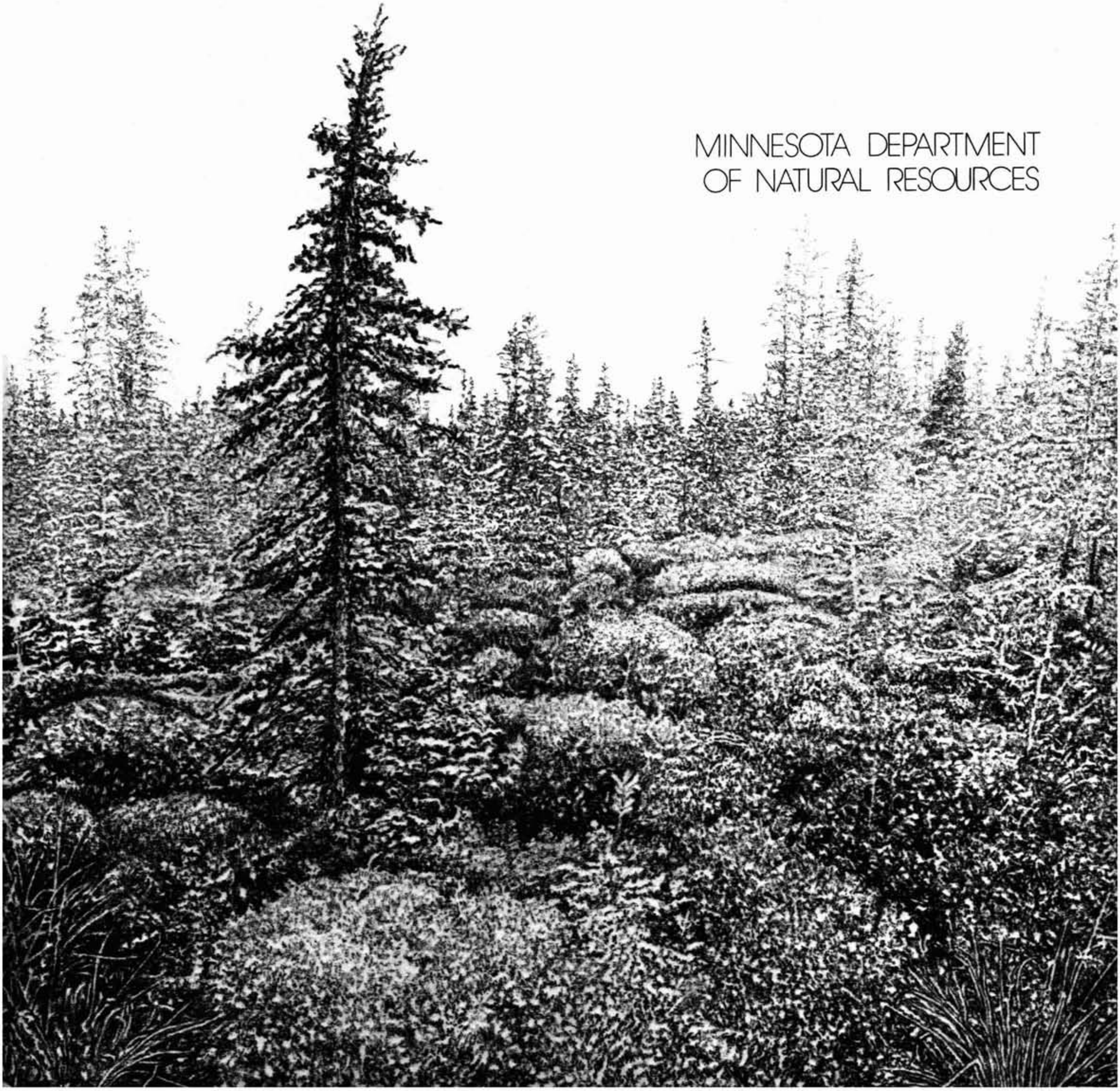
INVENTORY OF

PEAT RESOURCES

KOOCHICHING COUNTY, MINNESOTA



MINNESOTA DEPARTMENT
OF NATURAL RESOURCES

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INVENTORY OF PEAT RESOURCES KOOCHICHING COUNTY, MINNESOTA

L. S. Severson, H. D. Mooers, and T. J. Malterer

Technical Assistance: D.J. Olson, D.R. Mellem, S.L. Nelson,

R. L. Johnson, and H. M. Koslucher

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INVENTORY OF PEAT RESOURCES KOOCHICHING COUNTY, MINNESOTA

I. INTRODUCTION

Peatlands are one of Minnesota's many natural resources. Estimates of the area they cover range from 2.4 million hectares (5.9 million acres) to 3.1 million hectares (7.6 million acres), which is about 11 to 16 percent of the state's total area (see fig. 1). Over half of the peatlands are state-owned or state-administered land. Because most of these peatlands are presently undeveloped, Minnesota has the unique opportunity to develop sound management plans for the future of this resource.

In 1976, the Minnesota State Legislature mandated that the Department of Natural Resources (DNR), Minerals Division, initiate a peat program to collect information on Minnesota peatlands as a basis for developing policy alternatives for their management. The Minnesota Peat Inventory Project (MPIP) was developed as part of this program to begin an inventory of peatlands in Minnesota.

In 1977, the Legislative Commission on Minnesota Resources (LCMR) provided the DNR Minerals Division with funding to continue collecting baseline information about the location, type, and quantity of peat. Small peatland areas in Lake of the Woods, Koochiching, and Aitkin counties were surveyed at a reconnaissance level. With continued LCMR funding, the MPIP completed a reconnaissance-level peatland survey and published *Inventory of Peat Resources in Southwest St. Louis County, Minnesota* in 1979. The MPIP also published an inventory of the state's sphagnum moss peat deposits titled *Sphagnum Moss Peat Deposits in Minnesota* during that same year.

In 1979, the State of Minnesota received a grant from the U.S. Department of Energy (DOE) to determine the location and amount of fuel-grade peat in Minnesota that might be harvested and utilized for energy purposes in an environmentally acceptable manner. This grant has enabled the MPIP to accelerate the existing peatland survey and to collect additional baseline data. Under DOE funding, the surveying efforts began in Koochiching and Aitkin counties.

The subject of this report is the reconnaissance-level peatland survey of Koochiching County. The county has a total land area of approximately 822,400 ha (2,032,200 acres) of which approximately 464,600 ha (1,147,560 acres) are peatlands (see fig. 1).

This report consists of two parts: (1) a discussion of the resource and presentation of laboratory data, and (2) surficial geology and peat maps. Peat types and depths were recorded at over 1200 sites. From these observations, the inventory staff mapped the peat resource and determined peat volumes. The DNR laboratory staff at Hibbing characterized samples from 177 representative sites, and the DOE Coal Analysis Laboratory in Pittsburgh, Pennsylvania performed energy value analysis on samples from 51 of these sites. Together, the field and laboratory data were used to estimate the energy potential of the peatlands in the county.

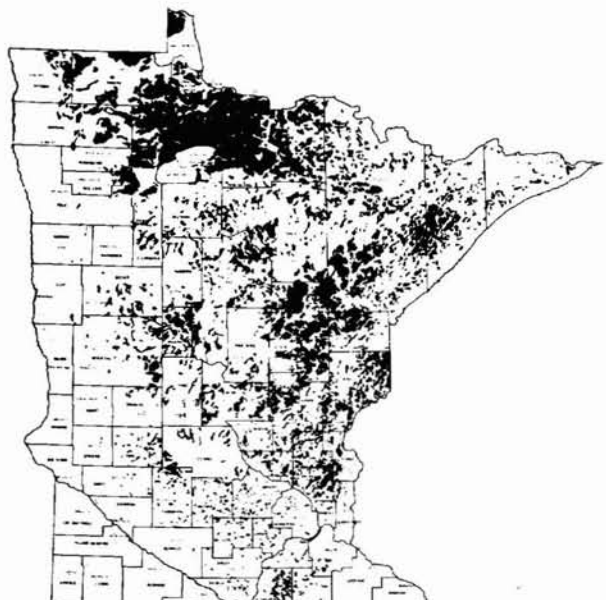

FIGURE 1. Distribution of Peat Resources in Minnesota

II. GEOLOGIC SETTING

General Geology

The bedrock in Koochiching County is fairly well exposed in some areas, mainly in the east-central, northeastern, and southeastern portions of the county and along the Rainy River in the northwest. In the northeastern and east-central regions, where the best exposures occur, the bedrock consists of early Precambrian metamorphosed graywacke, slate, mafic and felsic volcanics, gabbro-diabase, and granite gneiss. The northwest and southeast portions contain minor outcrops of Vermilion granite, schists, diabase dikes, greenstone, and undifferentiated intrusives.

In most areas, the bedrock is overlain by up to 30 m (~ 100 ft) of glacial drift usually composed of up to several meters of lake sediments, with as much as 60 m (~ 200 ft) of unconsolidated material occurring locally (Ojakangas et al. 1977).

The structure and chemical composition of the crystalline bedrock give it properties to resist erosion. Consequently, the bedrocks' resistance to erosion determines the location of preglacial lowlands or highlands which may influence the directional flow of glaciers.

Glacial Geology

The landscapes of Minnesota are a result of several advances and retreats of glaciers during the Pleistocene epoch (the time period of glacial activity). This glacial activity resulted in a nearly continuous cover of glacial tills, glaciofluvial deposits, and glacial lake sediments throughout the state.

The majority of surficial features in northern Minnesota are a result of the most recent glaciation, the Wisconsin Ice Stage, which spanned a period from 100,000 to 10,000 years ago (Flint 1971). During this stage, four major lobes repeatedly advanced and retreated in northern Minnesota, largely obliterating evidence of earlier glaciation. The glacial drift deposited by each lobe has a distinctive color, texture, and stone content depending on the area of its origin; thus the stratigraphy of the drift and the topography of the land can be used to interpret the glacial history of an area. The four lobes that affected northern Minnesota are as follows (see fig. 2(a)):

1) the Wadena lobe, which traversed the Limestone Belt of Manitoba and deposited a gray, sandy, calcareous till, containing a mixture of crystalline and limestone rocks in the Red Lakes lowland in northwestern Minnesota;
2) the Rainy lobe, which traversed the Precambrian Shield and entered Minnesota from the north-northeast and deposited a red to brown sandy, bouldery till composed primarily of Precambrian crystalline rock fragments, mainly granite;
3) the Superior lobe, which traversed the Precambrian Shield and the Lake Superior basin, advanced from the northeast and deposited a red-brown, loosely textured, sandy to gravelly till rich in volcanic rocks and Precambrian sedimentary rocks;
4) the Des Moines lobe, which traversed the Limestone Belt in southern Manitoba, followed the Red River Valley lowland and then diverted southeast across southern Minnesota and deposited a gray, calcareous, silty till rich in shale and limestone rock fragments.

Large sublobes were emitted from these major lobes. The St. Louis sublobe extended eastward from the Des Moines lobe across northern Minnesota, and the Grantsburg sublobe extended northeastward across east-central Minnesota into Wisconsin. The St. Louis sublobe played an important role in the geologic history of Koochiching County. It deposited a light buff to gray, calcareous, silty till and released meltwater that eventually inundated much of the area.

Glacial History of Koochiching County

Few glacial studies have been made pertaining specifically to Koochiching County since the work of Frank Leverette in 1932. The most recent work, done by Dr. C. L. Matsch in 1973, consists of a brief reconnaissance in the northwestern part of the county.

The record of glacial influence in Koochiching County is mainly a result of glaciation by the Rainy lobe followed by the St. Louis sublobe and inundation by the earliest stages of Glacial Lake Agassiz (see fig. 2(a) and (b)).

The Rainy lobe advanced from the northeast and flowed southward through the county abrading the bedrock surface and leaving striations and erosional bedrock forms. These features are most evident in the northeastern portion of the county. The ice stagnated at its maximum position to the south of Koochiching County and then retreated north, depositing a series of low recessional moraines trending generally east-west.

Several gravel pits in Koochiching County contain lake sediments consisting of up to 1.8 m (~6 ft) of laminated calcareous clay and silt separating the lower bouldery till of the Rainy lobe from the upper outwash of the St. Louis sublobe. This stratigraphic relationship documents the existence of an earlier proglacial lake, which formed after the retreat of the Rainy lobe and before the advance of the St. Louis sublobe from the west (Matsch 1973).

After this occurrence, the St. Louis sublobe advanced from the west-northwest, overriding part of the stagnated Rainy lobe and insulating it with a

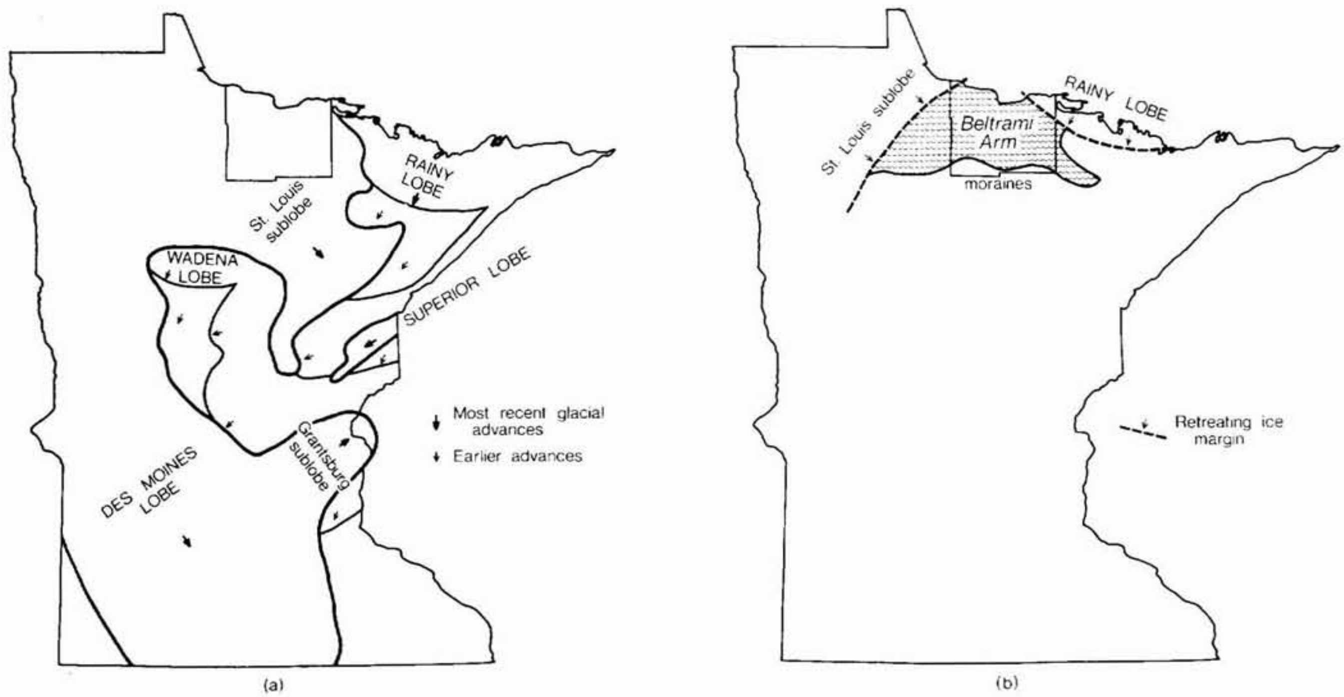

FIGURE 2. The Wisconsin Ice Stage: (a)Glacial Lobes That Affected Minnesota (Based on Wright 1972) and (b) Inferred Development of the Beltrami Arm of Glacial Lake Agassiz

cover of light buff to gray, calcareous, silty till. Several landforms related to the Rainy lobe were preserved from destruction by the sublobe because of the supporting stagnant ice (see appendix B).

As the St. Louis sublobe retreated, its meltwaters were impounded between the receding ice front and the previously deposited moraines in the south and east. Stagnant ice of the Rainy lobe formed the northern boundary for impoundment of the meltwater. This impoundment resulted in the development of the earliest Koochiching stage of the Beltrami Arm of Glacial Lake Agassiz (see fig. 2(b)). During the Koochiching stage, the lake stood at an elevation of 427 m ($\sim$1400 ft) and temporarily drained southeast via the Prairie River to Glacial Lake Upham (Eng 1979; Winter et al. 1973).

Although the main body of Glacial Lake Agassiz lasted about 5,000 years (from 12,500 to approximately 7,500 years ago [Flint 1971]), its occupation of Koochiching County during the early Koochiching stage appears to be of a much shorter time span. Because of its short duration, the lake's only effects were to smooth the landforms and to truncate and rework the more elevated moraines. Many of the low recessional moraines were reworked into boulder-strewn beach deposits such as occur at Pine Island. Lake Agassiz deposited laminated silts and clays in low-energy (water greater than 60 m [$\sim$197 ft] deep) environments. In the shallow, high-energy (wave-washed) environments, sandbars, spits, and beach ridges of sand and gravel developed. A series of somewhat parallel beaches developed at different elevations as the lake level gradually lowered in response to the melting of the ice front as it retreated northwestward.

Drainage of the lake accompanied by isostatic rebound (postglacial uplift) exposed the land surface to erosion, soil formation, the encroachment of vegetation, and the development of the present drainage network (Matsch 1973).

Physiography

Almost all of Koochiching County lies within the physiographic region known as the Beltrami Arm of Lake Agassiz (see fig. 3), a very level, poorly drained lake plain (Wright 1972). The lake plain is occasionally crossed by discontinuous sandy beaches, bars, and spits oriented in an east-west direction in the northern part of the county and in an arc trending generally from west to southwest in the south-central part of the county. The major portion of peat in the county occurs in this physiographic region.

The southeastern portion of the county includes a small portion of the Chisholm-Embarrass physiographic area. This region consists of low moraines and outwash plains deposited by the Rainy lobe.

Southwestern Koochiching County lies partly within the Bemidji physiographic area, which is a complex of moraines and outwash plains that are the result of deposition by the Wadena lobe and the St. Louis sublobe.

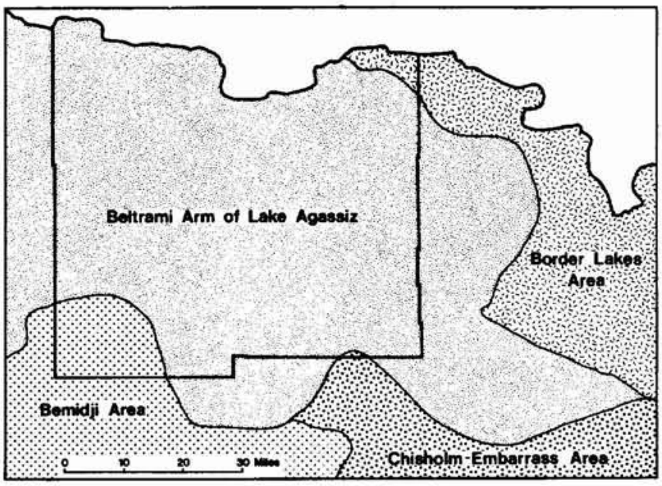

FIGURE 3. Physiographic Regions in Koochiching County, Minnesota (Based on Wright 1972)

The extreme northeastern corner of Koochiching County lies within the Border Lakes physiographic area in which glacial scouring produced parallel patterns of lakes and ridges with an east-west orientation reflecting the rock structure. Such rock ridges are evident in Koochiching County along the Rainy River.

Major rivers that drain Koochiching County are the Rainy, Big Fork, Little Fork, Black, and Sturgeon. These rivers are actively eroding and have cut down through 6-20 m (~ 20-60 ft) of lake sediments and glacial till, often reaching bedrock as at Big Falls and Manitou Rapids.

III. PEAT FORMATION

Requirements for Peat Formation

Peat is an organic soil consisting of partially decomposed plant matter. It forms in an unbalanced system where the rate of accumulation of organic materials exceeds the rate of decomposition (humification). This usually occurs in water-saturated environments where the wet condition limits the supply of oxygen and, therefore, limits the population of aerobic microorganisms that digest plant remains. These anaerobic conditions greatly reduce the decomposition rates and allow the plant matter to accumulate as peat (Kavanagh and Herlihy 1975).

Factors contributing to the formation of peatlands are climate and topography. A combination of these factors determines where and to what extent peatlands will occur. Peatlands occur most often in cool, humid climates where precipitation exceeds evapotranspiration. In north-central Minnesota, the summers are warm and short and the winters are long and cold. The area has a mean annual temperature of 3.8°C (38.8°F) and receives a yearly average of 65.1 cm (25.6 in) of precipitation. These conditions greatly reduce the potential evapotranspiration resulting in an environment favorable for peat accumulation. Such a climate has prevailed in north-central Minnesota since about 5,000 years B.P. (before present) (Terasmae 1977).

Peat deposits are usually found in basins or on low, flat, poorly drained areas where the water table is high and drainage is restricted. In Koochiching County, glacial processes produced vast areas that were well suited for peat formation. Glacial lake plains are ideal environments for peat formation. They are large, flat expanses that are generally covered with impermeable silt and clay soils, which restrict drainage and provide a water-saturated environment. Ground moraine is characterized by an undulating surface with immature drainage that is often ideal for the formation of peat. Outwash plains are usually composed of coarse sediments such as sand and gravel. These sediments are quite permeable; however, if a high water table is maintained by an impermeable substratum or by poorly developed drainage patterns, outwash plains are conducive to peat formation.

Pitted outwash plains and end moraines are characterized by numerous depressions and basins. These were formed by blocks of ice, left during glacial retreat, that melted and formed ice block depressions. These depressions are often the site of lakes and ponds and provide an excellent environment for peat accumulation.

Peat Formation Processes

There are two major processes by which peatland genesis can occur, lakefill and paludification.

Lakefill is the filling in of lakes and ponds by vegetation (see fig. 4). It begins with the deposition of limnic materials such as aquatic plants and some inorganic sediment. This is accompanied by reed and sedge growth around the margin of the basins. As the marginal vegetation dies and falls to the bottom, it forms a surface on which other plants grow. This mat of vegetation migrates into the basin and eventually fills it (Hammond 1975).

Paludification is the process of peatland formation caused by a gradual rise of the water table as peat accumulation impedes drainage (see fig. 5). It can occur after the lakefill process has been completed causing peat to creep up-slope out of the basin. It can also occur on nearly level ground, where it usually begins with reed and sedge growth. Paludification is a self-perpetuating process by which peat gradually covers the land surface and may move up gradual slopes and cross divides between watersheds. In this way, a peatland may often have a higher elevation than the mineral soil that surrounds it (Hammond 1975).

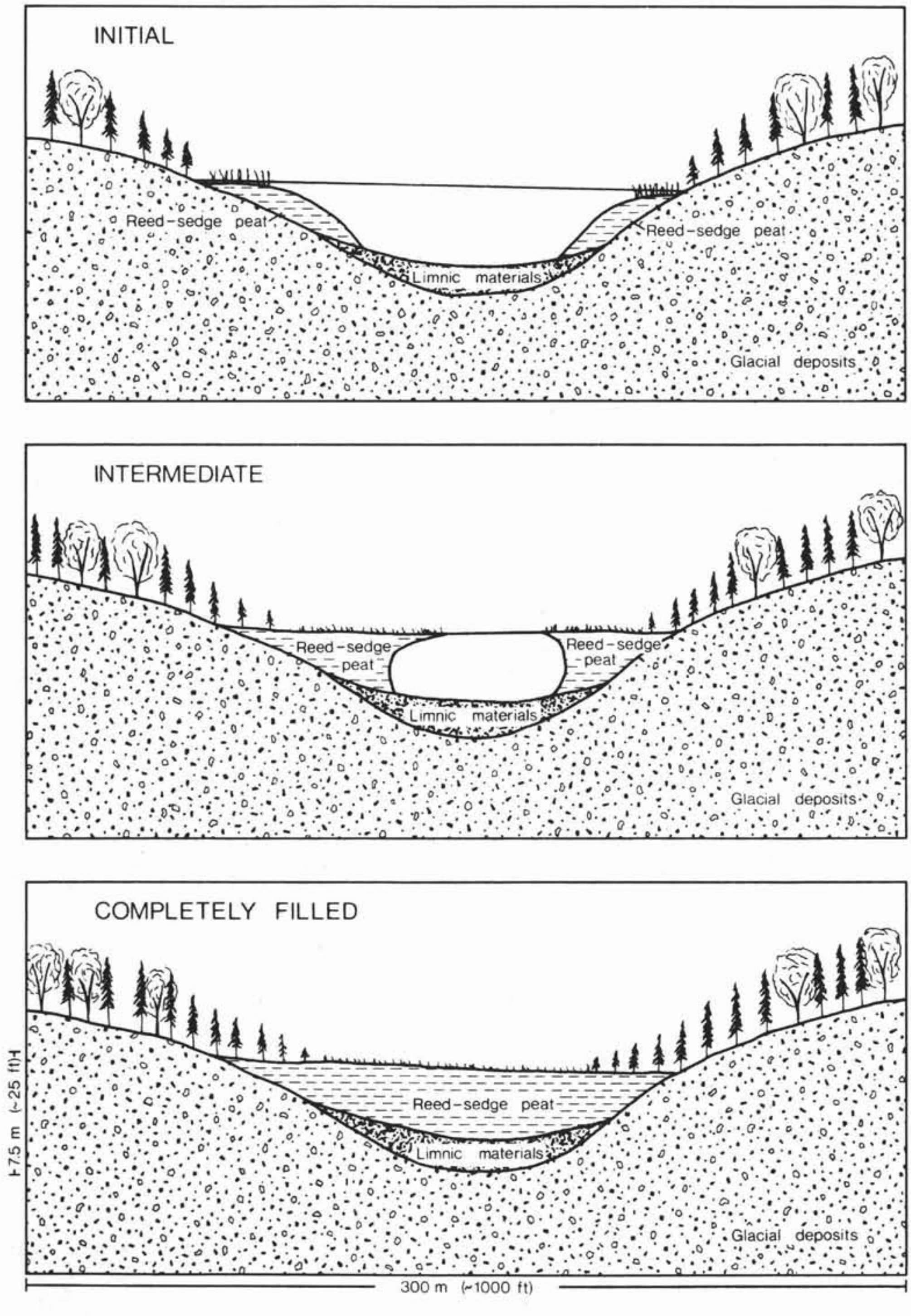

FIGURE 4. Lakefill Process of Peat Formation

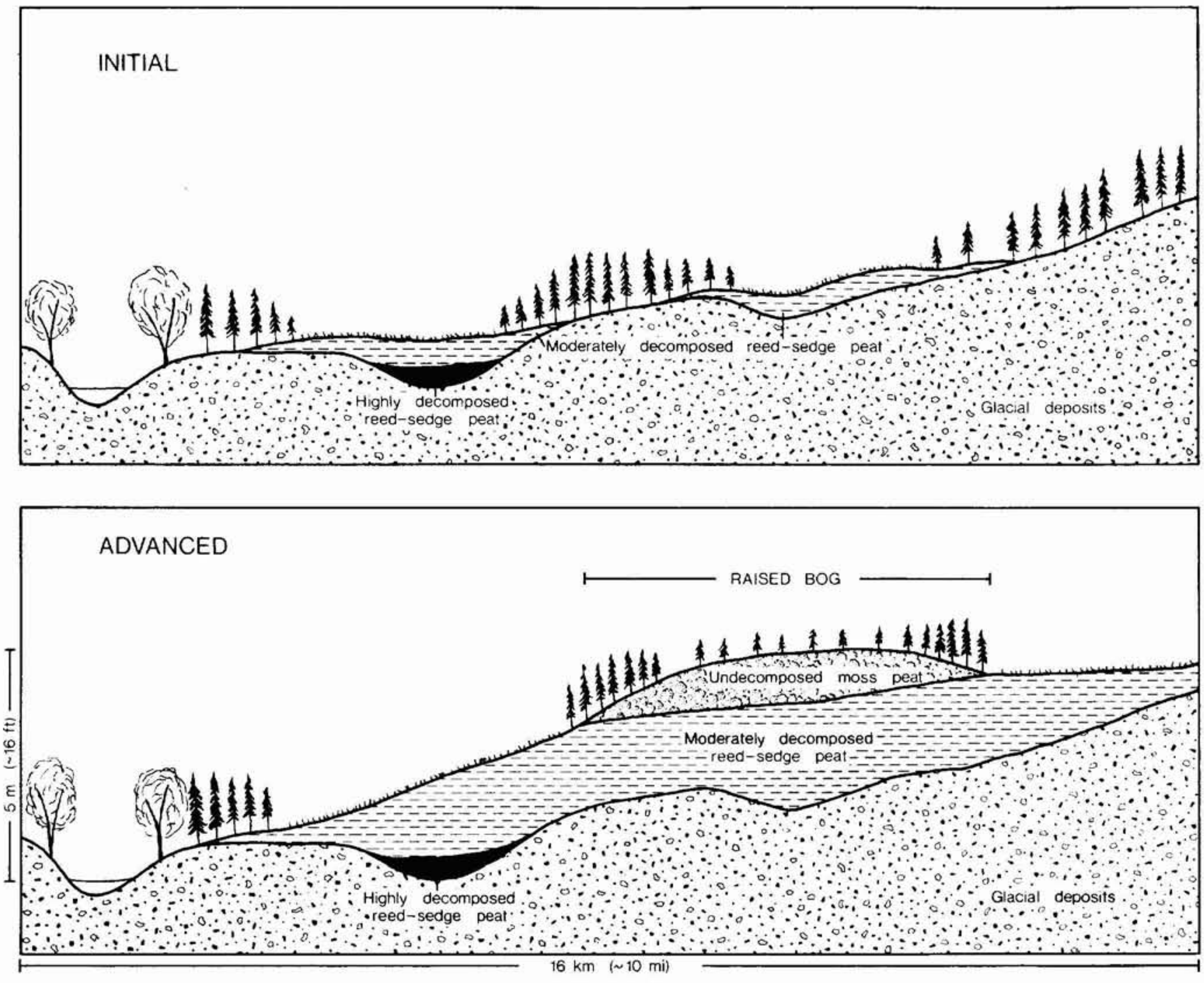

FIGURE 5. Paludification Process of Peat Formation

<u>**Chronology of Peat Formation in Koochiching County**</u>

As the glacial ice and glacial lakes retreated, a broad expanse of moraines, glacial lake plains, and other lake-modified features were exposed. Radiocarbon dates suggest that Lake Agassiz abandoned Koochiching County by about 9,000 years B.P. (Heinselman 1963). As the climate moderated, vegetation began to establish itself on the newly exposed land surface. Although the environment that existed is not known, the presence of grassland soils beneath peatlands to the west indicate that a wet prairie may have been present (Heinselman 1963). About 5,000 years B.P., a change in the climate brought about cooler, wetter conditions, and forest vegetation invaded the county (Heinselman 1963). These events also mark the beginning of conditions favorable to peat accumulation. Heinselman (1963) reported a radiocarbon date of 4,360 years B.P. from a basal peat in north-central Koochiching County. Another date from the western part of the county shows the basal peat was deposited 3,950 years B.P. indicating that the peatlands spread from east to west across the county (Glaser et al. 1979).

Basal peat types vary from one location to another. In many of the peatlands, forest peat was the first to accumulate. Forest peats consist of wood and shrub remains in a matrix of grass and sedges. In other areas, nonforest reed-sedge peats are characteristic of the basal layers. Aquatic peats were also deposited in a few lakes and ponds.

The margins of the peatlands spread by the paludification process forming a continuous blanket of peat over large areas. Within individual peatlands, accumulation rates of reed-sedge, forest, and mixed peats were not uniform; this resulted in a change in surface topography, and new drainage divides were formed. Water then drained away from these divides, isolating them from mineral-rich water and causing mineral depletion within the peat. Since sphagnum moss *(Sphagnum* spp.) can tolerate areas of low nutrient status, it invaded these areas and outcompeted less tolerant species. Sphagnum peats then accumulated over other peat types, often forming a dome that is commonly referred to as a raised bog. At present, areas where there is a cap of sphagnum moss peat occupy about 9.3 percent of the peatland area in the county.

IV. PEAT PROPERTIES AND CLASSIFICATION

Peat Properties

Peat has a number of physical and chemical properties that can influence its use (see appendix A). These include fiber content, water content, bulk density, mineral content, and pH.

Fiber Content

Peat fiber is the part of the plant remains that still retains recognizable cell structure. It is an important factor in determining the degree of decomposition of peat. As the peat decomposes, the percentage of fiber decreases. The fiber content and the degree of decomposition have a close relationship to the water content, bulk density, and mineral content.

Water Content

Peat has the capacity to absorb and retain large quantities of water. The amount held by the peat varies considerably according to the peat type and is reduced as mineral material increases. Relatively undecomposed fibrous peats can hold many times their own weight of water; with this capacity greatly reduced in well decomposed amorphous peats. This capacity depends on the peats structural features such as particle size and pore size distribution, which in turn are largely determined by the degree of decomposition (Puustjarvi and Robertson 1975.)

Bulk Density

Bulk density is a value representing the weight of a given volume of soil. It depends upon the organic, inorganic, and water content of the peat. As mineral material increases, the bulk density values increase. As water content increases, the bulk density values decrease.

Bulk density is related to the degree of decomposition and compaction. As the bulk density increases there is a drastic change in the pore size distribution even though the total pore volume changes very little (Walmsley 1977). As decomposition progresses, low bulk density peat containing large pores is replaced by a higher bulk density peat containing many smaller pores.

Mineral Content

Mineral content (ash) is the residue left after heating a sample to a sufficient temperature to drive off all combustible material. This residue comes partially from the original vegetation as well as from sediment brought into the peatland by runoff from mineral soil. In many peat deposits, there is a relationship between the amount of ash and the degree of decomposition; as the plant matter decomposes, its inorganic fraction increases (Walmsley 1977).

pH

pH is a numerical value that represents the hydrogen ion concentration of a solution. This value is used to represent the degree of acidity or alkalinity. The pH of a peat sample will vary depending on several criteria including composition and proximity of mineral soil and rock outcrops, vegetation types, and direction and rate of water flow through the peatland.

Peat Classification

Several peat classification systems have been developed. Each one was designed for a specific purpose and has both advantages and disadvantages depending on the application. The MPIP needed a system that was easy to use in the field and that was widely accepted.

For field use, the MPIP selected the system set up by the International Peat Society (IPS). The IPS has a three-point system based on degree of decomposition in which R1, R2, and R3 represent weakly decomposed, moderately decomposed, and highly decomposed peat respectively (table 1). The IPS also incorporated a ten-point scale (H1 - H10) devised by L. von Post in the early 1900s (table 2). von Post's scale is based on field identifiable visual and textural properties. A value of H1 is used for undecomposed peat and a value of H10 for completely decomposed peat. Values of H1 - H3 correspond to R1, H4 - H6 to R2, and H7 - H10 to R3.

For publication, the MPIP chose the soil taxonomy system used by the U.S. Department of Agriculture, Soil Conservation Service (SCS), which is also based on degree of decomposition. The major divisions are fibric, hemic, and sapric. Peats are placed in one of the groups by determining the amount of fiber that is over .15 mm in size. If 2/3 or more of the peat fiber is greater than .15 mm, the peat is fibric; between 1/3 and 2/3, hemic; and less than 1/3, sapric. Within soil taxonomy, peat can be further classified by criteria such as thickness of peat layer; botanical composition; presence or absence of mineral, limnic, or water layer; presence of rock; and soil temperature regimes. Fibric, hemic, and sapric of this system correspond very closely to R1, R2, and R3 of the IPS classification and for the purpose of this report are considered equivalent.

Peatland Classification

The peatlands of northern Minnesota can be separated into two major groups according to their source of surface water (Glaser 1980). Fens receive water that has percolated through mineral soil. The water is usually neutral or only slightly acidic and fairly rich in dissolved nutrients. Bogs are isolated from mineral-rich water and receive moisture and nutrients solely from precipitation. The bog waters are usually very acidic and poor in nutrients.

Fens and bogs also exhibit a number of surficial characteristics that can be used to classify them into different landforms. Water tracks are fens where mineral-rich water is channeled across an expanse of peat. These water tracks sometimes contain a series of linear ridges and hollows oriented perpendicular to the slope. Areas with this type of pattern are called ribbed fens. Also contained within these fens are teardrop shaped islands with heads of small tamarack and black spruce and tails of brush. These islands are oriented parallel to the direction of water movement with their tails pointing down-slope.

Raised bogs are often expressed by lines of black spruce radiating outward from a crest. The unforested openings between these lines of spruce are bog drains, where runoff is channeled away from the raised bogs.

Ovoid islands are a type of raised bog that is surrounded by water tracks. It is the channeling of the flow around the bog that induces the formation of the ovoid shape.

Table 1. 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
Fibric (R_1) 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 amounts of water, which can be easily pressed out and pours as a streamlet. Almost totally pure or slightly brownish. May contain dark humus spots.
Hemic (R_2) 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 partial drying.
Sapric (R_3) strongly decomposed peats	$<$ 40%	Lumpy-amorphous, consisting in main part of humus. In lumpy-amorphous peat greater fragments of plant residues/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.

Based on International Peat Society

TABLE 2. 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
H-1	Clear, colourless	None	Unaltered, fibrous, elastic	Undecomposed
H-2	Almost clear, yellow-brown	None	Almost unaltered	Almost undecomposed
H-3	Slight turbid, brown	None	Most remains easily identifiable	Very slightly decomposed
H-4	Turbid, brown	None	Most remains identifiable	Slightly decomposed
H-5	Strongly turbid, contains a little peat in suspension	Very little	Bulk of remains difficult to identify	Moderately well decomposed
H-6	Muddy, much peat in suspension	One third	Bulk of remains unidentifiable	Well decomposed
H-7	Strongly muddy	One half	Relatively few remains identifiable	Strongly decomposed
H-8	Thick mud, little free water	Two thirds	Only resistant roots, fibres and bark, etc., identifiable	Very strongly decomposed
H-9	No free water	Almost all	Practically no identifiable remains	Almost completely decomposed
H-10	No free water	All	Completely amorphous	Completely decomposed

From: Puustjarvi and Robertson, Peat in Horticulture.

V. KOOCHICHING COUNTY MAPS

The inventory of peat deposits within Koochiching County incorporates both field and laboratory measurements. These measurements were used to produce the accompanying maps, which are designed to show the distribution of peat types throughout the county and to incorporate DOE criteria for the determination of fuel-grade peat. The DOE criteria for fuel-grade peat are as follows: (1) peat that has an average energy value of 8,000 Btu/lb or more per profile in an oven-dry state, (2) peat that contains less than 25 percent ash, (3) peat deposits that are 150 cm ($\sim$5 ft) or deeper, and (4) peat deposits that cover a cumulative area of more than 32 ha (80 acres) per square mile.

The maps illustrate the location and extent of peatlands and raised bogs in the county. The tasks followed in the compilation of these maps were (1) preliminary field work and sampling, (2) energy-related sample site selection and sampling, (3) energy value analysis, and (4) final map compilation. The peat map portrays only the physical dimensions of the resource because the Btu content of the peat throughout the county was consistently within DOE's specifications.

The peat inventory of Koochiching County was a reconnaissance-level survey in which map boundaries between different units were determined by observations made at various intervals. This type of survey is very useful in undeveloped, inaccessible areas and can be used for planning purposes and for locating areas that require more detailed mapping.

The two maps accompanying this report, *Surficial Geology - Koochiching County* and *Peat Resources - Koochiching County*, 1980, illustrate the relation between peat and nonpeat areas and the relationship between different peatland types. The surficial geology map differentiates peatlands and the surrounding mineral soil areas. Within the peatland areas, surficial patterns are mapped and the peat observation sites are shown in relation to these patterns. The peat resource map illustrates the distribution of types and depths of peat found in the county. Used together, the two maps show how peatland location and depth are related to the geomorphic features of the county.

Surficial Geology Map

The surficial features of Koochiching County are composed of two basic types of material: mineral and organic. The mineral units include bedrock, exposed or near the surface; glacial and glaciofluvial deposits; and alluvium. The remaining units consist of organic material, peat.

In the compilation of *Surficial Geology - Koochiching County,* Eng delimited various geomorphic features and sketched peatland patterns by interpreting aerial photographs. USGS topographic maps provided references to the general location of landforms during compilation. Following preliminary mapping, selected areas were field checked. The mapping units were then reproduced on a general highway map of Koochiching County (1 inch:1 mile) and photographically reduced to 1/2 inch:1 mile. The explanation of mineral mapping units follows in Appendix B. Also shown on this map are the peat observation sites. Over 1,200 sites were visited by the MPIP staff. In a few areas, information from Heinselman (1963, 1970) and the Iron Range Resources and Rehabilitation Commission (1964) was used to supplement the MPIP data.

Peat Map

Field Procedures

The MPIP began the survey of Koochiching County with a general inspection of the area by using the surficial geology map of the county, aerial photographs, and USGS quadrangle maps. The relationship of peatlands to the geomorphic features that surround them can indicate depths of deposits, and the surficial patterns indicate the type of peatland present. The staff then chose peat observation sites and traverses based on peatland surficial patterns and the relationship to geomorphic features.

Field observation sites were reached by helicopter, by all-terrain vehicles when sites were near logging trails, and by foot when sites were within walking distance from roads. At each observation site a staff member described the soil profile, natural vegetation, microrelief, and depth to water table. A Davis sampler was used to bring up a small sample at various depths to determine peat thickness, degree of humification, botanical origin of each layer within the profile, and the underlying mineral soil texture. This information was then plotted on USGS quadrangle maps. Site descriptions for Davis observation sites are included in a second volume: *Inventory of Peat Resources, Koochiching County, Minnesota, Appendix E; Site Descriptions Without Laboratory Data.*

When all-terrain vehicles were used in gathering preliminary field information, the density of observations was increased and the staff collected samples using a power-driven Macaulay sampler, which is mounted on the vehicle. This sampler is used to collect an undisturbed sample of a known volume at various intervals in the profile. The samples were analyzed at the DNR laboratory in Hibbing for pH, bulk density, water content, and mineral content.

Mapping Procedures

Organic soil mapping units were established that differentiate depth, degree of humification, and botanical origin of peat. The preliminary field data, plotted on quadrangle maps, were used to delineate the peat mapping units. These data in conjunction with air photo interpretation were used to draw depth contours at intervals of 150, 300, 450, and 600 cm. Next, the areas capped by fibric, sphagnum moss peat (raised bogs) were delineated by class intervals showing depths of 20-60, 61-150, and 151-300 cm. Both sets of contour lines were drawn on USGS quadrangle maps. The quadrangles were then reduced to 1/2 inch: 1 mile, and the peat information was transferred to an overlay that was registered to the 1979 general highway map of Koochiching County that had the surficial geology units delimited.

Colors and patterns on the map depict four areas: mineral, peat less than 150 cm (~5 ft) deep, peat greater than 150 cm deep, and areas with sphagnum moss caps. Through the use of labels and contour lines, areas of peat deeper than 150 cm and sphagnum moss peat are further subdivided by depth.

On the map, total depth of peat is 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)
E 601 - 750 cm (~ 20-25 ft)

The type of peat is indicated by the total depth designation (e.g., A) used either alone to denote hemic peat, or in conjunction with a lower case letter to denote a fibric, sphagnum moss cap or sapric peat.

The fibric, sphagnum moss cap unit is subdivided by depths:

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

When any of these three designations are used with a total depth designation (e.g., 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 second, lowercase letter (e.g., a 20 - 60 cm). In these cases hemic peat comprises the rest of the profile.

Sapric peat is found in the areas denoted by Ax on the map, indicating that the total depth of the peat is 0 - 150 cm and consists entirely of sapric peat.

Due to the effects of generalization during map compilation and production, mapping units may contain minor inclusions of other mapping units.

VI. SELECTED DOE SAMPLING SITES

Selection of Sampling Sites

Koochiching County contains many peatland types that differ in their genesis and composition. Because of the size of the county and its inaccessibility, it was not possible to sample each area individually, therefore the MPIP staff selected areas that were representative of larger peatlands. A number of criteria were used as a basis for this selection. These included DOE criteria, peat depth and type, peatland topography, drainage patterns, vegetation patterns, relationship to mineral soil and rock outcrops, preliminary field data, and some lab analysis.

Seven representative peatlands in Koochiching County were selected for energy value analysis. They were the Pine Island, Hay Creek-Dinner Creek, North Black River, Black Bay, Wisner Trail, Norman Lake, and Ray SW peatlands. Six of these lie on the plain of Glacial Lake Agassiz. The Ray SW peatland is located in an area of ground moraine that was never inundated by the lake.

Specific Peatlands

Pine Island Peatland

The Pine Island peatland is located immediately to the south of one of the major beaches of Glacial Lake Agassiz (see fig. 6). The northern portion of this peatland is a raised bog that supports a dense black spruce forest. Ground cover is almost entirely sphagnum moss with an understory of ericaceous shrubs. To the south, this bog abruptly gives way to a fen, where the vegetation consists of scattered black spruce and tamarack, ericaceous shrubs, grasses, sedges, and small amounts of sphagnum moss.

The surface topography of the peatland is highest along an east-west axis running through the center of the raised bog. From here it slopes both north and south at about 35 - 75 cm/km (~2-4 ft/mi). Water drains from this divide both northward out of the peatland and southward into the fen and eventually into the Sturgeon River.

The Pine Island peatland has a continuous thin basal layer of highly decomposed sapric peat (see fig. 7). Overlying this is a horizon of hemic peat varying in thickness from 100-350 cm (~3-12 ft). Capping the peatland is a layer of fibric peat that reaches a maximum thickness of 180 cm (~6 ft). Fibric peat on the raised bog is composed mainly of sphagnum moss, while the thin fibric layer on the fen is a combination of relatively undecomposed grasses with some moss.

Hay Creek-Dinner Creek Peatland

The Hay Creek-Dinner Creek peatland is located in the eastern part of the Lost River peatland south of the Sturgeon River between Hay and Dinner creeks. It can be divided into two peatland types along a line from 1.2 km (~3/4 mi) south of Site 157 to 0.8 km (~ 1/2 mi) south of Site 142 (see fig. 8). North of this line is a bog that supports a dense forest of even-aged black spruce. The understory consists of ericaceous shurbs with grasses and sedges present in small amounts. Sphagnum moss dominates the ground surface, but several other moss species are also present. To the south of the line there is an abrupt change to a ribbed fen. Vegetation consists of scattered small tamarack with a few black spruce or northern white cedar in some areas. Bog birch and a few ericaceous shrubs are common on ridges; the hollows are dominated by sedges.

The peatland topography is highest in the southeast and slopes northwesterly at about 90 cm/km (~5 ft/mi). A narrow band 0.8 km (~1/2 mi) wide on the eastern margin of the peatland drains eastward into Dinner Creek. The remainder of the area drains northwesterly to Hay Creek.

Peat deposits in the Hay Creek-Dinner Creek peatland are dominated by hemic, reed-sedge peat (see fig. 9). In a few isolated areas, there is a thin horizon of sapric peat immediately above mineral soil. The northern portion of the peatland has a continuous cap of fibric, sphagnum moss peat.

North Black River Peatland

The North Black River peatland is located between the Black River and the West Fork Black River. This peatland consists of a large water track carrying nutrient-rich water that is bounded on its southern margin by a raised bog. On the northern margin, there are two raised bogs located adjacent to the West Fork Black River (see fig. 10).

Vegetation on the water track consists of a few scattered tamarack less than 300 cm (~10 ft) high. Black spruce are rare, but if present, are very small. Bog birch and a few ericaceous shrubs are found on hummocks and ridges. Most of the area is dominated by sedges. The bogs are forested with even-aged black spruce with an understory of ericaceous shrubs. Ground cover is a thick carpet of mosses in which sphagnum moss is usually dominant.

The North Black River peatland slopes east-northeasterly at about 90 cm/km (~5 ft/mi). The northwestern part of the area drains north into the West Fork Black River, while the rest of the area drains eastward.

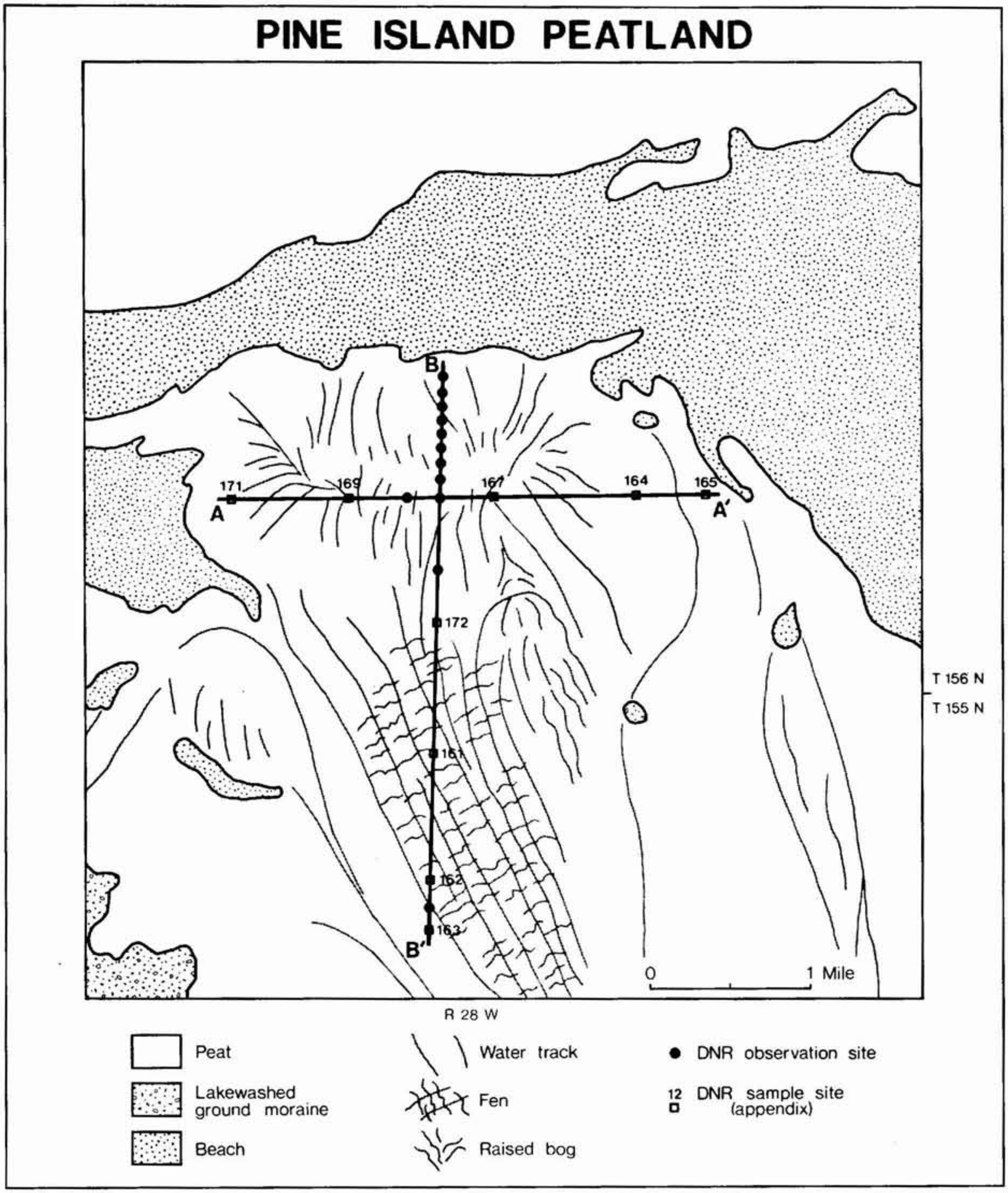

FIGURE 6. Pine Island Peatland with the Location of Cross Sections, Observation and Sampling Sites (Reference numbers refer to sample sites in Appendix D)

Peat stratigraphy is characteristic of other large fens in the county. In a few areas, there is a thin horizon of sapric peat above mineral soil (see fig. 11). The remainder of the water track is dominated by hemic, reed-sedge peat. In this horizon, the degree of decomposition varies slightly with depth, the upper layers generally being less decomposed than the lower ones. A thin cap of fibric, sphagnum moss peat covers the bogs.

Black Bay Peatland

The Black Bay peatland is located in the northeast corner of Koochiching County. This peatland has a raised bog, about 0.8 km (~1/2 mi) wide, running north and south through its center (see fig. 12). A fen containing three water tracks surrounds the raised bog. Two of the water tracks drain northwestward and empty into the Rat Root River, while the other drains eastward into Kabatogama

PINE ISLAND PEATLAND

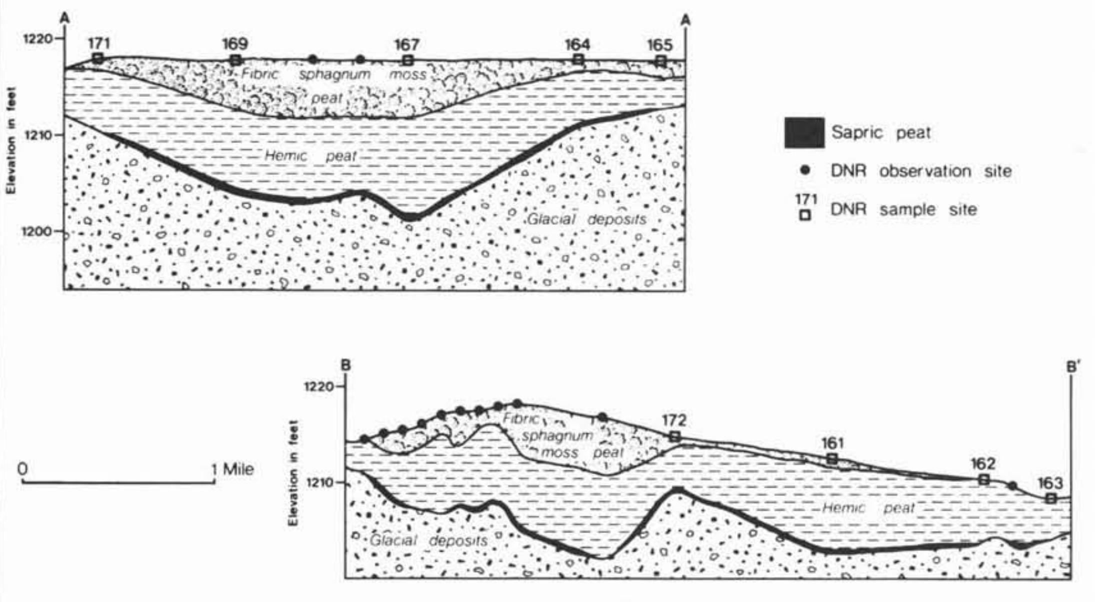

FIGURE 7. Cross Sections of Pine Island Peatland

Lake. These water tracks carry a mixture of nutrient-poor water derived from the raised bog and nutrient-rich water from mineral soil near the peatland margins.

The bog vegetation consists of a dense stand of black spruce, an understory of ericaceous shrubs, and a ground cover of sphagnum moss. Vegetation on the fen consists of grasses and sedges with a larger number of tamarack than is commonly present in other fens in the county. The major difference between this and the other selected peatlands is the lack of an abrupt change between the bog and fen vegetation.

Peat deposits in the Black Bay peatland are the deepest found in Koochiching County. At one site, a depth of 775 cm (~ 25.5 ft) was recorded (see fig. 12). Profiles are dominated by hemic, reed-sedge peat. In a few areas, a basal layer of sapric peat is present, and at one site, was 100 cm (~ 3 ft) thick. The raised bog has a cap of fibric, sphagnum moss peat up to 100 cm (~ 3 ft) thick.

Wisner Trail Peatland

The Wisner Trail peatland is located on the east side of Highway 71,17.5 km (~ 11 mi) southwest of the town of Littlefork. The central part is a raised bog that supports a forest of black spruce and ericaceous shrubs. A thick carpet of sphagnum moss covers the forest floor. Surrounding the raised bog is a forest bog and fen complex (see fig. 13). Vegetation, mainly black spruce, gradually changes to tamarack as the peatland type changes from bog to fen. Ericaceous shrubs are common throughout the area. The sphagnum moss carpet present in the bogs disappears on the fens. Scattered throughout the peatland are mineral soil islands and rock outcrops.

The peatland is highest along a north-south line through the center of the raised bog. West of this line, runoff drains northwest to the Bear River. East of this line, the water drains eastward toward the Littlefork River.

The Wisner Trail peatland has a thin discontinuous layer of sapric peat just above mineral soil. Overlying this, is a horizon of hemic, reed-sedge peat varying in thickness from 150 to 425 cm (~5-14 ft). A fibric, sphagnum moss cap is present over most of the bog areas reaching a maximum thickness of 150 cm (~ 5 ft) in the center of the raised bog (see fig. 13).

Norman Lake Peatland

The Norman Lake peatland, a large fen, is located north of the Tamarack River along the western margin of the county (see fig. 14). Vegetation consists of small, scattered tamarack, bog birch, willow, and aspen with sedges and cotton grass dominating the surface.

The surface of the peatland is nearly level, sloping only about 20-40 cm/km (~1-2 ft/mi) to the south. Drainage from the area empties into the Tamarack River.

Peat deposits are composed entirely of hemic, reed-sedge peat (see fig. 15). Thickness varies from 100 cm (~3 ft) to a maximum of 450 cm (~15 ft).

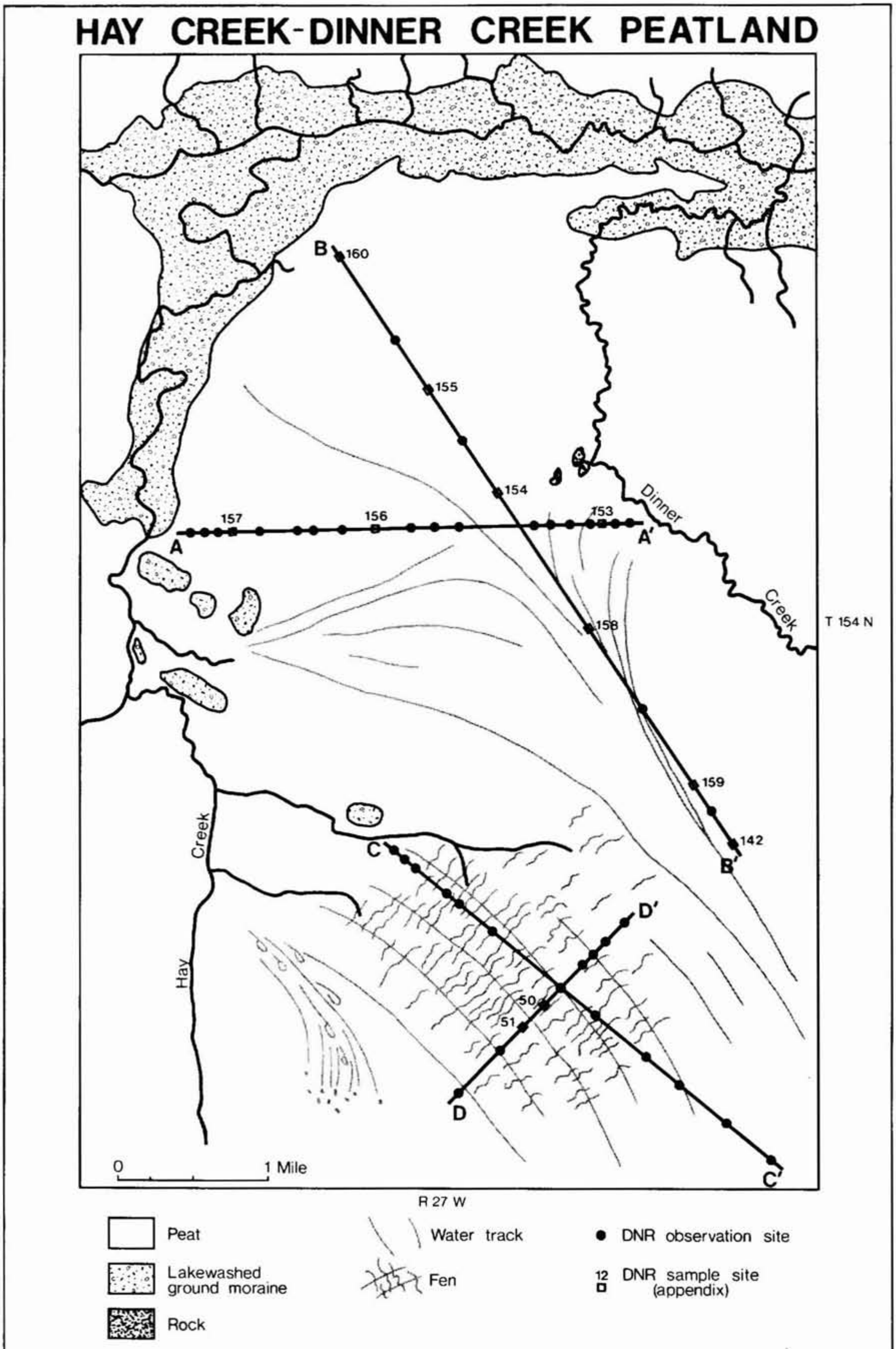

FIGURE 8. Hay Creek-Dinner Creek Peatland with the Location of Cross Sections, Observation and Sampling Sites

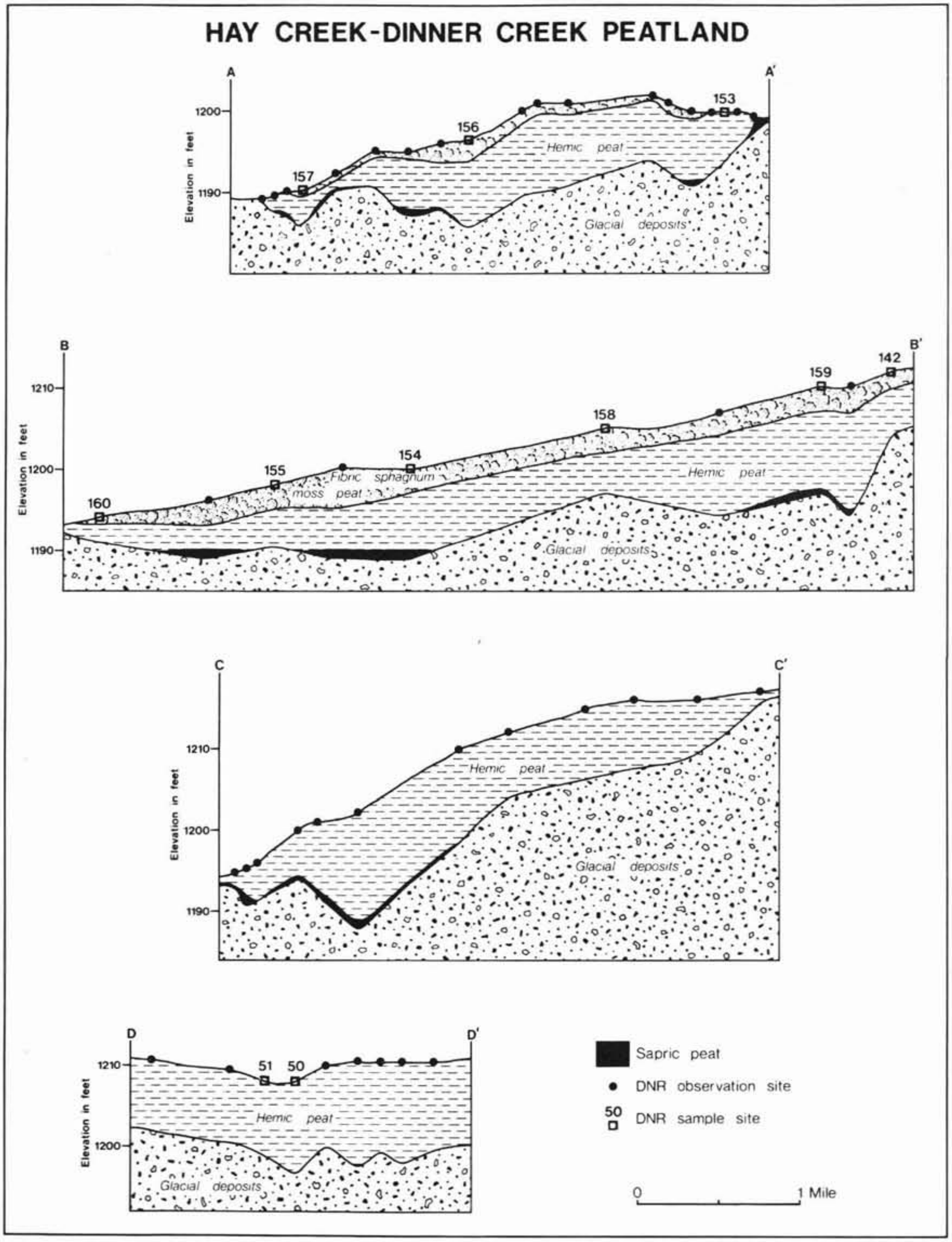

FIGURE 9. Cross Sections of Hay Creek-Dinner Creek Peatland

Ray SW Peatland

The Ray SW peatland is located 9.5 km (~6 mi) south of the town of Ray along the eastern margin of the county. The surrounding landscape is an area of ground moraine that was not inundated by the waters of Lake Agassiz (see fig. 16). The terrain is characterized by low rolling hills and numerous closed depressions.

The peatland is a bog that is heavily forested with black spruce and has an understory of ericaceous shrubs. The forest floor has a thick carpet of sphagnum moss. There are several mineral soil islands within the peatland that are forested with tall stands of aspen.

Peat deposits are composed entirely of hemic, reed-sedge peat (see fig. 16). The degree of decomposition is very consistent throughout the peatland.

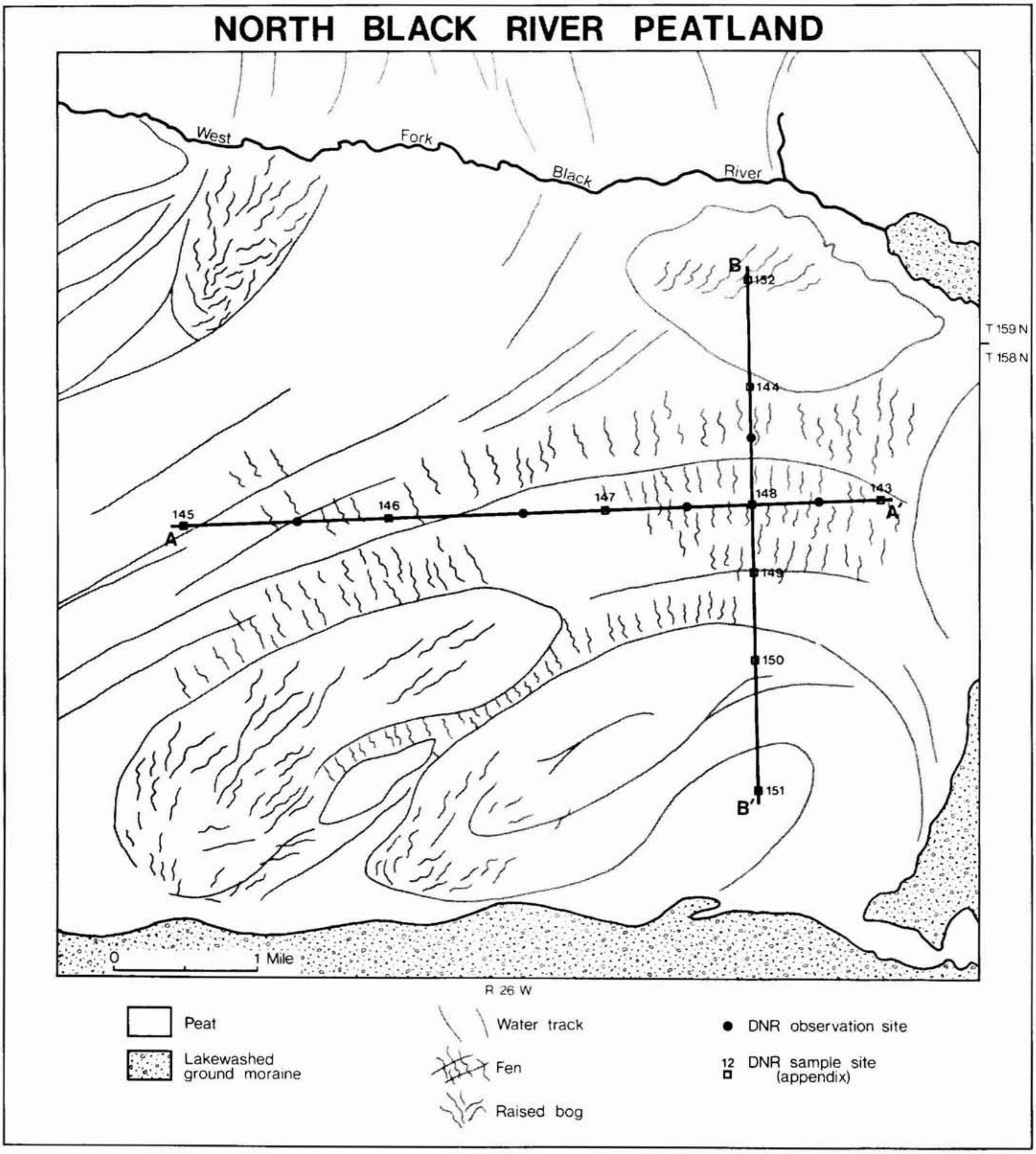

FIGURE 10. North Black River Peatland with the Location of Cross Sections, Observation and Sampling Sites

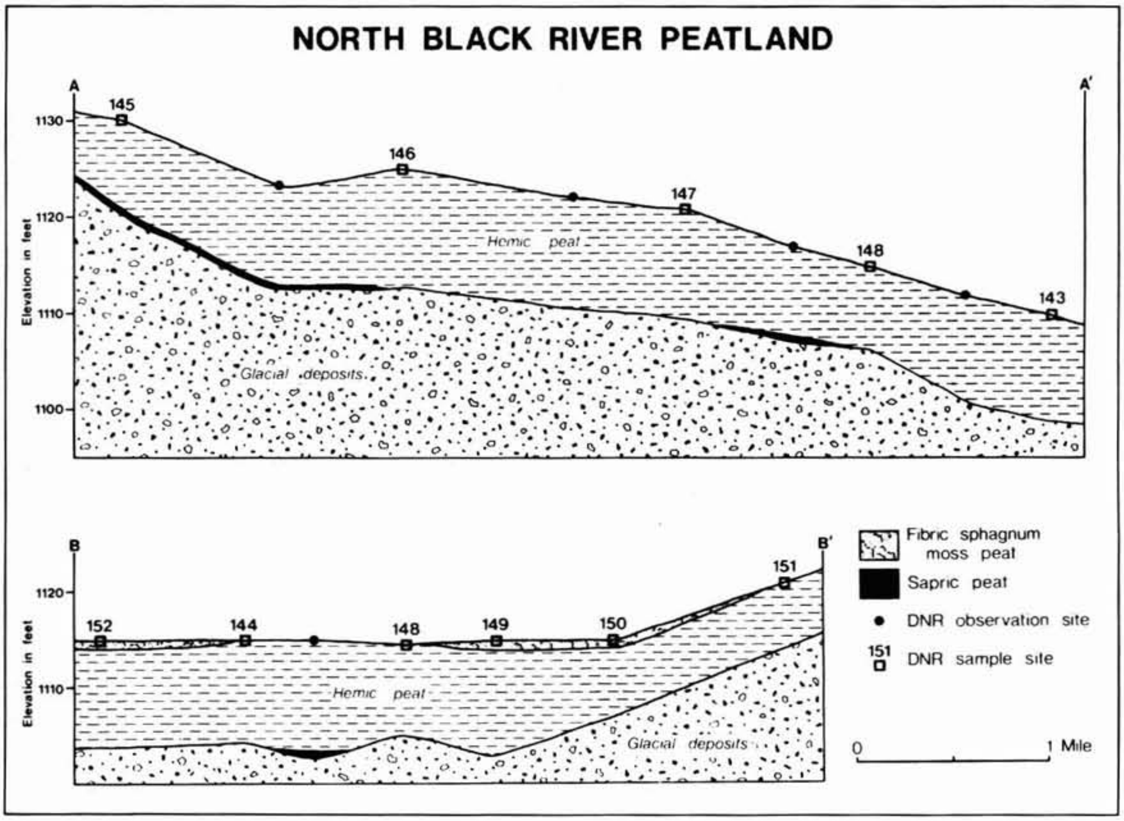

FIGURE 11. Cross Sections of North Black River Peatland

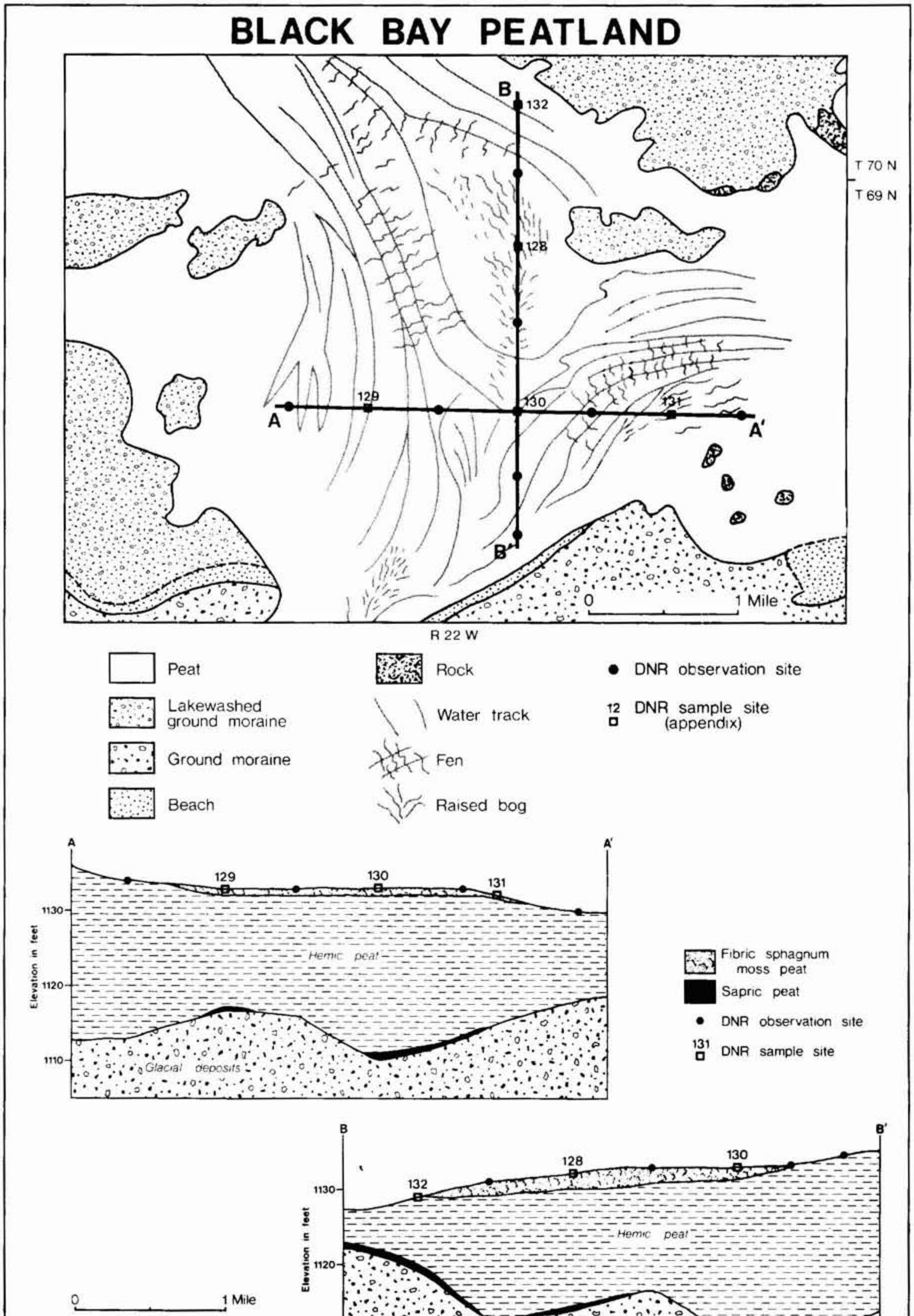

FIGURE 12. Black Bay Peatland, Cross Sections, and Site Locations

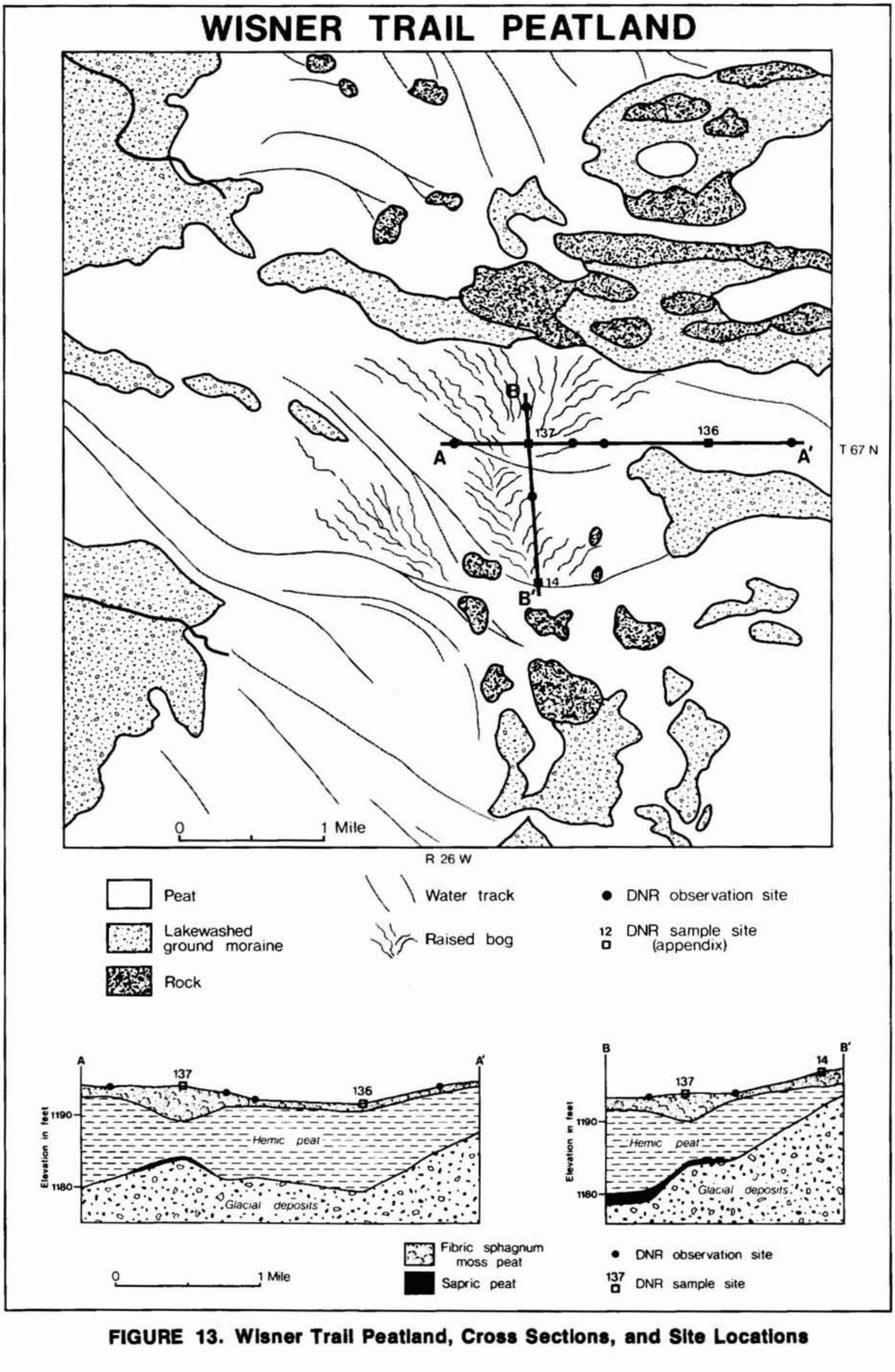

FIGURE 13. Wisner Trail Peatland, Cross Sections, and Site Locations

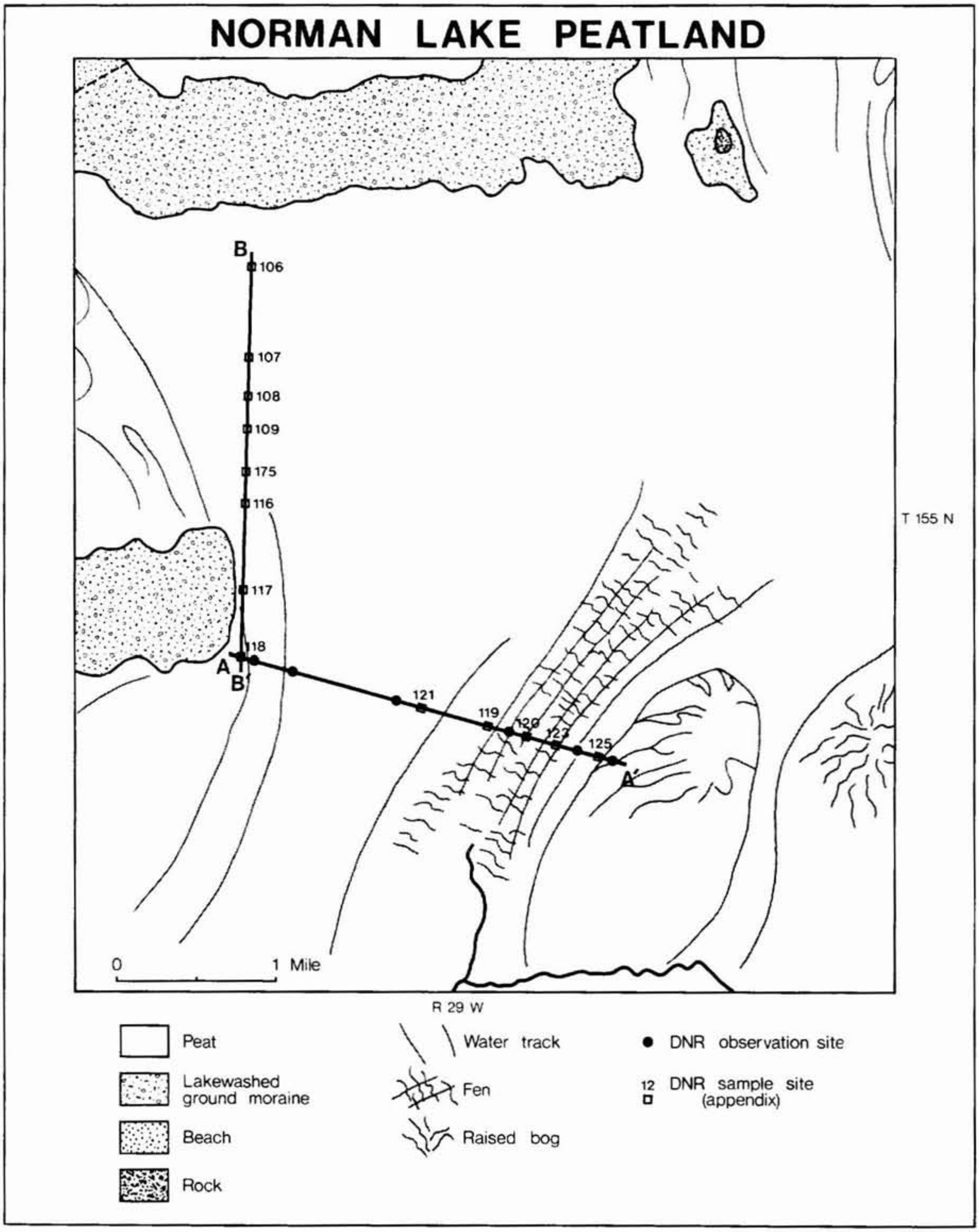

FIGURE 14. Norman Lake Peatland with the Location of Cross Sections, Observation and Sampling Sites

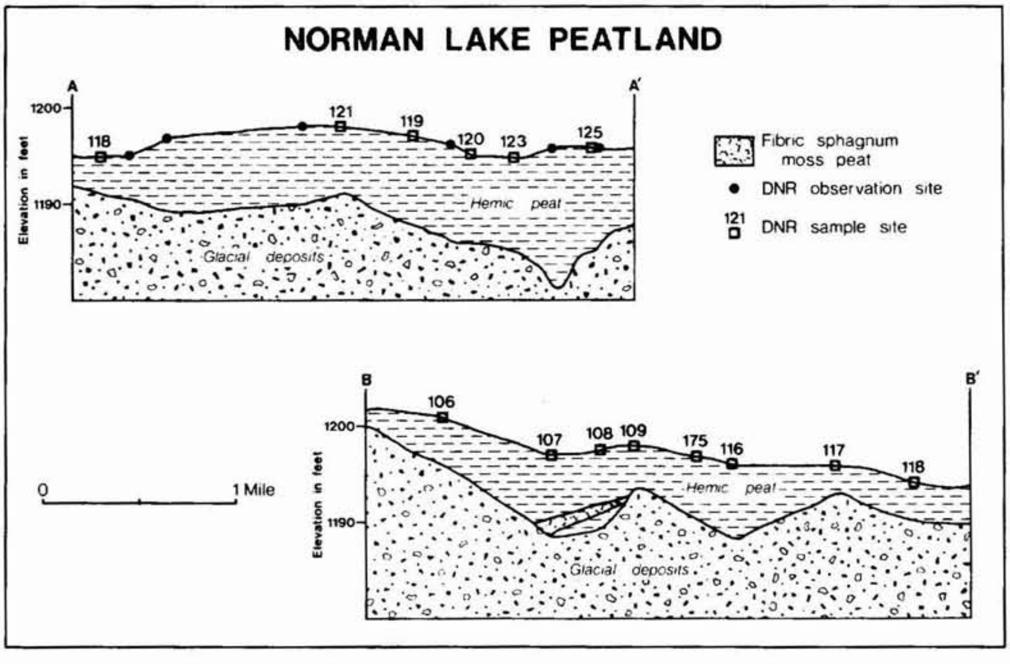

FIGURE 15. Cross Sections of Norman Lake Peatland

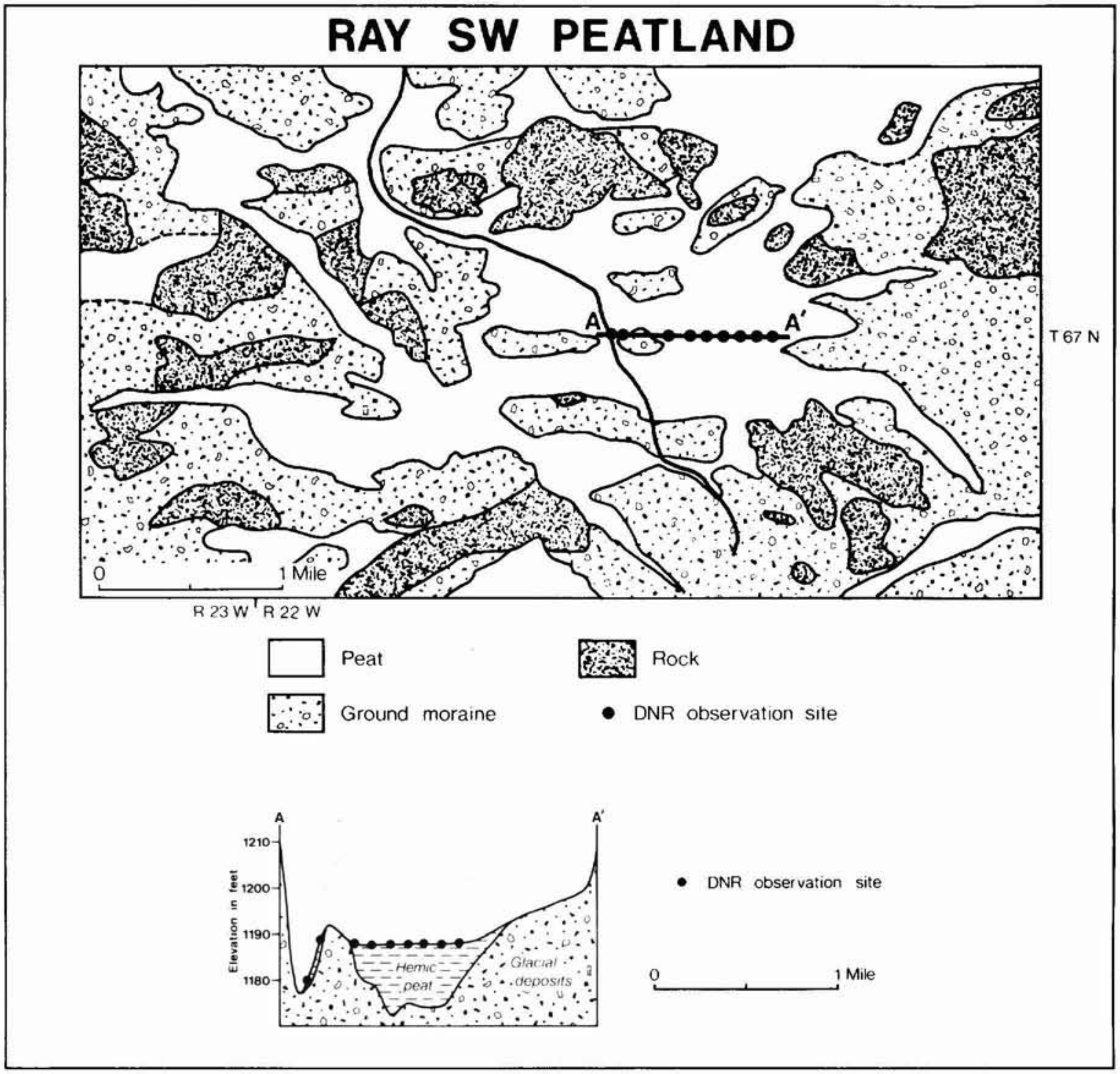

FIGURE 16. Ray SW Peatland, Cross Section, and Site Locations

VII. RESULTS

Peat Distribution

Peatlands cover approximately 56 percent of the total area in Koochiching County. The remaining 44 percent is composed of mineral soil and water. The areal extent of peat mapping units are delineated on the map *Peat Resources - Koochiching County,* and the areal extent of the mineral units are delineated on *The Surficial Geology - Koochiching County.* Table 3 illustrates the areal and volumetric tabulations for each peat mapping unit.

Hemic peat is dominant in the county, comprising 90 percent of the total peat area and 97 percent of the total peat tons. Mapping units A and B comprise about 86 percent of the total peat area. Mapping unit A, which represents hemic peat up to 150 cm (~5 ft) deep, comprises 64 percent of the total peat area. Unit B, which represents hemic peat 150-300 cm (~5-10 ft) deep, is 22 percent of the total peat area.

About 9.3 percent of the total peatland area contains a fibric, sphagnum moss cap. This fibric cap can be divided into three categories: a 20-60 cm (~0.7-2 ft) cap that occupies 7.5 percent of the total peatland area, a 61-150 cm (~2-5 ft) cap that occupies 1.5 percent, and a 151-300 cm (~5-10 ft) cap that occupies 0.3 percent. Fibric caps usually occur on raised bogs.

Sapric peat amounts to 0.78 percent of the total peatland area.

Peat Tonnages

Volumetric data for the peat in Koochiching County is converted to metric tons/ha-cm and U.S. tons/acre-ft, and total oven-dried metric and U.S. tons per mapping unit (table 4).

The bulk density is the determining factor in converting peat volumes to metric tons/ha-cm (U.S. tons/acre-ft). By using existing data, average bulk densities for each peat type in Koochiching County were calculated and used in computing oven-dried tonnages.

TABLE 3. Area and Volumetric Distribution of Mapping Units in Koochiching County, Minnesota

Map Unit	Peat Type	% Peat Area	Area ha	Area acre	Ave. Thickness cm	Ave. Thickness ft	Volume ha-cm	Volume acre-ft
Ax	Sapric	0.78	3,660	9,040	75	2.5	274,500	22,600
A	Hemic	63.66	295,860	730,520	75	2.5	22,189,550	1,826,300
B	Hemic	22.06	102,510	253,120	225	7.5	23,064,750	1,898,400
C	Hemic	3.52	16,350	40,360	375	12.5	6,129,680	504,500
D	Hemic	0.58	2,710	6,680	525	17.5	1,420,340	116,900
E	Hemic	0.12	570	1,400	675	22.5	382,730	31,500
Aa	Fibric				40	1.3	142,560	11,440
	Hemic				35	1.2	124,740	10,560
	Total	0.77	3,560	8,800	75	2.5	267,300	22,000
Ba	Fibric				40	1.3	893,590	71,710
	Hemic				185	6.2	4,132,860	341,900
	Total	4.81	22,340	55,160	225	7.5	5,026,450	413,700
Ca	Fibric				40	1.3	335,020	26,884
	Hemic				335	11.2	2,805,760	231,616
	Total	1.80	8,380	20,680	375	12.5	3,140,780	258,500
Da	Fibric				40	1.3	23,200	1,870
	Hemic				485	16.2	282,850	23,330
	Total	0.13	580	1,440	525	17.5	306,180	25,200
Ea	Fibric				40	1.3	7,200	570
	Hemic				635	21.2	114,300	9,330
	Total	0.04	180	440	675	22.5	121,500	9,900
Bb	Fibric				105	3.5	224,700	18,480
	Hemic				120	4.0	256,800	21,120
	Total	0.46	2,140	5,280	225	7.5	481,500	39,600
Cb	Fibric				105	3.5	299,250	24,640
	Hemic				270	9.0	769,500	63,360
	Total	0.61	2,850	7,040	375	12.5	1,068,750	88,000
Db	Fibric				105	3.5	150,150	12,320
	Hemic				420	14.0	600,600	49,280
	Total	0.31	1,430	3,520	525	17.5	750,750	61,600
Eb	Fibric				105	3.5	38,850	3,220
	Hemic				570	19.0	210,900	17,480
	Total	0.08	370	920	675	22.5	249,750	20,700
Cc	Fibric				225	7.5	148,500	12,300
	Hemic				150	5.0	99,000	8,200
	Total	0.14	660	1,640	375	12.5	247,500	20,500
Dc	Fibric				225	7.5	105,750	8,700
	Hemic				300	10.0	141,000	11,600
	Total	0.10	470	1,160	525	17.5	246,750	20,300
Ec	Fibric				225	7.5	33,750	2,700
	Hemic				450	15.0	67,500	5,400
	Total	0.03	150	360	675	22.5	101,250	8,100
	TOTAL		**464,770**	**1,147,560**				

Fibric peat has an average bulk density of about 0.08 gm/cm³ and yields approximately 8 metric tons/ha-cm (109 U.S. tons/acre-ft) of oven-dried peat. Fibric peat amounts to about 19,216,000 metric (21,230,000 U.S.) tons, 2.4 percent of the total peat tonnage in the county.

Hemic peat has an average bulk density of about 0.12 gm/cm³ and yields approximately 12 metric tons/ha-cm (163 U.S. tons/acre-ft) of oven-dried peat. Hemic peat amounts to about 753,510,000 metric (842,851,000 U.S.) tons, 97 percent of the total peat tonnage in the county.

TABLE 4. Peat Tonnage (oven-dried) per Mapping Unit in Koochiching County, Minnesota

Map Unit	Peat Type	Metric Tons × 1,000	U.S. Tons (Short) × 1,000
Ax	Sapric	4,666	5,220
A	Hemic	266,274	297,687
B	Hemic	276,777	309,439
C	Hemic	73,556	82,233
D	Hemic	17,044	19,054
E	Hemic	4,593	5,134
Aa	Fibric	1,140	1,246
	Hemic	1,496	1,721
	Total	2,636	2,967
Ba	Fibric	7,148	7,816
	Hemic	49,594	55,744
	Total	56,742	63,560
Ca	Fibric	2,680	2,930
	Hemic	33,669	37,753
	Total	36,349	40,683
Da	Fibric	185	203
	Hemic	3,394	3,802
	Total	3,579	4,005
Ea	Fibric	57	62
	Hemic	1,371	1,520
	Total	1,428	1,582
Bb	Fibric	1,797	2,014
	Hemic	3,081	3,442
	Total	4,878	5,456
Cb	Fibric	2,394	2,685
	Hemic	9,234	10,327
	Total	11,628	13,012
Db	Fibric	1,201	1,342
	Hemic	7,207	8,032
	Total	8,408	9,374
Eb	Fibric	310	350
	Hemic	2,530	2,849
	Total	2,840	3,199
Cc	Fibric	1,188	1,340
	Hemic	1,188	1,336
	Total	2,376	2,676
Dc	Fibric	846	948
	Hemic	1,692	1,890
	Total	2,538	2,838
Ec	Fibric	270	294
	Hemic	810	880
	Total	1,080	1,174
	TOTAL	**777,392**	**869,293**

NOTE: Computed using fibric peat at 8 metric tons/ha-cm (109 U.S. short tons/acre-ft), hemic peat at 12 metric tons/ha-cm (163 U.S. short tons/acre-ft), and sapric peat at 17 metric tons/ha-cm (231 U.S. short tons/acre-ft).

Sapric peat has an average bulk density of about 0.17 gm/cm³ and yields approximately 17 metric tons/ha-cm (231 U.S. tons/acre-ft) of oven-dried peat. Sapric peat amounts to about 4,666,000 metric (5,220,000 U.S.) tons, 0.6 percent of the total peat tonnage in the county.

Energy Value Analysis

Three hundred samples were collected in Koochiching County for energy value analysis. DNR and DOE analyses show that the seven representative peatlands are characteristic of the whole county.

A comparison of DNR-derived bulk density values for hemic peat shows the average for data from across the county is the same as that for data from the seven representative areas, 0.12 gm/cm³.

DOE analyses show little variation in values within any of the seven areas (tables 5-11). Standard deviation expresses the amount of variance from the average within the group of data. The largest difference exists between the lake plain peatlands and the Ray SW peatland in the morainic area which has an overall higher ash content and lower Btu values. Table 12 gives an overview of the whole county. The standard deviations are low, expressing the small variance between peatlands.

All energy value comparisons, except moisture content (measured as received), are based on moisture-free peat that contains less than 25 percent ash; a total of 280 samples. Samples with ash contents over 25 percent (20 samples) are not included in the following analysis because they do not meet the DOE requirements for fuel-grade peat.

TABLE 5. Energy Related Values for Pine Island Peatland (Reference # 161-172)

	Average	Range	Standard Deviation
Moisture	91.8%	81.1-95.9%	2.69
Btu/lb	8814	8006-9547	383.49
Ash	6.9%	2.6-14.3%	2.45
Volatile matter	66.5%	56.9-74.3%	3.96
Fixed carbon	26.6%	21.4-33.3%	2.40
Hydrogen	5.3%	3.3- 6.2%	0.36
Carbon	52.0%	47.9-54.9%	1.74
Nitrogen	1.9%	1.1- 3.2%	0.51
Sulfur	0.3%	0.1- 2.3%	0.32
Oxygen	33.4%	24.0-40.8%	3.52

TABLE 6. Energy Related Values for Hay Creek-Dinner Creek Peatland (Reference # 142, 153-160)

	Average	Range	Standard Deviation
Moisture	88.4%	83.3-91.8%	2.34
Btu/lb	9028	7907-9489	374.77
Ash	9.0%	5.2-16.1%	2.95
Volatile matter	64.5%	56.3-69.8%	3.00
Fixed carbon	26.6%	23.3-31.2%	1.77
Hydrogen	5.6%	4.7- 6.1%	0.32
Carbon	52.7%	48.6-54.8%	1.59
Nitrogen	2.3%	1.2- 3.3%	0.63
Sulfur	0.8%	0.2- 2.5%	0.64
Oxygen	29.7%	24.1-34.0%	2.46

NOTE: Reference numbers correspond to sample sites in Appendix D.

TABLE 7. Energy Related Values for North Black River Peatland (Reference # 143-152)

	Average	Range	Standard Deviation
Moisture	91.3%	86.6-94.9%	1.86
Btu/lb	9178	8169-9601	337.84
Ash	7.6%	4.6-16.8%	2.42
Volatile matter	65.2%	59.0-69.1%	2.35
Fixed carbon	27.3%	23.6-31.5%	1.87
Hydrogen	5.5%	4.8- 6.0%	0.25
Carbon	53.5%	47.2-56.2%	1.56
Nitrogen	2.3%	1.1- 3.0%	0.42
Sulfur	0.6%	0.2- 3.0%	0.59
Oxygen	30.6%	23.7-34.8%	2.17

TABLE 8. Energy Related Values For Black Bay Peatland (Reference # 128-132)

	Average	Range	Standard Deviation
Moisture	90.4%	83.2-94.4%	2.51
Btu/lb	9002	8230-9454	295.57
Ash	7.0%	3.0-14.4%	2.44
Volatile matter	64.0%	58.0-71.9%	3.29
Fixed carbon	29.0%	22.0-35.1%	2.59
Hydrogen	5.4%	4.9- 6.2%	0.31
Carbon	53.7%	50.8-55.8%	1.22
Nitrogen	2.0%	1.2- 3.0%	0.43
Sulfur	0.4%	0.2- 1.2%	0.23
Oxygen	31.3%	25.4-36.5%	2.06

TABLE 9. Energy Related Values for Wisner Trail Peatland (Reference # 136-141)

	Average	Range	Standard Deviation
Moisture	89.5%	82.6-93.9%	3.28
Btu/lb	8887	7720-9568	492.42
Ash	7.6%	3.0-18.6%	3.37
Volatile matter	65.7%	57.6-77.4%	4.78
Fixed carbon	26.7%	19.6-30.9%	2.84
Hydrogen	5.3%	4.6- 5.8%	0.29
Carbon	53.4%	46.4-55.6%	1.91
Nitrogen	1.7%	0.2- 2.8%	0.71
Sulfur	0.6%	0.1- 2.1%	0.59
Oxygen	31.4%	24.1-41.4%	3.72

TABLE 10. Energy Related Values for Norman Lake Peatland (Reference # 173-177)

	Average	Range	Standard Deviation
Moisture	90.7%	87.6-93.3%	1.42
Btu/lb	8906	8187-9335	293.99
Ash	8.9%	5.8-13.3%	1.79
Volatile matter	62.3%	59.0-65.0%	1.47
Fixed carbon	28.9%	25.8-30.9%	1.27
Hydrogen	5.1%	4.6- 5.5%	0.20
Carbon	52.6%	48.9-54.4%	1.41
Nitrogen	2.5%	1.8- 3.0%	0.26
Sulfur	0.4%	0.2- 1.7%	0.32
Oxygen	30.5%	26.1-31.9%	1.24

TABLE 11. Energy Related Values for Ray SW Peatland (Reference # 127, 133-135)

	Average	Range	Standard Deviation
Moisture	85.3%	81.8-92.2%	2.29
Btu/lb	8599	8091-9052	264.21
Ash	11.2%	6.5-20.2%	3.69
Volatile matter	60.1%	52.4-68.1%	3.82
Fixed carbon	28.7%	24.3-35.7%	3.16
Hydrogen	5.4%	4.5- 6.1%	0.45
Carbon	51.6%	47.8-54.2%	1.60
Nitrogen	2.0%	1.2- 3.2%	0.59
Sulfur	0.8%	0.2- 2.6%	0.67
Oxygen	28.9%	23.8-33.9%	3.12

TABLE 12. Energy Related Values for Koochiching County Peatlands (Reference # 127-177)

	Average	Range	Standard Deviation
Moisture	90.4%	81.1-95.9%	2.97
Btu/lb	8934	7720-9601	394.94
Ash	7.8%	2.6-20.2%	2.90
Volatile matter	64.7%	52.4-77.4%	3.87
Fixed carbon	27.5%	19.6-35.7%	2.52
Hydrogen	5.4%	3.3- 6.2%	0.34
Carbon	52.9%	46.4-56.2%	1.76
Nitrogen	2.1%	0.2- 3.3%	0.55
Sulfur	0.5%	0.1- 3.0%	0.50
Oxygen	31.3%	23.7-41.4%	3.14

Heating Value (Btu/lb)

Two hundred and seventy-six (92 percent) of the DOE analyzed samples have heating values greater than 8,000 Btu/lb, as well as less than 25 percent ash. The majority of the remaining samples came from very near the peat-mineral interface, where ash contents are usually highest. Heating values decrease as the concentration of ash increases (see fig. 17). Btu/lb values generally increase with depth but drop noticeably in samples from very near mineral soil. The average heating value in the county is 8,934 Btu/lb with a range of 7,720 to 9,601 Btu/lb.

A comparison of average heating values (moisture-free) for fibric, hemic, and sapric peat shows no large variance. Fibric averages 8,896 Btu/lb, hemic averages 8,976 Btu/lb, and sapric averages 8,757 Btu/lb. A difference does exist, however, when Btu/unit volume is computed. There are about 1.940854×10^9 Btu/acre-ft in fibric, 2.924220×10^9 Btu/acre-ft in hemic, and 4.053126×10^9 Btu/acre-ft in sapric. Sapric peat has a higher heating value per unit volume because of its high bulk density; however, it is less desirable for energy than hemic because of its higher ash content.

Koochiching County peat deeper than 150 cm (~5 ft) represents an estimate of about 10.11 quads (1×10^{15} Btu) of energy, and peat less than 150 cm deep represents about 5.47 quads of energy. The estimated total quads of energy in the county is about 15.58.

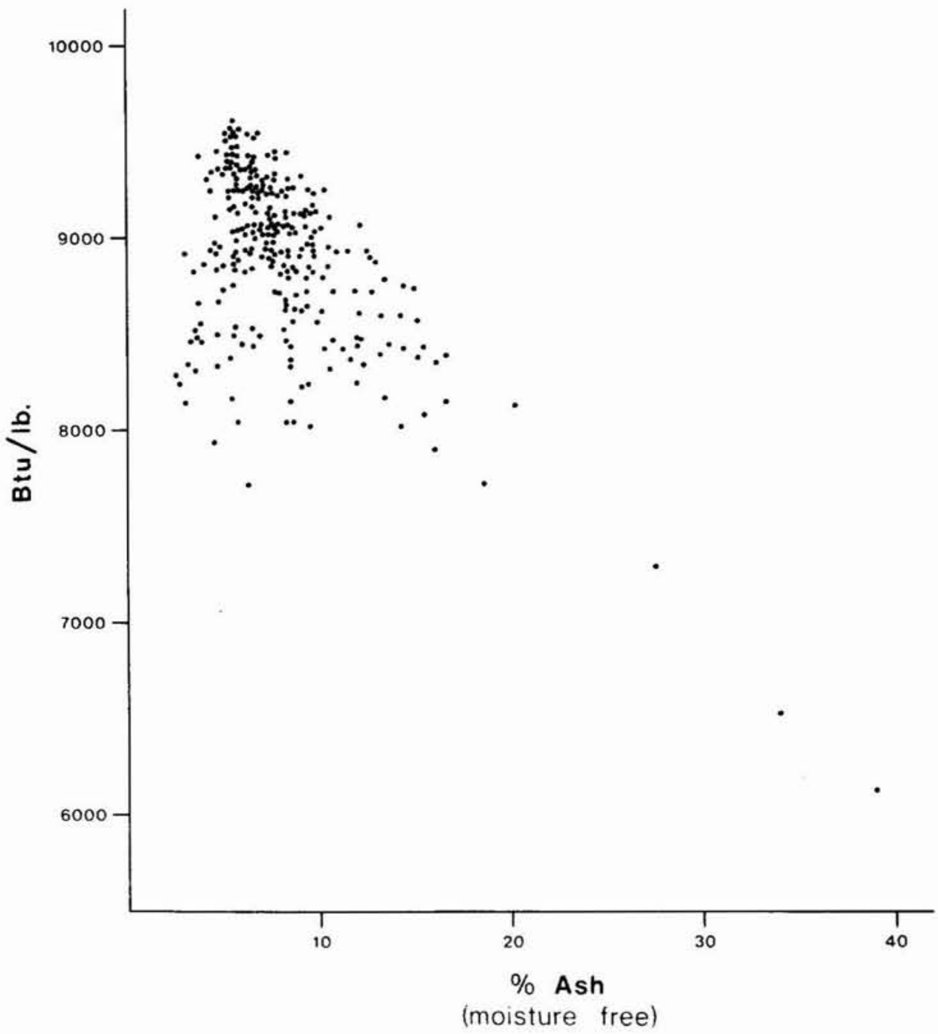

FIGURE 17. Relation of Btu/lb to Ash Content for Koochiching County Peat (moisture-free)

Proximate Analysis

Moisture

The moisture content in the peat sampled ranges from 81.1 percent to 95.9 percent and averages about 90.4 percent. Within a profile there is not much variance, although moisture tends to decrease with an increase in decomposition.

Volatile Matter

The volatile content varies within a profile, ranging from 52.4 percent to 77.0 percent and averaging about 64.7 percent.

Fixed Carbon

The fixed carbon content ranges from 19.6 percent to 35.7 percent and averages about 27.5 percent.

Ash

The ash content varies greatly within a profile, ranging from 2.6 percent to 20.2 percent and averaging about 7.8 percent. Two hundred and thirty-seven of the DOE analyzed samples contain less than 10 percent ash. The highest ash concentration is usually in sapric peat that occurs very near the peat-mineral interface. Ash values average 6.7 percent for fibric peat, 8.2 percent for hemic peat, and 14.9 percent for sapric peat. Where water drains directly off of mineral soil onto a peatland, the ash content in the topmost samples is higher.

Ultimate Analysis

Hydrogen

There is very little variance in hydrogen concentration within a profile and between peatlands. Hydrogen contents range from 3.3 percent to 6.2 percent and average about 5.4 percent.

Carbon

Carbon varies slightly within a profile. The carbon contents range from 46.4 percent to 56.2 percent and average about 52.8 percent.

Nitrogen

Nitrogen increases near the peat-mineral interface. Values range from 0.2 percent to 3.3 percent and average about 2.1 percent.

Sulfur

Sulfur also increases near the peat-mineral interface. Its values range from 0.1 percent to 3.0 percent and average about 0.5 percent.

Oxygen

The oxygen content decreases with an increase in decomposition and proximity to mineral soil. Values range from 23.7 percent to 41.4 percent and average about 31.3 percent.

VIII. SUMMARY

Koochiching County, Minnesota, has a total land area of 822,440 ha (2,032,220 acres) of which 464,599 ha (1,147,560 acres) are peatlands. Ninety-seven percent of the total peat tonnage is hemic peat, 2.4 percent is fibric peat, and 0.6 percent is sapric peat.

The DNR visited over 1,200 sites across the county to determine peat type, depth, quantity, and quality. At over 1,000 of these sites, only peat type and depth were recorded. At 126 of the remaining sites, 523 samples were collected for DNR laboratory analyses. At the remaining 51 sites, 300 samples were collected for DNR laboratory and DOE energy value analyses. All DNR and DOE laboratory results appear in Appendix D of this volume.

The DOE analyses show that there is little variation in energy values within and between peatlands in Koochiching County. Two hundred and seventy-six of the 300 DOE analyzed samples have a heating value greater than 8,000 Btu/lb and contain less than 25 percent ash. The majority of the remaining 24 samples were collected from very near the peat-mineral interface. The quantity and energy potential of Koochiching County peat is summarized in Table 13.

Sixty-five percent of the peat in the county is less than 150 cm (~5 ft) deep, and 35 percent is greater than 150 cm (~5 ft). The average depth of all peat in Koochiching County is 143 cm (~4.68 ft).

Work maps and original field sheets are on file at the Department of Natural Resources, Minerals Division, Hibbing, Minnesota, for public use.

Table 13. Quantity and Energy Potential of Koochiching County Peat

	Hectares	Acres	Tons-Dry Metric (thousands)	Tons-Dry U.S. Short (thousands)	Btu's	Quads*
By Depth						
< 150 cm (~5 ft) Deep	303,080	748,360	273,576	305,874	5.47×10^{15}	5.47
> 150 cm (~5 ft) Deep	161,676	399,200	503,816	563,419	10.11×10^{15}	10.11
TOTAL	464,756	1,147,560	777,392	869,293	15.58×10^{15}	15.58
By Type						
Fibric			19,216	21,230	0.38×10^{15}	0.38
Hemic			753,510	842,843	15.11×10^{15}	15.11
Sapric			4,666	5,220	0.09×10^{15}	0.09
TOTAL			777,392	869,293	15.58×10^{15}	15.58

*One Quad = 1×10^{15} Btu

IX. SELECTED BIBLIOGRAPHY

American Society for Testing Materials. 1971. Standard classification of peats, mosses, humus, and related products. D2607-69. Philadelphia, PA.

Boelter, D. H. and E. S. Verry. 1977. Peatlands and water in the northern lake states. USDA Forest Service General Technical Rep. NC-31. St. Paul, MN.

Brady, N. C. 1974. The nature and properties of soils. Macmillan Publishing Co., Inc. New York, NY.

Buol, S. W., F. D. Hole, and R. J. McCracken. 1973. Soil genesis and classification. Iowa State Univ. Press. Ames, IO.

Canada Soil Survey Committee. 1976. Manual on soil sampling and methods of analysis. J. A. McKeague (ed.), Soil Research Institute. Canada.

Elson, J. A. 1967. Geology of Glacial Lake Agassiz: *in* W. J. Mayer - Oakes (ed.), Life, land, and water, Conf. on environmental studies of the Glacial Lake Agassiz region [1966], Proc., Univ. Manitoba Press [Winnipeg].

Eng, M. T. 1980. Surficial geology - Koochiching County, Minnesota (map). Scale 1:125,000. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Eng, M. T. and M. J. Costello. 1979. Industrial minerals in Minnesota: A status report on sand, gravel, and crushed rock. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Farnham, R. S. 1978. The Minnesota alternative energy research and development policy formulation project. The Minnesota Energy Agency. Subcommittee 8, Peat.

Flint, R. F. 1971. Glacial and quaternary geology. John Wiley and Sons, Inc. New York, NY.

Fox, R., T. Malterer, and R. Zarth. 1977. Inventory of peat resources in Minnesota: A progress report. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Gary, M., R. McAfee, C. Wolf, editors. 1977. Glossary of Geology. American Geological Institute. Falls Church, VA.

Glaser, P. H., G. A. Wheeler, E. Gorham, and H. E. Wright. 1979. The patterned mires of the Red Lake peatland, northern Minnesota. *In* E. Gorham and H. E. Wright, Jr. Ecological and floristic studies of the Red Lake peatland. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Glaser, P. H. 1980. The Red Lake peatland. Unpublished.

Grigal, D. F., R. C. Severson, and G. E. Goltz. 1976. Evidence of aeolian activity in north-central Minnesota, 8000 - 5000 years ago. Geol. Soc. America Bull., v. 87.

Hammond, R. F. 1975. The origin, formation, and distribution of peatland resources. *In* D. W. Robinson and J. G. D. Lamb (ed.), Peat in horticulture. Academic Press. London.

Heinselman, M. L. 1963. Forest sites, bog processes, and peatland types in the Glacial Lake Agassiz region, Minnesota. Ecol. Monograph 33: 327-374.

__________ 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecological Monograph 40: 235-260.

International Peat Society, Committee on Peat Classification. 1976. Peat classification report of Commission 1. Helsinki, Finland.

Iron Range Resources and Rehabilitation Commission. 1964. Peat sampling: Porter Ridge Bog, Koochiching County, Minnesota. Unpublished.

__________ Peat sampling: Ridge Bog, Koochiching County, Minnesota. Unpublished.

__________ Peat sampling: Pine Island Bog, Koochiching County, Minnesota. Unpublished.

__________ Peat sampling: International Falls Bog, Koochiching County, Minnesota. Unpublished.

__________ Peat sampling: Nakoda Bog, Koochiching County, Minnesota. Unpublished.

__________ Peat sampling: North Pine Island Bog, Koochiching County, Minnesota. Unpublished.

Johnston, W. A. 1946. Glacial Lake Agassiz, with special reference to the mode of deformation of the beaches. Canada Geologic Survey Bull. no. 7. Kings Printer and Controller of Stationery. Ottawa.

Kavanagh, T. and M. Herlihy. 1975. Microbiological aspects. *In* D. W. Robinson and J. G. D. Lamb (ed.), Peat in horticulture. Academic Press. London.

Leverett, F. 1932. Quaternary geology of Minnesota and adjacent states. U. S. Geol. Survey Prof. Paper 161.

Malterer, T. J., D. J. Olson, D. R. Mellem, B. Leuelling, and E. J. Tome. 1979. Sphagnum moss deposits in Minnesota. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Matsch, C. L. 1973. Quaternary geology of northern Koochiching County, contract project, Minnesota Department of Natural Resources. Unpublished.

Matsch, C. L. and H. E. Wright, Jr. 1967. The southern outlet of Lake Agassiz; *in* W.J. Mayer-Oakes (ed.), Life, land, and water, Conf. on environmental studies of the Glacial Lake Agassiz region [1966], Proc., Univ. Manitoba Press [Winnipeg].

Minnesota Department of Natural Resources. 1979. Minnesota Peat Program: Legislative status report. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Moore, P. D. and D. J. Bellamy. 1974. Peatlands. Springer-Verlag New York Inc. New York, NY.

Nikiforoff, C. C. 1947. The life history of Lake Agassiz: alternative interpretation. Am. Jour. of Sci., v. 245, no. 4, p. 205-239.

Ojakangas, R. W., D. G. Meineke, and W. H. Listerud. 1977. Geology, sulfide mineralization and geochemistry of the Birchdale-Indus area, Koochiching County, northwestern Minnesota. Report of Investigations 17. University of Minnesota.

Olson, D. J., T. J. Malterer, D. R. Mellem, B. Leuelling, and E. J. Tome. 1979. Inventory of peat resources, SW St. Louis County, Minnesota. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN.

Plummer, C. E. 1949. Report of progress in peat development. Office of the Commissioner of the IRRR. St. Paul, MN.

Puustjarvi, V. and R. A. Robertson. 1975. Physical and chemical properties. *In* D. W. Robinson and J. G. D. Lamb (ed.), Peat in horticulture. Academic Press. London.

Rader, A. M. 1979. Synthetic natural gas from peat. Pages 291-296. *In* I and EC Product Research and Development, v. 18.

Rodgers, W. P. 1978. The coal primer. Valley Press, Inc. Van Buren, AR.

Schneider, A. F. 1961. Pleistocene geology of the Randall region, central Minnesota. Univ. of Minnesota Geol. Survey Bull. 40. Minneapolis, MN.

Soil Science Society of America. 1974. Histosols: their characteristics, classification, and use. Soil Sci. Soc. of Amer. Special Pub. 6. Madison, WI.

Soil Survey Staff. 1975. Histosols. p. 211-226. *In* Soil taxonomy, Agric. Handb. no. 436, USDA. U. S. Government Printing Office, Washington, D.C.

Soper, E. K. 1919. Peat deposits of Minnesota. Univ. of Minnesota Geol. Survey Bull. 16. Minneapolis, MN.

Terasamae, J. 1977. Postglacial history of Canadian muskeg. p. 9-30. *In* N. W. Radforth and C. O. Brawner (ed.), Muskeg and the northern environment in Canada. Univ. of Toronto Press. Toronto.

University of Chicago Press. 1969. A manual of style, 12th ed. Chicago, IL.

U. S. Department of Energy. 1979. Peat prospectus. U. S. DOE. Washington, D.C.

Villis, K., H. L. Hansen, J. J. Olson, and A. R. Aho. 1978. Vegetation types, species, and areas of concern and forest resources utilization of northern Minnesota's peatlands. Univ. of Minnesota, College of Forestry. Minneapolis, MN.

Walmsley, M. E. 1977. Physical and chemical properties of peat. p. 82-129. *In* N. W. Radforth and C. O. Brawner (ed.), Muskeg and the northern environment in Canada. Univ. of Toronto Press. Toronto.

Webster's second new international dictionary of the English language, unabridged. 1943. G. & C. Merriam Company. Springfield, MA.

Wright, H. E., Jr. 1972. Physiography of Minnesota. p. 561-580. *In* P. K. Sims and G. B. Morey (eds.), Geology of Minnesota: a centennial volume. Minnesota Geol. Survey. St. Paul, MN.

__________1972. Quaternary history of Minnesota. p. 515-547. *In* P. K. Sims and G. B. Morey (eds.), Geology of Minnesota: a centennial volume. Minnesota Geol. Survey. St. Paul, MN.

X. GLOSSARY

This glossary was compiled from several sources, but primarily from:

(1) Soil Science Society of America. 1970. Glossary of Soil Science Terms. Madison, WI.

(2) Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handb. No. 436, USDA. U. S. Government Printing Office. Washington, D.C.

(3) Gary, M., R. McAfee, C. Wolf, editors. 1977. Glossary of Geology. American Geological Institute. Falls Church, VA.

Anaerobic fermentation - the chemical splitting of complex organic compounds into relatively simple substances without the use of oxygen.

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

Clay - as a soil separate, the mineral soil particles less than .002 mm in diameter. As a soil textural class, soil material that 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 as viewed from above, expressed as a percentage of the total possible (100%) or of a particular group, e.g. black spruce cover of about 50%.

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

Evapotranspiration - the total amount of water taken into the atmosphere by evaporation from the surface and from the transpiration of living plants.

Fibers - in defining organic soil materials, fibers are pieces or fragments of plant tissue, excluding live roots, that are large enough to be retained on a 100-mesh sieve (.15 mm openings) and that retain recognizable cell structure.

Fibric peat - the least decomposed of peat types. It contains large amounts of fiber which is well preserved, and its botanical origin is readily identifiable.

Fixed carbon - in coal, coke, and bituminous materials, the remaining solid, combustible matter after removal of moisture, ash, and volatile matter, expressed as a percentage.

Glacial drift - all rock material (clay, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.

Ground cover - low growing plants such as mosses that form a dense layer on the ground surface.

Hemic peat - the moderately decomposed peat type which is partly altered physically and chemically. Fibers are largely destroyed when rubbed and are less easily identified than in fibric peat.

Humus - the more or less stable fraction of the organic soil matter remaining after the major portion of plant and animal residue has decomposed. Usually dark in color.

Hydrocarbon - any organic compound that contains only carbon and hydrogen such as methane (CH_4), propane (C_3H_8), etc. As the number of carbon atoms increases, the state of matter changes from gas (methane, propane), to liquid (gasoline, oil), to solid (waxes).

Isostatic rebound - the tendency of the earth's crust to remain in a state of equilibrium. Land masses are depressed under the weight of an ice sheet; as the ice retreats, the extreme weight is removed and the land surface rebounds to its preglacial configuration.

Limnic materials - materials deposited in lakes. These materials are primarily chemical and biological precipitates (plants and animals).

Loam - the textural class name for soil having a moderate amount of sand, silt, and clay. Loam soils contain 7 to 27% clay, 28 to 50% silt, and less than 52% sand.

Lobe, glacial - one of the lobate protrusions of the margin of an ice sheet.

Mean - arithmetic average.

Microrelief - relief of a peatland surface from the top of hummocks or ridges to the bottom of hollows.

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

Moraine - an accumulation of material which has been transported or deposited by glacial ice. Moraine material is usually an ungraded mass of sediment ranging in size from clay to boulders.

Peat - organic soil containing less than 25% ash, exclusive of plant cover, consisting of partially decayed plant matter.

Peatland - term including all classes of peat-covered terrain. Includes bogs, fens, etc.

pH - a numerical symbol for the degree of acidity or alkalinity of a solution. A pH value of 7 indicates a neutral solution; pH values of 0 to 7 indicate decreasing acidity, and values from 7 to 14 indicate increasing alkalinity.

Profile, soil - a vertical section of the soil through all its horizons and extending into the parent material.

Proximate analysis - analysis of a peat or coal sample to determine amount of volatile matter, fixed carbon, moisture, and ash.

Sand - individual rock or mineral fragments in soils having diameters ranging from .05 to 2 mm. The textural class name of any soil that contains 85% or more sand and not more than 20% clay.

Sapric peat - the most highly decomposed peat. An amorphous mass consisting largely of humus. Fibers, except for the larger ones, are not identifiable.

Silt - individual mineral particles that range in diameter from .002 mm to .05 mm. Soil of the silt textural class is 80% or more silt and less than 12% clay.

Soil - a naturally occurring, unconsolidated material on the earth's surface that has been influenced by parent material, climate, microorganisms, and topography, all acting through time to produce soil that may differ from the material from which it was derived in many physical, chemical, mineralogical, biological, and morphological properties.

Standard deviation - a statistical measure of the variability within a group of data. The variation from the mean.

Stratigraphy - science dealing with the formation, composition, and correlation of stratified sequences.

Texture, soil - the relative proportions of sand, silt, and clay particles in a mass of soil.

Till - unstratified and unsorted glacial drift deposited directly by the ice and consisting of clay, silt, sand, gravel, and boulders intermingled in any proportion.

Ultimate analysis - analysis of a substance to determine its content of basic elements and their proportions. For peat and coal the most common analyses are for hydrogen, sulfur, nitrogen, carbon, and oxygen.

Understory - a layer of foliage in a forest beneath the crown cover and above the ground cover.

APPENDIX A
THE USES OF PEAT AND PEATLANDS

Less than 10 percent of Minnesota's peatlands have been developed. Peatlands present several options for their use. Use can be divided into nonconsumptive and consumptive. Nonconsumptive uses include (1) timber production, (2) preservation, (3) agricultural crop production, and (4) biomass production. Consumptive uses, which require extraction of the peat, are (1) use in the horticultural industry, (2) extraction of industrial chemicals, and (3) use as a fuel. The type of peat formation, volume of the deposit, and geographical location are important factors that influence the feasibility of each use.

Nonconsumptive

The main nonconsumptive use of peatlands in northern Minnesota is for the production of timber, mainly black spruce, tamarack, and northern white cedar. About 60 percent of Minnesota's peatlands are forested (MN DNR 1979). Some peatlands support only stunted trees, while others may produce high-quality stands. The relationship between environmental factors and optimum growth is complicated, but it appears that the most productive tree growth usually occurs where the slope is greater than 1.5 m/km (~8 ft/mi) (Boelter and Verry 1977). This condition better ensures a balance between nutrient supply and aeration which is favorable for growth.

A second nonconsumptive use is preservation. The majority of Minnesota's peatlands are still relatively undisturbed. These areas support flora and fauna unique to wetland areas. Koochiching County contains 8,900 hectares (22,000 acres) of preserved land known as the Lake Agassiz Peatland Natural Area. This area possesses many peatland patterns that are unique and rare in other areas of the world.

A third nonconsumptive use is for agricultural crop production. This use requires drainage and fertilization. Many crops can be grown on peatlands, but due to northern Minnesota's short growing season, potatoes, carrots, radishes, wild rice, cranberries, and turf grass have the greatest potential. Sapric and hemic peat are used for agriculture, although sapric peat has more potential because of its structure, high bulk density, and high humus content.

A fourth nonconsumptive use of peatlands is for the production of biomass such as wood, cattails, reeds, sedges, and grasses. These crops can be used in direct burning to produce heat and electricity or converted to synthetic gas.

Consumptive

The largest consumptive use of peat in the United States at this time is by the horticultural industry, where it is used as a soil amendment and a germinating and rooting medium. A good soil amendment possesses (1) the ability to hold and supply large quantities of water, (2) a structure capable of entrapping large volumes of air, and (3) the capacity to absorb and retain plant nutrients in available form (high cation exchange capacity). Sphagnum and hypnum moss peats possess these characteristics and, therefore, are the most valuable peat types for horticultural use.

A second consumptive use of peat is as a raw material for the chemical industry. Chemical components that can be extracted are peat bitumens, carbohydrates, and humic acids. These components yield products that can be used in shoe and furniture polish, paints, in alcohol production, and in agriculture to improve nutrient uptake, root formation, and resistance to pests by plants. Peat coke, a product of peat, can be used for electrodes in the heavy chemical industry and in the production of activated carbon. Each component or product requires peat of a distinct chemical composition.

The third consumptive use of peat is as a fuel. This includes use in gasification, biogasification, and in direct burning.

Peat that is gasified must first be recovered, dewatered, and transported to processing plants. Several types of gasifiers are in the experimental stages. Gasification produces a low or medium-Btu fuel gas, synthesis gases, and liquid fuel.

A second means of gas production, biogasification, is also in the experimental stages. This method does not require dewatering; in fact, additional water is needed to produce a peat-water slurry. In this process, bacteria, which act as catalysts for anaerobic fermentation, are innoculated into the slurry. Methane and other by-product gases are produced, and the methane is separated off for use as a fuel. By-products such as inorganic wastes, residual microorganisms, and nondigestible peat components can be used in animal feed and soil conditioners or concentrated to a solid waste suitable for land disposal.

Direct combustion of peat can be used to produce heat, electrical power, and/or steam. Peat is also compressed into briquettes and used for heating homes.

Hemic peat has the highest energy value, while fibric has the lowest. This is due to the fact that the cellulose fibers in fibric peat are not sufficiently decomposed to promote the organic density and the fixation of carbon (DOE 1979). Sapric peat is less desirable than hemic due to its higher ash content.

Many other uses of peat exist. These include the tertiary treatment of sewage and the use of peat as a binder in taconite pellets.

APPENDIX B
DISCUSSION OF MINERAL MAPPING UNITS
BY MORRIS T. ENG

Alluvium

This unit represents well-sorted alluvial sediments deposited by postglacial streams.

Offshore Sand

Offshore sand represents a gently undulating sand plain consisting of light reddish brown to buff-colored medium-to-fine sand that was originally deposited along the retreating ice front of the St. Louis sublobe. Meltwater streams discharged their load of material directly into early Lake Agassiz. Strong shoreline currents sorted out the sand from the larger gravel-sized particles and redeposited it some distance away from the shoreline.

Eventually Lake Agassiz withdrew, and the sands became stabilized by a vegetative cover for a long period of time. This was followed by a dry period about 8,000 to 5,000 years ago when the climate modified and became droughty. The prolonged dry conditions led to destruction of the existing vegetation cover, resulting in an increase in the effects of wind erosion and deposition. Sand dunes developed throughout north-central Minnesota during this time (Grigal et al. 1976). Later, cooler and more humid conditions returned, and the dunes stabilized as a more continuous vegetative cover returned.

Offshore sand is limited to a small area in the northwest corner of Koochiching County between the headwaters of the Black River and the East Fork Rapid River. Evidence of dune sand can be found in this area near the Indian Pines fire tower and near Wayland. Sand can be expected to be present beneath the peat in this region.

Lake Bottom Sediments

This unit represents a very gently undulating lacustrine plain consisting primarily of clay, silt, and fine sand that was deposited in the quiet, deep-water environments of Lake Agassiz. The boundary between this unit and the lakewashed ground moraine is usually transitional, but the lake bottom sediments have a more level terrain, thicker deposits of clay and silt, and very few surface stones. Deep-water lake sediments are light buff to light brown in color and are composed of laminations of clay and silt. Unstructured lake bottom sediment composed of light buff-colored silt with mottled dark brown inclusions is also contained in this unit. These are suggestive of deposition in an ice-controlled lake environment.

Lakewashed Ground Moraine

Lakewashed ground moraine represents a gently undulating topography of ground moraine associated with the St. Louis sublobe that was inundated, smoothed, and modified by Glacial Lake Agassiz. The surface may contain pebbles and occasional large rocks that remained after the finer fraction was washed out of the till by lake currents. This unit occupies the better drained areas between the former shorelines of Lake Agassiz and areas adjacent to streams.

Ground Moraine

Ground moraine represents an undulating topography with gently sloping swells, sags, and depressions. It is composed of light gray to buff-colored, silty, calcareous till that was deposited by the St. Louis sublobe.

End Moraine

This unit represents a rough to rolling topography with many ice-block lakes. It consists of light gray to buff-colored, silty, calcareous till that contains a high content of limestone and shale rock fragments that was deposited by the St. Louis sublobe.

Steeply sloping landforms associated with ice-contact sand and gravel deposits are common in this unit.

Moraine Overlap

Moraine overlap represents a rolling topography of recessional moraines composed of light reddish brown, noncalcareous sandy, bouldery till deposited by the Rainy lobe. This till is overlapped by a light gray to buff, calcareous, silty till deposited by the St. Louis sublobe. This stratigraphic relationship developed as the eastward advance of the St. Louis sublobe overrode the recessional moraines and stagnant ice left by the retreat of the Rainy lobe to the north and northeast. Surface boulders and pebbles are quite common.

Rock

This unit represents bedrock exposed at the surface or landforms that owe their configuration to near-surface rock formations. An attempt was made to use the lineations within individual outcrops for distinguishing between major rock types and identifying geologic structure. The internal structure of older metamorphic rocks generally shows an orderly arrangement of parallel lineations, which are often in alignment over long distances from one outcrop to another. The internal structure of the younger intrusive rocks is typically nonlineated, and local fractures indicate they have penetrated and displaced the older rocks.

Sand and Gravel - Kames, Eskers, Ice-Contact Deposits, Glacial Outwash, and Beaches

The formation and placement of sand and gravel in this area is directly related to Pleistocene hydrologic systems that sorted the glacial drift into different grain sizes. Melting of the glaciers produced a vigorous outflow of water that formed large streams capable of transporting an enormous sediment load. Fine-grain silt and clay-sized particles were rapidly eroded and carried off in suspension for many miles downstream. Strong currents tumbled and rolled the larger particles causing them to become rounded and redeposited as gravel. The overloaded streams constantly shifted their channels, thereby changing the flow velocity, rate of deposition, and type of material being deposited. The better gravel deposits are those that have been reworked many times by strong currents and transported long distances beyond the ice front.

Kames

Kames are prominent cone-shaped hills of sand and gravel formed by sediment-laden water plunging into a hole or crevasse in the ice. They are frequently found in clusters and are characteristically sandy near the top, grading to gravel towards the bottom. Several kame-type deposits occur near Northome within the end moraine associated with the St. Louis sublobe.

Eskers

Eskers are narrow sinuous ridges formed by subglacial streams flowing through tunnels within the glacier. The gravel deposited in eskers is composed of stream-bottom sediments. Gravel pits opened in eskers usually display a complex slump-bedded pattern of deposition, reflecting the subsidence of supporting ice walls. The quality of gravel in these deposits is very irregular because of the hydraulic effect of ice movement on streamflow. The esker shown on the map about two and one-half miles south of Northome is associated with the St. Louis sublobe.

Ice-Contact Deposits

Ice-contact features include deposits that are formed in direct contact with melting glacial ice. One example of an ice-contact deposit is a crevasse filling. In this county, crevasse fillings are associated with the stagnant ice fronts of the Rainy lobe and the St. Louis sublobe; subsequently, they were lakewashed by Glacial Lake Agassiz. Ice-contact slopes are steep slopes marking the interface of till against glacial ice. This feature is generally found in landforms within the end moraine complex and is useful to mark the former position of the ice.

Glacial Outwash

This unit represents a broad, flat, or gently sloping plain composed of sand and gravel deposited by overloaded glacial streams. These streams continuously shifted their channels and merged to fill in large expanses with a plain of uniformly stratified sand and gravel. Outwash deposits are preferred for mining because they are more predictable as to their quantity and quality of gravel than the material found in other deposits.

Beaches

Beaches represent a low, essentially continuous ridge of sand and gravel marking a former shoreline of Glacial Lake Agassiz. Former shorelines of the Beltrami Arm of Glacial Lake Agassiz extend in an arc across Koochiching County trending generally west to southeast. Some of the shorelines were built on low recessional moraines, where waves and currents reworked the material washing away the finer particles and leaving only sand and gravel.

APPENDIX C
LABORATORY METHODS

Water Content

Water content is determined on a weight basis at the moisture condition of the sample as received from the field. A field-moist core sample is weighed, oven-dried to a constant weight (~105°C for 24 hrs), cooled, and reweighed with the difference expressing the weight of water in the sample.

Water content expressed as (1) a percentage of total weight represents the moisture present in the soil, and as (2) a percentage of dry weight represents the water-holding capacity of the soil.

$$\text{Total wt. (\%)} = \frac{\text{wt. of water (g)} \times 100}{\text{field-moist sample wt. (g)}}$$

$$\text{Dry wt. (\%)} = \frac{\text{wt. of water (g)} \times 100}{\text{oven-dry sample wt. (g)}}$$

Bulk Density

To determine bulk density, a field-moist core sample of known volume is oven-dried to a constant weight (~105°C for 24 hrs). Bulk density is expressed on a dry weight—-wet bulk volume basis by using the following equation:

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{oven-dry core wt. (g)}}{\text{vol. of core (cm}^3\text{)}}$$

Mineral Content

To determine mineral content, an oven-dried peat sample is prepared by putting it in a blender for a thorough mixing. A one-gram portion is placed in a crucible and ignited in a muffle furnace at 500°C for one hour. Upon cooling, the ash is weighed and the percent mineral (ash) content is calculated by using the following equation:

$$\text{Mineral content (\%)} = \frac{\text{wt. of ash (g)} \times 100}{\text{1 (g) oven-dry sample}}$$

pH

The pH of peat is measured in (1) a suspension of deionized H_2O and (2) in a suspension of 0.01 M $CaCl_2$ solution. The procedure for both measurements involves lightly packing 15 cc of field-moist peat into a 100 cc container to which 15 cc of solution is added. The suspension is mixed, and following an hour equilibrium time, the pH value is measured with a pH meter.

pH is 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 of peat are determined by the DOE Coal Analysis Laboratory using standard ASTM laboratory procedures.