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The Associate Committee on Soil and Snow Mechanics is one of about thirty special committees which assist the National Research Council in its work. Formed in 1945 to deal with an urgent wartime problem involving soil and snow, the Committee is now performing its intended task of co-ordinating Canadian research studies concerned with the physical and mechanical properties of the terrain of the Dominion. It does this through sub committees on Snow and Ice, Soil Mechanics, Muskeg, and Permafrost. The Committee, which consists of about fifteen Canadians appointed as individuals and not as representatives, each for a 3-year term, has funds available to it for making research grants for work in its fields of interest. Inquiries will be welcomed and should be addressed to: The Secretary, Associate Committee on Soil and Snow Mechanics, c/o The Division of Building Research, National Research Council, Ottawa, Canada.

Suggested Classification of Muskeg for the Engineer

by

Norman W. Radforth

McMaster University,

and

Royal Botanical Gardens, Hamilton, Ont.

A paper presented before the 66th Annual General and Professional Meeting of The Engineering Institute of Canada, at Vancouver, May 1952.

Foreword

The Associate Committee on Soil and Snow Mechanics of the National Research Council has been concerned, since the start of its work, with studies of the terrain of Canada. Muskeg constitutes a large proportion of the total area of the country, although situated in the less accessible areas, its significance is not always appreciated by the city dwellers.

As the boundaries of national development steadily advance, the problems which muskeg can create when it is traversed, or when it interferes with engineering work, are becoming increasingly important. The Associate Committee is therefore pleased to be able to publish this first major report on a project which it has supported financially, and in which it has long been interested.

After an early investigation of the chaotic use of even the word "muskeg" in Canada, the Committee was glad to find in Dr. Radforth a scientist whose special field of interest was palaeobotany, through which discipline an approach to the scientific study of organic terrain alone seemed possible.

Working closely with the Defence Research Board, which is primarily interested in the interpretation of muskeg conditions from the air, the Committee has supported Dr. Radforth in field work at Churchill, Manitoba, in visits to European muskeg areas, and in his laboratory investigations at Hamilton, Ontario, at McMaster University, and the Royal Botanical Gardens.

Dr. Radforth has accumulated a vast amount of information, many samples of muskeg and an unusual library of photographs of organic terrain. Using this, and his wide field experience, he has managed to develop a rational system of classification for a material long regarded as "unclassifiable".

The suggested classification is admittedly a first approach only to a singularly difficult problem. Its imperfections will be shown only by its use. Its improvement and further development will come only after such field application. The Associate Committee and Dr. Radforth will therefore welcome comments and criticisms and, in particular, reports upon the use of the suggested classification in the field.

R. F. Legget

Chairman, Associate Committee on Soil and Snow Mechanics. National Research Council.

The interpretation of mineral soil aggregates has become a well-established study, and is now being approached from many directions in the scientific and engineering realms. Some branches of the field are relatively new. Their development is just beginning to broaden. The consideration of mechanical problems relating to mineral soils, for instance, is comparatively young.

By comparison with this, however, knowledge concerning the interpretation of organic soils is negligible. No organized reference system for organic soils is in existence. Until it is, the utilization, treatment and adjustment of organic soils for engineering purposes will remain a difficulty.

Under these circumstances, the comparison of results in problems of foundation engineering wherever an organic soil is involved will always be troublesome and at best, inadequate. This is particularly true when the soil medium in question is almost completely organic: the material called "muskeg".

Possibly because of its biological origin, muskeg is an extremely complex material. In degree of complexity, it compares favourably with that of any mineral soil and its variability is likewise well marked. Moreover, in assessing this material for engineering purposes, depth, form and other features that refer to the soil body as a whole, are just as significant for the organic as for the mineral soil.

Finally, in applying engineering techniques and interpretations, attendant factors such as water and physiographical phenomena are just as important for organic soils as for mineral soils as agents influencing soil character.

In the present study the writer has had in mind the need for adequate portrayal of muskeg features. It is thought, however, that this objective is secondary in importance to the development and presentation of a system whereby intelligent reference can be made to muskeg.

While it is true that this primary objective relates more to the need of the engineer interested in problems of trafficability, construction and foundation engineering, it is hoped that the information will be of use to foresters, geographers, biologists, pedologists, conservationists, and indeed to all those associated in one way or another with muskeg.

The Expression "Muskeg"

The writer has gone to considerable lengths to determine what is intended by the word "muskeg" by those who use the term. The results of the inquiry have been enlightening but bewildering. The range of meaning ascribed to muskeg is so broad that the word has questionable value when used as a precise reference term. Some would include swamp under the heading of "muskeg". Others would differ and claim that it signifies the shore of a bog-lake. It has been used as synonymous with tundra. It has been employed to designate imponded areas completely covered with vegetation, or the thickly carpeted floor

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The author, Dr. Radforth (right) with R. F. Legget, M.E.I.C., chairman of the annual meeting session at which the paper was presented.

of open spruce woodland, and in many instances has been supplied as an acceptable reference term to signify "peat-bed".

When used in any of these ways, no special size limit is specified. Frequently it is applied in describing large areas of land more or less continuous for several thousands of square miles. This is especially so in the case of the Canadian North and Northwest. On the other hand, it may be utilized as referring to small patches of overburden, particularly in the eastern, western and southern parts of Canada and in some parts of the United States.

The flexibility and vagueness of meaning that "muskeg" implies leads to confusion, and provides serious difficulty when practical and intelligent use of the expression is attempted for purposes of discussion and report. This situation is further aggravated when the expression is used to label the field material itself. Because of this difficulty, it is tempting to eliminate "muskeg" as a reference term altogether. To discard it completely, however, would invite other problems.

Though the term is attended by such lack of agreement, it has, none the less, come into frequent use and doubtless will continue to be used. Also, though its meaning is not clear, those who have become accustomed to using it in connection with their work, regard it with some respect. They are content to ascribe to it their own particular set of values, no matter how this might be at variance with the views of others.

Literally interpreted, "muskeg" suggests simply "peat-bog" (Chippewan Indian, maskeg, meaning "grassy bog"). Though this definition is not adequate as it stands, it does furnish a fundamental meaning which can be widely appreciated, and which shows promise of acceptable expansion. Primarily, the idea of organic constitution is inferred. There is also in the literal definition the suggestion that a high percentage of water influences the character of the organic medium.

A third idea which may be inherent in the literal translation is spatial delimitation. This possibility coincides with the suggestion of some, that the term "bog" includes the saturated organic matter held in a more or less saucer-shaped depression, frequently two or three miles in diameter. This view does not support the impression that muskeg may be an extended sheet of organic material, with a depth generally uniform over great distances, in excess of say, twenty miles.

A workable definition of "muskeg" might thus be simply "organic terrain". The possible weakness may, however, be dismissed if it is agreed that the expression relates not only to materials, but also to states or conditions. Certainly, if any translation of "muskeg" is to exclude this proposal it will have to be regarded as inadequate at the outset.

The expression "organic terrain" seems to allow for the inclusion of the base of the organic matter and the top of the underlying mineral soil in considerations relating to "muskeg". It also allows any reference to topographic conditions and ground surface characteristics in general. The designation does not preclude the use of the expression "organic deposit". It does suggest, and in a sense specifies the nature of the deposit. Some organic deposits such as coal, lignite, oil and submerged peat beds would be excluded by the expression.

Organic Terrain Deposits

The kind of organic deposit included in the expression "organic terrain" has widespread distribution. In contemplating the limitation of "organic terrain" as a reference expression, the writer feels that geographic implications are important.

Organic terrain deposits occurring in Europe, Asia and North America all merit study. In Canada organic terrain predominates in areas having horizons separated by as much as a thousand miles. Such country may be found in the Yukon, in Saskatchewan, and Manitoba. Smaller areas, but still significantly large, occur in British Columbia, Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland.

Organic terrain also occurs in Washington, Oregon, North Dakota, Michigan, New York and the New England States. To a lesser degree it occurs in other regions within the United States. Perhaps the best known geographic regions in which organic terrain occurs are in the British Isles and in northern Europe. The largest continental areas containing deposits comparable with those of Canada are in Siberia.

The great bulk of the deposit, wherever located, arises as an accumulation of vegetable matter. The thickness of the material varies considerably. It may be one to a few inches in depth, or it may be between one and two hundred feet in depth. Whatever the depth, it is still significant as a potential problem, or as a predominant element providing character or limitation for large areas. For any given expanse of this kind of overburden the depth is more often than not variable. Constancy in depth is, however, a condition not uncommon, particularly in the far North.

Organization, The Basis for Classification

Any system of classification presupposes the existence of organization in whatever medium is to be classified. The higher the degree of orderliness in the medium under study, the better will be the chances for recognizing organization, and the more the promise of rendering a classification that will justify the widest acceptance. Whatever the form of classification, if it is to be successful, its procurement depends upon the manifestation of organization.

It is also important to realize that the procedure of revealing organization may depend on reference to natural relationships within the medium being classified, or on the other hand to artificial relationships arbitrarily revealed. It must also be expected that if the material to be classified is highly complex, the classification system ultimately derived may be also complex. It may include not one, but several, sets of classification systems. In cases of this kind, one system may parallel another, or one system may be subsidiary to another.

It would be unfortunate if, in establishing the basis for classification for a medium that has so far evaded interpretation, an attempt were not made to distinguish between identification and classification. In this account, classification will be used to segregate and define *properties* of materials and conditions. Identification will be used in referring to *examples* of materials and conditions. Thus, examples will be regarded as identifiable through classifiable properties. Thus, it seems proper to emphasize that the recognition of classifiable properties within the organic terrain is the fundamental task.

Survey of Conditions for Classification

Having set out the terms of reference for the basis of classification, it now remains to explore the material and conditions which confront the field observer. This exploration involves two realms: that which embraces the hidden or underground aspects, and that which involves surface features lying in full view.

Subsurface Constitution

In any sort of construction problem involving "muskeg", the field observer generally feels that the materials he is dealing with fall into the category of black, unstable muck. This is inadequate if the engineer desires as clear and complete a picture of organic soils as he insists upon for soils derived from a mineral source. It is therefore necessary that the constitution of organic terrain from the aspect of particle size, form and distribution should be studied and incorporated into the main framework of classification.

This will serve to parallel the increasingly important information existing with regard to the particulate constitution of mineral soils. In the latter field, not only is particle size an important factor for the engineer, but *kinds* of particles, their frequency of occurrence and their distribution, are also important. The relationship between one kind of particle and another in the physical, chemical and mechanical sense is also significant. It is not surprising, therefore, that the same point of view should be accepted and utilized with reference to an interpretation of organic terrain.

Size and Disposition of Constituent Particles

Interpretation of organic terrain depends upon reference to particles or units of two orders of size; one microscopic, the other observable with the naked eye (macroscopic) in the field. The attention of the reader is first directed to the latter.

On the assumption that the field engineer makes adequate preliminary investigation of the organic terrain materials, he will readily appreciate that dead plant remains, appearing as visible units of the terrain, differ widely as to size, quantity and spatial relationships. At one place in the organic blanket he is traversing, he may encounter "black muck" which, when dry, does not fall away but remains in "chunks" or "cakes". These have a fine granular texture, with larger units in negligible abundance.

Instead of this condition he may come across one in which the sample consists of non-woody (soft, resistant) fibres, short and interlacing to form a mesh. Or he may have selected instead a sample in which the fibres (again non-woody and quite numerous) are long, perhaps up to a foot in length, contrasting with an inch or two for the previous sample. These may be ribbon-like and oriented more or less in a vertical plane.

Or he may discover an example consisting mostly of woody, interlacing and thread-like fibres, forming a mat which offers considerable mechanical strength. These threads may be only a few inches in length, but could be several feet long and follow a tortuous course, conforming to no particular plane. The survey may reveal the possibility of the presence of examples in which the fibres are recognizable as tree roots or branch systems, which make it difficult to procure samples.

In some instances, this woody mesh may be made up of short "chunks", in others of extended "pole-like" units of different lengths. It is not the purpose of this article to discuss isolated mechanical properties or sets thereof which these various examples might furnish. It does, however, seem desirable to emphasize the structural contrast that exists between say, the first and last mentioned examples. Mechanical problems relative to these would also show obvious contrast.

Much could be written about variation in quantity of given particle types occurring within a unit volume of terrain. Shape, as well as size and content of the units, would figure prominently. Suffice it to state here that quantitive range with respect to frequency of given particle type must include levels near 0 per cent, as well as levels close to 100 per cent.

It is well to remember that before the observer there is a range of possible unit sizes which includes both particles of granular size just visible to the naked eye, and units which may be the size of fence posts or even larger. Regardless of orientation it is a natural assumption that some sort of three-dimensional mesh, net or web, will inevitably be present in the organic terrain. The interstices of the mesh may be very small or may be quite large, depending upon the size of the units making up the mesh.

Particularly where the interstices are large, it is not difficult to conceive that a mesh of a second order of size may exist in the interstices of the first order. Where the interstices are extremely small their contents are made up of particles microscopic in size, along with various organic derivatives which together form a material essentially colloidal in nature.

Cohesion and compactability of examples will obviously show up differently, depending upon the nature of the mesh, the size of the particles and the constitution of the interstices. Disintegration and tendency to flow or shift or shear, or to resist compressional forces, are other features that will vary with the physical characteristics of the materials expressed, and depending, too, on their orientation.

Spatial relationships suggest a consideration of the vertical dimension or depth of the organic terrain. The question may arise for instance, as to whether there is a change in range of particle size throughout the depth. This is frequently the case, and the situation may be readily revealed by exposing a profile through the organic blanket. It is important to recognize that this change is, in most cases an orderly one, conducive not only to inspection for quality, but also to measurement.

Where there is change in range of particle size and size of mesh there is noticeable change in the banding or layering that exists in the peaty material. The banding conforms or corresponds with the structural change, making structural correlations and comparisons possible in a given profile or volume of terrain. There are frequent examples, of course, in which the particulate constitution of the organic material is the same for all practical purposes throughout the depth of a section.

Finally, reference should be made to the horizontal dimensions which implies coverage over area. Where the peaty material is uniform in texture throughout its depth, examples are known of its covering areas four or five miles in extent. The deposit as a whole may have a shape which relates to physiographical characteristics of the area in question.

Shapes of deposits more often than not conform to recognizable features or conditions prevalent either in the landscape, or through the nature of the organic material under observation. Where the construction of the material is not the same throughout its depth, but is noticeably banded as revealed in profile, the frequency of change in peat construction over an area is comparatively high.

It can now be seen that reference to organic terrain on the basis of particle size and distribution cannot be considered adequate if use of expressions such as "black muck" are insisted upon. Intelligent appraisal of conditions existing in organic terrain will never be possible, as long as it is thought only necessary to refer to peaty material as constituted of leaves, twigs and other plant remains.

Water Content and Drainage

There must be acknowledgement of the presence of water either in liquid or solid form in relation to a survey of conditions for classification. The peaty material in the organic terrain forms a natural reservoir for water, and conditions are known where drainage is almost impossible. Regardless of particle size, shape and arrangement, the constitution of peat is such that it can retain large volumes of water. It can be shown that like volumes of peaty material differing in physical make-up will drain at different rates, will recharge at different rates and will have different potentialities for maximum water retention.

Structure and amount of organic terrain are also related to natural drainage channels, some of which are obvious to the eye because they exist as river-like systems; others of which are not so obvious, in that they travel within the peat or at the peat-mineral interface, and can only be recognized through impounding.

Before drainage in relation to organic terrain can be adequately assessed, seasonal climatic data have to be related to local field and organic terrain conditions. Enough has been surveyed to establish the claim that water content is not merely related to organic terrain. It enters into its constitution, and must be regarded as a part of "muskeg", along with the peaty material. Thus, water (liquid or solid) enters into the definition of organic terrain, and definitions are fundamental to classification.

Organic-inorganic Interface

In consideration of mineral soils, it often occurs that the engineer must direct his attention to regions within a soil body, where a soil identified as having one set of properties is related physically to a soil identified as having another set of properties. This region of interrelationship is often more important than either of the two parent bodies concerned in the relationship.

Sometimes the zone of contact is very narrow and mainly in one plane. Sometimes there are faults in it, and other structural deformities. Occasionally it may be a zone of some depth—a kind of transition bed which may vary in thickness throughout the zone. In the case of each of the parent bodies referred to, it must be recognized that the attributes of each include a consideration of the fact that the one soil body has the other as its neighbour.

A similar situation arises with reference to the peaty layer of the organic deposit and the mineral soil sub-layer in contact with it. The zone of contact is often quite thin and sharply marked. On the other hand, the writer has worked with an interface material which was mineral matter highly charged with organic material nearly a foot in depth, forming an interbed which varied in thickness and in structural composition.

It is not always the case, as is commonly supposed, that the mineral substrate is fine textured, falling into the category of silts and clays. On the contrary, organic overburden often lies directly upon a coarse grained substrate of a sandy, sometimes gravelly constitution. Indeed, it is not infrequent to find that the peaty layer may be in contact with coarse gravels containing quite large boulders. If the organic layer is only a foot or two in depth, the contour of the boulders or rocky outcrops is imparted to the peaty overburden, and becomes a topographic feature of the organic terrain.

Examination of the zone of interface often reveals wide differences as to relative amounts of water. Sometimes the interface is almost completely fluid. On the other hand, it may be just moist. Water by reason of its presence and abundance is an important component of the interface zone.

Interface problems may be just as great as those involved within the organic layer itself. This is not to suggest, however, that in specific problems, as for instance with highway subsidence involving failure of foundation materials, it is necessarily the interface that must be held responsible. Where a whole roadbed slides to one side, possibly the worst kind of failure found in "muskeg" country, studies suggest that failure is more often a function of structural relationships within the organic layers, which have not been accounted for in surveys that preceded construction.

Emphasis, so far, has been placed on sub-surface constitution. Composition of organic material, water relations and organic-inorganic interface have each been referred to separately. The ultimate system of classification may reveal a relationship linking the three subtopics. Even at this stage of "muskeg" interpretation, prediction of the constitution of the mineral sublayer is not ruled out once the constitution and extent of the organic layer has been determined.

Surface Coverage

For foundation, drainage, construction and trafficability problems, those concerned usually give first consideration to the soil body. With mineral soils, examination of exposures and interpretations from borings are always useful. The same should apply with organic soils. Profile exposures are none too frequent in this case, however, and while borings are always possible, the presence of other field marks can prove useful. In the latter connection, an observer traversing organic terrain is tempted to make use of the upper level of the organic layer. This comprises the aerial and subaerial parts of all the living plants affording coverage for the dead organic material in the rest of the organic overburden.

The Living Organic Layer

For purposes of this survey of conditions for classification, the most important matter is to emphasize that the living organic material is an essential part of the organic terrain. It is certainly included in the literal translation of "muskeg" referred to earlier. Recognition of this means a corresponding extension of the list of properties which have to be used to describe organic terrain.

The field investigator has the responsibility of recording field conditions, as he experiences them in studying organic terrain. He is always alert to the possibility of finding plant types which he may use as valid indicators for various purposes. More often than not, he attempts to find the common name for any plant which he may select. The writer is quite certain that this idea was not initiated by botanists, but by field workers of other professions, trades and vocations.

In an attempt to confirm the validity of this procedure and its degree of usefulness, the writer, particularly in his work in the Churchill area, made a fairly complete collection of plants typical of the organic terrain of those regions. Most of the striking, colourful types of plants have, however, proved troublesome when used as indicators. Perhaps this is partly because certain plant types of the nature referred to are not faithful as indicators for given terrain conditions.

This, however, does not eliminate plants of the living organic layer as analytical indices. Independent field investigators and observers have developed habits of referring to particular kinds of vegetative coverage. Though non-botanists, they apparently had little difficulty in establishing common denominators on which they could compare their experiences, by reference to vegetation properties for which they provided their own descriptive terms. In discussions bearing on these matters such terms as trees, shrubs grasses and mosses would be used. Such reference methods are not new to engineering surveyors, as shown by old survey records. With crude reference terms where precise designations are required, the advice of a trained field botanist is always of value. These preliminary attempts at coverage recognition provide encouragement for the botanist (field ecologist).

The Topographic Factor

In its broadest meaning, topography suggests description of form outline of land areas. Physical features, relating to unevenness of contour, take a prominent position in terrain consideration. In practice, location of drainage basins is also important, but in organic terrain appraisals, expediency rules that attention be given to terrain unevenness. Where water bodies are concerned, the nature and stability of the organic foundation lining the water course must be observed, both beneath the water and at the banks. Whatever the point of view of the field surveyor responsible for the interpretation of field conditions, he is bound to concern himself with over-all form and form trends, if any, as he attempts to traverse organic terrain.

It has been suggested that topographic difference in organic overburden is sometimes due to irregularities in the mineral foundation of the organic blanket. On the other hand, much of the unevenness seen from the surface is due to topographic change within the organic material itself. In studies of mineral soils it is not always easy to demonstrate the reason for topographic change. The same difficulty arises for the organic soils. In the north, frost phenomena are prevalent, and these are the controlling agents in contour establishment and regulation. Other agents are water and wind.

There is evidence that these factors sometimes act together to produce some of the shapes of the organic terrain. Perhaps the most influential agent, however, is one that is a function of the vegetation (dead and living) which forms the organic overburden. This is recognized partly through change in character of the peaty material, and partly through growth habits of certain plants as they augment and accumulate organic debris at their growth sites.

Even if contour phenomena were eliminated as necessities in "muskeg" interpretation, field appraisers and those whose task it is to deal with "muskeg" would be among the first to insist that methods be devised to account for them, to assist in classification and in intelligent appraisal. Coverage and topography are important also in aerial interpretation of organic terrain. But whether the observer is in the air or on the ground, coverage and topography are the conspicuous factors of the organic blanket on which he is primarily dependent.

The Seasonal Aspect

An appraisal of the conditions for classification of organic terrain is not complete without reference to the time factor, as this associates itself through seasonal aspects. In most parts of Canada, "muskeg" is completely frozen throughout the winter. Possible exceptions to this may arise due to the lower depths of very deep deposits being protected from frost for at least a part of the winter by the insulating values of the upper layers of the deposit.

With the approach of high temperature conditions in the far north in later spring and early summer, melting of the active ice commences on and within the organic mass. Due chiefly to drainage lag, for which the peaty materials are partly responsible, the accumulation of water is very marked. This is notably true when rainfall in the early summer is high. If, on the other hand, rainfall is not excessive, and if winds are frequent and strong, excess water and the growth of ponds may not be too noticeable, as compared with average conditions.

The wasting of the active frost layer during the summer months is a slow process. This applies, of course, chiefly in the far north as for example, around Churchill and towards Le Pas in the south. The condition has its effect on the appearance of the coverage, imparting to it seasonal aspects which are characteristic for each time period during summer and early autumn months. The seasonal aspect will vary depending upon coverage and other properties of the organic deposit. Mechanical properties of the various kinds of peaty materials will also show relationship to this seasonal factor.

In field inspection, it is difficult to resolve the seasonal factor into something tangible which can be evaluated in terms other than qualitative. Some assistance is, however, afforded through the medium of colour. With the advance of season there are local and general background colour changes in the coverage. Though the task is not easy, it is possible to measure and record colour response in superficial segments of the coverage, as well as in background coverage. This is done with the aid of the Munsell Colour System.*

**Munsell Book of Color:* Pocket Edition, Munsell Color Co. Inc., 1929-1942.

The Classification System

It is now possible, against the foregoing background, to suggest the main lines of the classification system so far developed to meet the need for accurate identification of muskeg. This is a first presentation only, given in summary form on the basis of work extending throughout five field seasons and winter laboratory working periods.

Coverage Pattern and Typing

Classification depends upon the possibility of revealing organization and relationship. If this can be done, a major first step will have been accomplished. The only other fundamental prerequisite to classification is to plan for a level of adequacy appropriate to the degree of complexity of the materials and conditions being classified. For organic terrain, with its high degree of complexity, several subsidiary systems are required.

One of these systems should be based on coverage. For the purposes of this account, priority should be given to it, in that it is the first factor of the terrain which the observer notices when he encounters a "muskeg" expanse. If coverage classification is to be in terms of a subsidiary system, it would be of little value if its relationship to another subsidiary system dealing with another main factor of the terrain were not anticipated.

In segregating coverage character, therefore, the plan has been devised in accordance with the following rules:—

(1) Only those features of coverage most likely to show direct relationship with features of the dead organic material comprising the bulk of the "muskeg" deposit, will be utilized.

(2) The expressions used in classification will be those best suited to the recognition of organization in the coverage;

(3) The expressions and the level of organization ultimately depicted will be such that they can be used also for aerial inspection and interpretation. Travel over "muskeg" is predominantly by air.

(4) The terms employed will be such that they can be readily understood and utilized by non-botanists; and

(5) Types of coverage that the terms express must be photographed, and authentic photographs must be available for wide use.

As may well be expected, meeting the challenge of this grouping called for much checking and rechecking from the air and from the ground, both in field observation and in laboratory analysis of results. An added complication arose through the need for anticipating trafficability problems and mechanical problems in general, sometimes relating to industrial, sometimes to engineering and sometimes to agricultural, geological, forestry or military requirements.

The accompanying table (Table I) presents the descriptive information for nine coverage class types. Photographs depicting these types appear in Figs. 8-16. An examination of the schedule given in the table will show that the properties mentioned are not referable to species of plants. They relate instead to qualities of vegetation. These are principally stature, degree of woodiness, external texture and certain growth habits easily recognized by an inexperienced observer, especially with the help of photographs. Examples of plant material are given following each colour-type description.

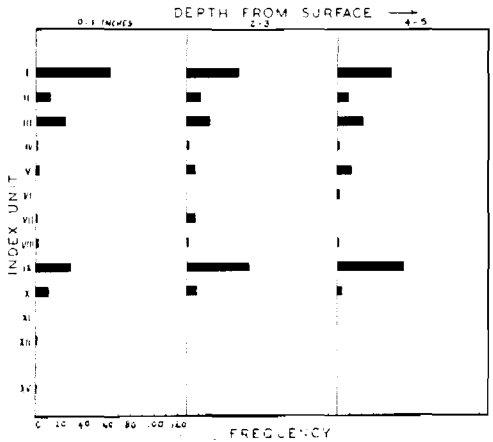
Commenting briefly on method of application, it is important to note in the first place that, when an observer records an appropriate class designation by letter, that letter by reason of its relationships in the table signifies the properties suggested. Seldom do these properties defining the coverage exist alone. They occur rather in combination with properties for which other class letters are symbolic. In other words, one seldom finds pure classes existing by themselves.

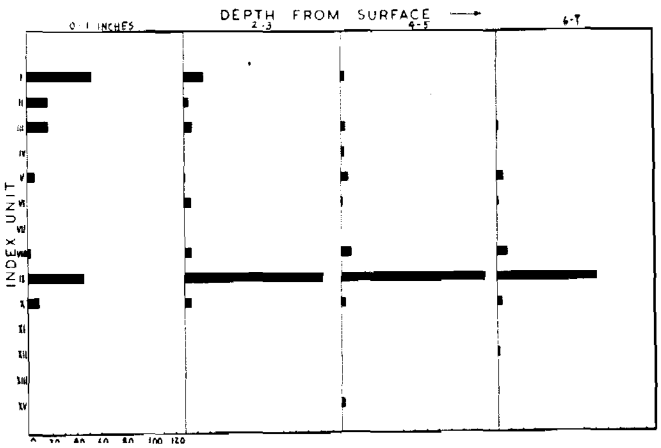
For given areas requiring analysis, practice seems to decree that, if one set of coverage class properties is not present to the extent of twenty-five per cent, it lacks enough prestige to give it significant prominence in the composite cover description. The complete description may sometimes, therefore, be given, though not often, in terms of one, two or three letters.

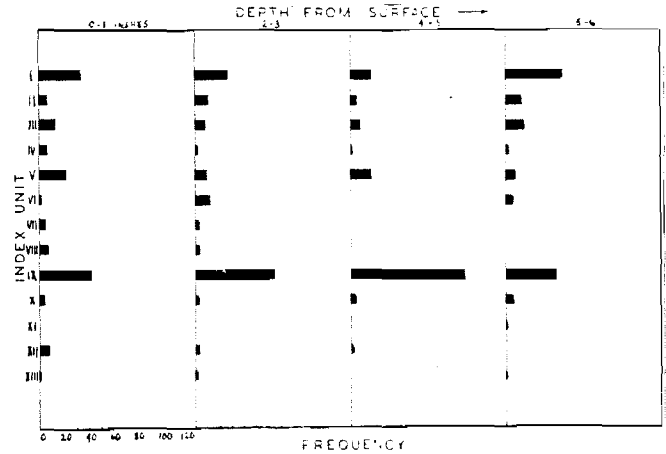
The reader might expect an overwhelming number of combinations of classes. For selected areas in the Churchill region and far to the south, however, this is not the case. For instance, the descriptions involving the use of the letters F - E - I are quite frequent. In the formula, or combinations of letters,

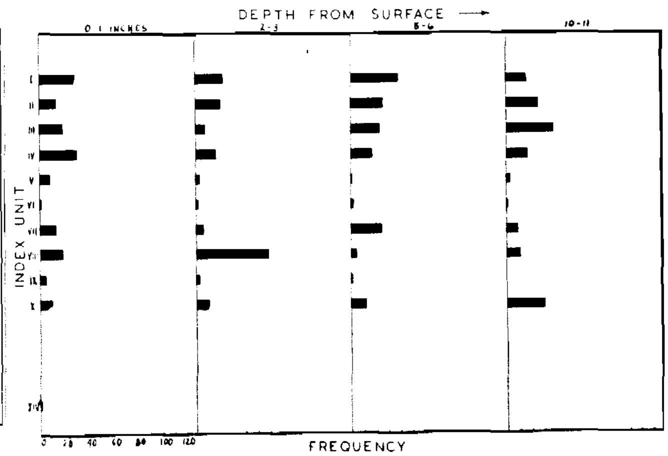
Table I—Summary of Properties Designating Nine Pure Coverage Classes

Coverage Type (Class)	Woodiness vs. Non-woodiness	Stature (approx. height)	Texture (where required)	Growth Habit	Example
A	woody	15 ft. or over	—	tree form	Spruce Larch
B	woody	5 to 15 ft.	—	young or dwarfed tree or bush	Spruce Larch Willow Birch
C	non-woody	2 to 5 ft.	—	tall grass-like	Grasses
D	woody	2 to 5 ft.	—	tall shrub or very dwarfed tree	Willow Birch Labrador tea
E	woody	0 to 2 ft.	—	low shrub	Blueberry Laurel
F	non-woody	0 to 2 ft.	—	mats, clumps or patches, sometimes touching	Sedges Grasses
G	non-woody	0 to 2 ft.	—	singly or loose association	Orchid Pitcher plant
H	non-woody	0 to 4 in.	leathery to crisp	mostly continuous mats	Lichens
I	non-woody	0 to 4 in.	soft or velvety	often continuous mats, sometimes in hummocks	Mosses









Top left to lower right: Fig. 1, Fig. 2, Fig. 3, Fig. 4.

that letter which represents the most prominent set of properties is placed first. If other letters are involved, they follow in the formula in order of prominence.

Thus, the formula gives a description of coverage composition in terms of properties and lays emphasis on the set of values most typical for the area. It is instructive to select at random areas of, say, ten square miles in extent and to analyse them by application of the methods suggested. Within a given area so selected, the frequency and degree of influence that each set of class properties shows is easily derived from the sets of formulae obtained. The formula having greatest frequency will also be revealed.

Finally, if the formulae are mapped, directional trends are exhibited. If several areas are compared with reference to properties, the degree of importance with reference to these factors can be derived, and the pattern exhibiting coverage properties becomes manifest. In short, coverage organization is revealed.

Referring again to the guiding principles, there is good reason to suggest that points 2 to 5 have been satisfied. The aspect of aerial interpretation is being tested on the basis of the method prescribed here, and evidence has been suggested to show that it can be applied satisfactorily. Improvements and adjustments of a secondary nature will doubtless be forthcoming, but fundamentally, main requirements are met. Discussion concerning the application of the method and system in relation to rule (1) will be left to follow the discussion of the next subsidiary system.

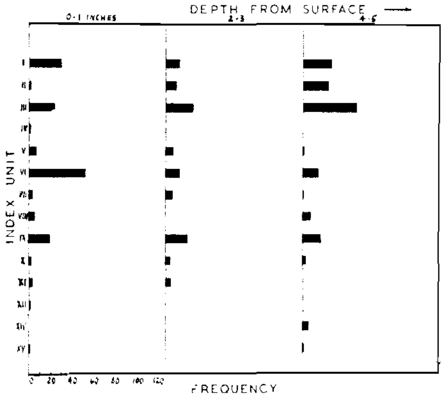
Indexing for Subsurface Character

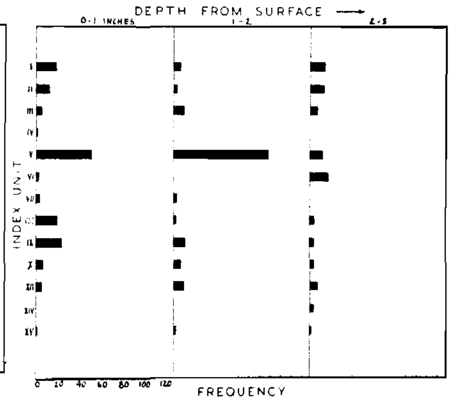
Turning now to the dead organic material in the organic terrain, a different approach is needed to derive a workable classification system. In making the survey of the materials available to which classification is to be prescribed, reference has been made so far to macroscopic features only. Attention of the reader has been called to information suggesting the presence of a mesh structure and related interstices. There is some evidence suggesting that differentiation of peat samples might be accomplished through an understanding of mesh size, construction and prevalence.

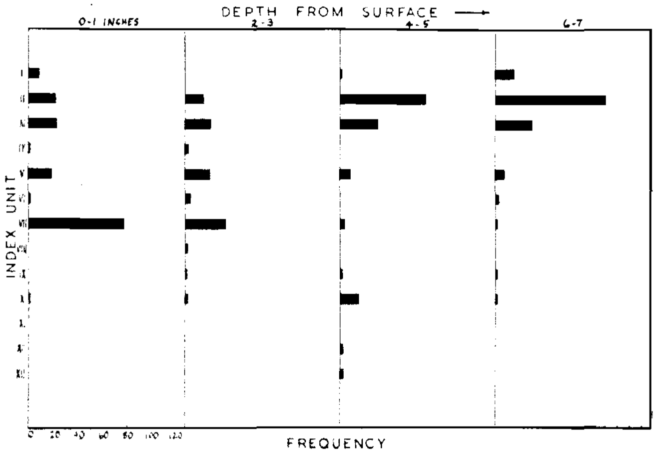
This alone is not enough, because during the formation of the organic body the mesh characters might well remain relatively constant, particularly with the larger sizes of mesh, while characters of the peaty material might change. The nature of a secondary mesh, for instance, could easily change in constitution without noticeable change in the structural relationships of the primary mesh. The material in the interstices might also change with time, in amounts sufficient to alter the physical properties of the peaty deposit as a whole.

Consequently, if some method of classification could be devised to give a record of the succession of vegetation, built into the deposit as a whole in the course of time, this would provide a more certain basis. It would also permit a better understanding of the macroscopic ingredients from the point of view of both classification of properties and the appreciation of mechanical problems.

To accomplish this task, it is necessary to look to a study of microscopic constituents. As the components of past vegetation matured and contributed their remains to peat formation, their presence was recorded by the numerous pollen grains, which are normally preserved as they fall into the peat. Many of these are doubtless carried some distance before they alight. It is, however, a reasonable







Top left to right: Fig. 5, Fig. 6. Lower: Fig. 7.

assumption that large numbers, if not the majority, fall in the area where they are produced and provide a continuous record of the vegetation.

Should it occur that, during this recording, climatic conditions at intervals are such that the surface of the deposit is dessicated, preservation would be interrupted and the continuity of the record broken. This, however, is not a serious matter if these fragments (microfossils) are to be used to symbolize that vegetation which had been preserved, and whose record had not been destroyed by climatological conditions. It is only the existing portion of the deposit that is before the observer for interpretation. It is to these microfossils that the writer turned for help in classification problems relative to sub-surface conditions.

In the initial part of the investigations there was much hesitancy concerning this approach. This was partly because much of the field work was being carried out in the north, sometimes at latitudes further north than Fort Churchill, Manitoba.

Most of the work done in connection with microfossils has, however, been related to forest history and the study of past climates. For this the chief kind of microfossil utilized is that derived from tree pollens, and in the north there are vast areas which are treeless. For the present work the kind of microfossil which would carry most influence would be that which has been produced by plants growing on the site under examination. The question arose whether there were enough of these relicts throughout the peaty deposit to provide material that would stand statistical analysis. It took two summers to convince the writer that this was a reasonable possibility, and detailed analyses were then pursued on a broad and intensive scale.

This approach for recent organic deposits is entirely new, particularly when it is associated with the idea of revealing properties for classification purposes. It is not new, however, applied to coal structure, stratigraphy, and utilization problems. The difficulty of readapting techniques of analysis and providing new ones caused some complications. Planning and carrying out the field work on a sufficiently broad scale was time-consuming.

The materials studied for microfossils were obtained from the field, either as cylindrical cores taken with a peat borer (Hiller Model), or as channel samples from an exposed peat profile. The ultimate analyses were made from portions one cubic inch in size, removed at intervals from different levels of each core. Usually every second inch was examined. The microfossils were released from the rest of the peaty matrix with the use of chemical reagents (ten per cent potassium hydroxide is most frequently used by palaeobotanists for this purpose). Following washing and centrifuging, a few drops of the sediment were transferred to microscope slides for permanent record.

It was from each of these sets of preparations that microfossil identifications and counts were made. For this, the usual practice adopted by palaeobotanists is to count two hundred microfossils with the aid of a microscope fitted with a mechanical stage, then determine from this the proportion of each kind or category of microfossil. Sometimes the total number counted may be less than two hundred where statistical comparisons seem to warrant it. This was the method adopted for the investigations reported here.

When it was reasonably certain that enough samples had been analysed to reveal a complete range of microfossil types, attention was centred on variation in frequency for each kind of microfossil, at different depths in the peat and in many locations over a wide area.

The fundamental aim was to utilize the microfossils as identifiable reference units, which would point to state, organization, and change, if any, for all manner of peaty profiles and examples which showed even slight structural differences. For the non-botanist, recognition need only be given to the fact that in the process of analysis these microfossils are related to the plants from which they are derived. If this is appreciated, it is then only necessary to call each microfossil category an index unit and to give it a number. The strictly botanical aspects can be dealt with elsewhere.

One more brief point requires explanation before the inspection of results should be made. This has reference to microfossil frequency. Not only is the actual presence of particular microfossils significant; numbers at given levels in the peaty deposit provide data equally, if not more significant, in evaluating results. It must be emphasized also that wherever numbers of index units are mentioned, *relative numbers* are inferred.

Attention may now be directed to Fig. 1. Each of the three sections of the diagram records the occurrence and relative frequency of the microscopic index units for three depth intervals within a core sample. The core was analysed according to the method described earlier.

There should be no difficulty in understanding the terminology expressed at the co-ordinates of the graph in the figure. Each configuration in successive histograms designates both presence and frequency for an index unit. Because these configurations differ as to length, collectively they provide a histogram pattern useful in classifying the condition with respect to the microfossil features for the appropriate depth. For the three sets of histograms indicated, observe there is close similarity in appearance and therefore in classification value. Examination of the detail within each histogram reveals important information. It is of primary importance to recognize the more general feature, namely that which demonstrates relationship in histogram pattern.

Similarity, in the form of faithful repetition suggests stability in the constitution of the peaty deposit throughout its depth. This is in addition to the more fundamental fact that these methods provide the means for a practical comparison —one which is confirmable and which lends itself to quantitive measurement.

It is encouraging to the investigator, and to all those who desire to interpret organic terrain conditions, to discover that these first data assist in establishing confidence in the matter of classification of the dead organic material, not only in principle, but also at the level of practical necessity.

Referring now to Figs. 2, 3 and 4, similarity in histogram pattern will also be observed. It is true that there are slight differences. These are of a secondary nature, however, and can be rationalized when matters of detail are under consideration. This lends support to the view that the analytical methods have validity, and that a reliable basis for classification is established.

The next significant feature of the results is that for a given set of histograms, the set of patterns is peculiar to that example. For instance, a comparison of Figs. 1 to 4 shows that marked contrast exists among the four examples, in spite of the high degree of similarity in each. Thus peats, stable in constitution throughout their depth, may differ in constitution one from the other. This then is another major and encouraging demonstrable fact revealed through application of these methods. It is further proof of organization, it affords classifiable data, and it refers directly and indirectly to constitutional features utilized as factors in the interpretation of peaty materials in the muskeg. Deliberate attempts have been made to avoid the use of botanical expressions, in order that field reference may be made in terms understandable to all.

There is yet a third general organization feature discernible. For this, reference should be made to Figs. 5, 6, and 7. A comparison of these histogram sets shows:—

(1) Dissimilarity of histogram pattern for each set;
(2) Each set differs in pattern from the others;
(3) Organization still reflected in spite of variation as suggested in points 1 and 2;
(4) Constitutional trends (not stability) which have arisen with growth in depth of the peaty deposit; and
(5) Each item (1 to 4) can be assessed on a quantitative measureable basis.

The data used in these graphs are derived from only seven bore samples from the Churchill area. Hundreds of such samples have now been taken, and many of them examined for index unit relationships. Samples are also available from northern Sweden, the Orkney and Shetland Islands, as well as from several places in Canada. When enough histogram patterns are available for wide comparison, relative prevelance of pattern, and hence relative prevalence for organization trends, may well be discernable.

In the meantime a workable and adaptable system for identifying peats is now available. That it is workable has been demonstrated. That it is adaptable has been only partly demonstrated. In connection with the latter, the question arises, how can the system be utilized in demonstrating organization from the standpoint of structural features, significant from the aspect of mechanical problems? The answer depends in part on a consideration of other subsidiary systems of classification, two of which have not yet been reviewed. One of these which deals with topography will be presented next.

Descriptive Terminology for Topographic Features

In the section dealing with the relationships and importance of the topographic factor to problems of surface coverage classification, an account of the precise terms of classification for topography was omitted, for inclusion under this main chapter on classification. As was the case in selecting type categories for vegetation coverage, and in selecting type index units for subsurface appraisal, so with topography type expressions are necessary. It is important in making the selection that they prescribe to all contour phenomena, that they conform if possible to expressions already in use, and that they be as few in number as circumstances permit.

Table II—Terminology and Properties for Topographic Classification

Contour Type	Formation	
a	Hummock	includes Tussock and Nigger-head, has tufted top, usually vertical sides, occurring in patches, several to numerous.
b	Mound	rounded top, often elliptic or crescent shaped in plane view.
c	Ridge	similar to Mound, but extended, often irregular, and numerous; vegetation often coarser on one side.
d	Rock gravel plain	extensive exposed areas.
e	Gravel bar	eskers and old beaches.
f	Rock enclosure	grouped boulders overgrown with organic deposit.
g	Exposed boulder	visible boulders interrupting organic deposit.
h	Hidden boulder	single boulder overgrown with organic deposit.
i	Peat plateau (even)	usually extensive and involving sudden elevation.
j	Peat plateau (irregular)	often wooded, localized, and much contorted.
k	Closed pond	filled with organic debris, often with living coverage.
l	Open pond	water rises above organic debris.
m	Pond or lake margin (abrupt)	
n	Pond or lake margin (sloped)	
o	Free polygon	forming a rimmed depression.
p	Joined polygon	formed by a system of banked clefts in the organic deposit.

Through field experience it has developed that the accompanying table of expressions is adequate in classifying topographic properties (Table II). Many of the features listed in the table occur, as far as this writer is aware, only in regions north of, say, Le Pas, and more frequently as one proceeds northward. The system is therefore somewhat detailed for prevailing conditions in the south or in northern Europe. All the criteria mentioned are useful, however, especially in aerial inspection and in enhancing applications of the classification system devised for vegetative coverage of the organic terrain. Reference to this aspect will be made later.

Other Physical Phenomena

The importance of drainage in muskeg problems has already been indicated. For purposes of classification, drainage becomes a secondary problem and its features can best be understood by a more thorough knowledge and application of the subsidiary classification systems mentioned in preceding sections. It would seem that this same view still holds, even if we regard the water factor not from the point of view of drainage, but rather from the aspect of presence or absence of water in given terrain examples, both fluid and solid. No subsidiary classification system seems necessary, therefore, to deal with the water factor.

As has been suggested, the water factor is largely a function of seasonal and climatological influence. The latter seems to be secondary from the point of view of classification for organic terrain; the former, though directly pertinent, is highly intangible and difficult. The utilization of colour, however, to display seasonal trends, and visible indices in the terrain is not impracticable. Much is being done to exploit it for classification purposes, as well as for aerial interpretation of organic terrain.

If an attempt is made to assess colour in terms of absolute values rather than range, it will meet with certain failure. When, however, classification is based on range, and is applied to the contrasting vegetation groupings represented in coverage formulae, there is much to be gained. By the application of the Munsell Colour System the seasonal factor in the organic terrain can be intelligently appraised. It is hoped that a future report will be prepared to cover this phase of the work. Pocket editions of the Munsell System are obtainable for field use, and range of colour formulae can be worked out on the spot for various coverages at different times.

Little can be said at this stage about classification with respect to organic and mineral soil interface. Temporary assistance, however, can be attained for this purpose through a discovery of interface conditions wherever sampling is desirable. Reference has already been made to the fact that various kinds of substrates can be expected when exploring at the base of the organic layer, whether this be a few inches or many feet in depth.

Colour in terms of hue, degree of greyness, and intensity in the subject material, along with interface character expressed in qualitative terms, can readily be added to information derived through the application of the other subsidiary systems, to give the over-all picture of the inter-relationship of properties for the organic terrain.

Application of the System and its Potential Value

Whatever the final form may be for a suggested system of classification of "muskeg", it is clear that the integration of several subsidiary systems is required. This idea is directed towards the need for differentiating muskegs, whereas rules of classification normally demand that an adequate definition be given first of the general material to be classified. "Muskeg" has become the term designating organic terrain, the physical condition of which is governed by the structure of the peat it contains, and its related mineral sub-layer, considered in relation to topographic features and the surface vegetation with which the peat co-exists.

The next logical step in "muskeg" classification is to apply the subsidiary systems to given examples of "muskeg". Part of this is best done in the field, as in the case of mineral soils. The remainder can be done in the laboratory, again as is done with mineral soils after appropriate bore samples have been procured and analysed in systematic order. On the record sheet attached to each sample will appear, "coverage description" (Table I). Following this will be the terminology pertinent to topography classification (Table II).

In both of these cases care should be taken to note the position of the sample or samples, relative to the limits of the coverage formula location, and the proximity to topographic change. This factor may be recorded in terms of linear measurement. Third on the list are the Munsell reference formulae appropriate to the position of the sample

Data Sheet I

Sample	Bore 173.
Location . . .	Fort Churchill, Manitoba. Area P_5, A run at intersection with B in the airphoto. (Sonne x26, x38, x201, x202, x210).
Date	30 August, 1948.

INTERPRETIVE DATA (FIELD)

	Direct Method	Photo Method (Sonne)
Coverage description	H E (Table I)	H E
Topographic classification . . .	i (Table II)	i
Munsell formula	10.0Y $\frac{5\text{-}6\text{-}78}{2\text{-}4}$	2.5Y $\frac{8}{6\text{-}8}$ 7.5Y $\frac{8}{8}$
	2.5GY $\frac{6\text{-}7\text{-}8}{2\text{-}4}$	5.0Y $\frac{8}{6\text{-}8}$
Proximity to topographic change	50 ft. approx.	50 ft. approx.
Field photos	x29 Nos. 13 to 16	

Data Sheet II

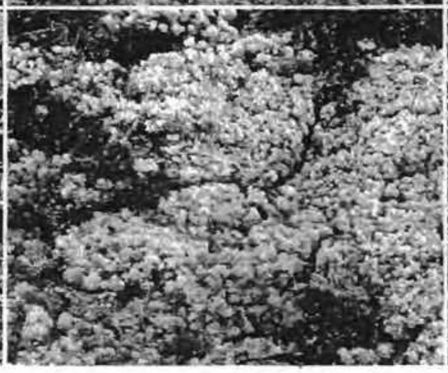
INTERPRETIVE DATA (LABORATORY)

Slide Nos.	1040, 1046, 1127.
Analysis Sheet	No. 14.
Intervals Examined . . .	0-1″, 1-2″, 2-3″.
Index Units . . . . (Occurrence & Frequency)	Histogram pattern deposited in laboratory Royal Botanical Gardens, Hamilton. (See Fig. 3 and remarks below.)
Macroscopic Features . . .	Not sharply banded, fine mesh, granular to non-woody at base changing to: granular to woody fibrous at top resting on sand/gravel base. Near to highly decomposed less stable non-woody fibrous derivative.
Remarks	Histogram pattern reveals predominance of index unit IX at all depths but decreasing at the surface. Units V and IV and VI are prominent at the surface.








Top row: Fig. 8. Coverage Class A.
Fig. 9. Coverage Class B.
Fig. 10. Coverage Class C.
Centre row: Fig. 11. Coverage Class D.
Fig. 12. Coverage Class E.
Fig. 13. Coverage Class F.
Bottom row: Fig. 14. Coverage Class G.
Fig. 15. Coverage Class H.
Fig. 16. Coverage Class I.

or samples in the field, and based on coverage colour in the region where the samples were taken. Information concerning date and local prevailing climatological conditions should be appended to this record.

This information should then be sent to the laboratory, along with the sample or samples, in order that further data can be added following analysis. This will appear in the form of series of histogram patterns showing index unit relationships. These will be few or several, depending upon the number of bore samples procured and the extent and detail of information desired. Appended to this should be notes concerning the macroscopic or gross structural features of the peaty material, as they appear in the sample or samples. Field notes concerning the proximity of other structural types in neighbouring locations would be useful in the appendix. This would be particularly the case if bore samples were few in number and the area concerned was one which appeared to contain a variety of structural types of organic terrain conditions. An example of a reference sheet accompanying a field sample is shown in the accompanying Data Sheets.

The analysis suggests fine textured wood-fibrous organic matrix will predominate, but will be interrupted at intervals of twenty-five to a hundred feet with discontinuous areas of coarser, mechanically resistant woody matrix. This general type of terrain will thin out in some areas, giving place to relatively low-lying non-woody fibrous peat. The latter kind of matrix will probably be fairly continuous as a common base for all the organic coverage.

Topography will be generally moderately irregular, with abrupt and frequent amplitude of change averaging about a foot. Ponding will not be so great as to render traversability unpractical. The terrain will be moderately well drained. Sub-surface ice contour will be irregular with isolated well covered prominences until towards the end of August. Tree coverage is generally sparse for this kind of peaty coverage.

When the classification picture thus derived is complete, interpretation of the organic terrain conditions is then possible. To those who have not worked with "muskeg" it may seem unfortunate that so much by way of classification data is required. Those who have worked with mineral soils however, will perhaps not be surprised because the degree of complexity involved in this procedure does not exceed that which the mineral soils demand.

In any event, it would appear that with organic soils, this apparently high level of complexity is further reduced through the possible existence of relationship between subsurface and surface conditions in the organic terrain, and which are shown in the classification record.

Thus, where coverage class F predominates for a given set of examples, and index unit IX in the histogram configurations is consistently prominent throughout the depth of the organic matter, it is highly probable that the macroscopic or visible component of the peat that will predominate is of the fibrous ribbon-like structure, and that this condition will hold for the entire depth of the muskeg at that place.

It is a simple matter to check on this with histogram configurations available, but it is most convenient, especially for those anxious for quick field appraisal methods, to discover that by scanning the coverage and making sure of the appropriate formula, they can assess the structure of that which lies beneath. This would obtain for the situation as represented in Fig. 1. It would also hold for the situation as shown in Fig. 2, and for the same reasons.

It would also apply for the case indicated in Fig. 3, but the situation which brings index units IV, V, VI, into relatively greater prominence would also be reflected in the surface coverage formula. Predominance of woodiness, and greater strength of fibre would be noted in the peaty material—factors which again could have been predicted. Shift in character of histogram pattern as exemplified in Figs. 6 and 7, also relates to surface properties as depicted in coverage formulae.

For the peaty material represented in Fig. 7, fine woody fibrous mesh at the top with coarser and stronger mesh at the base would be expected. The writer believes most of this detail could be predicted from knowledge of the vegetation coverage formula. In this case as with the others, laboratory analysis provides the best means for confirmation, particularly if the knowledge is to be applicable for areas extending a good distance beyond the zone of sampling.

The index unit composition (Fig. 4), suggests a gross structure predominantly non-fibrous, and non-woody, changing near the surface, however, to a slightly fibrous-woody constitution. In order to predict this from surface observations, however, more formulae depicting coverage conditions would have to be secured than usual. Also without laboratory analysis the change in peaty constitution might not be detected. Certainly its extent could not readily be estimated.

For a superficial examination, especially for purposes of aerial interpretation, surface and subsurface relationship holds to a workable and encouraging degree. There is no doubt but that the microfossil analysis on the index unit basis suggests structural character, particularly with regard to occurrence and possible extent of secondary mesh and presence or absence of constitutional stability.

Referring more generally to potential value of the suggested classification system, it should be noted that it is the combined or integrated (master) result, rather than a single subsidiary system, which lends itself to adequate interpretation and possible solving of mechanical problems. Such problems range from trafficability to drainage; from insulation and utilization problems to questions involving possibility of support for forest coverage in developmental and control programs.

The correlating of organic terrain features is most important for Canada. Like subsurface geology, it is a subject which depends upon intelligent prediction. Complete success in this can follow only from proper application of field and laboratory classification records. As these accrue, not only will the possibility for better correlating benefit, but the classification system will improve. Certainty can be obtained only by the study of many samples. To this end the writer asks the help of all and invites everyone to have "muskeg" samples sent to him from any area in Canada.

The system is the first ever devised to assist in identifying and distinguishing "muskeg" samples; to reveal and to record the organization in "muskeg"; and to serve as a basis of appraisal for "muskeg" structure and its mechanical properties. It will be used also for opening the way to intelligent aerial interpretation. The attempt to establish this to the exclusion of botanical expressions has been deliberate, in order that all who work with "muskeg" and who are interested in it may use the system and make suggestions in the anticipation of refinement and improvement. There is much to be contributed to the new and specialized field of applied botany on which "muskeg" interpretation depends—a field which for want of a better expression has been designated as palaeovegetography!

Acknowledgements

The writer wishes to acknowledge the interest of the National Research Council and the Defence Research Board, which have provided financial assistance towards this and related investigations. Special thanks are due to Robert F. Legget, Chairman of the Associate Committee on Soil and Snow Mechanics, National Research Council, and Director of the Division of Building Research of the National Research Council of Canada. He has been a source of sustained inspiration and encouragement.

To colleagues, assistants and students whose help in the field and in the laboratory and whose interest in "muskeg" continues, the writer is grateful. Appreciation is due also to Colonel Graham W. Rowley, Arctic Research Section, Defence Research Board, and to members of the "Sub-Committee Muskeg" of the Associate Committee on Soil and Snow Mechanics, N.R.C., for their encouragement, criticism and suggestions. √

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NATIONAL RESEARCH COUNCIL

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

LIST OF TECHNICAL MEMORANDA

No.	*Date*	*Title*
1	August, 1945	Proposed field soil testing device.*
2	September, 1945	Report classified "restricted"
3	November, 1945	Report classified "confidential"
4	October, 1945	Soil survey of the Vehicle Proving Establishment, Ottawa.*
5	November, 1946	Method of measuring the significant characteristics of a snow-cover. G. J. Klein.*
6	November, 1946	Report classified "confidential"
7	March, 1947	Report classified "restricted"
8	June, 1947	Report classified "confidential"
9	August, 1947	Proceedings of the 1947 Civilian Soil Mechanics Conference.
10	October, 1947	Proceedings of the Conference on Snow and Ice, 1947.
11	March, 1949	Proceedings of the 1948 Civilian Soil Mechanics Conference.
12	May, 1949	Index to Proceedings of Rotterdam Soil Mechanics Conference. (Soil Mechanics Bulletin No. 1).
13	June, 1949	Canadian papers: Rotterdam Soil Mechanics Conference.
14	December, 1949	Canadian papers presented at the Oslo meetings of the International Union of Geodesy and Geophysics.
15	April, 1950	Canadian survey of physical characteristics of snow-covers. G. J. Klein.
16	April, 1950	Progress report on organic terrain studies. N. W. Radforth.
17	August, 1950	Proceedings of the 1949 Civilian Soil Mechanics Conference.
18	November, 1950	Method of measuring the significant characteristics of a snow-cover. G. J. Klein, D. C. Pearce, L. W. Gold.
19	April, 1951	Proceedings of the 1950 Soil Mechanics Conference.
20	May, 1951	Snow studies in Germany. Major M. G. Bekker, Directorate of Vehicle Development, Department of National Defence.
21	August, 1951	The Canadian snow survey 1947-1950, D. C. Pearce, L. W. Gold.
22	October, 1951	Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1950–June 1951).
23	May, 1952	Proceedings of the Fifth Canadian Soil Mechanics Conference, January 10 and 11, 1952.

*Out of print.