of the taken sample.	Can be pressed out or flows by few drops; usually thick and of dark color/humus. In drained peat slightly colored with humus coagulated in consequence of partly drying.
R3 Strongly decomposed peats	<40%	Lumpy-amorphous, consisting in main part of humus. In lumpy-amorphous peat greater fragments of plant residue/wood, rhizomes, greater rootlets/occur. Friable, disintegrates under pressure. Amorphous peat strongly plastic, with sporadic greater plant residues.	Uniform mass, can be pressed out between fingers of the clenched fist in the amount of a half or the whole of the taken sample.	Cannot be pressed out, instead the humus mass is squeezed.

found in bogs, the bog species do not constitute the dominant vegetation cover. Fens are often open and meadowlike in appearance, and the cover is dominated by sedges, with occasional grasses and forbs. Occasionally, small shrubs (such as bog birch) and scattered, stunted trees (such as tamarack, northern white cedar, and black spruce) occur. Swamps, in contrast to fens, are dominated by either trees (such as northern white cedar, black ash, black spruce, and tamarack) or by tall shrubs (such as alder and willow). Herbaceous vegetation forms the understory.

Some peatlands contain landforms that can be classified by their physical characteristics. These landforms result from the interaction of water flow, water chemistry, and vegetation. Several examples from Minnesota follow.

Water tracks are areas in which mineral-rich water is channeled across a peatland expanse (fig. 4). Because of the nutrient-rich conditions, fen vegetation occurs. Within water tracks, one can find several types of vegetation patterns, including patterned fens and peat islands of various sizes and shapes (Wright and Glaser 1982). Patterned fens, also called ribbed fens, consist of a series of alternating, sinuous ridges (strings) of vegetation and parallel, water-filled troughs (flarks) oriented perpendicular to the surface flow of the water (fig. 4). Teardrop-shaped islands are an example of the small peat islands found in the water tracks. These islands are oriented parallel to the water movement and have heads of small tamarack and black spruce and tails of brush extending downslope (fig. 4).

Raised bogs are a type of bog characterized by a dome-shaped accumulation of fibric sphagnum moss peat, usually overlying hemic herbaceous peat (fig. 5). They begin to form on local watershed divides within peatlands where isolation from mineral-rich water favors

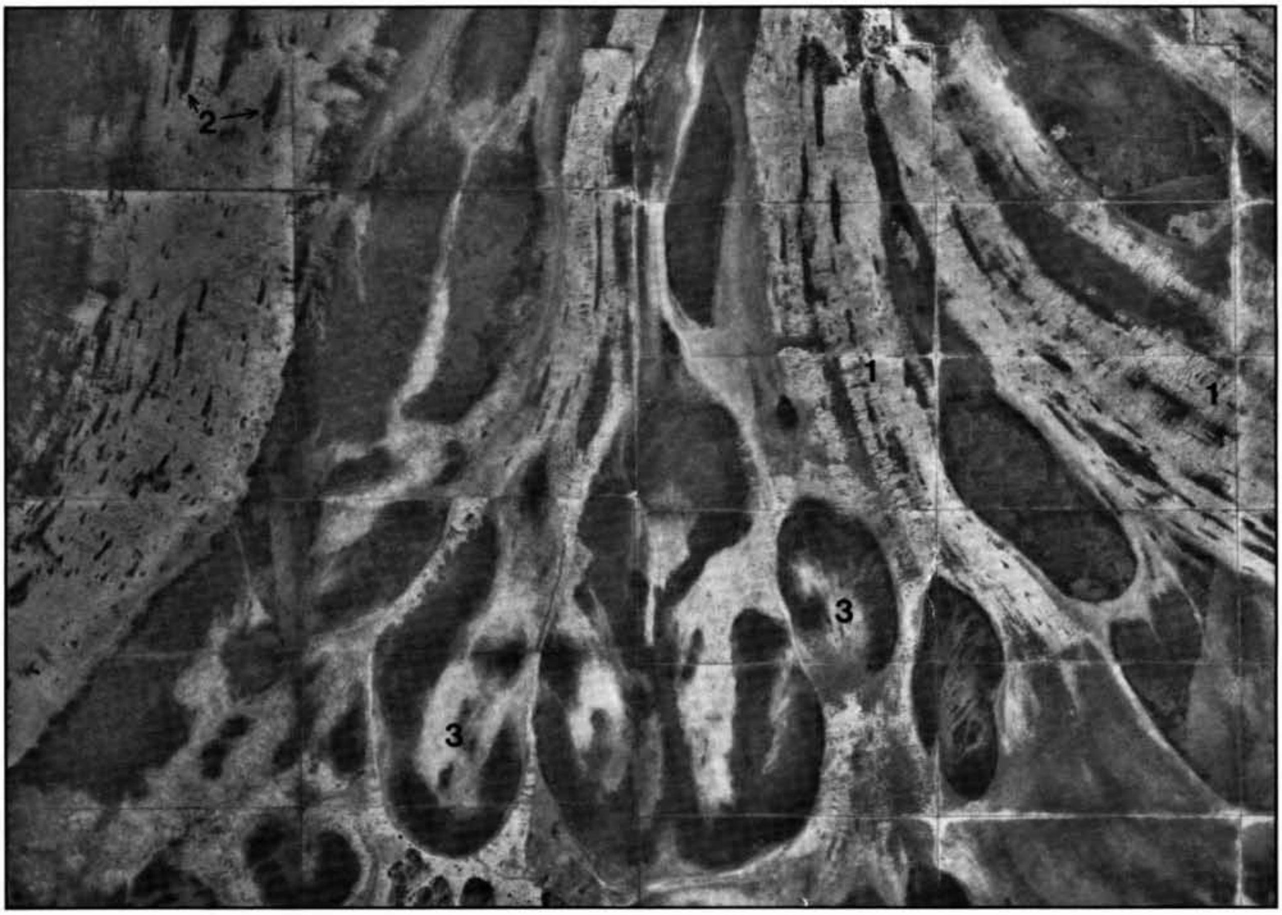

Fig. 4. Aerial Photograph Showing Peatland Landforms. Landform features include (1) water track with ribbed fen, (2) teardrop-shaped island, and (3) ovoid islands. (Red Lake Peatland, Beltrami County, Minnesota)

sphagnum moss growth (Heinselman 1970). Because of the acidic and saturated conditions, there is a low rate of decomposition of the organic matter. Peat accumulates more rapidly on these sites, and the deposit becomes convex in shape, when viewed in cross-section, and increasingly dependent on precipitation as the major source of water and nutrients (Heinselman 1975, Boelter and Verry 1977, Walker 1970). Typical raised bog vegetation patterns can be interpreted on aerial photographs as lines of black spruce radiating outward from a central point or axis (fig. 6). Unforested openings between these lines of spruce are bog drains, where runoff is channeled away from the bog crest (Glaser, et al. 1981). Further downslope the drains coalesce to form open and broad sphagnum lawns.

Ovoid islands are a type of bog whose shapes are delimited by water flow (fig. 4). These islands are believed to be formed by the headward expansion of bog drains, which can lead to fragmentation of bog forest into clusters with water flow directed around their margins (Wright and Glaser 1982).

Generally, the distinguishing features of the various landform types can be readily identified on aerial photographs. In some peatlands, however, the features, particularly the radiating pattern of black spruce on raised bogs, have been obscured by fire scars, making an interpretation of the features more difficult.

PEAT STRATIGRAPHY

The stratigraphy of a peat deposit refers to the layering of peat within a deposit. The material in each peat layer originates from peatland vegetation; thus, the analysis of plant remains of successive peat layers can be used to reconstruct the succession of peatland plant communities. An analysis of the decomposition of peat material in each layer can be used to reconstruct the hydrological conditions during the existence of the peatland.

A typical, simplified cross-section, described using

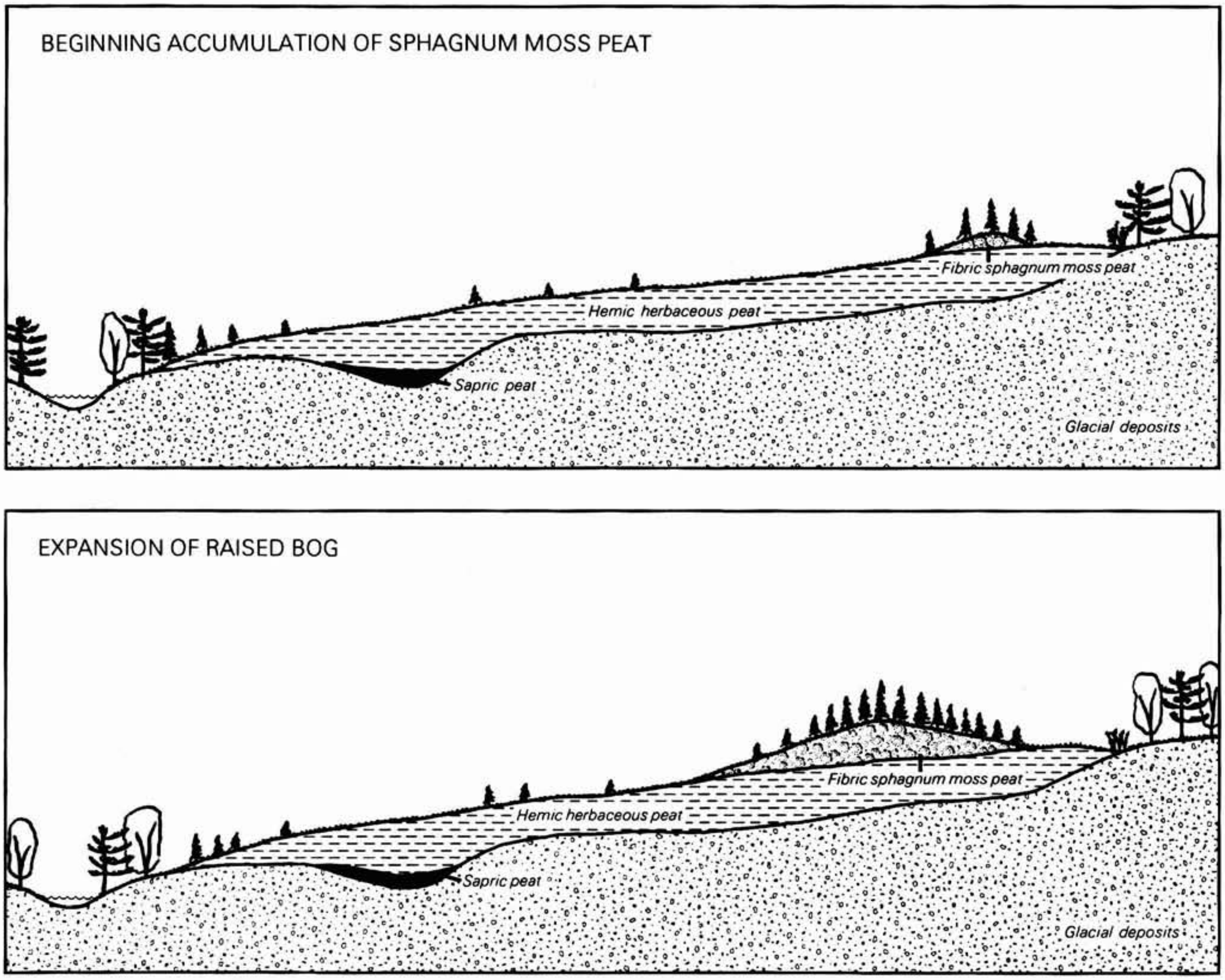

Fig. 5. Raised Bog Formation

the SCS nomenclature for organic soil materials, consists of a very thin basal layer of sapric peat, covered by a relatively thick layer of hemic peat, and overlain locally by fibric peat. Basal peat accumulations are usually composed of fen or swamp vegetation and are generally strongly decomposed because the aerobic conditions during initial peat accumulation favor a rapid rate of decomposition. As the peat continues to accumulate, the resultant rise in the water table produces saturated, anaerobic conditions that slow the rate of decomposition and result in hemic peat accumulation. In Minnesota, most of the hemic peat accumulation is decomposed fen vegetation. The local accumulations of weakly decomposed fibric peat are composed primarily of sphagnum moss remains.

Variations in this typical profile occur. For example, sapric and fibric peat formed from similar plant communities may be interlayered with hemic peat. This layering may reflect short-term climatic changes, such as drought or excessive precipitation. Recent man-related activities, such as ditching, often result in sapric surface layers adjacent to the ditches.

USES OF PEAT

The depth, type, areal extent, and location of a peat deposit are factors that may determine its use. For example, peat energy projects require extensive areas of hemic or sapric peat because these types of peat have a high heating value per pound dry weight. In horticultural operations, fibric sphagnum moss peat has the highest value as a soil amendment because of its high water-holding and cation exchange capacities.

Another use of peat is as a chemical raw material for

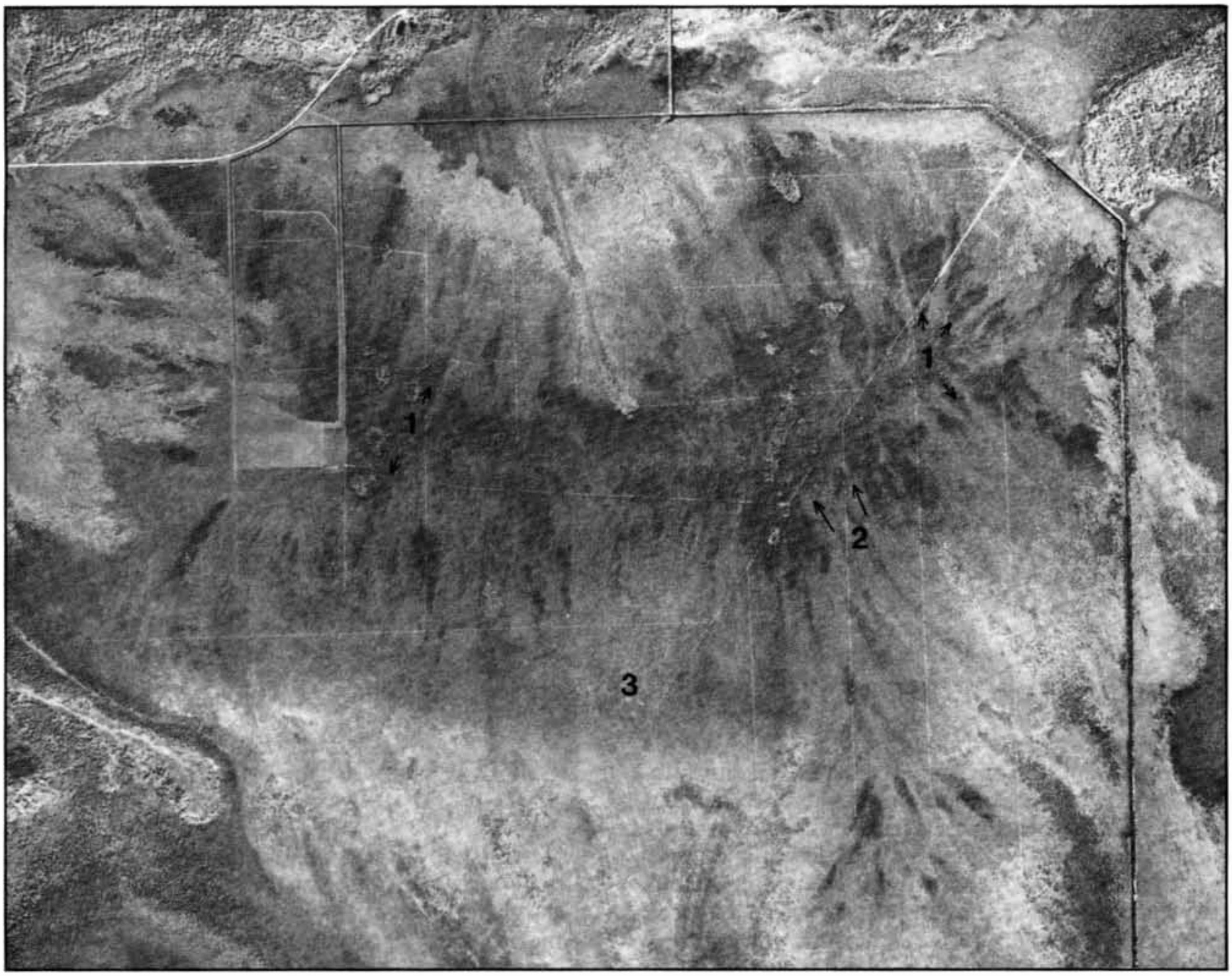

Fig. 6. Aerial Photograph Showing a Raised Bog. Features include (1) a radiating pattern of black spruce, (2) bog drains, and (3) sphagnum lawn.
(Pine Island Peatland, Koochiching County, Minnesota)

the production of industrial commodities such as peat coke, waxes, and yeasts. The botanical origin and decomposition of the peat determines the amount of these products that can be obtained. For example, greater quantities of carbohydrates, used in the production of yeasts, can be extracted from sphagnum moss peat than from other peat types (Fuchsman 1978).

In addition to these extractive uses of peat, there are several nonextractive uses of peatland. These include agriculture, forestry, wildlife management, sewage treatment, preservation, recreation, and the production of energy crops. For a detailed discussion of peat uses, see *Minnesota Peat Program Final Report* (MDNR 1981).

PEATLANDS IN BELTRAMI AND LAKE OF THE WOODS COUNTIES

AREA SELECTED FOR SURVEY

The MPIP survey of Beltrami and Lake of the Woods counties focused on the areas of greatest peat accumulation, as measured by both the areal extent and depth of the deposits. The inventoried area contains numerous large peatlands, including the Red Lake Peatland, one of the largest contiguous peatlands in the conterminous United States (Glaser, et al. 1979). In contrast, southern Beltrami County contains only small, scattered peatlands and therefore, was not included in the survey. The westernmost portion of Beltrami County contains shallow peatlands and was excluded to conform with the purpose of the MPIP survey to identify peatlands greater than 150 cm deep.

DEVELOPMENT OF THE PRESENT LANDSCAPE

The distribution of peatlands in this area is a result of the depositional and erosional processes of glacial and post-glacial times. During the last glaciation of North America, the Wisconsin Stage, the ice advanced several times across the area. The last glacier to affect these counties was the St. Louis sublobe of the Des Moines lobe, which advanced from the northwest and deposited ground moraine across the study area (fig. 7).

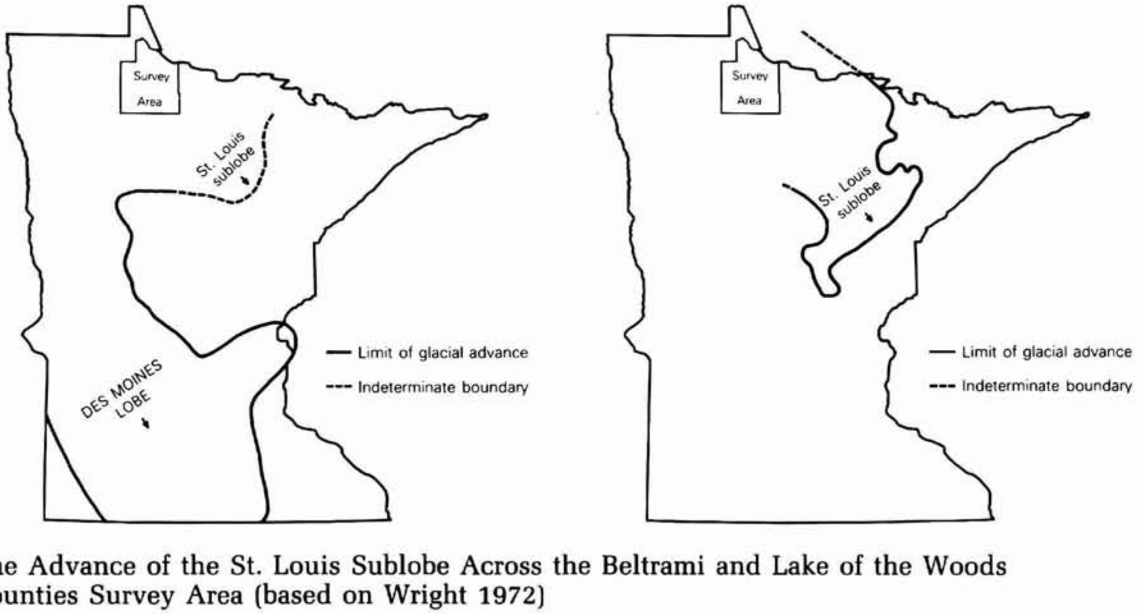

Fig. 7. The Advance of the St. Louis Sublobe Across the Beltrami and Lake of the Woods Counties Survey Area (based on Wright 1972)

As the ice sheet wasted, the meltwater was ponded between the ice front and terminal moraines and higher ground on the south and east, creating Glacial Lake Agassiz (fig. 8). The lake covered at least a part of the study area from about 12,000 to 9,900 years ago (Griffin 1977, Wright 1972, Clayton and Moran 1982). Wave action reworked the glacial till and deposited beach-lines, off-shore sand, and lake bottom sediments (Eng 1979 and unpublished). As the lake drained, a broad, flat, gently undulating plain remained.

Peat accumulation did not begin immediately after the lake drained. Pollen analysis indicates that the climate became warmer and drier for a time and the vegetation changed from boreal forest to prairie. The climate then changed again, becoming cooler and wetter and conducive to peat formation. A peat core obtained from a site in the Red Lake Peatland (located in T.155N., R.33W., Sec. 11) records about 3,000 years of peat accumulation (Griffin 1977). Earlier peat accumulation may have occurred, but any layers were probably burned away in fires. Initial peat accumulation consisted primarily of sedges. Sphagnum moss peat accumulation in this area did not begin until about 2,000 years ago, although sphagnum mosses may have been present earlier (Griffin 1977).

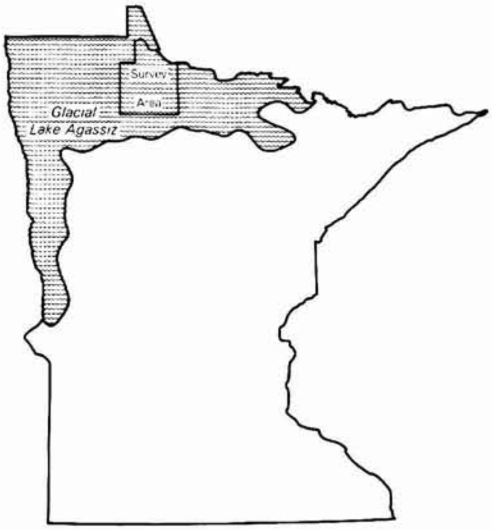

Fig. 8. The Area Covered by Sediments of Glacial Lake Agassiz (based on Wright 1972)

SURVEY

The MPIP inventoried the peatlands in the area to identify (1) the areal extent, depth, and type of peat, and (2) those peatlands containing fuel-grade peat. Fuel-grade peat as defined by the U.S. Department of Energy (DOE) (1) has a heating value of 8,000 Btu/pound or more in an oven-dried state, (2) contains less than 25% ash, (3) occurs in deposits that are at least 150 cm (~5 ft) deep, and (4) covers a cumulative area of more than 30 ha (80 ac) per 2.6 km^2 (1 mi^2).

The inventory was a reconnaissance-level survey, which is useful for resource management and for identifying areas that require more detailed mapping. In this type of survey, the boundaries between mapping units are based on field observations, aerial photograph interpretation, and the general appearance of the landscape (Soil Survey Staff 1951).

This report and the accompanying map, *Peat Resources, An Area of Beltrami and Lake of the Woods Counties, Minnesota* (in back flap), present the results of this inventory work.

Field Procedures

The survey began with the interpretation of 1:24,000 United States Geological Survey (USGS) quadrangle and orthophotoquadrangle maps and 1:80,000 aerial photographs. MPIP staff used these maps and aerial photos to identify the peatlands to survey. Peatland landforms were used as indicators of the botanical origin and the amount of decomposition of the surface layers of the peat.

Observation Sites

MPIP staff members selected field observation sites to provide data on the stratigraphy and depth of the peatlands. The data were collected along traverses and at random locations within the peatlands. Because of the vastness of the peatlands in these counties, field crews reached the majority of the sites by helicopter when clearings permitted landing. Other sites were reached either by all-terrain vehicle when located near trails or on unforested, unditched peatlands, or by foot when located within walking distance of roads. Access by all-terrain vehicle or by foot increased the density of the observation sites.

At over 650 sites, the field crews described the peat profile, vegetation, and microrelief. A Davis sampler was used to bring up a small sample at regular intervals (about every 30 cm) in the profile. These samples were examined to determine the degree of decomposition according to the von Post scale, the botanical origin of the layers according to the IPS classification, and the texture of the underlying mineral material. These data are available at the Department of Natural Resources, Minerals Division, Hibbing or St. Paul, Minnesota.

Sample Sites

Inventory staff sampled 133 representative peatland sites for laboratory analysis. Several factors were considered in the selection of these sites, including the peatland landform type and the depth and layering of the peat accumulation.

Staff members used a Macaulay sampler to collect undisturbed peat samples of known volume within specific layers of the deposit. At 121 sites, the field crews collected samples from a core for analysis at the

MPIP laboratory in Hibbing. At the 12 remaining sites, two cores in close proximity to each other were sampled within layers of the same peat type. Samples from one core were analyzed at Hibbing, and samples from the second core were sent to the DOE Coal Analysis Laboratory at the Grand Forks Energy Technological Center, Grand Forks, North Dakota, for energy value analysis.

Additional Information

To supplement the field data, the MPIP staff examined three additional sources of information. These data were obtained from the SCS, the Iron Range Resources and Rehabilitation Board (IRRRB), and an unpublished doctoral dissertation by Finney.

In Beltrami County, SCS soil scientists are currently gathering and compiling information to publish a detailed Soil Survey of the county (to be completed by 1989). The MPIP used the SCS profile descriptions where applicable.

MPIP staff also examined the IRRRB (1966) report entitled, *Peat Resources of Minnesota, Red Lake Bog*. The IRRRB inventoried the major raised bog complex in the Red Lake Peatland, primarily to assess the quality and the quantity of the sphagnum moss peat resource. Their report contains 80 site descriptions that include the total depth of peat and the type, pH, ash content, and water holding capacity of the top seven feet of the peat at one foot intervals.

Finney's (1966) thesis focused on the structure of raised bogs, as revealed by the configuration of the deposits and the stratigraphy of the peat layers in four raised bogs in northern Minnesota. One of the raised bogs studied was the raised bog complex in the Red Lake Peatland. Finney made three transects of the raised bog and recorded the thickness of the peat strata and the depth to the underlying mineral material.

Mapping Procedures

Compilation of the *Peat Resources* map began with an examination of field data to determine which mapping units were appropriate for a peatland. The mapping units, which were developed during earlier MPIP surveys, differentiate the depth, the degree of decomposition, and the botanical origin of the peat. Staff members converted the field descriptions from the ten-point von Post scale to three categories for the mapping units. SCS terminology for organic soil materials was used to identify these classes, which are related to the von Post scale in the following manner: fibric (H1-H3), hemic (H4-H6), and sapric (H7-H10).

The peat mapping units were delineated through the use of two sets of contour lines. One set differentiates the total depth of peat in increments of 150 cm (~5 ft). The other set identifies the depth of the fibric sphagnum moss peat accumulations of raised bogs. The class intervals for this set of delineations are 20-60, 61-150, and 151-300 cm (~1-2, 2-5, and 5-10 ft).

MPIP staff drew each set of contour lines on 1:24,000 USGS quadrangle maps. The locations of the lines are based primarily on (1) the site descriptions, which were plotted on the quadrangles and served as the control points for drawing the contours, and (2) aerial photograph interpretation, which was particularly important for delineating the areal extent of the raised bogs. Where appropriate, the MPIP staff used the SCS, IRRRB, and Finney data to verify delineations.

Once the contour lines were drawn, the quadrangles were reduced to a scale of 1:126,720 (1/2 inch : 1 mile). The peat delineations were then transferred to an overlay registered to the 1981 highway maps of Beltrami and Lake of the Woods counties on which the peat/mineral boundaries were drawn (based on Eng 1979 and unpublished).

Minor inclusions may occur within these mapping units due to the effects of generalization during map compilation and production. Two types of generalization that affect the map are (1) the map scale, which restricted the size of the mapping unit that could be delineated and labeled to approximately 30 ha (80 ac); and (2) the number and location of the observation and sample sites that served as the control points.

Laboratory Analyses

Laboratory analyses provide data to characterize the peat and determine its suitability for various uses. In addition to collecting field data, physical and chemical parameters were measured to help classify the peat soils.

MPIP Analyses

The MPIP performed analyses for ash content, moisture content, bulk density, and pH on 378 samples from 133 sample sites. The laboratory methods appear in Appendix A, and the data appear in Appendix B.

Ash is the residue left after a sample is heated to a sufficient temperature to drive off all combustible material. The residue comes from the original peat-forming vegetation as well as from sediment brought into the peatland by runoff from mineral soil and as atmospheric dust. As a result of mineralization during decomposition, ash content increases as the degree of decomposition increases (Walmsley 1977).

Moisture content is a measure of the amount of water that peat absorbs and retains. The amount of water that can be retained depends largely on the degree of decomposition and the botanical origin of the peat. Less decomposed peats have a greater water-holding capacity than those that are more decomposed. The moisture content of sphagnum moss peat is greater than for other peat types. The cellular structure of the moss leaves and stems and the large surface area of the plant, which results from the many small, overlapping leaves and the dense, interwoven growth pattern, increase the water-holding capacity of the plant and, thus, the peat.

Bulk density is a measure of the weight of a given volume of soil. The volume of a sample is usually measured wet because soil volume changes with water content (Walmsley 1977). The bulk density depends upon the organic, mineral, and moisture contents of the peat. As the mineral content increases, bulk density increases; as the moisture content increases, bulk density decreases. Because bulk density increases with increasing decomposition of the peat, bulk density values can be used as an indirect measure of the degree of decomposition.

pH values describe the hydrogen ion concentration of a solution. The pH values range from 1 to 14, with values less than 7 indicating acidity and values greater than 7 indicating alkalinity. The pH of peat is primarily dependent on the water chemistry, botanical origin, and the decomposition of the peat. Most peat types are acidic (pH values of about 4 to 7) or circumneutral (about pH 7).

DOE Analyses

The DOE laboratory conducted energy value analysis on 26 peat samples from 12 sample sites. The analysis consisted of a determination of the heating value, proximate analysis, and ultimate analysis. The data appear in Appendix C.

Heating Value

Heating value is a measure of the energy released by a fuel when it is completely burned. It is expressed in Btu/pound of material, but for energy estimates that are regional or national in scope, Btu values are converted to quads of energy (1 quad = 1×10^{15} Btu).

Proximate Analysis

Proximate analysis provides data on the characteristics of a peat fuel when it is burned. It is expressed in percentages of moisture, volatile matter, fixed carbon, and ash.

Volatile matter is the gaseous fraction of the fuel, composed mainly of hydrogen and hydrogen-carbon compounds, that is removed by heating the fuel.

Fixed carbon is that portion of the fuel that remains after the volatile matter is driven off before combustion. It is burned in a solid state, such as on a stoker, or as particles in a suspension boiler.

Ash is the inorganic fraction of the fuel that remains after combustion and must be removed from the combustion facility.

Ultimate Analysis

Ultimate analysis identifies the constituents of peat in percentages of carbon, hydrogen, oxygen, sulfur, and hydrogen. The components are used in combustion calculations and for determining plant efficiencies and potential pollutants.

RESULTS

Peatlands in Beltrami and Lake of the Woods Counties

Peatlands in the surveyed area contain peat derived from sedges, reeds, sphagnum and other mosses, and wood fragments. The peat ranges from slightly to strongly decomposed. The fibric peat is generally composed of sphagnum mosses, but fibric peat composed of reeds and sedges or a combination of mosses, reeds, and sedges can be found. The hemic peat is predominantly herbaceous peat and occasionally moss peat. Wood peat layers also occur. The origin of the sapric peat is probably herbaceous or wood, but the high degree of decomposition prevents fiber identification in the field. The absence of limnic materials underlying the peat accumulation at the survey sites indicates that these peatlands formed by the paludification process.

Three diagrams follow to illustrate the peatland types found in the surveyed area. Each diagram consists of a map view and a cross-section drawn along a selected transect. The map views are based on Eng (1979 and unpublished), and the cross-sections are based on the MPIP field data. Surface elevations are from 1:24,000 USGS quadrangle maps.

Figure 9 is an example of a peatland that formed by paludification on the bed of former Glacial Lake Agassiz. The peatland is located in the northeast corner of Lake of the Woods County in an area covered by lakewashed ground moraine, beach deposits, and lake bottom sediments. Most of the peatland has fen vegetation, but an indistinct raised bog pattern is apparent on the eastern edge of the peatland near the Rapid River. The transect passes through a patterned fen in which water flow is to the northeast. The entire peat profile is composed of hemic herbaceous peat that is as deep as seven feet (2.1 m) at the sample sites.

Two ovoid islands occur in a peatland located in the south-central part of Lake of the Woods County (fig. 10). The southern ovoid island exhibits a radiating pattern of black spruce from a central crest; however, in the western half of the island some of the patterning has been obscured by a fire scar. The island has bog vegetation that includes a continuous carpet of sphagnum moss, black spruce, and ericaceous species. The cross-section of this island shows a dome-shaped accumulation of fibric sphagnum moss peat overlying hemic peat. The peat depths reach ten feet (3 m) and include a fibric sphagnum moss cap of three feet (0.9 m).

Within the water track that divides and sharply defines the ovoid islands, minerotrophic species such as tamarack, bog birch, and ferns exist. Hemic and sapric peat comprise the profile.

The northern ovoid island is divided by internal water tracks that have an east-west orientation. The radiating pattern of black spruce is absent or indistinct on portions of the island. Minerotrophic indicator species are found in the internal water tracks. The peat accumulation along this part of the transect is shallow, less than five feet (1.5 m) deep, and consists of 1-2 feet (0.3-0.6 m) of fibric sphagnum moss peat overlying hemic peat.

The third map view and cross-section (fig. 11) is from Minnesota's largest raised bog complex, located north of Upper Red Lake in Beltrami County. This raised bog has a strongly developed pattern of black spruce radiating outward from a linear crest. Approximately one mile (1.6 km) south of the bog crest, the vegetation type changes from forested bog to open bog. The peat accumulation along this transect reaches 14 feet (4.3 m), of which the upper 7-10 feet (2.1-3.0 m) is fibric sphagnum moss peat near the crest.

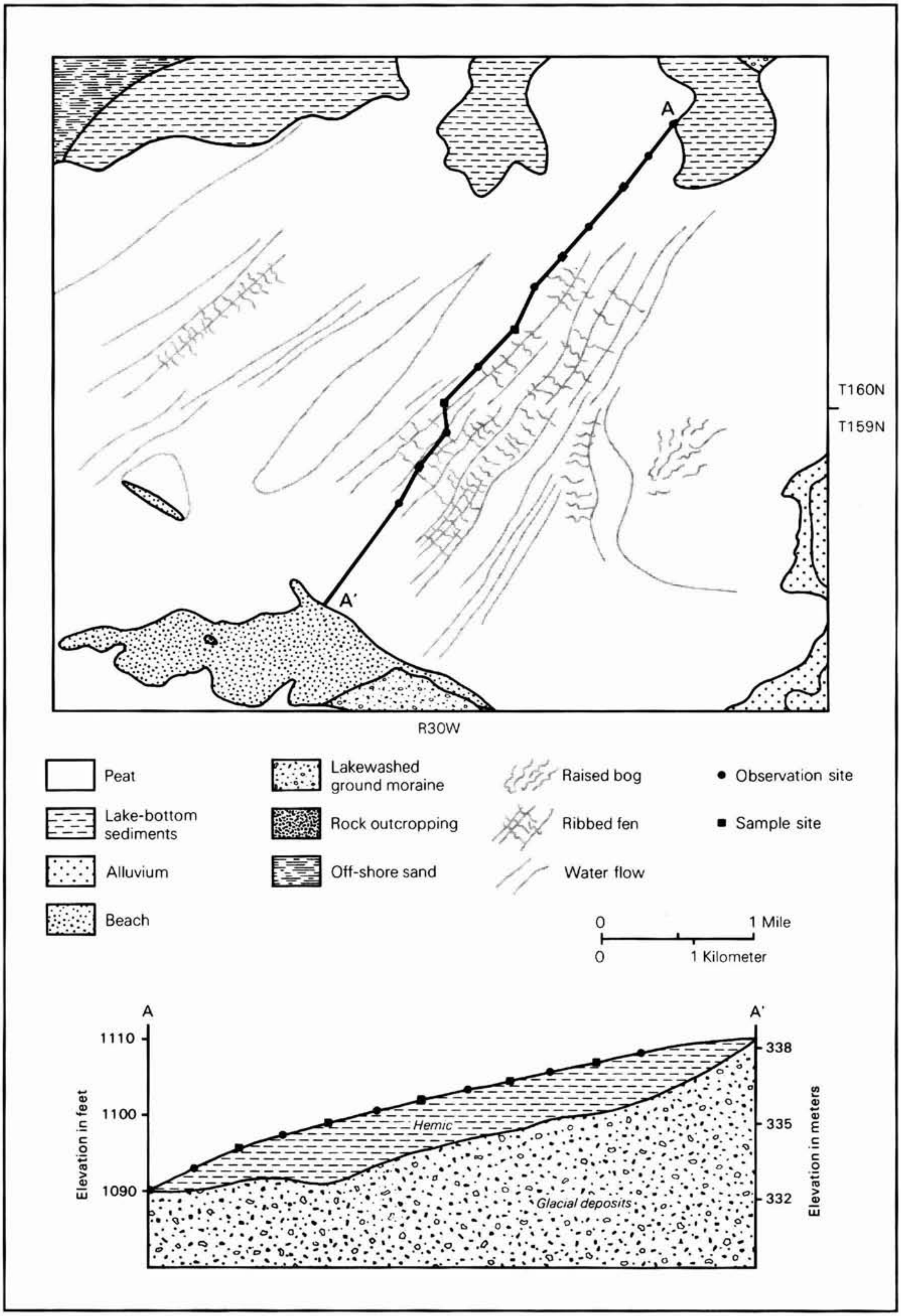

Fig. 9. Peatland Formed by Paludification in Lake of the Woods County

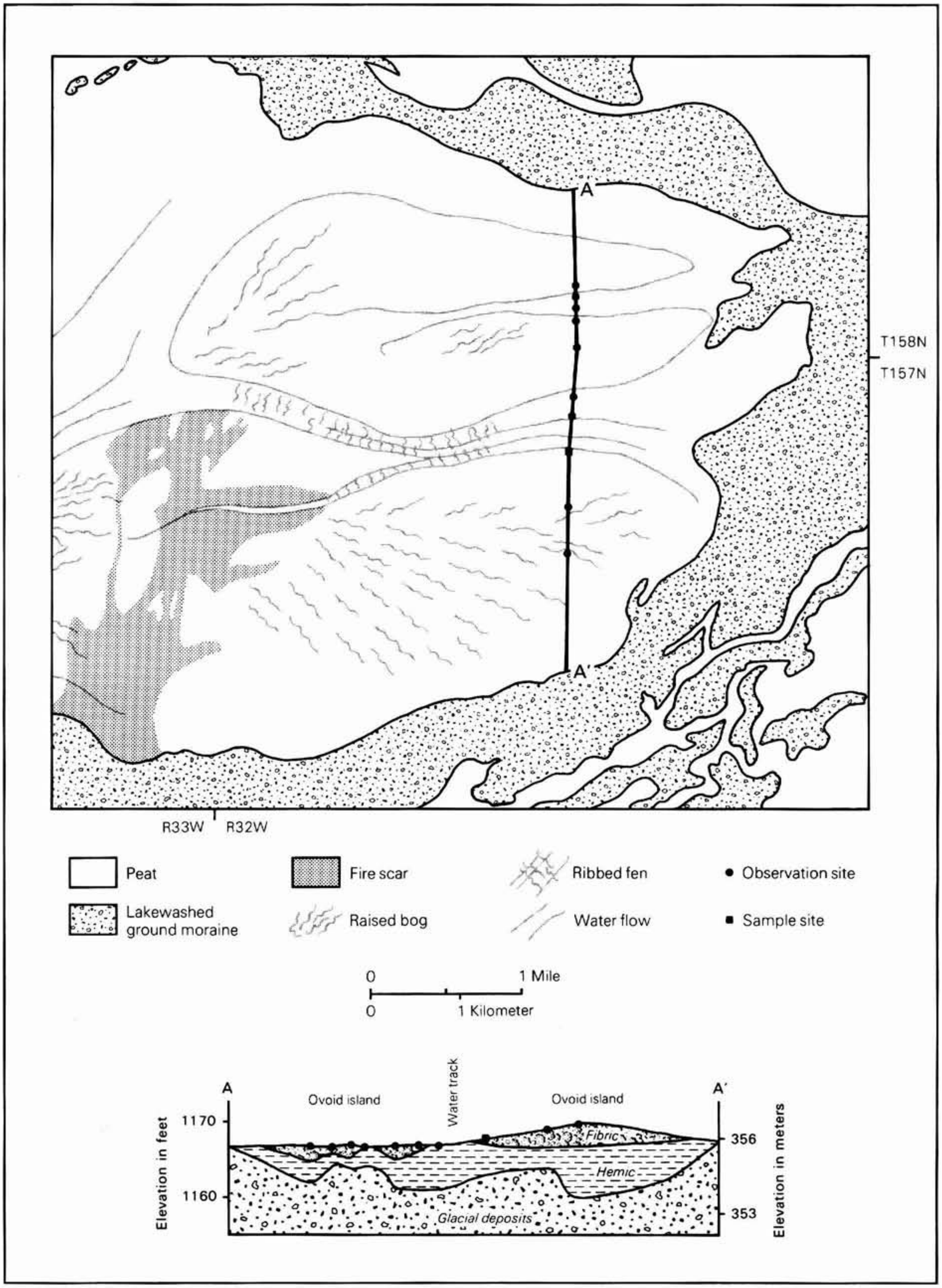

Fig. 10. Peatland Landforms in a Peatland in Lake of the Woods County

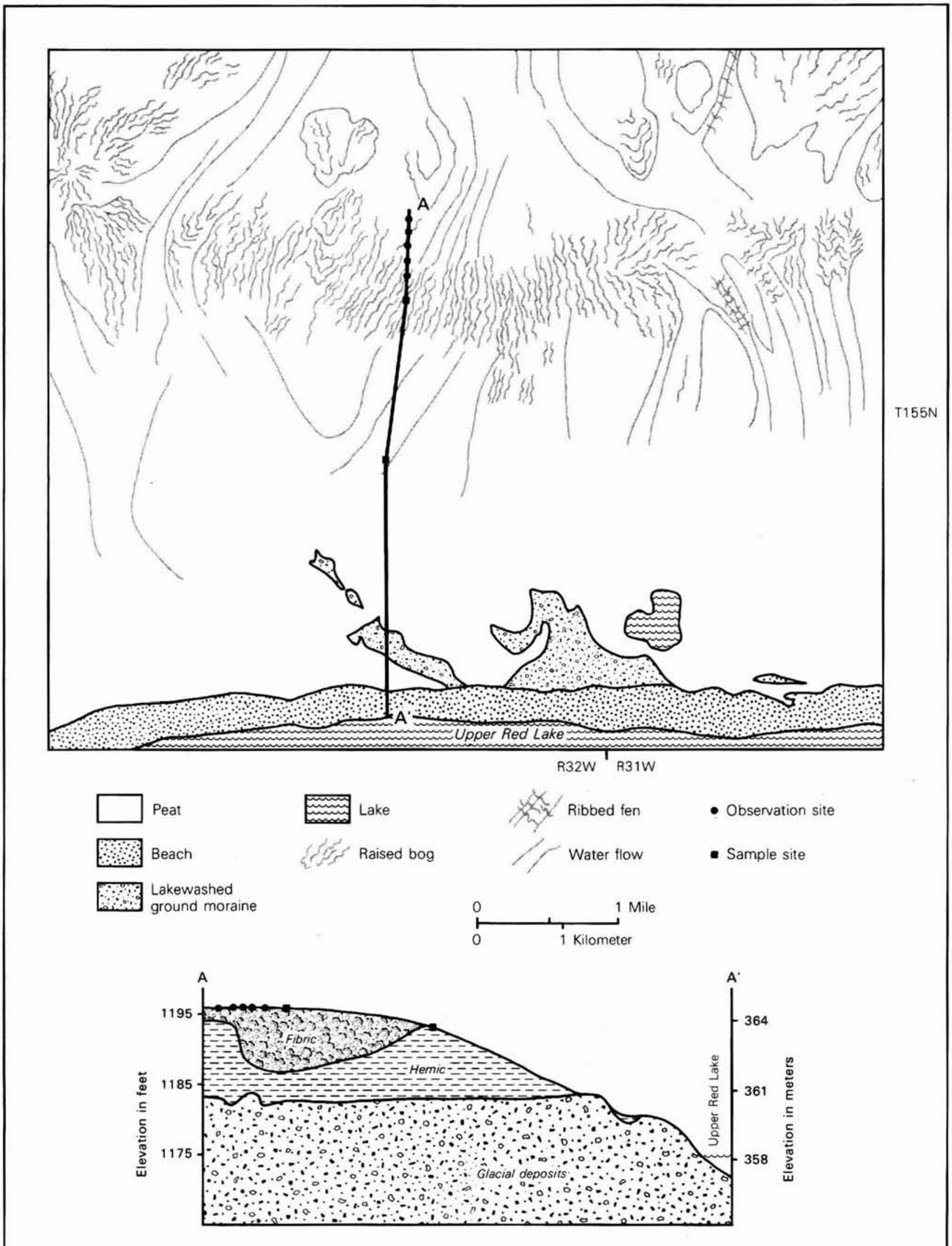

Fig. 11. A Raised Bog in Beltrami County

Laboratory Data

The results of both the MPIP and the DOE analyses of the peat samples are presented in summary form in Tables 3-9.

MPIP Data

The summary data for ash content, moisture content, bulk density, and pH for 378 samples are presented in Tables 3-6. The sample data are presented by site, depth, and type in Appendix B.

The summary data indicate relationships between the parameters and decomposition (fig. 12). These correlations follow results found elsewhere (e.g., Walmsley 1977); that is, the ash content, bulk density, and pH increase with increasing decomposition, while moisture content decreases with increasing decomposition.

DOE Data

The summary data for heating value, proximate analysis, and ultimate analysis for 26 samples are presented in Tables 7-9. Only one sample of sapric peat was analyzed at the DOE laboratory; therefore, the values from this sample are not included in tabular form. Moisture content is measured as received; other values are based on moisture-free samples. Appendix C contains the DOE data.

Twenty-four of the 26 samples met the DOE criteria for fuel-grade peat based on heating value and ash content (i.e., a heating value greater than 8,000 Btu/pound and an ash content less than 25%). The relationship between the decomposition of the peat and the heating value for each peat type is shown in figure 12. Two samples have a heating value less than 8,000 Btu/pound and are therefore not included in the summary analysis. One sample was taken from near the bottom of a shallow deposit (depth about 90 cm), while the other sample was taken from nearer the surface of a deeper deposit.

Resource Estimation

The design of the map, *Peat Resources, An Area of Beltrami and Lake of the Woods Counties, Minnesota,* uses color and patterns to emphasize those peatlands meeting the DOE criteria for fuel-grade peat. Four types of areas are depicted on the map: peat greater than 150 cm deep, peat less than 150 cm deep, areas with sphagnum moss peat accumulation, and mineral soil. Since samples of all three peat types, fibric, hemic, and sapric, generally have heating values greater than 8,000 Btu/pound with an ash content less than 25%, the depth and areal extent of the peatlands became the factors for determining fuel-grade peat.

Fuel-grade peatlands, shown in dark orange on the map, are greater than 150 cm deep and cover at least 30 ha (80 ac). Shallow peatlands, peatlands that are less than 150 cm deep and therefore do not meet the DOE fuel-grade peat criterion for depth, are shown in light orange. The black stipple pattern on peatlands designates peatlands covered by an accumulation of fibric sphagnum moss peat (raised bogs). Through the use of labels and contour lines, the areas of peat greater than 150 cm deep and the areas covered by sphagnum moss peat are further subdivided by depth. Mineral soil areas are displayed in gray.

On the map, the mapping units for total depth of peat are indicated by the following designations:

A	0-150 cm	(~ 0- 5 ft)
B	151-300 cm	(~ 5-10 ft)
C	301-450 cm	(~10-15 ft)
D	451-600 cm	(~15-20 ft)

When used alone, the total depth labels (e.g., A) denote a profile composed entirely of hemic peat. A total depth designation used in conjunction with a lower-case letter suffix indicates a hemic peat profile with a fibric moss peat cap or a profile composed of sapric peat.

The mapping units that indicate the fibric sphagnum moss peat accumulation of a raised bog have a total peat depth designation accompanied by one of the following labels, which indicate the amount of relatively undecomposed moss peat accumulation:

a	20- 60 cm	(~1- 2 ft)
b	61-150 cm	(~2- 5 ft)
c	151-300 cm	(~5-10 ft)

An example of one of the mapping unit labels for an area of a raised bog is Aa. The peat unit has a total depth indicated by the first letter (e.g., A 0-150 cm) and has a fibric sphagnum moss peat cap of the depth indicated by the lower-case letter (e.g., a 20-60 cm). Hemic peat composes the remainder of the profile.

The symbol Ax designates sapric peat areas on the map. The profile is predominantly sapric peat and has a depth of A (0-150 cm).

Staff members used the areal extent, depth, bulk density, and Btu values to estimate the energy potential of the peat in this area. To calculate the areal extent of the peatlands, the mapped information was entered into the computer system at the Land Management Information Center of the Minnesota State Planning Agency to obtain acreage counts for each mapping unit. Next, staff members determined the value of the mid-point for each mapping unit so that volumes of peat could be calculated. For example, the mid-point of the B unit, which is 151-300 cm deep, is 225 cm. Laboratory analysis provided values for the bulk density and the heating value of the sampled peat. From these values, the average bulk density and heating value for each peat type were calculated.

The quantity of peat, expressed in peat tonnage, was estimated for each mapping unit by multiplying the areal extent and average depth of each mapping unit by the average bulk density value for the appropriate peat type or types.

Multiplying the quantity of peat by the average heating value for each peat type provided an estimate of the peat energy potential.

Peatland Area

Peatlands cover 314,000 ha (775,000 ac) of a total area

TABLE 3

SUMMARY OF MPIP ANALYSES

	Average	Range	Standard Deviation	Coefficient of Variation
Ash Content (%)	9.1	3.0-24.6	3.08	33.8
Bulk Density (g/cc)	0.13	0.04-0.24	0.04	30.8
Moisture Content (total wt) (%)	87.7	78.5-95.3	3.05	3.5
Moisture Content (dry wt) (%)	765	366-2013	243	31.8
pH (H_2O)	5.2	3.4-6.6	0.63	12.1
pH ($CaCl_2$)	4.8	2.8-6.0	0.68	14.2

NOTE: Data from 378 samples containing less than 25% ash.

TABLE 4

MPIP ANALYSIS—FIBRIC SAMPLES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Ash Content (%)	5.7	3.0-11.6	3.00	52.6
Bulk Density (g/cc)	0.07	0.04-0.10	0.02	28.6
Moisture Content (total wt) (%)	92.5	89.2-95.2	2.27	2.5
Moisture Content (dry wt) (%)	1353	828-1981	439	32.4
pH (H_2O)	4.4	3.7-5.6	0.61	13.9
pH ($CaCl_2$)	3.5	2.8-5.4	0.75	21.4

TABLE 5

MPIP ANALYSIS—HEMIC SAMPLES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Ash Content (%)	8.9	3.2-22.5	2.75	30.9
Bulk Density (g/cc)	0.12	0.04-0.23	0.03	25.0
Moisture Content (total wt) (%)	87.8	79.7-95.3	2.80	3.2
Moisture Content (dry wt) (%)	767	394-2013	217	28.3
pH (H_2O)	5.3	3.4-6.6	0.62	11.7
pH ($CaCl_2$)	4.8	2.8-6.0	0.64	13.3

TABLE 6

MPIP ANALYSIS—SAPRIC SAMPLES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Ash Content (%)	13.6	7.4-24.6	4.32	31.8
Bulk Density (g/cc)	0.18	0.10-0.24	0.04	22.2
Moisture Content (total wt) (%)	83.2	78.5-87.4	2.36	2.8
Moisture Content (dry wt) (%)	505	366-695	82.0	16.2
pH (H_2O)	5.4	4.5-6.2	0.37	6.9
pH ($CaCl_2$)	5.1	4.4-5.6	0.30	5.9

TABLE 7

SUMMARY OF DOE ANALYSES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Btu/lb	8714	7460-9411	507.06	5.8
Ash Content (%)	7.7	3.7-15.7	3.44	44.7
Moisture Content (total wt) (%)	91.3	79.1-97.8	3.62	4.0
Volatile Matter (%)	65.3	57.8-70.5	3.59	5.5
Fixed Carbon (%)	27.0	20.1-30.2	2.08	7.7
Hydrogen (%)	4.81	3.57-5.33	0.41	8.5
Carbon (%)	52.17	46.26-55.26	2.34	4.5
Nitrogen (%)	1.99	0.72-3.07	0.80	40.2
Sulfur (%)	0.62	0.14-2.6	0.75	121
Oxygen (%)	32.7	24.7-38.5	3.72	11.4
Bulk Density (g/cc)*	0.10	0.05-0.18	0.04	40.0
pH (H_2O)*	5.0	3.7-6.0	0.68	13.6
pH ($CaCl_2$)*	4.3	2.8-5.5	0.84	19.5

NOTE: Data from 24 samples containing less than 25% ash.
* Analysis performed in MPIP laboratory (samples from DOE site, but from a second profile).

TABLE 8

DOE ANALYSIS—FIBRIC SAMPLES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Btu/lb	8354	7460-8781	440.6	5.3
Ash Content (%)	6.0	3.7-9.4	2.16	36.0
Moisture Content (total wt) (%)	93.4	90.9-97.8	2.46	2.6
Volatile Matter (%)	68.4	65.5-70.5	1.76	2.6
Fixed Carbon (%)	25.6	20.1-29.0	2.84	11.1
Hydrogen (%)	4.98	4.71-5.24	0.19	3.8
Carbon (%)	50.93	46.26-53.71	2.54	5.0
Nitrogen (%)	1.10	0.90-1.67	0.27	24.5
Sulfur (%)	0.17	0.15-0.20	0.02	11.8
Oxygen (%)	36.8	34.2-38.5	1.52	4.1
Bulk Density (g/cc)*	0.07	0.05-0.09	0.02	28.6
pH (H_2O)*	4.1	3.7-4.5	0.32	7.8
pH ($CaCl_2$)*	3.2	2.8-3.6	0.36	11.3

* Analysis performed in MPIP laboratory.

TABLE 9

DOE ANALYSIS—HEMIC SAMPLES

	Average	*Range*	*Standard Deviation*	*Coefficient of Variation*
Btu/lb	8863	7504-9411	481.23	5.4
Ash Content (%)	8.0	4.8-15.7	3.48	43.5
Moisture Content (total wt) (%)	90.7	79.1-94.5	3.74	4.1
Volatile Matter (%)	64.4	57.8-70.4	3.26	5.1
Fixed Carbon (%)	27.6	24.8-30.2	1.53	5.5
Hydrogen (%)	4.77	3.57-5.33	0.44	9.2
Carbon (%)	52.70	48.05-55.26	2.19	4.2
Nitrogen (%)	2.28	0.72-3.07	0.67	29.4
Sulfur (%)	0.69	0.14-2.6	0.71	102.9
Oxygen (%)	31.5	26.4-38.1	2.71	8.6
Bulk Density (g/cc)*	0.10	0.05-0.18	0.03	30.0
pH (H_2O)*	5.3	4.5-6.0	0.45	8.5
pH ($CaCl_2$)*	4.8	3.6-5.5	0.50	10.4

* Analysis performed in MPIP laboratory.

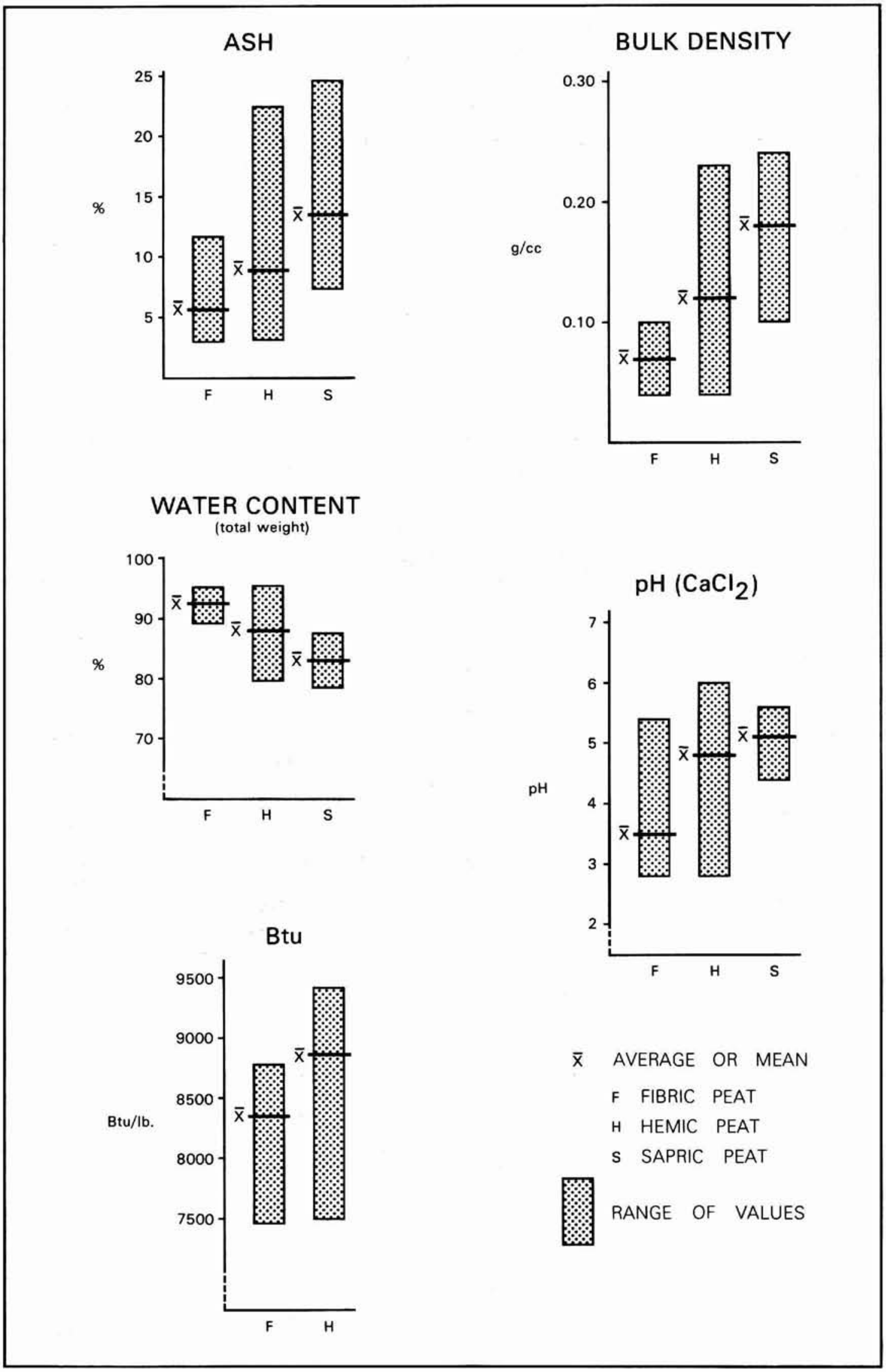

Fig. 12. Degree of Decomposition Versus MPIP Analyses and DOE Heating Value (Btu) Analysis

TABLE 10

AREAL EXTENT AND VOLUMES OF MAPPING UNITS IN THE BELTRAMI AND LAKE OF THE WOODS COUNTIES SURVEY AREA

Map Unit	*Peat Type*	*Percent Peat Area*	*Area* ha	*Area* ac	*Average Thickness* cm	*Average Thickness* ft	*Volume* ha-cm	*Volume* ac-ft
A	Hemic	72.5	227,490	562,100	75	2.5	17,061,750	1,405,250
B	Hemic	17.5	55,030	136,000	225	7.5	12,381,750	1,020,000
C	Hemic	1.7	5,240	13,000	375	12.5	1,965,000	162,500
D	Hemic	0.03	100	300	525	17.5	52,500	5,250
Aa	Fibric				40	1.3	13,000	10,400
	Hemic				35	1.2	113,750	9,600
	Total	1.0	3,250	8,000	75	2.5	243,750	20,000
Ba	Fibric				40	1.3	370,800	29,770
	Hemic				185	6.2	1,714,950	141,980
	Total	2.9	9,270	22,900	225	7.5	2,085,750	171,750
Ca	Fibric				40	1.3	128,000	10,400
	Hemic				335	11.2	1,078,700	89,600
	Total	1.0	3,220	8,000	375	12.5	1,207,500	100,000
Bb	Fibric				105	3.5	145,950	11,900
	Hemic				120	4.0	166,800	13,600
	Total	0.4	1,390	3,400	225	7.5	312,750	25,500
Cb	Fibric				105	3.5	602,700	49,700
	Hemic				270	9.0	1,549,800	127,800
	Total	1.8	5,740	14,200	375	12.5	2,152,500	177,500
Bc	Fibric	0.1	440	1,100	225	7.5	99,000	8,250
Cc	Fibric				225	7.5	420,750	34,500
	Hemic				150	5.0	280,500	23,000
	Total	0.6	1,870	4,600	375	12.5	701,250	57,500
Ax	Sapric	0.2	710	1,800	75	2.5	53,250	4,500
TOTAL			313,750	775,400			38,316,750	3,158,000
TOTAL AREA COVERED BY PEAT RESOURCES MAP			482,270	1,191,800				

of 482,000 ha (1,192,000 ac) in the surveyed area. Hemic peat covers 289,000 ha (711,000 ac), 91.8% of the peatland area; sapric peat covers 700 ha (1,800 ac), 0.2% of the peatland area; and areas of hemic peat overlain by a fibric sphagnum moss cap cover 25,000 ha (62,000 ac), 8% of the peatland area.

Areas with peat accumulations greater than 150 cm cover 82,000 ha (204,000 ac), or approximately 26% of the total peatland area. The areal extent for each mapping unit is shown on Table 10.

Peat Tonnages

The total quantity of oven-dried peat in the area is 450,600,000 metric tons (504,600,000 U.S. short tons). Hemic peat comprises 436,400,000 metric tons (488,800,000 U.S. short tons), sapric peat 1,000,000 metric tons (1,100,000 U.S. short tons), and fibric peat 13,200,000 metric tons (14,700,000 U.S. short tons).

The quantity of peat found in accumulations greater than 150 cm deep is 242,600,000 metric tons (271,800,000 U.S. short tons). Peat tonnages for each mapping unit are presented on Table 11.

Peat Energy Potential

The estimated energy potential for the peat deposits in the inventoried area is 8.94 quads. The estimated energy potential for those deposits meeting the DOE fuel-grade criteria is 4.81 quads.

The estimated energy potential for peat deposits meeting the DOE fuel-grade criteria, but excluding fibric moss peat, which has horticultural value, is 4.61 quads. Table 12 is a summary of the quantity and energy potential of peat resources in the surveyed area.

TABLE 11

PEAT TONNAGE (OVEN-DRIED) PER MAPPING UNIT IN THE BELTRAMI AND LAKE OF THE WOODS COUNTIES SURVEY AREA

Map Unit	*Peat Type*	*Metric Tons (×1,000)*	*U.S. Tons (Short) (×1,000)*
A	Hemic	204,700	229,100
B	Hemic	148,600	166,300
C	Hemic	23,600	26,500
D	Hemic	600	900
Aa	Fibric	900	1,000
	Hemic	1,400	1,600
	Total	2,300	2,600
Ba	Fibric	2,600	2,800
	Hemic	20,600	23,100
	Total	23,200	25,900
Ca	Fibric	900	1,000
	Hemic	12,900	14,600
	Total	13,800	15,600
Bb	Fibric	1,000	1,100
	Hemic	2,000	2,200
	Total	3,000	3,300
Cb	Fibric	4,200	4,700
	Hemic	18,600	20,800
	Total	22,800	25,500
Bc	Fibric	700	800
Cc	Fibric	2,900	3,300
	Hemic	3,400	3,700
	Total	6,300	7,000
Ax	Sapric	1,000	1,100
TOTAL		450,600	504,600

NOTE: Computed using fibric peat at 7 metric tons/ha-cm (95 U.S. short tons/ac-ft), hemic peat at 12 metric tons/ha-cm (163 U.S. short tons/ac-ft), and sapric peat at 18 metric tons/ha-cm (245 U.S. short tons/ac-ft).

TABLE 12

QUANTITY AND ENERGY POTENTIAL OF THE PEAT RESOURCES IN THE BELTRAMI AND LAKE OF THE WOODS COUNTIES SURVEY AREA

(By Peat Type, in Mapping Units >150 cm Deep and ≤150 cm Deep)

Peat Type	*Areal Extent*[1] *ha*	*ac*	*Tons-Dry Metric (×1000)*	*Tons-Dry U.S. Short (×1000)*	*Btu's*[2]	*Quads*[3]
Fibric						
>150cm	21,930	54,200	12,300	13,700	0.23×10^{15}	0.23
≤150cm	3,250	8,000	900	1,000	0.02×10^{15}	0.02
					0.25×10^{15}	0.25
Hemic						
>150cm	82,300	203,500	203,300	258,100	4.58×10^{15}	4.58
≤150cm	230,740	570,100	206,100	230,700	4.09×10^{15}	4.09
					8.67×10^{15}	8.67
Sapric						
≤150cm	710	1,800	1,000	1,100	0.02×10^{15}	0.02
TOTAL			450,600	504,600	8.94×10^{15}	8.94

[1]The areal extent of peatlands is not summed because fibric peat overlies hemic peat and the areal extent of these units would therefore be added twice.
[2]The Btu values per pound dry weight used in these calculations are Fibric peat - 8354, Hemic peat - 8863, Sapric peat - 8561
[3]One quad = 1×10^{15} Btu

SUMMARY

The MPIP staff described the peat profiles at approximately 850 sites. Samples were obtained from 133 representative sites selected for MPIP laboratory analysis. Samples from 12 of these sites were also sent to the DOE laboratory for energy-related analysis.

Peatlands cover 314,000 ha (775,000 ac), or 65% of the total area surveyed in Beltrami and Lake of the Woods counties. The total amount of oven-dried peat is about 450,600,000 metric tons (504,600,000 U.S. short tons).

The peatlands meeting the DOE criteria for fuel-grade peat cover 82,000 ha (204,000 ac), or 26% of the total peatland area. The quantity of peat in these peatlands is about 242,600,000 oven-dried metric tons (271,800,000 oven-dried U.S. short tons). These peatlands cover at least 80 contiguous acres (30 ha) and are composed of peat that (1) has an average energy value of 8,714 Btu/pound (moisture-free), (2) has an average ash content of 7.7%, and (3) is at least 150 cm (~5 ft) deep.

The estimated potential energy of these peatlands is 4.81 quads for those deposits greater than 150 cm deep.

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APPENDIX A

LABORATORY METHODS

Moisture Content

To determine moisture content, a wet sample was weighed, oven-dried to a constant weight (105°C for ~24 hours), cooled, and reweighed. Moisture content is expressed as (1) a percentage of total weight and as (2) a percentage of dry weight. Moisture content was calculated as follows:

$$\text{Total weight, percent} = [(A - B) \times 100]/A$$
$$\text{Dry weight, percent} = [(A - B) \times 100]/B$$

where:

A = grams of wet sample and
B = grams of oven-dried sample.

Bulk Density

To determine bulk density, a wet sample of known volume was oven-dried to a constant weight (105°C for ~24 hours), cooled, and weighed. Bulk density was calculated as follows:

$$\text{Bulk density, g/cm}^3 = B/C$$

where:

B = grams of oven-dried sample, and
C = volume in cm^3 of as-received sample.

Ash Content

To determine ash content, an oven-dried sample was thoroughly mixed in a blender. A one-gram portion was placed in a crucible, ignited in a muffle furnace (500°C for 1 hour), cooled, and reweighed. Ash content was calculated as follows:

$$\text{Ash, percent} = (D \times 100)/E$$

where:

D = grams of ash, and
E = one-gram of oven-dried and mixed sample.

pH

The pH of peat was measured in (1) a suspension of deionized H_2O and (2) in a suspension of 0.01M $CaCl_2$ solution. The procedure for both measurements involved lightly packing 15 cc of an as-received peat sample into a 100 cc container, adding 15 cc of solution, and mixing. Each suspension was set aside for an hour to equilibrate before measuring with a pH meter.

pH was measured both in water and in a calcium chloride solution because the pH readings in water can be modified by salts, whereas, the observed pH in calcium chloride solution is virtually independent of the initial amount of salts present in the soil (ASTM 1971). Calcium chloride suspensions are almost independent of dilution because of the release of hydrogen ions through cation exchange, whereas, water suspensions have a greater dilution effect, resulting in a slightly higher pH value (Canada Soil Survey Committee 1976).

Proximate and Ultimate Analyses

Proximate and ultimate analyses were performed at the DOE Coal Analysis Laboratory using standard ASTM laboratory procedures.

GLOSSARY

This glossary was adapted from the following sources:

American Geological Institute. 1972. *Glossary of Geology*. Washington, D.C.

Soil Science Society of America. 1979. *Glossary of Soil Science Terms*. Madison, WI.

Soil Survey Staff. 1975. *Soil Taxonomy, Agricultural Handbook No. 436*. U.S. Department of Agriculture. Washington, D.C.: U.S. Government Printing Office.

Btu. British thermal unit, the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Clay. A soil separate that consists of mineral particles less than .002 mm in diameter. A soil textural class in which the soil material is 40% or more clay, less than 45% sand, and less than 40% silt.

Crown cover. The amount of plant surface that covers the ground when viewed from above, which is expressed as a percentage of the total possible cover (100%), e.g., a black spruce crown cover of about 50%.

Ericaceous. Plants of the heath family, including bog rosemary, leatherleaf, Labrador tea, and swamp laurel.

Fiber. A fragment or piece of plant tissue, excluding live roots, that is large enough to be retained on a 100-mesh sieve (openings 0.15 mm in diameter) and that retains recognizable cellular structure of the plant from which it came.

Fibric peat. Organic soil that has a high content of undecomposed plant fibers and a bulk density less than about 0.1 g/cm^3.

Ground cover. Low growing plants, such as mosses and sedges, that form a layer on the ground surface.

Ground moraine. The debris that is deposited as a glacier melts. The accumulation of this material forms an extensive, fairly even, thin layer of till with a gently rolling surface.

Hemic peat. Organic soil that has an intermediate degree of plant fiber decomposition and a bulk density between about 0.1 and 0.2 g/cm^3.

Humus. The relatively resistant, usually dark-brown to black, fraction of soil, organic matter, peats, or compost, which is formed during the biological decomposition of organic residues.

Loam. A soil textural class in which the soil material contains a moderate amount of sand, silt, and clay. Loams contain less than 52% sand, 28 to 50% silt, and 7 to 27% clay.

Lobe, glacial. A large, rounded, tongue-like projection that extends from the margin of the main mass of an ice sheet.

Microrelief. Small-scale differences in topography. In this report, microrelief is the distance from the top of a hummock to the bottom of a hollow in a peatland.

Mineralization. The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Moraine. A mound, ridge, or other distinct accumulation of unsorted, unstratified material, predominantly till, that is deposited by glacial ice.

Profile, soil. A vertical section of the soil through all its horizons.

Sand. A soil separate that consists of mineral particles between 0.05 and 2.0 mm in diameter. A soil textural class in which the soil material contains 85% or more sand and the percentage of silt plus 1.5 times the percentage of clay does not exceed 15%.

Sapric peat. Organic soil that has a high content of plant material so decomposed that the original plant structure cannot be determined and that has a bulk density of about 0.2 g/cm^3 or more.

Silt. A soil separate that consists of mineral particles that range in diameter from 0.002 to 0.05 mm. A soil textural class in which the soil material is 80% or more silt and less than 15% clay.

Soil. Both the organic and inorganic matter that comprises the unconsolidated surface material of the earth. This material is made up of organic matter, inorganic matter, water, and air, and results from the interaction, over time, of climate, micro- and macro-organisms, and topography on the parent material.

Terminal moraine. A moraine that has been deposited at or near a more-or-less stationary edge or at a place marking the cessation of a glacial advance.

Texture, soil. The relative proportions of the various soil separates in a soil.

Till. Unstratified and unsorted glacial material deposited directly by the ice and consisting of clay, silt, sand, gravel, and boulders intermingled in any proportions.

Understory. A layer of foliage in a forest that is beneath the crown cover and above the ground cover.

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