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BY

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Structure as a Basis of Peat Classification

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ABSTRACT

Despite the fact that methods exist for identifying and classifying peat qualitatively on a structural basis, they are inadequate when quantitative expression of structure is attempted. This imposes a limitation on geotechnical analysis and comparison of peat type.

A concept is developed whereby macro- and micro-structure of peat are accounted for in terms that are consistent with the behaviour of peat. Structure is understood as being the morphology and arrangement of the constituent organic elements in the peat, both in its macro and micro aspects. A single homogeneous non-woody, fine-fibrous peat type is analyzed to test the concept.

It is concluded that structure of peat presents a natural basis for a quantitative classification of the material, in both its dry and wet states. The complexity of peat in situ can be reduced to relatively few gross structural types; a macro- and microscopic examination of these types should result in the development of a mathematical model for each type, and should represent adequately the natural condition.

RÉSUMÉ

Il existe des méthodes pour identifier et classer les tourbes au point de vue qualitatif en se basant sur leur structure. Elles ne conviennent pas lorsqu'on désire obtenir une expression quantitative de la structure. Cette situation impose des limites à l'analyse géotechnique et à la comparaison des types de tourbe.

On a mis au point un concept de base d'après lequel on rend compte de la macrostructure et de la microstructure de la tourbe d'une manière compatible avec le comportement de celle-ci. La structure est considérée comme constituée par la morphologie et la disposition des éléments organiques qui constituent la tourbe, à la fois dans ses aspects macroscopique et microscopique. A titre d'essai d'application du nouveau concept, on donne une analyse d'un type de tourbe homogène, non ligneuse, et à fibres fines.

On arrive à la conclusion que la structure de la tourbe offre une base naturelle permettant de classifier ce matériau à la fois à l'état sec et à l'état humide. La complexité de la tourbe in situ peut être ramenée à un nombre relativement minime de types généraux de structure. L'examen macroscopique et microscopique de ces types devrait permettre d'aboutir à la mise au point, pour chaque type, d'un modèle mathématique qui devrait fournir une représentation convenable de l'état naturel.

It has been pointed out (MacFarlane, 1965) that one of the obstacles to the validity of comparing results of research into the engineering properties of peats has been the lack of an adequate system of classification. Systems in current use (including the Radforth system, widely used among engineers in Canada) are not yet rigorously quantitative. This has imposed a limitation on investigators working on the engineering characteristics of peats, in that they are unable to describe adequately the material they are studying.

The question of classification has been the subject of much inquiry, and has resulted in the development of a wide variety of classification systems for peatlands and peats; generally these have not been too applicable to engineering use. Among the several authorities who have contributed to an understanding of peat materials and their classification, of particular interest to engineers is the field method developed by von Post (1937) that has been rather widely used in Europe. In this system the degree of decomposition is designated by a ten-grade system determined

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from visual examination of the organic mass. The grade is determined on the basis of colour and amount of water as well as plasticity, structure, etc., of the material squeezed out of a wet sample in the hand. This method has advantages, as its application testifies; were it to be less subjective and more quantitative its purpose would be more effective.

A similar system was developed in Russia (Varlygin, 1924) consisting of three degrees of decomposition designated by the letters A, B and C. Intermediate grades are designated AB and BC. This also is based on visual evidence.

Canadian peat authorities who have made contributions to classification techniques include N. W. Radforth (whose classification system will be referred to later in this paper) and J. A. Pihlainen (1964), who attempted to develop a method of mechanical analysis for peat. Pihlainen's method involves an empirical laboratory approach for obtaining a quantitative assessment of peat by mechanically separating the "fibres" and "granules" of a dried peat sample by shaking them through a slit screen.

Barry (1954) has suggested that what is needed is not a new classification system but clarification of the existing systems. This is undoubtedly true, but it seems apparent that the multiplicity of systems indicates, among other things, that none is entirely satisfactory.

What, then, are the basic requirements of an adequate classification system for peat? The authors believe that it should have the following features:

1) It should reflect natural conditions; i.e., it should represent the peat as it exists in situ.
2) It should be as simple as is reasonable and have general application.
3) It should be definitive and quantitative.

This view is confirmed by Farnham (1963), who suggests that if a system of classification is to have the greatest usefulness the peats should be classified on the basis of relatively simple but specific morphological properties that are easily discernible by the field investigator. It should not be based on ill-defined broad climatic and geographic criteria.

A study by MacFarlane of the engineering characteristics of peats, in particular their consolidation characteristics, has led to consideration of the structure of peat and the effect on this structure of the application of compressional loads. The immediate question is: can one refer to peat structure in mathematical terms?

PEAT STRUCTURE

Any soil may be regarded as a system of two or three spatially co-existent phases: a solid phase, a liquid phase, and usually a gas phase. This three-phase concept applies to peats equally as well as to mineral soils, except that the "solid" phase in its microscopic aspect is itself a secondary system of biological entities consisting of cellular structures with contained liquid and/or gas. Some knowledge of the relation between these phases, as well as of the structure of the solid phase, is basic to an understanding of the engineering characteristics of peats.

The question of peat structure has been discussed by Radforth and colleagues (Radforth, 1956; Radforth and Eydt, 1958; Radforth, Eydt and Stewart, 1961) who used the term "structure" in a botanical and morphological sense. In the context of this paper, structure means the morphology and arrangement of the constituent peat elements, in both the macro- and microscopic aspects. As peats are comprised of fossilized remains of plant communities, they contain elements of varying morphology, complexity and texture. One form of plant remains may be the most predominant visually, another may be secondary in importance, another tertiary, and so on. On the other hand, several kinds of elements may appear to be predominant and to contribute importantly to the overall properties of the peat. The structure of peat implies an arrangement of these primary, secondary, tertiary elements into a certain structural pattern. Occasionally, certain structural constituents occurring infrequently, but with strong influence on physical state, may require major emphasis as elements in structural pattern.

The visible macrostructure of peat is undoubtedly dependent upon the type and arrangement of the elements that are not so clearly distinguishable. In other words, the nature of the arrangement of the smaller units in the microstructure markedly influences the macrostructure.

It is this structure (inclusive of arrangement) in its various aspects that affects the retention or expulsion of water in the system, gives it strength, and differentiates one peat type from another. In studying the structural relations of peat, one is interested primarily in the degree to which peats exhibit a characteristic structure, the stability of this structure, and the physical properties that are dependent upon a particular and characteristic structure.

As defined, structure involves the arrangement of peat elements in certain patterns; the type of arrangement varies with

TABLE I
Structural Units of Peat Deposits and Some of Their Physical Characteristics (After Dachnowski, 1924)

Groups of Peat-forming Vegetation	Types of Peat	Character of Peat Layers	Colour of Peat Layers	Texture of Peat Layers	Structure of Peat Layers
Aquatic	Macerated Colloidal	Pulpy (sedimentary)	Olive green brown to black	Coarse to very finely divided	Compact impervious stiff plastic or loose friable
Marsh	Reed Sedge Brown moss	Fibrous	Gray red or yellow-brown	Coarse to fine fibred	Dense matted felty or porous spongy
Bog	Bog moss Heath Shrub				
Swamp	Willow-alder shrub Deciduous forest Coniferous forest	Woody	Dark brown to Blackish brown	Coarsely fragmented to granular	Compact and granular or loose wicker-like

the amount and nature of the secondary, tertiary, and so on, constituents. Pore space exists between the various elements as well as (for various hollow organics) within the elements. The external pores may be large or small, continuous or discontinuous, depending upon the type and arrangement of the elements. According to Baver (1956), difference in inorganic soil structure may be expressed by:

1) the structural patterns of the various horizons in the profile,
2) the extent of aggregation (for peats this might be interpreted as the extent of intermingling of secondary and other elements), and
3) the amount and nature of the pore space.

Whatever method is used to designate the structure of peat, it must reflect the fundamentals of its growth and organization. Not only should this designation identify structural states, it should facilitate quantitative assessment of the physical and mechanical conditions pertaining to those states.

The approach described by Baver in 1) above is best exemplified by one of the earliest and best known designations in North America for peat types, the stratigraphic system developed by Dachnowski (1924). Dachnowski classified peats on the basis of their mode of origin and the fossilized plant material they contain, relating these to particular horizons in peat bogs. He named ten peat types and divided them into three main categories: sedimentary peats, fibrous peats, and woody peats (Table I). The differentiation is basic and refers roughly to the preponderance of the various plant constituents and to textural, structural and other characteristics. Dachnowski, however, considered structure to be a property of a particular peat layer—its compactness, density, whether matted or not—rather than an arrangement of the various constituents relative to each other or the inherent characteristics of the constituents.

Roughly falling into approach 2) is that part of the Radforth (1956, 1968) classification system for muskeg for which peat is a component. Radforth bases peat types on size, texture, and arrangement of proximal components. He designated 17 categories, the physical elements discernible by visual examination of peat samples. They represent recurring states and are therefor significant (Table II): woody fibrous (derived from tissues originally lignified); non-woody fibrous (originally non-lignified and probably cellulose in origin); and amorphous-granular constituents, representing highly variable and consistently irregular minute organic aggregates that are an important component of many peats.

The use of these elements in their various proportions is helpful in designating peats qualitatively; but greater help would be forthcoming if quantitative evidence were available to give additional meaning to the various designations. Radforth and Eydt (1958) carried the question of structure a little further when they investigated the relative proportion of different types of plant tissue in samples of peat examined under a microscope. They suggested that this sort of examination might permit some extrapolation of such engineering properties as bearing capacity but did not carry their study further than this.

The third approach to structure is related to porosity. The arrangement of the peat elements determines the amount and nature of the *external* pores of the soil. The *internal* pores are determined by the plant type. Soil porosity, for inorganic soils, may be defined as that percentage of the soil volume not occupied by solid particles (Baver, 1956). Although the amount and nature of the pores depend upon the size and character of the arrangement of elements, pore size alone cannot describe a particular type of structure.

The contribution of porosity to the soil structure relation is emphasized by the work of Ohira (1962) in his study of Japanese peats. He developed a model structure for peat and described its fundamental physical properties in mathematical terms. His model structure is related to a statistical analysis of a large number of determinations of basic physical properties of peats in Japan, and his description is briefly paraphased as follows:

TABLE II
Muskeg Sub-surface Constitution (After Radforth, 1956)

Predominant Characteristic	Category	Name
Amorphous-Granular	1.	Amorphous-granular peat
	2.	Non-woody fine-fibrous peat
	3.	Amorphous-granular peat containing non-woody fine fibres
	4.	Amorphous-granular peat containing woody fine fibres
	5.	Peat predominantly amorphous-granular containing non-woody fine fibres held in a woody fine-fibrous framework
	6.	Peat predominantly amorphous-granular containing woody fine fibres, held in a woody, coarse-fibrous framework
	7.	Alternate layering of non-woody, fine-fibrous peat and amorphous-granular peat containing non-woody fine fibres
Fine-Fibrous	8.	Non-woody, fine-fibrous peat containing a mound of coarse fibres
	9.	Woody, fine-fibrous peat held in a woody, coarse-fibrous framework
	10.	Woody particles held in non-woody, fine-fibrous peat
	11.	Woody and non-woody particles held in fine-fibrous peat
Coarse-Fibrous	12.	Woody, coarse-fibrous peat
	13.	Coarse fibrous criss-crossing fine-fibrous peat
	14.	Non-woody and woody fine-fibrous peat held in a coarse-fibrous framework
	15.	Woody mesh of fibres and particles enclosing amorphous-granular peat containing fine fibres
	16.	Woody, coarse-fibrous peat containing scattered woody chunks
	17.	Mesh of closely applied logs and roots enclosing woody, coarse-fibrous peat with woody chunks.

Peat consists of a large number of closely packed, hollow organics of the same size. The specific gravity of the organics is represented by G_o and their porosity by n_o. Part of the exterior voids is filled with finer soils (specific gravity represented by G_s); the rest are filled with moisture and gases. Formulae for the fundamental properties of the structural model (porosity, wet and dry density, moisture content, specific gravity and organic content) are presented in terms of C_d, the "coefficient of deposition," which varies with the shape of the organic material and the state of contact.

On the basis of a number of assumptions related to the numerical values of the various physical properties, Ohira postulated a structural model for a kind of peat having the following characteristics:

1) a large number of closely packed hollow organics with porosity n_o of 90 - 98 per cent and a specific gravity G_o of 1.5;
2) a coefficient of deposition C_d of 0.8;

3) part of the voids between the organic elements filled with soils having a specific gravity G_s of 2.70 (i.e., non-organic soils); 4) the remainder of the voids saturated with moisture and gas, with a porosity of 2 - 10 per cent.

Ohira shows that the theoretical values of the fundamental properties of the model, based on the above values, are in close agreement with actual experimental values.

This quantitative approach is both unique and important, although the structural model is somewhat limiting in that it represents but one peat type (i.e., the so-called "fibrous" peats with an admixture of mineral soils) and is not entirely valid for the wide range of peats designated in Table II.

The two extremes of the peat structural spectrum are represented by Radforth's Category 17 and Category 1. The former is characterized by an open mesh of highly-preserved, fossilized elements including, with other macro- and microconstituents, large woody elements. Category 1 is made up of highly disintegrated botanical tissues and identifiable microfossils; macroscopically, its constituents are structurally formless. Although an extremely large number of types could exist between these two extremes, for all practical purposes only a relatively few do occur (Radforth, 1956).

The Ohira approach can be applied to peats characterized by a predominantly fibrous element, with a secondary element of amorphous-granular or even mineral soil. The "pure" fibrous and the "pure" amorphous-granular present quite another problem.

The amorphous-granular peat mass at the bottom end of the structural spectrum is normally a coagel of degenerated organic matter and a small quantity of mineral substances of a colloidal size (Naumovich, 1957). The disperse phase in this condition forms a continuous lattice, whose nuclei contain a colloidal solution of the peaty substance. Depending upon the size of the particles, this peat is essentially a polydisperse system, the water being the dispersing medium. The disperse (solid) phase consists of vegetative remains and the products of their degradation or modification: humic acids, bitumens, and other organic and mineral constituents.

In mineral soil concepts the completely disperse, individual or primary particles are usually referred to as textural or mechanical separates (Baver, 1956). The aggregates or secondary particles, which are formed by grouping of the mechanical separates, are generally considered the structural units of a mineral soil. It may be claimed that the opposite is true for peat in that the structural units are the primary particles—the complex botanical entities relatively unchanged structurally. The secondary elements are the result of chemical and physical degeneration of the primary units, although if the secondary particles are in the colloidal size range they will tend to group together in floccules and to form a lattice comparable to that found in inorganic soils.

Conventionally, colloidal size means particles less than 0.001 mm (1 micron) in diameter. The concept of colloidal properties is based on the surface effect of electrical charges on the movement and behaviour of a particle in relation to the effect of gravity. It can readily be seen that the complex physico-chemical forces will result in a quite different structural model for peats with a high colloidal fraction, compared with a structural model for peats that are chiefly fibrous. Also, it must be emphasized that for recurring peat types that are combinations of the two major contributors the complex physico-chemical forces will be disposed in model form in a fashion different again from either the model for the amorphous-granular or the fibrous.

Apart from the references to the colloidal fraction in peats, the foregoing has referred mainly to the macrostructure of peats, although the importance of the microstructure is not rejected. It can be realized that the microstructure is ultimately a more complex matter than the macrostructure and that, like the latter, it varies a great deal from fibrous and woody peats to sedimentary and amorphous-granular peats. The arrangement and structure of the cells of the peat constituents depend entirely upon the plant material making up the peat and upon the physical disintegration and biochemical change it has experienced.

The cells of a well preserved peat constituent vary a great deal in size and structure. Their structural differences reflect the different functions they perform in the living plant. A group of structurally similar cells performing the same function is called a *tissue. Fibres* are very elongated cells with tapering ends, occurring singly or variously, and grouped in strands to contribute to a gross fibre. In fossilized plant material the cells are devoid of living content and contain water or gas (including air). The strength of a given element is supplied by the cell wall (and any additives deposited during fossilization), which has its own unique structure.

Fundamentally, the cell wall is composed of a complex mesh-like matrix of cellulose (Eames and MacDaniels, 1947), but also contains pectic substances (lignin, etc.). In minute structure this basic cellulose matrix is made up of aggregates of delicate fibrils that grade down in size to the limits of microscopic visibility. The fibrils are believed to be made up of *micellae,* aggregates of molecules (arranged in chains characteristic of cellulose), probably in crystalline form. The fibrils form complex, three-dimensional systems that adhere firmly and are continuous throughout the wall. Within the meshes of this matrix channels and pores form another system in which various substances are deposited. These substances fill the interstices and form a secondary structural system. A cell wall may be made up, therefore, of two main substances such as cellulose and lignin or cellulose and a hemicellulose.

LABORATORY STUDIES

In this preliminary attempt to examine the structure of peat it was deemed expedient to select, initially, a homogeneous peat morphologically characteristic of a peat type commonly occurring in nature, even though the species of the predominant plant constituents may vary.

The particular peat chosen for this investigation is termed "non-woody fine fibrous" (Radforth, 1956). It was obtained by N. W. Radforth near Moonbeam, Ontario, at the site of a slip failure of Highway 11, and was designated "Moonbeam peat." The sample material (in the McMaster University Muskeg Laboratory) was in an excellent state of preservation and evidenced a low degree of disintegration and modification. The chief specific constituent was identified as *Hypnum cuspidatum* (Jewell, 1955), with an occasional intrusion of a sedge (*Carex* sp.) and a very

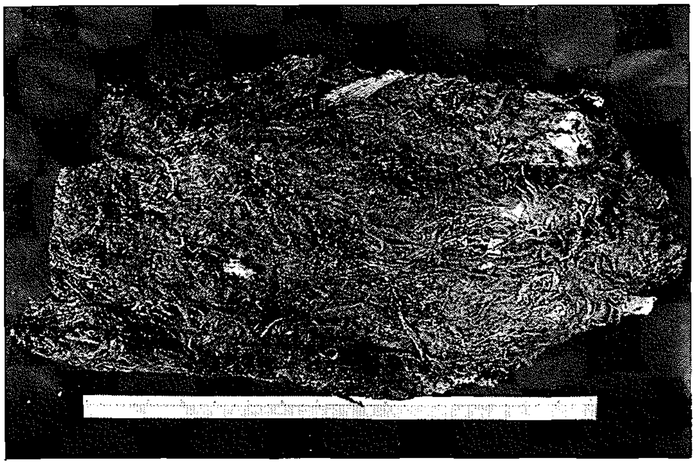


Figure 1. Moonbeam peat showing orientation of discrete elements.

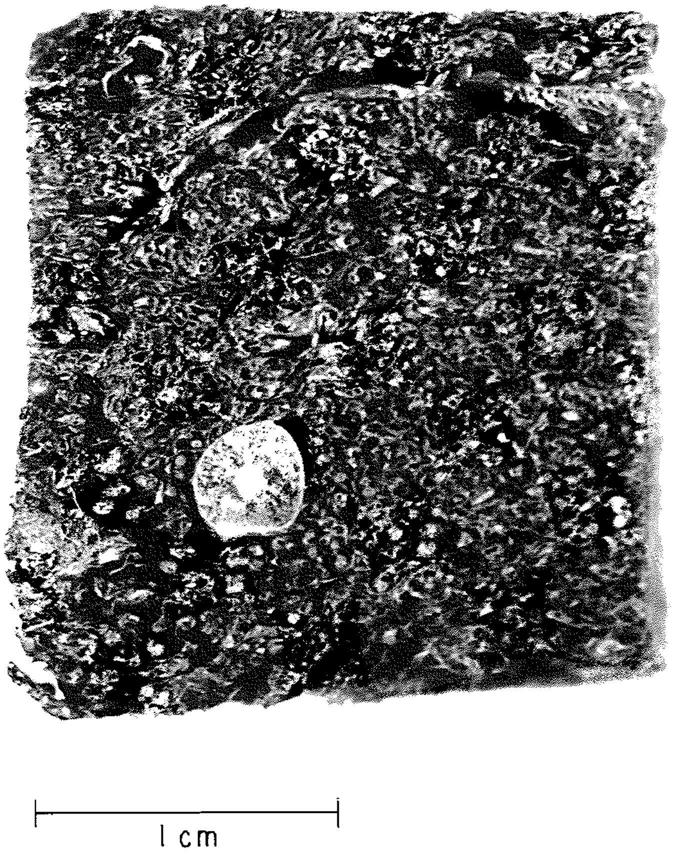


Figure 2. Cross-section of 2-cm cube of Moonbeam peat, showing gross structure (magnification 4X).

occasional intrusion of a small woody element. The characteristic macrostructural feature of this peat is its homogeneity, not only in its generic constitution even to a single species, but also in the arrangement of the peat elements. Axes of the fossilized plant material are oriented horizontally and parallel to one another, presenting an appearance of consistent uniformity. This is illustrated in Figures 1 and 2, which show plan and cross-sectional views (the latter magnified) of the dried peat. Homogeneity of arrangement is a function of growth habit, natural deposition and fossilization of the chief constituent species.

Viewed under the microscope, the peat elements (i.e., the discrete fossilized particles) consist of a central axis, occasionally with branches, and a spiral system of leafy appendages, the latter curled about the axis or branch, thereby providing an enormous number of capillary pores. The axes are actually hollow tubes with an average outside diameter of 0.24 mm when wet. Upon drying, this shrinks to 0.216 mm, on the average, representing a shrinkage perpendicular to the stem axis of 47.5 per cent. Lengthwise, the stem shrinks relatively little upon drying, confirming Frey-Wyssling's (1957) observations for unfossilized stem. The walls of the central axis are three to five cells thick; the leaves only one cell thick. The elements vary in length from 5 mm to 32 mm, the median being 15 mm, and the average length of 32 random samples being 15.8 mm. The number of leaf appendages per millimeter of branch length was also examined under a microscope and found to be 8.5, on the average.

Cell structure within the leaves and axis is regular and uniform in appearance. The cellular structure of the *Carex* element in the peat is not nearly so evident under the microscope as that for *Hypnum.*

The peat has a water carrying capacity of close to 1,500 per cent of dry weight (or 94 per cent of total weight). The true specific gravity of the soil solids is 1.32. Loss on ignition is 96 per cent. The dry density of the peat sample is 0.139 gm/cc and and the total porosity 89 per cent.

The peat sample was examined microscopically by two separate methods, the first by impregnating the sample with a Polyester resin (Markon 9HV), which hardened to almost rock-like consistency, then obtaining thin sections as for rock. The method of preparation of the section was as described by Thaler (1964). This section permitted a study, under high magnification, of the overall porosity of the sample, of the shape and size of the peat constituents, and of their positional relation one with another. Figure 3 illustrates this method.

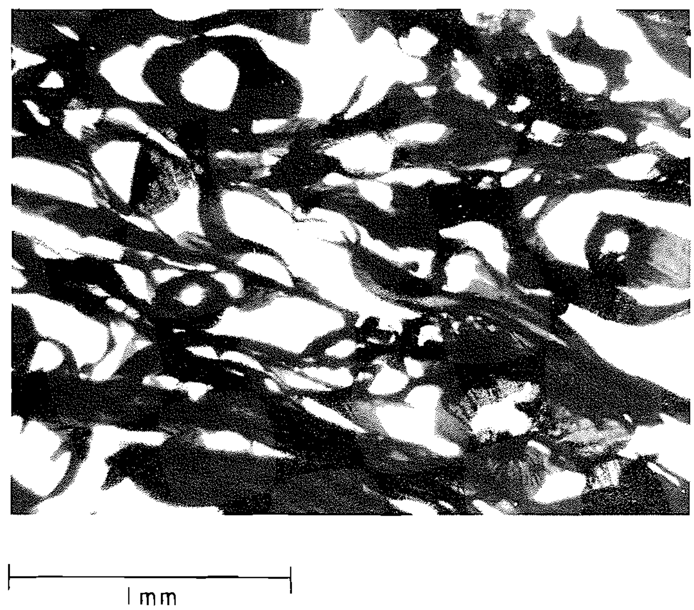


Figure 3. Photomicrograph of thin section of Moonbeam peat showing structural arrangement.

In the second method a small cube sample of peat was examined microscopically in a specially designed loading chamber while subjected to compressional loads. Photomicrographs were taken at various loads. This permitted examination, under low magnification, of the gross structure and any change in this structure with increasing load. This is illustrated by Figure 4, which represents zero load, and by Figure 5 which represents a load of 65.6 psi (4.61 kg/sq cm). These figures clearly show that the basic constituent of the sample peat is a tubular element with an attached "halo" of leaves within a matrix of leaves and other organic debris.

APPRAISAL AND CONCLUSIONS

In considering a mathematical formula in which a given peat type might be represented by a dimensionless number several micro- and macrostructural features of the peat could be incorporated. For example, microstructural features that might be included are: the length of the discrete peat elements (dimensional symbol L), their diameter (L), the wall thickness of the tubular element (L), the number of leafy appendages per unit length (1/L), and the average leaf area (L^2). Macrostructural features might include such fundamental properties as wet density (ML^{-3}), dry density (ML^{-3}), per cent moisture, specific gravity, porosity, void ratio, and per cent ash, all of which are related directly or indirectly to

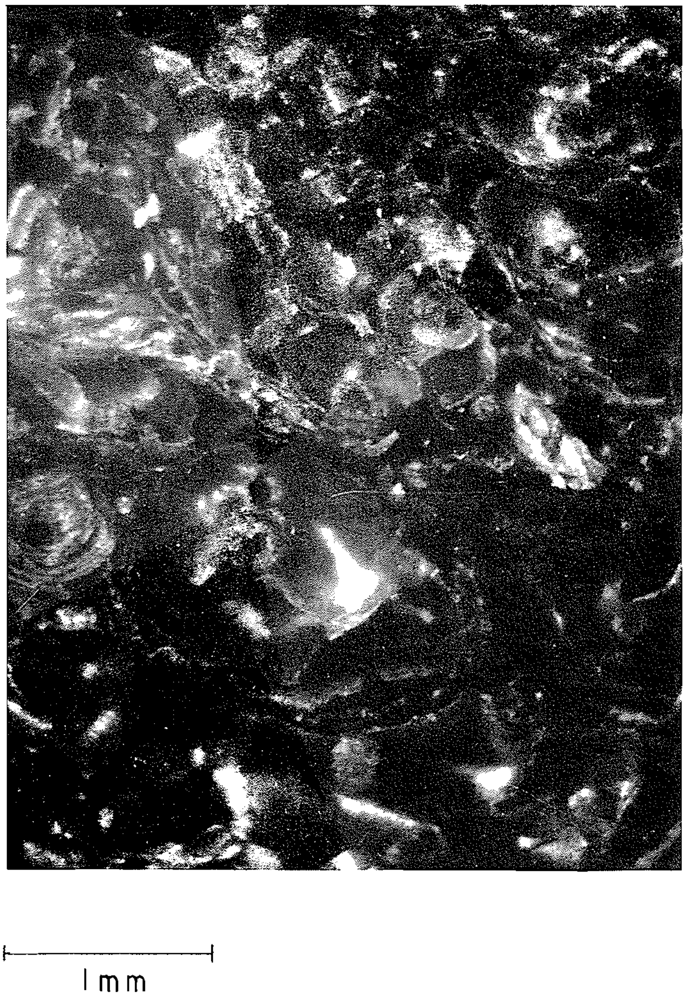


Figure 4. Photomicrograph of cross-section of dry peat sample in loading chamber, zero load.

Figure 5. Photomicrograph of cross-section of dry peat sample in loading chamber, load of 65.6 psi.

the structure of the peat. This approach is still somewhat premature, however, until further examples of the particular peat type under consideration have been examined in detail.

It is necessary, initially, to generalize to a considerable extent and to develop a structural model for peat to represent a range of micro- and macrostructural features. The predominant discrete organic element in the Moonbeam peat is a characteristic element in many peats — not necessarily taxonomically, but morphologically — hence the designation "fibrous peat." For the Moonbeam peat, specifically, it is a *Hypnum;* elsewhere it may be a *Sphagnum* or certain other mosses. It is possible at this stage, therefore, to describe this characteristic element in fairly precise terms and to give it a name. It is suggested that this element be designated an AXON and that the definition be as follows:

AXON—well preserved, non-woody, fossilized plant component of peat, consisting of tubular axis, system of scaley appendages, with the cellular structure clearly defined. The maximum outside diameter of the linear component of the axon (when wet) is 1 mm. The Moonbeam peat may be termed, therefore, axonic peat rather than "non-woody, fine-fibrous peat."

It is not yet possible to include in the definition quantitative expressions for the various components of the axon. Not only will these vary with the several plant species, but they will also depend upon the extent of disintegration and modification of the fossilized plant element. Further investigation is required into this aspect of the problem, but it is hoped it will lead to expression for other distinctive discrete elements of the more qualitatively recognized peat types.

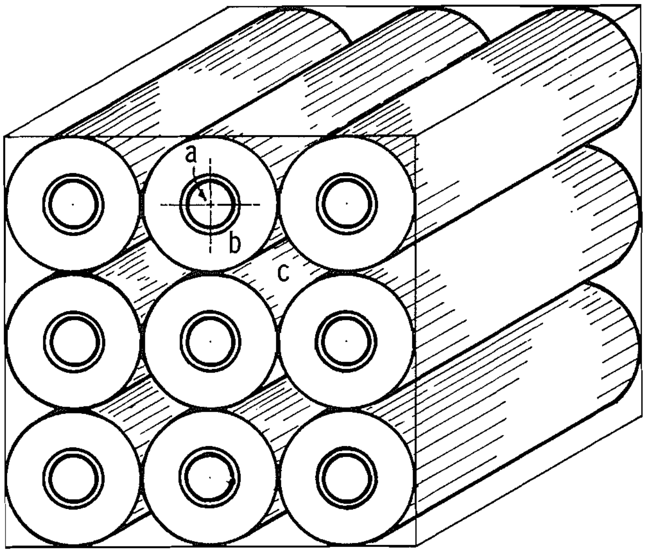
With regard to the arrangement of the axons, an examination of Figure 2 and 3 indicates loose packing. In Figure 3, for example, the stems of the axons comprise only 14 per cent of the total cross-sectional area shown in the figure. Scales and organic debris comprise some 54 per cent of the total area and external void spaces (i.e., not including the void spaces in the hollow tubular axes) make up the remaining 32 per cent. On a macrostructural basis, Figure 2 illustrates quite well the proximity of the axons to each other and, the extent of void spaces.

Consequently, it is now possible to postulate, as a first approximation, a structural model of the Moonbeam peat (Figure 6). It may be represented as a loosely packed arrangement of tubular organic elements (axons) of the same general configuration, consisting of a relatively incompressible stem, a, and a highly compressible peripheral zone, b, of scales. A part of the voids, c, is filled with organic fragments, the remainder with water and gases, including air. The angle of contact of the loosely packed elements is 90 degrees.

The following points are salient:

1) The structure of peat presents a natural basis for a quantitative classification of the material, in both its dry and its wet states.

2) The complexity of peat as it occurs in nature can be reduced to a relatively few gross structural types.



a. Central axis
b. Spiral system of attached scale leaves
c. External void spaces

Figure 6. Structural model of Moonbeam (axonic) peat.

3) A macro- and microscopic examination of these gross structural types should result in the development of a mathematical model for each type that would represent adequately the natural condition.
4) The major components of peats can be reduced to relatively few structural entities that can be quantitatively assessed.

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