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NATIONAL RESEARCH COUNCIL

ASSOCIATE COMMITTEE ON GEOTECHNICAL RESEARCH

# PROCEEDINGS

of the

# ELEVENTH MUSKEG RESEARCH CONFERENCE

6 and 7 May 1965

Prepared by

I. C. MacFarlane and Miss J. Butler

TECHNICAL MEMORANDUM NO. 87

OTTAWA

May 1966

# FOREWORD

This is a record of the Eleventh Muskeg Research Conference, which was held in the Lecture Building of Laurentian University, Sudbury, Ontario, on 6 and 7 May, 1965. The Conference was sponsored by the Associate Committee on Soil and Snow Mechanics of the National Research Council. A list of those in attendance is included in Appendix "A" of these Proceedings.

Four technical sessions were held, during which 14 papers were presented, together with a number of prepared discussions. Chairmen of the sessions were Mr. C. O. Brawner, Mr. I. C. MacFarlane, Dr. J. Terasmae, and Mr. G. Tessier. A wide variety of topics was covered, including consolidation testing of peat, engineering classification systems, black spruce growth on peat lands, utilization of peat, aerial interpretation factors, road construction, and trafficability and mobility problems.

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Le Comité Associé de la Mécanique des Sols et de la Neige se fera un plaisir de faire parvenir sur demande la traduction française des communications présentées dans ces comptes rendus.

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## INTRODUCTORY REMARKS

Dr. N. W. Radforth introduced Dr. S. G. Mullins, President of Laurentian University, who warmly welcomed delegates to the Conference. He expressed pleasure that the University is being utilized for meetings of this type and predicted that the practical results of the Conference discussions may well be felt for many years to come.

Dr. Radforth commented favourably on the remarkable progress made by Laurentian University in such a short time. On behalf of the Associate Committee on Soil and Snow Mechanics of the National Research Council, he expressed appreciation for the excellent facilities which were made available for the Conference. He pointed out that the ACSSM is interested basically in two things: (1) An expression of the purpose of NRC (to generate, coordinate and disseminate information dealing with fundamental and applied studies); (2) Canadian terrain in all its aspects. There is a new note now in muskeg studies arising out of two factors: (a) objectives in access have been met in part with the development of new vehicles and concepts; (b) the importance of water supply in the North is now becoming very important and organic terrain is the largest reservoir in the country for water. Consequently, as the Muskeg Subcommittee starts into its second decade, there is this new hydrological aspect of development.

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# I.1 THE PROGRESS OF CONSOLIDATION IN AN ORGANIC SOIL

Nyal E. Wilson* and M. B. Lo**

Abstract

This research involves the determination of the progress of consolidation through an organic soil. X-rays were taken of the consolidating soil to record the settlement at different levels so that a relationship could be established between the behaviour of a thin layer of peat and the behaviour of layers of peat making up a thick sample. The occurrence of secondary consolidation, during the progress of consolidation through the layer, was investigated.

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# I.1 L'EVOLUTION DE LA CONSOLIDATION DANS UN SOL ORGANIQUE

Nyal E. Wilson et M. B. Lo

Résumé:

L'objet de cette étude a été de suivre l'évolution de la consolidation dans un sol organique. L'échantillon du sol soumis à l'étude a été analysé aux rayons-X afin d'enregistrer le tassement à différents niveaux de manière à ce qu'une relation puisse être établie entre le comportement d'une couche mince de terre noire et celui de plusieurs couches formant un échantillon épais de terre noire. On a enquêté sur la part de la consolidation secondaire prise pendant l'évolution de la consolidation dans une couche de terre noire.

* See Appendix "A" for affiliation.

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When a load is applied to a saturated soil, the load is carried initially by the water as "excess pore water pressure". As consolidation proceeds, the load is transferred to the soil structure and dissipation of the excess pore water pressure occurs. Consolidation is associated with the drainage of water and a volume change.

Terzaghi developed the mathematical solution for one-dimensional consolidation (Terzaghi, 1925); this solution is based on a number of simplified assumptions. One of these assumptions is that secondary consolidation does not exist and that the time lag of consolidation is due entirely to the permeability of the soil. Organic soils are not in the category where secondary consolidation should be ignored. The limitations of the assumptions used in Terzaghi's theory of consolidation have led to considerable research and many modified theories. Most of these theories have tried to separate the process of consolidation into two parts, namely, "primary consolidation", which is associated with the drainage of water from the soil, and "secondary consolidation", which continues to occur after the pore water pressures have been reduced to almost zero. None of these theories can explain the nature of secondary consolidation and the significance of secondary consolidation in the prediction of settlements in the field on the basis of laboratory testing. In the research described herein, the consolidation of peat is studied from a fundamental viewpoint.

In consolidation calculations, void-ratio is defined as the average value of the ratio between void volume and solids volume through the height of the sample during the consolidation process; this definition is not valid until the water-content reaches equilibrium. Consolidation proceeds from the drainage face and it is possible to have the consolidation process complete at this face and to have no consolidation at some distance from this face. As secondary consolidation is dependent upon the rate of consolidation (or the strain rate), it must be considered in the zones where the strain rates are high.

As the strain rates in laboratory testing are many magnitudes greater than in the field, the division of consolidation into primary, secondary (and, perhaps, tertiary) is important.

## Apparatus

Radiographic technique was used in this research to record the movements at different levels within the consolidating peat sample.

## Consolidometer

The consolidometer cylinder, $4\frac{1}{2}$" in diameter by 6" high, was made of lucite. Reference levels were scribed on the outside of the cylinder to facilitate the placement of level markers. The piston was fitted with a porous stone (Norton #P260) and the loads were applied by dead weight. Provision was made for the measurement of pore water pressures in the base of the consolidometer.

## X-ray Equipment

A 130 Kilovolt X-ray apparatus, at a distance of 30 inches from the peat sample, was used to make a continuous recording of the movements. Due to the excessive stray radiation, it was necessary to surround the X-ray source with a heavy lead shield; the source was left running continuously and recordings were made by opening a lead shutter. Details of the equipment, including the X-ray control panel and lead shield, are shown in Figure 1.

Kodak X-ray film (type KK), with 0.005 inch thick lead intensifying screens, was used. The lead screens were used to absorb the long wave length scattered radiation and intensify the primary radiation.

## Markers

Lengths of wire solder were placed horizontally in the peat sample as markers; these lead markers were 3" long and 0.015 inches in thickness. They were placed along the centre line of the sample at half-inch intervals vertically. Horizontal and vertical markers were located on the outside of the consolidometer as reference lines.

## Sample Preparation and Test Procedure

Amorphous-granular peat, from Parry Sound, was used in this research. The water content at the start of the test was 725% of dry weight; the ignition loss was 25.5% of dry weight.

The sample was prepared by slowly filling the consolidometer with the peat. Markers of lead solder were located at half-inch vertical intervals during the placement of the sample. To check that no settlement of the lead markers occurred under their own weight, a dummy sample was left standing without any load, and it was found that there was no perceptible settlement. The weight of a marker was 0.06 grams.

At the end of the tests, the sample was removed and the water-content checked through the sample.

## Analysis of Movements

The results of the X-ray recordings were plotted to analyze the behaviour of individual layers within the sample.

The settlements, at different levels, were plotted versus logarithm of time (Fig. 2). This graph shows the general trend of the movements at different levels and indicates that consolidation at the base of this sample did not commence until consolidation was almost complete at the surface.

As the progress of consolidation is dependent upon a few factors, namely, applied stress, permeability and layer thickness, the results were replotted to eliminate the influence of layer thickness. The settlements were related to the original height (i.e., strain) and plotted as (1 - strain) versus logarithm of time (Fig. 3). This graph shows that the ultimate strains for layers at different levels are similar and also are similar to the strain for the entire sample. The conclusion that can be drawn from this graph is that the settlement of a thick stratum is proportional to the settlement for a thin sample but that the time to reach the ultimate settlement is not linearly related to the thickness.

Figure 3 also shows that the upper layer consolidates rapidly but that subsequent layers take longer to consolidate; this delay is probably due to the rapid change in permeability of the upper layer.

As secondary consolidation is a function of strain rate (Taylor, 1942), the data was replotted to determine the strain rates (Fig. 4). This graph shows the strain rate on logarithm scale plotted versus logarithm of time for different levels within the sample and shows that a significant change in the rates of consolidation occurs during the consolidation process. It has been found that this change occurs earlier than the end of primary consolidation (as determined from the e - log.t curve) and earlier than the dissipation of the pore water pressure to zero (Wilson, Radforth, MacFarlane and Lo, 1965). This change in rate occurs when the primary consolidation is predominated by the secondary effects.

Referring to Fig. 4, the pore water in the top layer can drain readily after the application of the load and the rate of consolidation of this layer is initially very high and gradually reduces. In the early stages of the consolidation process, there is no consolidation of the lower layers. After some time elapses and the rate of consolidation of the top layer reduces, the next layer starts to consolidate and the rate of consolidation increases from zero to a maximum and then decreases; the maximum value is less than the maximum for the top layer. This pattern of changing rates of consolidation is repeated for all of the layers. It can be seen that soil within the sample increases in consolidation rate at some time after the load is applied and it is within this period of high strain rates that secondary effects are important.

## Conclusion

This research shows that consolidation of peat is a continuous process starting at the drainage face and proceeding into the sample. The rate of consolidation, which affects the magnitude of secondary consolidation, varies with the elapsed time after loading. From this observation, it can be concluded that secondary consolidation occurs at different levels and times throughout the sample. It is due to this secondary consolidation occurring throughout the consolidation process that settlement predictions, using the classical Time Factor Equation, are invalid.

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## REFERENCES

Taylor, D. W. "Research on Consolidation of Clays". Department of Civil and Sanitary Engineering, Massachussetts Institute of Technology, 1942.

Terzaghi, K. "Erdbaumechanik". Vienna, F. Deutiche, 1925.

Wilson, N. E., Radforth, N. W., MacFarlane, I. C. and Lo, M. B. "The Rates of Consolidation for Peat". Proceedings, 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, 1965.

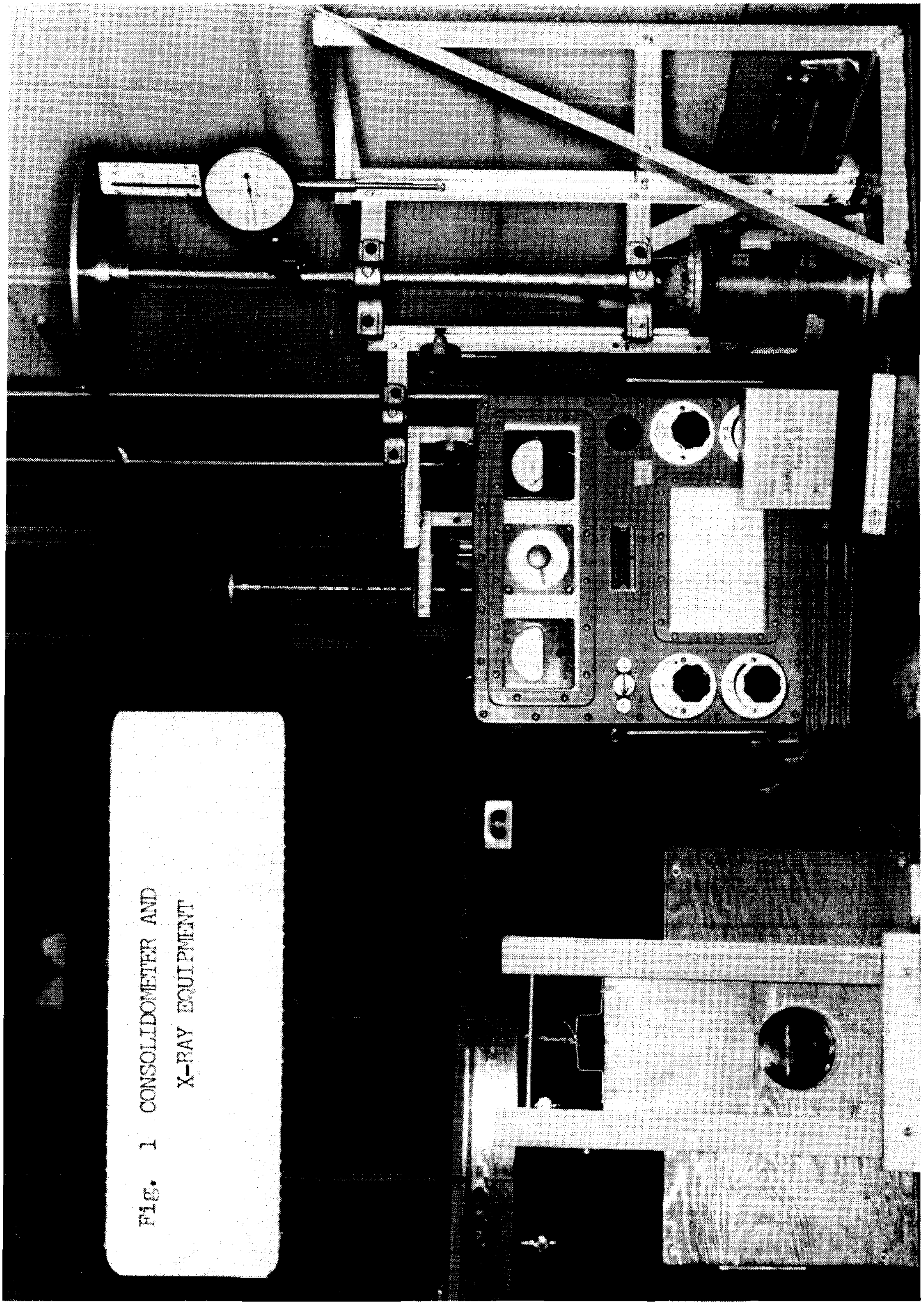


Fig. 1 CONSOLIDOMETER AND X-RAY EQUIPMENT

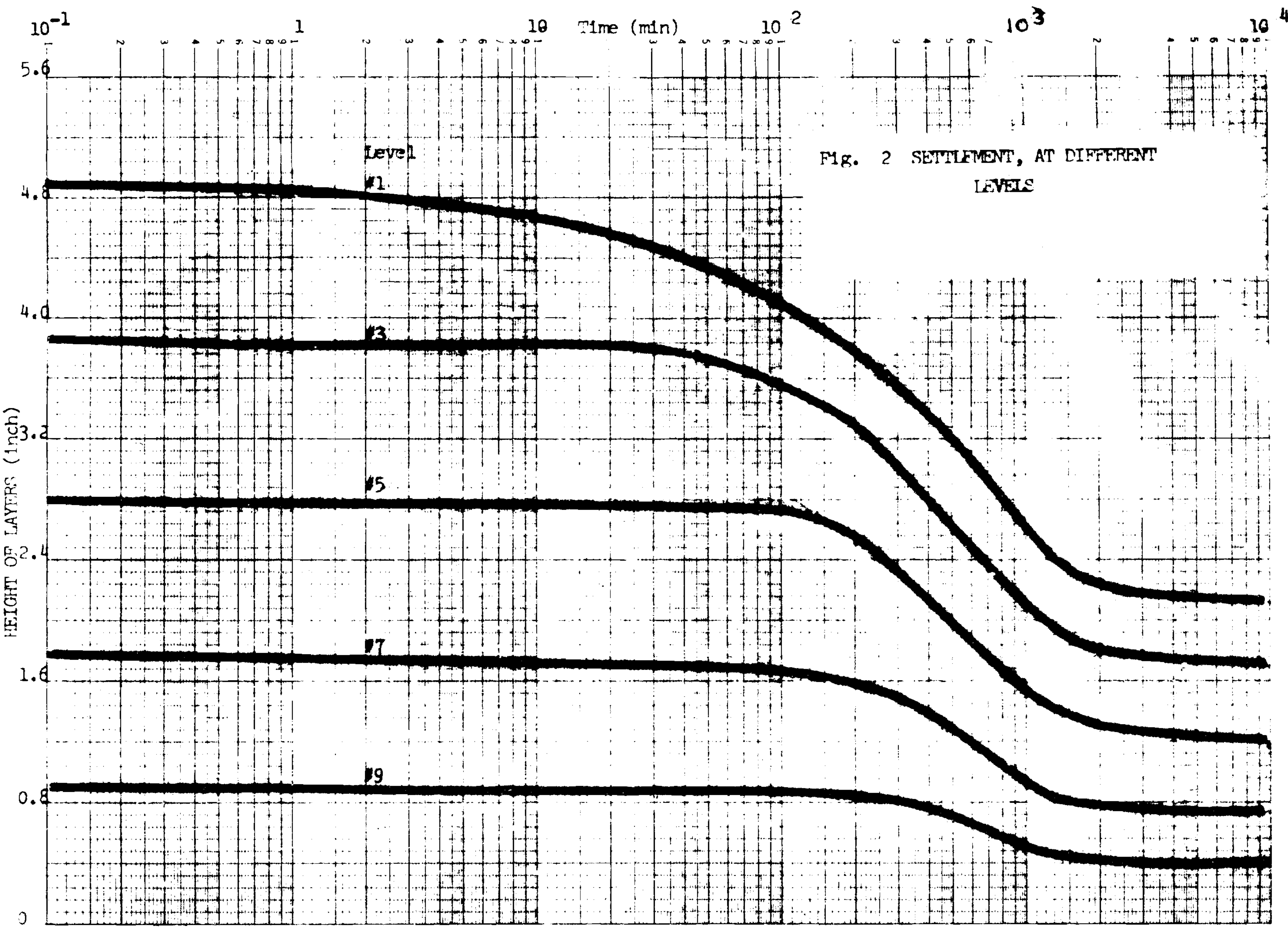



Fig. 2 SETTLEMENT, AT DIFFERENT LEVELS

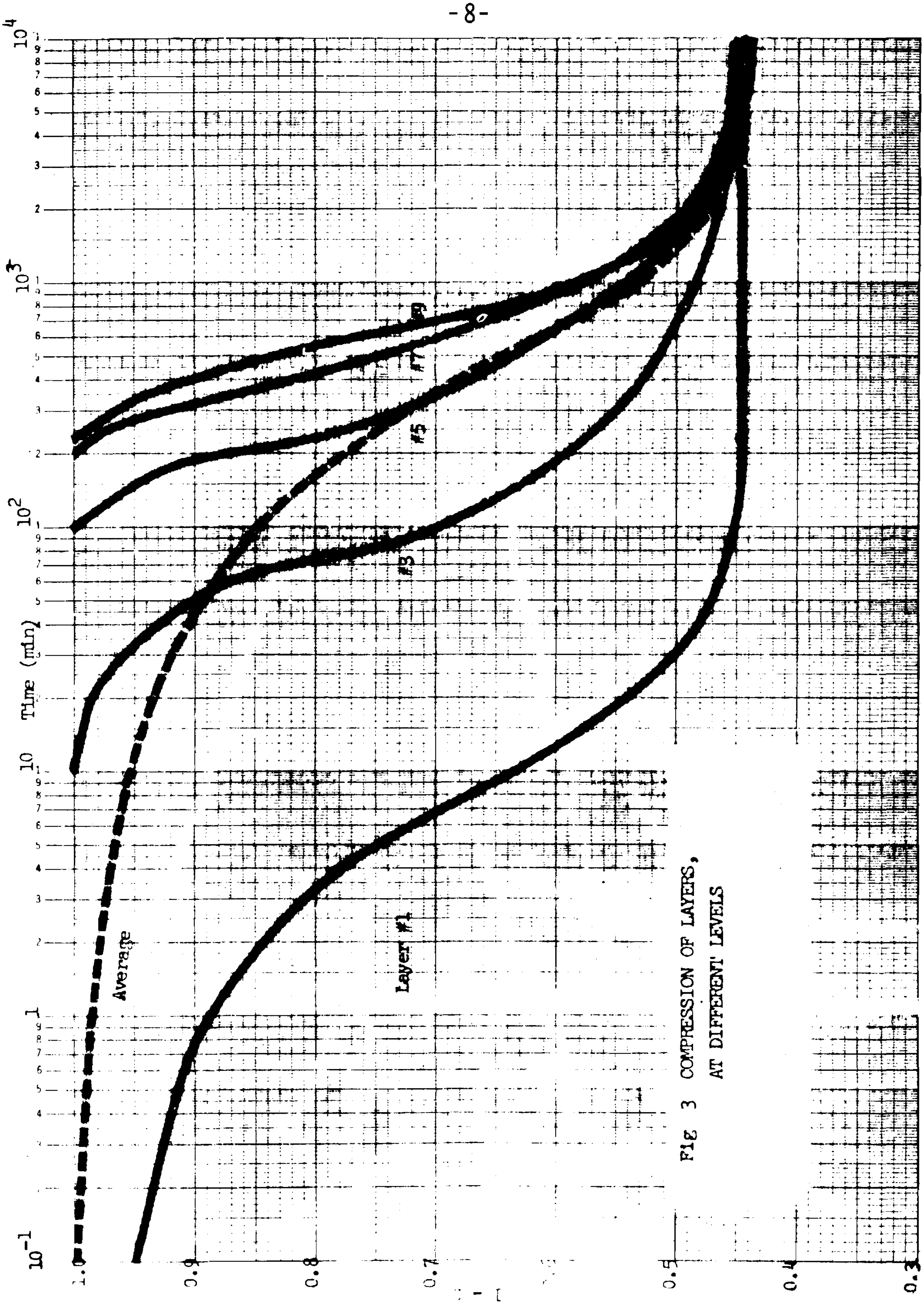



Fig 3 COMPRESSION OF LAYERS, AT DIFFERENT LEVELS

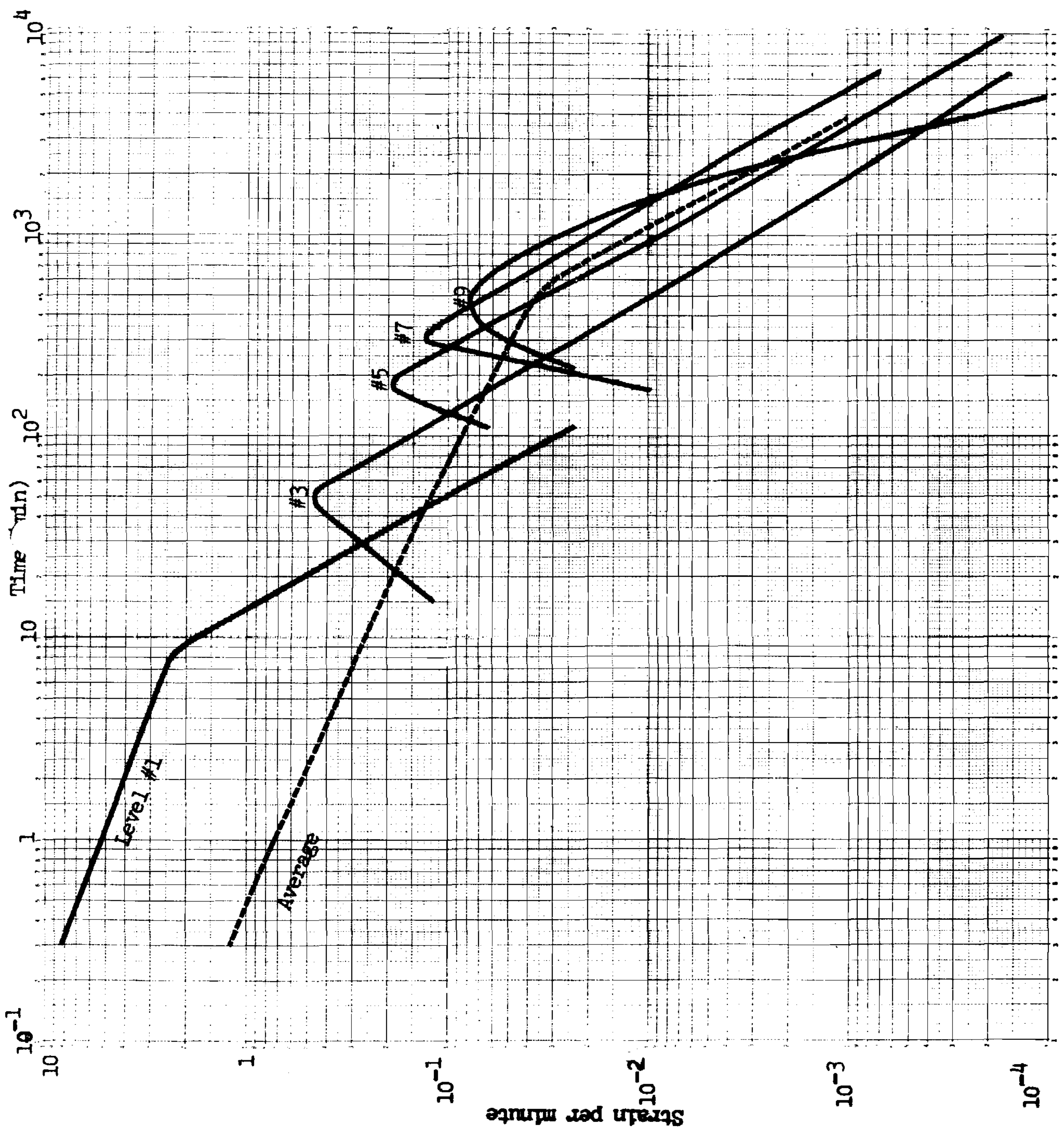



Fig. 4 RATE OF CONSOLIDATION, AT DIFFERENT LEVELS

Discussion (I. C. MacFarlane)

For several years, at these Conferences we have been having discussions on - and some controversy about - the consolidation of peat. Despite the time devoted to it in field and laboratory research and in discussion, there is still much to be learned about it. Secondary compression in particular is an incompletely understood and complex phenomenon; nevertheless, it plays an important part in the overall consolidation process of many soils and, in particular, organic soils and peats. Any attempt to solve the vexing problem of secondary compression in peat is welcomed, especially if it bears on the possibility of making more accurate field predictions. Professor Wilson is to be commended, therefore, for his continuing work on this project and for this preliminary report on a particular phase of the overall study.

It would appear, firstly, that Professor Wilson's curves - and particularly Fig. 3 - show that he is dealing mainly with primary consolidation, not with secondary consolidation, i.e. pore water pressure phase. His settlement log time curves are the classical "S" shaped curves. The rate at which consolidation occurs is limited by the dissipation of the pore water pressure; consequently, by the permeability of the peat, as Professor Wilson suggested. In a thick sample such as that described, the progress of consolidation might be traced by measuring pore water pressures at various levels in the sample. In the surface layer, the primary phase is over and it is well into the secondary phase before the primary phase really begins in the bottom layer. In between these two extremities, we have various intermediate phases, which depend on the changing permeability above. Once each layer has passed the primary phase, consolidation will continue at a rate independent of the layer thickness.

This project can be compared to a field loading test with settlement gauges installed at various depths in the deposit and plotting settlement against log time. It would be interesting to see a two-pronged research project of this nature, with such a field program and a lab program, as outlined by Professor Wilson, carried out simultaneously.

I have a number of questions, the answers to which may help clarify some points in this paper:

1. How was the peat sample placed into the consolidometer; was it poured in or ladled in?

2. Was there any visual evidence of layering in the sample during consolidation? Were the 1/2-inch intervals for the markers chosen entirely arbitrarily?

3. No mention is made of the actual loading. Does this report represent a single test, or an average of several? What was the magnitude of loading? I presume that it was a single load.

4. Has Professor Wilson tried to measure or to calculate (or does he propose to) the permeability of this material at intervals throughout the test?

5. What sort of time lag was experienced before there was a response to the pore water pressure at the bottom of the sample?

In his reply, Professor Wilson stated that there is a mechanical problem in measuring the pore water pressure at different levels in a sample which is consolidating. It is difficult to see how this might be done. Consequently, it is not possible to calculate the effective stress gradient throughout the sample at a fixed interval after load application.

With regard to whether the consolidation is primary or secondary, Professor Wilson said that he prefers to think in terms of rates of consolidation and changes in rate of consolidation. In this case, there is marked change in rate of consolidation which occurs at a time somewhat in advance of the end of primary consolidation as determined by the classical methods. The phenomenon is described in another paper (Wilson et al, 1965).

Professor Wilson replied to Mr. MacFarlane's specific questions as follows:

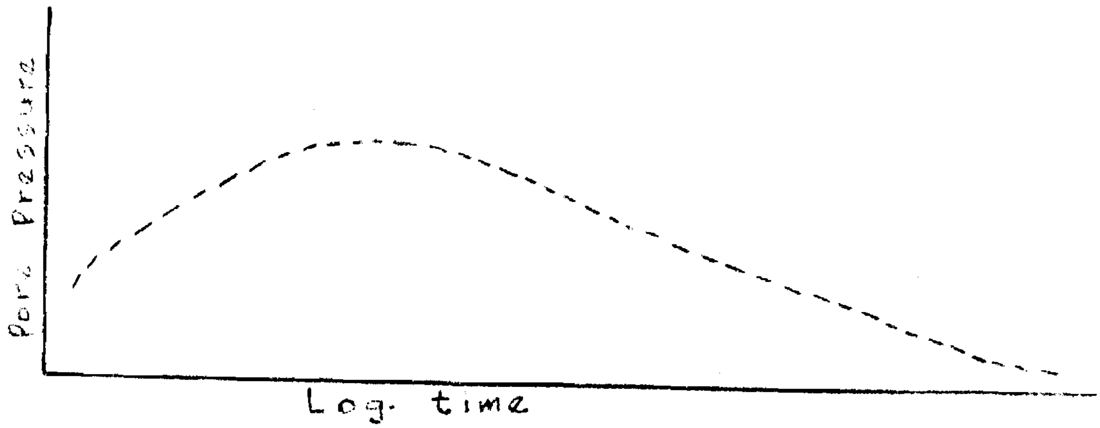
1. The peat sample was a remoulded sample and was actually poured into the consolidometer.

2. The markers were placed arbitrarily. There was no evidence of layering in the sample during consolidation. By using the term "layer" it is not meant to imply that there were visually observed layers. The word "zone" might be more appropriate than "layer".

3. The sample had a single, 2 psi load.

4. The permeability of the peat was not measured.

5. There was a time lag in the pore water pressure response at the bottom of the sample, as is indicated by the curve below (not to scale).




General Discussion

Mr. Ehrlich wondered where the line is drawn between organic and mineral soil. Replying at Professor Wilson's request, Dr. Radforth said that this is really a matter both of arbitrary decision and of degree. Peat is fossilized plant remains and is not organic silt. It is an arbitrary decision to take it out of the realm of peat and into organic silt. This arbitrary limit is usually 50% by weight of mineral soil.

Mr. Ehrlich enquired further about organic silt. Dr. Radforth said that again this is a matter of definition and definitions vary between the different disciplines.

Mr. McEwen suggested that the proper criteria is the method by which the material is formed. Anaerobic formation would rule out moor, etc. Dr. Radforth agreed that genesis is important but felt that the difficulty of this approach is that engineers prefer to deal with the question of what is in hand and not with the matter of genesis. He emphasized also that Professor Wilson's peat is only one kind of peat.

Mr. Ashdown observed that the consolidation commences at the drainage surface and the upper zones consolidate first. The top surface is the normal escape route for the water. He wondered about the three-dimensional effect in the sample. Professor Wilson replied that it is still not fully understood what is happening in the one-dimensional condition, as the peat undergoes a change of state during consolidation. Until this aspect is better understood, he doubted the value of going into the three-dimensional considerations.

# I.2. THE CLASSIFICATION OF PEAT AND PEAT DEPOSITS FOR ENGINEERING PURPOSES

K. Flaate

Abstract

It is necessary for those working with engineering problems of peat and peat deposits to have a common classification system. Up to the present time, it has not been possible to agree on one; the main reason seems to have been that the existing systems are too complicated. There may also be the feeling that the classifications are not related to engineering properties.

In an attempt to satisfy the demand, an engineering classification system for peat soils is presented. This is based mainly on the von Post system, and uses well-known terms and descriptions. It has not been possible to recommend a classification of peat deposits; however, it is pointed out that the approach of von Post seems most logical for a general system.

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# I.2. LA CLASSIFICATION DE LA TERRE NOIRE ET DES DEPOTS DE TERRE NOIRE POUR LES BESOINS DE L'INGENIEUR

K. Flaate

Résumé:

Il est nécessaire d'avoir une classification commune répondant aux besoins de ceux qui touchent aux problèmes de terre noire et de dépôts de terre noire. Jusqu'à présent, il n'a pas été possible de s'entendre sur une classification; la principale raison semble être que les classifications actuelles sont trop compliquées. On peut ajouter à cela que ces classifications semblent ne pas se rapporter aux propriétés mécaniques.

Dans une tentative de satisfaire à la demande, cette communication présente une classification mécanique des terres noires, qui est basée principalement sur le système de von Post et qui utilise des termes et des descriptions bien connues. Cependant, il n'a pas été possible de recommander une classification des dépôts de terre noire; on signale de plus que l'approche de von Post semble être des plus logique dans un système général.

Classification in general is necessary in order to simplify the study of the various members of a large and complex family of subjects. If the information is arranged in a certain manner, it will provide the greatest possible command of the knowledge and lead most directly to the acquisition of further knowledge. Furthermore, classification makes it easier to remember and to think clearly about the cosmic systems. This is the experience in all fields of science.

The same reasoning must be applied to peat and to peat deposits. Although peat soils can be placed within a large group of organic soils, it is necessary to distinguish between them. There is probably much more variation in the engineering properties within the peat soil group than within any other group of soils. The same consideration applies to peat deposits, which certainly show more relative variation than any other group of deposits.

A number of classification systems for peat and peat deposits are in existence. They have been devised to suit various purposes although most of them have a botanical basis. While best fitted for use in agriculture and forestry, at least some of them have been used for engineering purposes. These classification systems, which usually are very satisfactory for the specific purposes for which they were devised are generally too elaborate for engineering applications. Consequently these systems are excised and diminished.

Only one of the current, more detailed classification systems has been made for engineering purposes, namely that of Radforth (1952). Although this system has been widely published, it has not been used as much as one might expect, even in Canada. Since other systems seem divorced from the engineering problems, and therefore are difficult to apply, many engineers make use of their own descriptive terms. This lack of a common basis for description and classification, therefore, makes it difficult to obtain the full value from tests and case histories in peat and peat deposits.

## Existing Classification Systems

Peat and peat deposits are utilized in agriculture, forestry, construction and for industrial purposes. In some respects this has been the case for hundreds of years. Great attention has been paid to peat deposits for more than a century for the development of agriculture and forestry and as a possible source for raw materials. Extensive mapping has taken place in a great many parts of the world and in this connection numerous classification systems, more or less elaborate, have been worked out.

A classification system generally needs a basis and in most cases one will find that this basis varies according to the purpose of the investigation. Even in those cases where the mapping has been performed rather like a registration of the deposits, the classification systems have not been worked out without thinking on the possible utilization of the deposits. From this it follows also that in general one does not use only a single property or characteristic as a basis. Most systems have been developed around several characteristics.

It is necessary to distinguish between the classification of the peat deposit and of the peat soil within the deposits and most workers do this. In general it will be found that the basis for the classification of the peat soil and of the peat deposit is one or more of the following features:

a) Terrain on which the peat is formed

b) Surface vegetation of the deposit

c) Surface characteristics of the deposit

d) Plant remains composing the peat

e) Physical and chemical characteristics of the peat

f) The possible uses of the deposit

g) Geographical location

It is an interesting experience to study a few of the already existing classification systems. One can fully appreciate the great amount of work put into this field only after having made this study. Many systems have proved to work well in agriculture, in forestry or in fuel production and thus a great amount of practical experience is tied to these already existing systems. One will generally find, however, that most systems are limited, for instance, by the topographic, climatic and botanical conditions where they originated. Some are adjusted to local conditions and needs; others intend to be more general systems.

Fundamental work has been done by Potonie (1906) in Germany, Soper (1922) in the USA, Holmsen (1923) in Norway and von Post (1926) in Sweden. Classification systems have been worked out more recently by Thurmann-Moe (1941) in Norway, Radforth (1952) in Canada and Rigg (1958) in USA. No attempt is made here to list all the valuable contributions that have been presented in this field. Many others would be worth mentioning but it is not possible to do so in a short paper. Even if this could be done, there would doubtless be others which had not come to the author's attention.

In classification of the soil, most workers have not restricted themselves to what can be called peat soil. They have also included the other types of soils that are formed in the process of peat formation.

Among all the valuable studies, there is justification in drawing special attention to the work done by von Post. The investigations carried out by the Swedish Geological Survey under him and later workers seem to be the most comprehensive study of peat and peat deposits ever made. After a thorough study of the peat soils and all the other soils that are found in a peat deposit, identification methods and a classification system were worked out. The different ways of peat formation were studied and profiles from a large number of deposits were obtained. This work has had a strong influence on later workers in the field. One of the main inventions of von Post was the introduction of a 10-graded scale for determining the degree of decomposition of peat soils.

## Engineering Approach to Peat

The different uses of peat and peat deposits create many engineering problems which need to be solved. Since the utilization of peat land for various purposes is expected to increase, the number of problems to be solved are also steadily growing. Also, with increased knowledge of the properties of peat and peat deposits, their utilization will be more intense and will present new problems to the engineer. The engineer is mainly concerned with the following activities:

a) Off-road access

b) Transportation facilities

c) Drainage structures

d) Above-ground structures

e) Industrial production.

In order to solve the problems that arise, the engineer must determine the properties of the deposit and of the peat itself. Engineering problems in peat in most cases will have to be solved by a study of the following engineering properties:

(a) Bearing capacity, (b) Deformation, and (c) Drainage. These factors are governed by the topography, vegetation and extent of the deposit and by the physical properties of the peat soils as expressed by water content, permeability and strength. Every classification system to be used for engineering purposes attempts to tie these properties to the identification characteristics.

## Engineering Classification

There are several reasons why engineers have not fully adopted any of the existing systems. One reason is that the systems have not had a scheme that was simple enough and have contained too many special terms for everyday use. Another reason is that they do not seem to reflect adequately the engineering properties of the soil and the deposit. This statement is based partly on impressions since no system has been used sufficiently in engineering to make a direct comparison. A system must have a concise and familiar terminology if it shall serve its purpose. It is further desirable for an engineering classification to be related to current systems in order to obtain maximum benefit of the work that is being carried out with peats in many associated fields.

The proposed system for classification of peat soils is shown in Table 1, and von Post's scale in Table 2. It is believed that this simple descriptive classification system, which utilizes common terms, can be related to the engineering properties. The author strongly advocates the use of a few simple standard tests in peat since more complicated methods are seldom justified in such heterogeneous deposits. In Table 3 are shown the routine laboratory tests that should be performed to determine the physical properties of peat soils. In most cases many simple tests give a better picture of the properties than a few elaborate ones.

An engineer will accept a system for classification of peat deposits if it can give him information on vegetation, depth and the type of soil in the deposits. The author has not been able to find an existing system or to propose one himself that can satisfy these requirements. Some systems may work when climate, topography, ground-water conditions and geology do not vary to a great extent. Such "local" systems are of great value. The author is not able to recommend any of the systems for general use, but would like to draw attention to the system used by von Post.

This seems to be the most logical one and it combines the effects of topography, ground-water conditions and climate. The system is illustrated schematically in Fig. 1, which is taken from Granlund and Magnusson (1957). Depths and soil types can be foreseen in some cases and for some types of deposits. In most instances, however, the picture is complicated by the previous changes in the environmental conditions at the site. The present vegetation, for instance, is no clue to the depth of the deposit or the composition at depth in the most common condition.

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## REFERENCES

Granlund, Erik ock Magnusson, Nils Harald. "Sveriges Geologi" (The Geology of Sweden), Svenska Bokförlaget, Stockholm, 1957. (in Swedish)

Holmsen, Gunnar. "Vore Myrers Plantedekke og Torvarter". (The Vegetation and Peat Type in our Peat Deposits), Norges Geologiske Undersökelse No. 99, Kristiania (Oslo), 1923. (in Norwegian)

Leverin, H. A. "Peat Moss Deposits in Canada", Canada Dept. of Mines and Resources, Bureau of Mines, No. 817, Ottawa, 1946.

Löddesöl, Aasulv and Lid, Johannes. "Myrtyper og Myrplanter" (Peat Types and Peat Plants), Gröndahl & Söns forlag, Oslo, 1950, 95pp. (in Norwegian)

Pihlainen, John A. "A Review of Muskeg and its Associated Engineering Problems". U.S. Army Cold Region Research and Engineering Laboratory. Technical Report 97, 1963, 56pp.

Post, Lennart von och Granlund, Erik. "Södra Sveriges Torvtilgangar" (The Peat Resources of Southern Sweden), Sveriges Geologiska Undersökning, Arsbok 1925, No. 2, Stockholm, 1926 (in Swedish)

Potonie, H. "Klassifikation und Terminologie der Rezenten Brennbaren Biolithe und lhrer Lägerstätten". Abhandlungen der Königlich Preussischen Geologishen Landesanstalt u. Bergakademie. Berlin, Heft 49, pp.94, 1906. (in German)

Radforth, N. W. "A Suggested Classification of Muskeg for the Engineer". Engineering Journal, 35:2, Montreal, 1952.

Rigg, Georg, B. "Peat Resources of Washington". Washington Division of Mines and Geology. Bulletin No. 44, Department of Conservation, Olympia, Washington, 1958.

Shaler, N. S. "Preliminary Report on Sea Coast Swamps of the Eastern United States:, U.S. Survey, Annual Rpt. No. 6, pp. 353-398, 1885.

Soper, E. K. and Osbon, C. C. "The Occurrence and Uses of Peat in the United States", United States Geological Survey, Bulletin No. 728, Washington, D.C., 1922.

Thurmann-Moe, P. "Om bedømmelse av myr og vannsyk skogsmark til planteproduksjonen". (Determination of the Suitability of Peat Bogs and Swampy Woodland for Plant Production). Meddelelser fra Norges Landbrukshøgskole, Vol. XXI, 1941. (in Norwegian).

Waksman, Selman A. "The Peats of New Jersey and Their Utilization". State of New Jersey Geologic Series, Bulletin No. 55, A and B. New Jersey Department of Conservation and Development, Trenton, New Jersey, 1942.

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Discussion (A. Rutka)

First of all I would like to thank the author for bringing to our attention the classification system proposed by von Post. I had not been familiar with this classification system, and therefore cannot comment too extensively on it, particularly from the practical viewpoint.

Engineers usually develop and use a classification system to fit their specific needs. Unfortunately, these systems cannot be tied into other systems, and therefore no correlation of experiences can be carried out.

The von Post system appears to be simple and practical. It involves the typing of the peat (sedimentary, moss, grass, wood, amorphous) and then determining the degree of decomposition of the peat on a scale of 1 - 10. The scale of decomposition is determined by pressing a chunk of peat in the hand and observing the material and colour that passes through the fingers, and the material that remains in the hand. It seems certain that, with a little bit of experience, the exact degree of decomposition on the scale can be determined.

Interestingly, this is the general approach that is used in the classification of peat by the Ontario Department of Highways, with two exceptions. We have fewer categories of decomposition, and the degree of decomposition is determined by visual observation.

Our scale of decomposition may be broken into three categories: fibrous or non decomposed, partially decomposed, and completely decomposed. The decomposition, along with a description of the moisture content, gives a general qualitative idea of the supporting value of the peat.

(Continued on Page 24)

Table 1

Descriptive Classification of Peat Soils

| Descriptive Classification | | | Information for Identification | | |
|---|---|---|---|---|---|
| Type of Soil | Degree of Decomposition (von Post's scale) | Special Features | Structural Appearance | Mode of Formation | Parent Material |
| Sedimentary peat | $H_1 - H_{10}$ | Describe here the presence of special features in the soil like logs and roots. | Mossy, grassy or woody to amorphous, with mineral soil mixture | Sedimented in water | Remains of plants water amimals and mineral soils in varying composition |
| Moss peat | $H_1 - H_8$ | | Mainly mossy | Formed in place | Mainly remains of sphagnum mosses |
| Grass peat | $H_1 - H_8$ | Point out predominant layers or pockets of specific materials which are present in the soil mass itself | Mainly grassy | Formed in place | Mainly remains of grasses and sedges |
| Wood peat | $H_1 - H_8$ | | Mainly woody | Formed in place | Mainly remains of trees and bushes |
| Amorphous peat | $H_8 - H_{10}$ | Use concise terminology | Amorphous | Formed in place | Not possible to determine by visual inspection |

| Degree of Decomposition von Post's scale | Information for Identification |
|---|---|
| $H_1$ | Completely unconverted and mud-free peat which, when pressed in the hand, only gives off clear water. |
| $H_2$ | Practically completely unconverted and mud-free peat which, when pressed in the hand, gives off almost clear colourless water. |
| $H_3$ | Little converted or very slightly muddy peat which, when pressed in the hand, gives off marked muddy water, but no peat substance passes through the fingers. The press residue is not thick. |
| $H_4$ | Badly converted or somewhat muddy peat which,when pressed in the hand, gives off marked muddy water. The pressed residue is somewhat thick. |
| $H_5$ | Fairly converted or rather muddy peat. Growth structure quite evident but somewhat obliterated. Some peat substance passes through the fingers when pressed but mostly muddy water. The press residue is very thick. |
| $H_6$ | Fairly converted or rather muddy peat with indistinct growth structure. When pressed,at most 1/3 of the peat substance passes through the fingers. The remainder extremely thick but with more obvious growth structure than in the case of unpressed peat. |
| $H_7$ | Fairly well converted or marked muddy peat but the growth structure can still be seen. When pressed,about half the peat substance passes through the fingers. If water is also given off, this has the nature of porridge. |
| $H_8$ | Well converted or very muddy peat with very indistinct growth structure. When pressed, about 2/3 of the peat substance passes through the fingers and at times a somewhat porridgey liquid. The remainder consists mainly of more resistant fibres and roots. |
| $H_9$ | Practically completely converted or almost mud-like peat in which almost no growth structure is evident. Almost all the peat substance passes through the fingers as a homogeneous porridge when pressed. |
| $H_{10}$ | Completely converted or absolutely muddy peat where no growth structure can be seen. The entire peat substance passes through the fingers when pressed. |

Table 2

Degree of Decomposition (after von Post)

Table 3

Routine Laboratory Tests in Peat.

| Type of Test | General Comments |
|---|---|
| Water content | The natural water content should be determined on all samples if the sample loses water as it is extruded, correction should be made for this. |
| Unit weight | The unit weight should be measured directly or indirectly. For instance if water is lost, correction can be made for this. |
| Ignition loss | The ignition loss should be determined on all samples. This test gives a sufficiently accurate number for the "organic content". |
| Strength tests | If the soil is appropriate, unconfined compression test should be made. The maximum strength and the corresponding deformation should be given. |
| Compressibility | The consolidation test is one of the most important for peat soils. Sampling and testing techniques and equipment must be described. |
| Acidity reaction | The pH-value should be determined. |

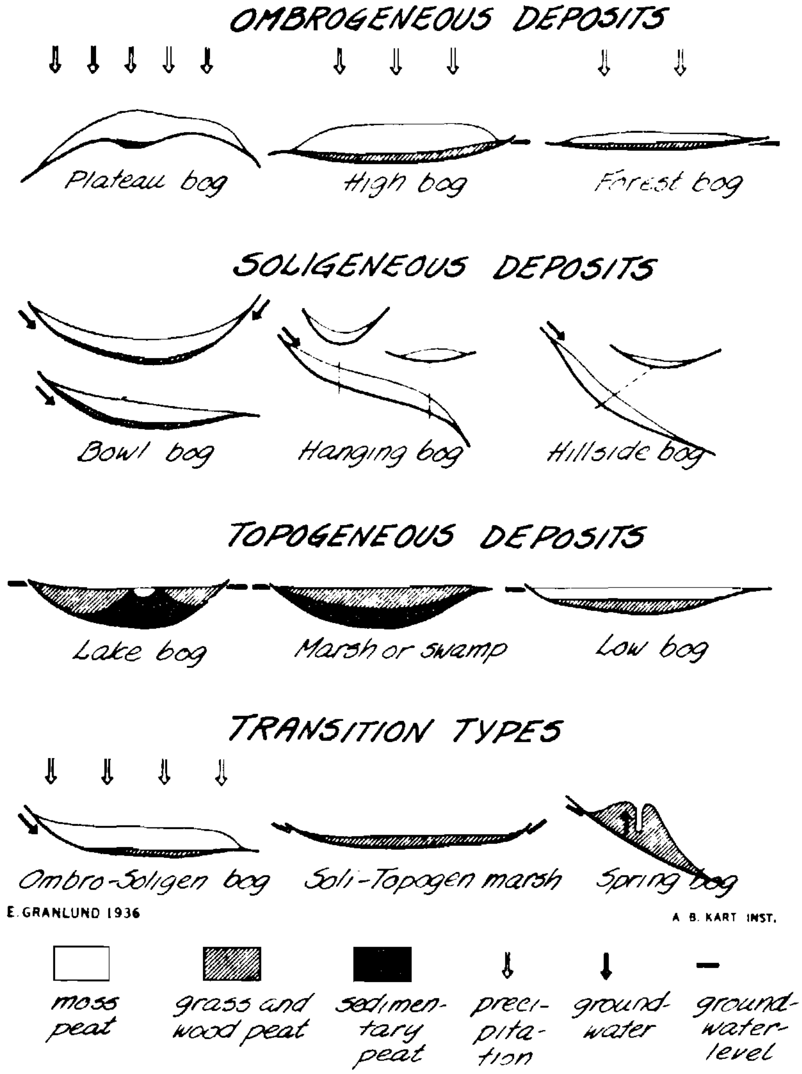


FIGURE 1

MAIN TYPES OF PEAT DEPOSITS
(from Granlund & Magnusson, 1957)

Mr. Flaate believes that a few simple standard tests for the determination of the physical property of the peat can be related to the descriptive classification system. Such tests as water content, unit weight, ignition loss, strength tests, compressibility and acidity reaction, are suggested. It is true that many of these tests are simple and easy to perform, but it is difficult to utilize many of the test results even after they are obtained, due to the very wide scatter of test results.

It is extremely difficult to obtain a good representative sample for the unconfined and consolidation tests, due to the wide variations in the peat itself, with respect to the vertical profile. For highway purposes, where so many muskegs are crossed, it is not too practical to carry out most of the tests suggested on a routine basis. Of course, special attention can be given to critical muskegs that need detailed investigations from the construction and stability point of view.

The vane test, in my opinion, is a good test to obtain some idea of the strength of the peat. Here again different results can be expected with different sized vanes, and some standardization of vane sizes seems to be in order.

One of the reasons why not too much work has been done on the physical properties of the peat by the Ontario Department of Highways, and no doubt by other engineering organizations, is that the real problem is not with the peat, but rather with the underlying soft clay. Muskegs are very seldom over 10' in depth, and the underlying clays where they occur, are up to 100' in depth. The shear strength of the clays is usually much less than the peat.

The von Post approach to the classification of peat could have a good application for engineering purposes. It is dependent, however, upon several engineering tests. It is difficult to obtain good representative samples of peat, and further, the test results can be expected to vary greatly within the deposits. It, therefore, may not be too practical for many engineering routine applications.

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<u>Closure</u> (K. Flaate)

The writer wishes to thank Mr. Rutka for his valuable comments. It is certainly not easy to come to an agreement on an engineering classification system for peat soils. The writer feels, however, that it is necessary to do this in order to be able to communicate and exchange experience. Neither can a sensible soil survey in peat in connection with construction operations be made without a classification system which can be related to engineering properties.

The writer is of the opinion that the factors to use in the classification is the parent material and the degree of decomposition. They are both rather easily determinable and are believed to be two factors that will largely govern the engineering properties. The classes for the soil types are only five in number and have easily recognizable descriptive terms. When it comes to the degree of decomposition, the writer feels that he cannot do a better job than already done by von Post and his scale is therefore adopted for determination of this property.

The writer does not mean that the laboratory test in Table 3 is a part of the classification system, but, to prove the value of a classification system, it will have to be tried out. This means that it will have to be related to laboratory test and case histories in the field. A standard procedure for these simple laboratory tests should have been established long ago so that the results would have been more comparable. This was the writer's intention with Table 3. He further hopes that the readers will made use of the proposed system in their work to try it out. It is so simple to use that this easily can be done.

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## I.3. PEAT STRUCTURE AS A BASIS OF CLASSIFICATION

I. C. MacFarlane

Abstract

Many classification systems have been developed for peats, but they are all qualitative and have generally not been too acceptable to engineers. This paper suggests that the structure of peat presents a natural basis for a quantitative classification of the material, both in its dry and wet states. One particular peat type was studied in its micro and macro aspects and the basic unit of the peat described and named. It is postulated that the major components of peats can be reduced to relatively few structural entities which can be quantitatively assessed.

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## I.3. LA STRUCTURE COMME BASE D'UNE CLASSIFICATION DE LA TERRE NOIRE

I. C. MacFarlane

Résumé:

Plusieurs classifications ont été développées pour les terres noires, mais elles sont toutes qualitatives et n'ont généralement pas répondu adéquatement aux besoins de l'ingénieur. Cette communication suggère que la structure de la terre noire devienne une base générale pour une classification de ce matériel sec aussi bien qu'humide. On a fait une étude micro et macromoléculaire d'un type déterminé de terre noire et on a décrit et défini l'unité de base de cette terre noire. On postule que les composants principaux des terres noires peuvent être réduits à relativement peu d'entités structurales qui peuvent être évaluées quantitativement.

By "Structure" is meant the arrangement of the constituent peat elements, both in the macro and in the microscopic aspects. Since peats are comprised of fossilized remains of plant communities, they will 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 elements may appear to be equally predominant and to contribute equally to the overall properties of the peat. The structure of peat implies an arrangement of these primary, secondary, tertiary, etc., elements into a certain structural pattern.

The difference in soil structure may be expressed by:

(a) the structural patterns of the various horizons in the profile;

(b) the extent of aggregation (or in the case of peats; the extent of intermingling of secondary and other elements); and

(c) the amount and nature of the pore space (Baver, 1956).

Dachnowski (1924) classified peats on the basis of their mode of origin and the fossilized plant material of which they are composed. He named ten distinct peat types which fall into three main categories: sedimentary peats, fibrous peats and woody peats. These designations refer roughly to the preponderance of the various plant constituents and to the textural, structural and other characteristics. Dachnowski, however, considered structure to be a property of a particular peat layer such as its compactness and density, rather than as an arrangement of the various constituents relative to each other.

Radforth (1956) based peat types on size, texture, and arrangement of proximal components. He designated 16 categories of peat, the physical elements of which can be seen from a visual examination of peat samples and which he thought were significant. These are the woody fibrous (derived from tissues originally lignified), the non-woody fibrous (originally non-lignified and probably cellulose in origin), and the amorphous-granular constituents, the latter representing the highly variable and consistently irregular minute organic aggregates which are such an important component of many peats.

The contribution of porosity to the soil structure relationship 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. Ohira shows that the theoretical values of the fundamental properties of the model, based on certain calculated values, are in close agreement with actual experimental values.

The peat chosen for this investigation is termed "non-woody fine fibrous" peat (Radforth, 1956) obtained from near Moonbeam, Ontario. The chief generic constituent was identified as Hypnum Cuspidatum (Jewell, 1955) with an occasional intrusion of a sedge (Carex) and a very occasional intrusion of a small woody element. The characteristic macro-structural feature of this peat is its homogeneity, not only in its generic constitution, but also in the arrangement of the peat elements.

Microscopically, the peat elements consist of a central axis, occasionally with branches, and with a spiral system of leafy appendages, the latter curled about the stem or branch and thereby providing an enormous number of capillary pores. The stems are actually hollow tubes with an average outside diameter of 0.24 mm. when wet. The cell structure within the leaves and stem is regular and uniform in appearance.

The peat was examined microscopically by two separate methods. The first of these was by impregnating the sample with a resin which hardened to almost rock-like consistency, then obtaining thin sections as for rock. This 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 relations one to another.

In the second method, a small cube sample of peat was examined microscopically in a specially designed loading chamber while it was being subjected to compressional loads. Photomicrographs were taken as the peat was subjected to the various loads. This permitted the examination, under low magnification, of the gross structure of the peat and the change in this structure with increasing load.

The predominant discrete organic element in the "Moonbeam" peat is a characteristic element in many peats - not necessarily genetically, but morphologically - hence the designation "fibrous peat". In the specific case of the "Moonbeam" peat, it is a hypnum, elsewhere it may be a sphagnum or other bog moss plant. It is possible, 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 preliminary definition of an axon be as follows:

> "AXON - well preserved, non-woody fossilized plant component of peat, consisting of tubular stem, system of leafy appendages, and with the cell structure clearly defined. The maximum outside diameter of the stem component of the axon (when wet) is 1 mm."

Various components of the axon will vary with the various plant species and will also depend upon the extent of disintegration and decomposition of the fossilized plant element. Further investigation is required into the question of quantitative expressions for these axonic components.

The "Moonbeam" peat may be termed, therefore, "axonic peat" rather than "non-woody, fine-fibrous peat". In due course, expressions can be developed for the other distinctive discrete elements of the various peat types.

In conclusion:

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

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

3. A macro and microscopic examination of these gross structural types should result in the development of a mathematical model for each type, which should adequately represent the natural condition.

4. The major components of peats can probably be reduced to relatively few structural entities which can be quantitatively assessed.

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## REFERENCES

Baver, L. D. "Soil Physics". John Wiley and Sons Inc., New York, 1956. 489 pp.

Dachnowski, A. P. "The Stratigraphic Study of Peat Deposits". Soil Science, XVII, p. 107-133, 1924.

Jewell, A. L. "The Observer's Book of Mosses and Liverworts". Frederick Warne and Co. Ltd., London, 1955. 128 pp.

Ohira, Y. "Some Engineering Researches on the Experiments of the Physical Properties of the Peat and on the Sounding Explorations of the Peaty Area in Hokkaido, Japan (1)". Memoirs of the Defence Academy, II:2, 253-282, 1962.

Radforth, N. W. "Range of Structural Variation in Organic Terrain". Transactions of the Royal Society of Canada, XLIX: Series III; Sect-5, 1956.

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## Discussion

Dr. Radforth stated that Mr. MacFarlane had tackled a tough problem. In his paper he has mentioned that, of the 16 categories of peat, relatively few commonly occur. It is felt that the categories should be extended to 17, since, out on the West Coast (Prince Rupert area) there is another major peat type with the major element being 6 in. to 9 in. in diameter. In such peat one does not dig ditches, they are sawed out! "Axonic" peat does not refer to texture but rather to form. The peat type in British Columbia (Category 17) is totally different, i.e., it is woody in texture. One good thing about the "Axonic" peat is that this condition recurs over and over again. The sample described comes from Moonbeam; the same type can be found in Prince George, B.C.

Professor Irwin referred to the analogy of organic and mineral soils mentioned in the paper. He would not like to see an additional soil classification system arrive on the scene. He wondered if some liaison might be established with the Canada Soil Survey, who are working on a peat classification. Any classification must be simple and Professor Irwin doubted if it was practical to go to a microscopic examination. He hoped that whatever classification is devised can be tied into the Canada Soil Survey Classification.

Mr. Brawner doubted that it would ever be possible to get a universally accepted and used peat classification system for agriculturalists, engineers, foresters, etc. This is not even the case for mineral soils. Geologists and others use different terms from those used by engineers. He suggested that a classification system should be based on behaviour characteristics. Then the soils will all be under the same classification, irrespective of geographical origin.

Mr. Adams commented that porosity has a great deal to do with the behaviour of peat and asked if there has been any effort to determine the porosity of discrete peat elements. Mr. MacFarlane replied that, apart from the work carried out by the Japanese (as reported in his paper), there has been no research on this particular facet of porosity.

Mr. Tessier wondered if this system was being devised for field or laboratory use. Mr. MacFarlane said that initially its greatest use would be in the laboratory.

Dr. Radforth pointed out that classification will depend upon what the user wants. Different systems can be expected, but this is all right as long as we can relate them to each other.

## II.1. THE SIGNIFICANCE OF DENSITY AS A PHYSICAL PROPERTY IN PEAT DEPOSITS

N. W. Radforth and J. R. Radforth

Abstract

The hypothesis is advanced that physical and perhaps chemical variations in peat types are manifest in structural changes in peat. Density, a physical property, may therefore be available as an indicator of size and organization of the structural components of peat. In the absence of a method for obtaining undisturbed peat samples, an instrument now in advanced stages of development has been constructed to measure peat density *in situ*.

Some preliminary field results and an analysis of their significance are presented. The results suggest a means of differentiating peat and mat density in depth according to curve characteristics and of relating muskeg cover to underlying peat structure. Also the curves provide graphical information on density change in the mat zone and near the mineral base. Finally, the results appear to support earlier claims that organic terrain should be examined for vertically oriented density zoning as well as horizontal layering.

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## II.1. LA SIGNIFICATION DE LA DENSITY EN TANT QUE PROPRIETE PHYSIQUE DES DEPOTS DE TERRE NOIRE

N. W. Radforth et J. R. Radforth

Résumé:

On émet l'hypothèse que les variations physiques et peut-être chimiques dans les types de terres noires se manifestent dans les changements structuraux de la terre noire. La densité, une propriété physique, peut donc servir d'indicateur de la grosseur et de l'arrangement des composants structuraux de la terre noire. En l'absence d'une méthode pour obtenir des échantillons non remaniés de terre noire, un instrument dont le développement a atteint présentement un stade avancé a été construit pour mesurer la densité de la terre noire "in situ".

Cette communication commente quelques résultats préliminaires obtenus sur le terrain. Les résultats suggèrent un moyen de différencier la densité de la terre noire et celle de la zone intermédiaire en profondeur d'après la courbe

caractéristique et d'établir la relation entre la couverture (végétation) et la terre noire proprement dite. De plus, les courbes fournissent les informations sur le changement de densité dans la zone intermédiaire, près de la couche minérale sous-jacente. Finalement, les résultats semblent appuyer les suggestions préalables voulant que le sol organique soit examiné pour les zones verticales de densité aussi bien que pour les zones horizontales.

## Structure of Peat as a Function of Density - A Basic Concept

Appreciation that variation exists in the physical and mechanical properties of peat has been accepted in scientific and, lately, in engineering activity. An examination of bibliographic background on the subject of organic terrain will support this claim. An attempt was made to utilize knowledge on this subject by classifying physical difference according to descriptive and pictorial aids in handbook form by MacFarlane (1958).

It will be expected that variation in chemical constitution will likewise exist. This situation, too, is already acknowledged and amply supported by the literature (cf. Ponomareva,1962). That physical and chemical differences are interrelated or that definitive controls exist which result from interdependence between physical and chemical properties has not been directly explored. By inference, relationship between chemical and physical properties must arise when there is contrast between botanical components in given samples. For example, it is reasonable to assume that related difference will appear in the conspectus of chemical and physical properties of so-called sedge peat and sphagnum peat. Perhaps attempts to reveal this interrelationship are not encountered because knowledge of the environment of organic terrain suggests that physical and chemical properties are subject to change by action of other factors influential enough to mask any effect of the interrelationship.

Despite the complexity in causation governing characterization of peat and the differences that result therefrom, there are orders of similarity in peat constitution. This similarity has been emphasized by Radforth (1955) in the claim that peat types recur in nature. Suguitan (1963) has shown that likeness may be expressed through comparative palynological study even though the samples tested are geographically and hydrologically isolated. More recently Spaakman (1964) in his study of Florida peat has shown difference on a palynological basis. His work indicates that given peat types recur and apparently type has geomorphic and hydrological significance; similarity may be perpetuated even as a function of a salinity factor acting in the environment of the peat in the course of the initiation and accumulation.

As a result of existence of peat types and their recurrence, distributional phenomena become apparent and as the senior author pointed out 10 years ago (Radforth,1955). organization in organic terrain is revealed in such a way and in such extent as to permit prediction of physiographic conditions (which also recur) in the terrain.

Although use has been made of these phenomena in scientific and engineering endeavour (Enright,1962) application is limited because peat type, as expressed in any system of reference, is delineated by terms that are too generalized. Textural designations such as fibrosity, woodiness or non-woodiness, and amorphous granular now in use are helpful, and combinations of them facilitate identification of peat types on a basis validly claimed as structural, but, despite this, physical and chemical properties vary for a given type in a degree that may be significant in either scientific or engineering application.

In seeking to correct this deficiency, the authors have resorted to fundamental physical properties of peat as a means of expressing structural order. Whether fibre, wood, cellulotic remains, granular or colloidal particles involved as constituent expressions of peat type, the arrangement and spacing of these entities is just as significant as their description in expressing character. Also the medium in which these entities are held (water, in nature) is important. Finally, aspects of particular arrangement and amount must be understood before chemical properties can be adequately explained. These reasons and the needs of application themselves have encouraged the writers to emphasize density and water relations of peat <u>in situ</u> as the primary features of physical reference. In collateral investigation "form" of constituent particles is under investigation (MacFarlane and Radforth, 1965) in the proposal that density and water effect will be related to particular form. In the entire complex, density appears to be a primary indicator of the distribution of structural arrangement, and the aim of the authors in writing this paper is partly to present the foregoing reasoning leading up to this decision. The remainder of the objective lies in presenting preliminary progress on examining the feasibility of expressing density relations in peat as it occurs <u>in situ</u>.

## Methodology in Evaluating Density of Peat in the Field

There is no method known to the authors which will sample peat in its natural state as a component of organic terrain and leave it unchanged. Therefore any attempts heretofore at evaluation of density must reflect values for disturbed states which might even include distortion induced in sampling.

Accordingly, recourse has been made to in situ density measurement in the hopes that distortion of measurements can be reduced to an acceptable level. An instrument has been designed and constructed in relation to a series of objectives consistent with the capabilities of the instrument at various stages of development. The primary objective has been to attempt measurement of average in situ peat density throughout a roughly defined volume within the peat. In this way densities of peat types underlying various vegetal cover formulae can be compared. This has been attempted to a limited degree using an instrument whose theoretical foundation was established by Radforth and Ashdown (1961).

Briefly, operation of the instrument involves the following steps. An access tube is inserted vertically in the peat and a probe containing a source of gamma radiation and a scintillating crystal detector is lowered into the tube. Quanta of gamma energy are emitted into the peat surrounding the access tube, and an amount of radiation assumed to be proportional to the peat density is reflected to the detector. The detector converts gamma pulses to electrical pulses which are conducted out of the access tube via co-axial cable to a scaler which amplifies and counts the pulses. Thus the number of pulses counted per unit of time is proportional to the density of peat in the vicinity of the probe.

It is useful to note several aspects of this type of measurement and their implications. First, the material surrounding the source is usually a mixture of peat and water and it is the density of this mixture which the instrument measures. Hence, density measurements will be even more instructive when moisture content data is available.

Secondly, it has been assumed that, for practical purposes, the volume of peat whose density is measured is roughly spherical in shape with the centre of the sphere situated at the gamma source. The density measurement provided by the instrument represents the average density of all the material within the sphere. It has been calculated that for densities in the range from 0.5 to 1.0 gm $cm^{-3}$, the diameter of the sphere will vary from 6 to 2 ft. approximately. Thus the instrument satisfies the requirement stated by the objective mentioned above.

Some field data have now been obtained with the density meters and reference is made here to Fig. 2. These data were obtained from two confined muskegs near Parry Sound, Ontario, in mid-December 1964. The curves represent the relationship between depth of the gamma source in the ground and the density of the peat-water mixture. Curves 1 and 2 were obtained in EFI hollows and curve 3 was obtained in an FI patch within an FEI area. All locations were covered by about 6"-8" of snow, ice, and water. The peat deposits were about 6 ft. deep and the mineral sublayer consisted of rock.

Readings were taken by the authors every 10 cm. down the length of the access tube starting at the bottom. The counting interval was one minute at each position.

Curves 1 and 3 indicate similar average peat densities under similar cover types. The measurements for curve 2 were obtained about 20 minutes after the access tube had been inserted in the ground. As has already been mentioned, there was considerable free water flooding on the surface of the bog and it is suggested that water flowed down the outside walls of the access tube during the time interval between tube insertion and density measurement. This is a possible reason for the density difference between curve 2 and curves 1 and 3. This suggestion is supported by the observation that in cases one and three, if successive measurements were taken at one position of the source over a five to ten-minute period, the readings increased in size as indicated by points 1, 2, 3, and 4 on curve 1. Also curves 1 and 3 have a slight slope indicating the possibility of increasing moisture surrounding the source as it was moved closer to the ground surface and as time passed. Since water has higher density than peat, increased moisture content would be revealed as increased density.

A second line of investigation has been initiated involving a modification in the instrument setup, as shown in Fig. 3. Instead of one access tube, there are two. The gamma source is lowered down one tube and the detector is lowered to the same level in the other tube. By doing this it is hoped to take advantage of the sensitivity of the instrument and explore for density variations within relatively narrow horizontal regions.

From a consideration of the geometry of this parallel configuration, it is suggested that the volume of material involved in the density measurement is approximately described by an ellipsoid. The dimensions of the ellipsoid will depend on the spacing between the source and detector and on the density of the material between them.

Results were obtained with the modified instrument at Copetown Bog near Hamilton, Ontario, where other research has been performed in the past (Stewart,1960). Tests were performed in EI cover and the results are shown in Fig. 4. The two curves represent data obtained with 94 cm. and 50 cm. spacing of the access tubes. One of the access tubes was 100 cm. long so that testing was limited to about 70 cm. in depth.

Increased sensitivity is revealed by the "50 cm." curve over the "94 cm." curve. Points on the curves were obtained by averaging three counts at each position and variation of individual counts from the averages was less than 2.75% for the 94 cm. curve and less than 0.6% for the 50 cm. curve. The improvement obtained with the closer spacing is attributed to a decrease in the relative significance of background count when counts in the order of $1 \times 10^5$ are involved.

The second feature revealed by these curves is that there can be a significant density variation in 10 cm. horizontal regions in the peat. It is important to note that on these curves an increase in counts/minute corresponds to a decrease in density.

Future endeavour will include the procurement of similar data, using both methods, from other muskeg areas exhibiting a variety of vegetal cover classes and moisture regimes. Density measurements will be complemented by in situ moisture content determinations and these data will be correlated with vegetal cover to ascertain the distributional relationship between peat density, moisture content, and vegetal cover.

In addition to density measurement, it is also of interest to determine peat moisture content. This can be accomplished by replacing the gamma source with a source of fast neutrons. The neutrons lose much of their energy in collision with the nuclei of hydrogen atoms in water and are then detected as slow neutrons.

Our own moisture probe has only just arrived at completion of its development and we are satisfied from laboratory tests that it functions in the desired fashion. There has as yet, however, been no opportunity to apply it in field tests similar to those performed in December 1964 with the density probe.

It is intended to use the moisture probe in the field simultaneously with the density probe in order to obtain complementary data.

In addition, these data will be compared with cone penetrometer measurements from work supported by the U.S. Army Corps of Engineers and already reported by Radforth and

Ashdown (1963). There is a possibility that structural zoning in peat may be revealed on a similar basis by the two instruments.

Acknowledgment

The authors are indebted to the Defence Research Board for facilitating application of this instrument and to the National Research Council of Canada for additional financial assistance involved in the design and production of the instruments.

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## BIBLIOGRAPHY

Enright, C. T. "The Muskeg Factor in the Location and Construction of an Ontario Hydro Service Road in the Moose River Basin." Proc. Eighth Muskeg Research Conference, NRC-ACSSM, Tech. Memo. 74, 1962.

MacFarlane, I. C. "Guide to a Field Description of Muskeg." NRC-ACSSM, Tech. Memo. 44, 1958.

MacFarlane, I. C. and Radforth, N. W. "Physical Behaviour of Peat Derivatives under Compression." Proc. Tenth Muskeg Research Conference, NRC-ACSSM, Tech. Memo. 85, 1965.

Ponomareva, V. V. "Role of Humus Substances in the Formation of Brown Forest Soil." Soviet Soil Science, Dec. 1962, p. 1335.

Radforth, N. W. "Range of Structural Variation in Organic Terrain." Roy. Soc. Can., Trans., Ser. III, Sec. V, Vol. 49, 1955, pp. 51-67.

———————— "Organic Terrain Organization from the Air." Handbook No. 1 (Altitudes less than 1000 ft.). Defence Research Board, Dept. Nat. Defence, DR No. 95, 1955.

———————— and Ashdown, K. H. "The Procurement of Physical and Mechanical Data from Organic Terrain." Proc. Sixth Muskeg Research Conference, NRC-ACSSM, Tech. Memo. 67, 1961.

———————————————— "Design in Organic Terrain and Its Effect on Trafficability." Proc. First Regional Meeting International Society for Terrain-Vehicle Systems, 1963.

Spackman, W., Riegel, W., and Dolsen, C. P. "Geological and Biological Interactions in the Swamp-marsh Complex of Southern Florida." Proc. Geol. Soc. Am. 77th Annual Meeting, 1964.

Stewart, J. M. "Cuticle in Organic Terrain as Applied to Copetown Bog." M.Sc. Thesis, McMaster University, 1960.

Suguitan, L. S. "Palynological Evaluation of Five Muskeg Landscape Patterns." Ph.D. Thesis, McMaster University, 1963.

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Discussion (R. W. Irwin)

It is much easier to criticize the work of others or point out weaknesses than to come up with something original or better yourself. The neutron soil moisture probe measures a volume defined by:

$$d = \sqrt[3]{\frac{100}{\%\ w\ (\text{vol.})}}$$

where "d" is the diameter of a sphere in inches and "w" is the moisture content of the soil being measured. Neutrons cannot be collimated readily since we measure scattered neutrons.

Gamma rays can be collimated to a narrow beam to give resolution in the position at which the readings are taken. The geometry of measurement or volume is straight line optics with a point source and a solid angle subtended by the scintillation counter. The photomultiplier tube is set at a reproducible distance from the source. The pulse threshold is set slightly below the energy peak of the source to reduce the background and only measure the direct radiation. The resolution detected without bias is a layer thickness of 1/2 inch. This procedure would increase the usefulness of the author's instrument over that shown in Fig. 3.

While the resolution of the gamma and neutron systems do not match and may be a problem in some cases there may not be too much difficulty in saturated soils such as organic soil.

The transmission of gamma rays follows the Beer-Lambert exponential inverse square law:

$$I_x = I_o \left[\exp(-\lambda \mu_o dx)\right]/x^2 \qquad \text{where}$$

$I_o$ = initial intensity of energy beam
$I_x$ = intensity of beam transmitted through a distance x
$\mu_o$ = wet bulk density
$\lambda$ = mass absorption coefficient.

It can be seen that the distance between source and counter is critical and that a plot of the logarithm of the count rate against wet density is linear. Dry density is of more value to us and therefore the water content of the soil must be known to the same degree of accuracy as the wet density. At our present state of knowledge this is not very easily determined for organic soils.

In Fig. 2 of the paper, the large volume measured masks the minor differences in density which might be expected in such a case and the 10 centimeter increments of depth do not add to the accuracy of measurement.

Microprofiles of soil density have heretofore not been possible, but with some modifications the authors' work with soil density measurement with gamma rays would seem to have value in soil genesis, trafficability and classification of muskeg.

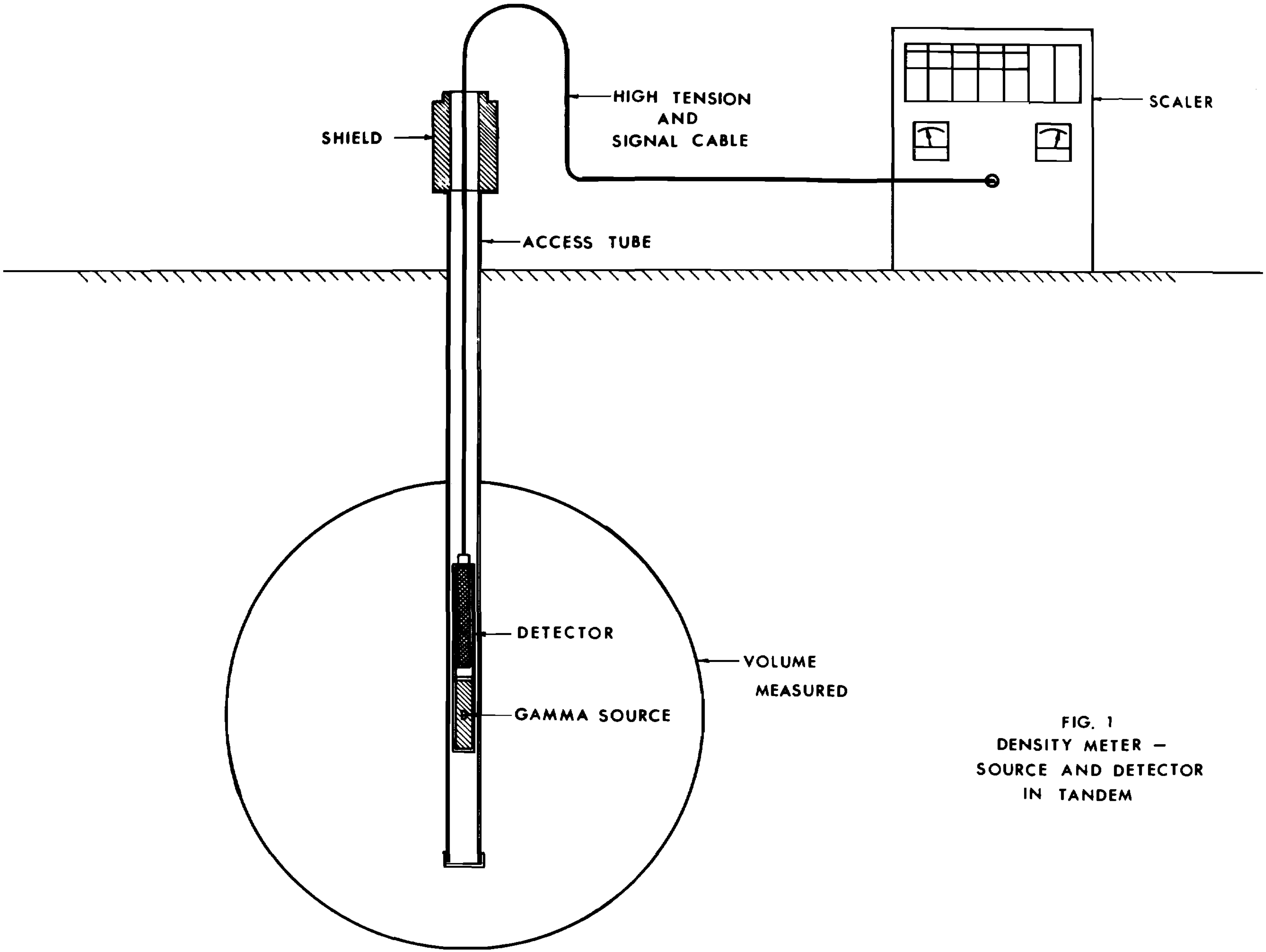



FIG. 1
DENSITY METER –
SOURCE AND DETECTOR
IN TANDEM

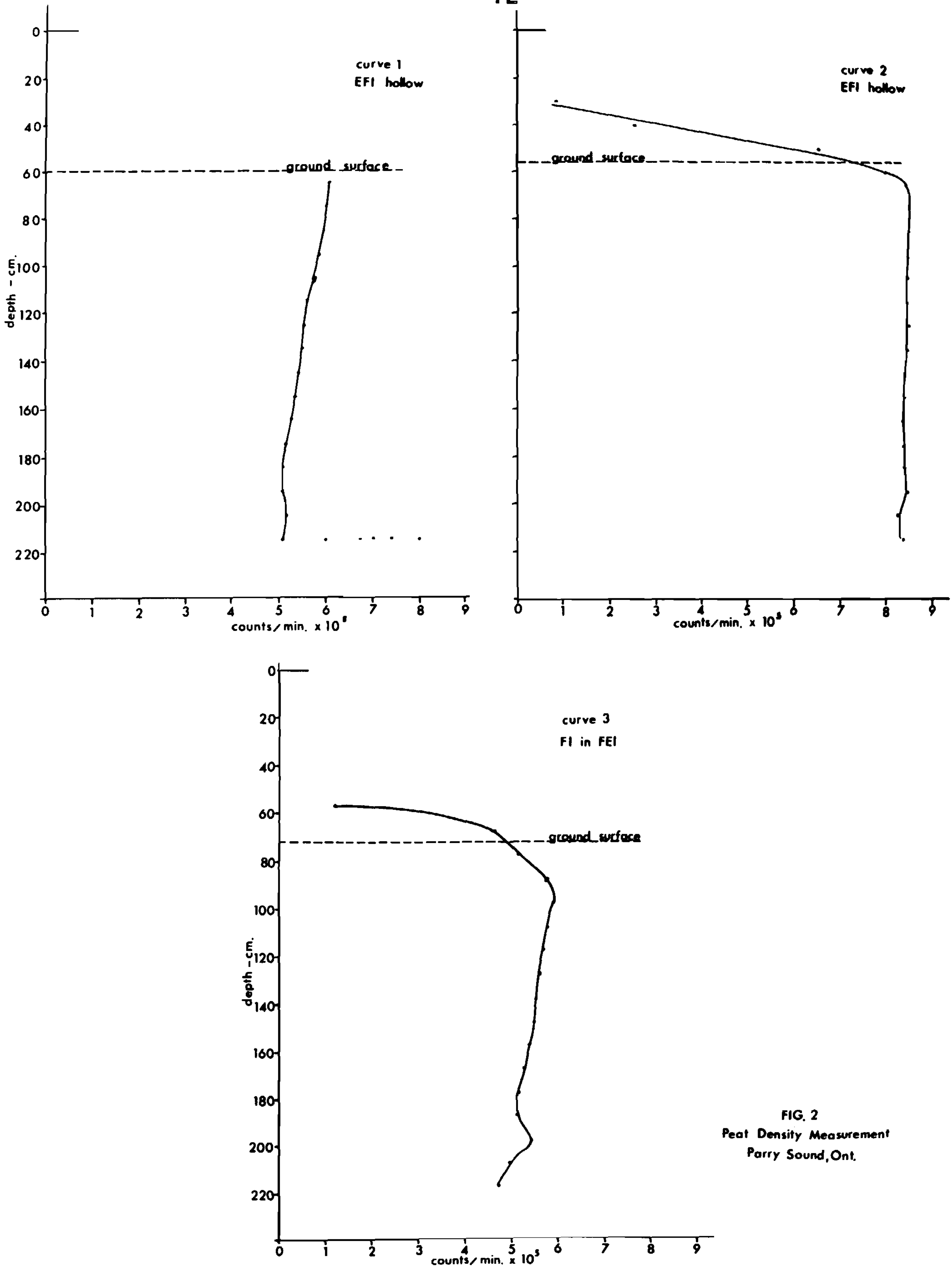



FIG. 2
Peat Density Measurement
Parry Sound, Ont.

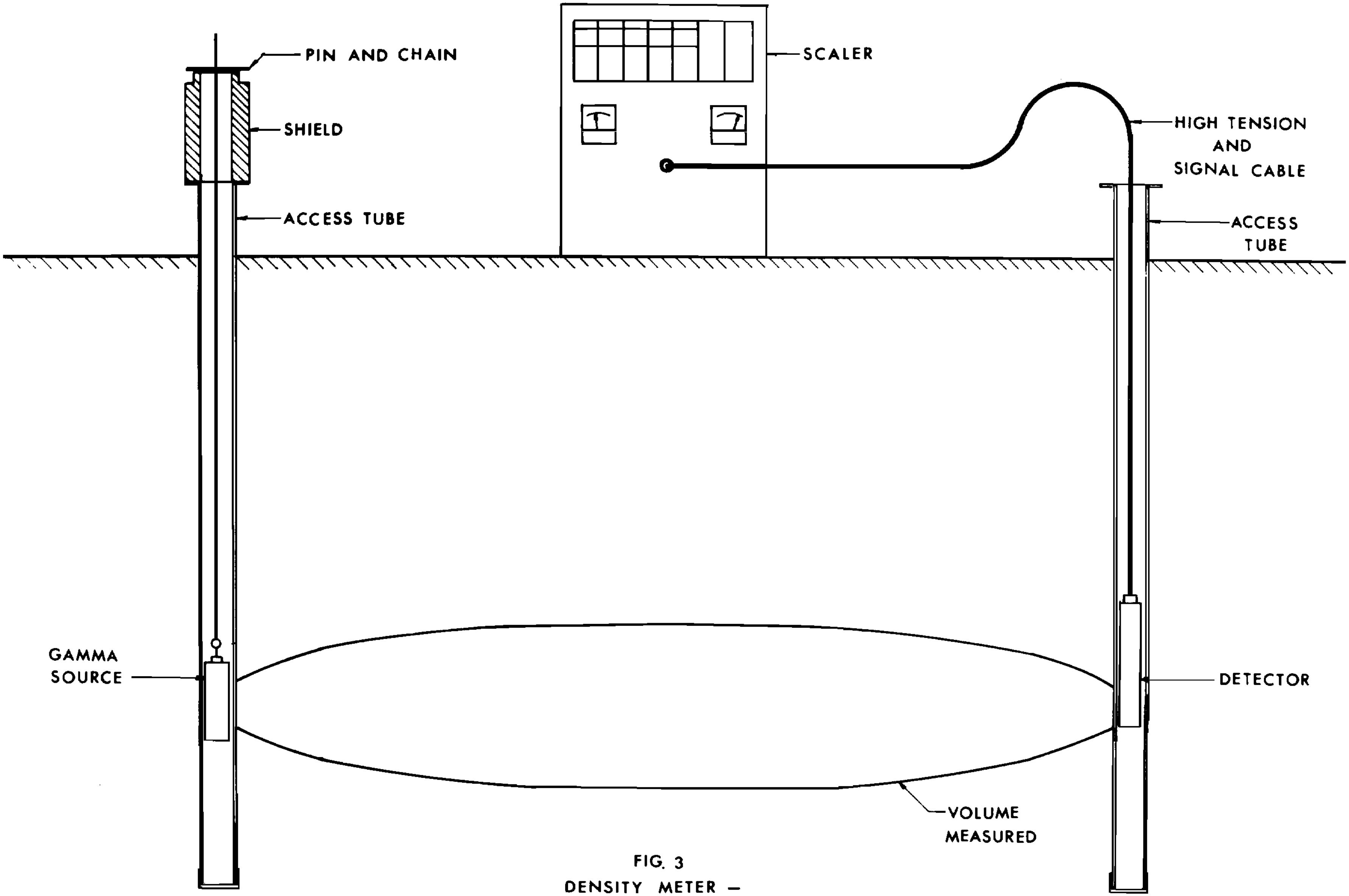
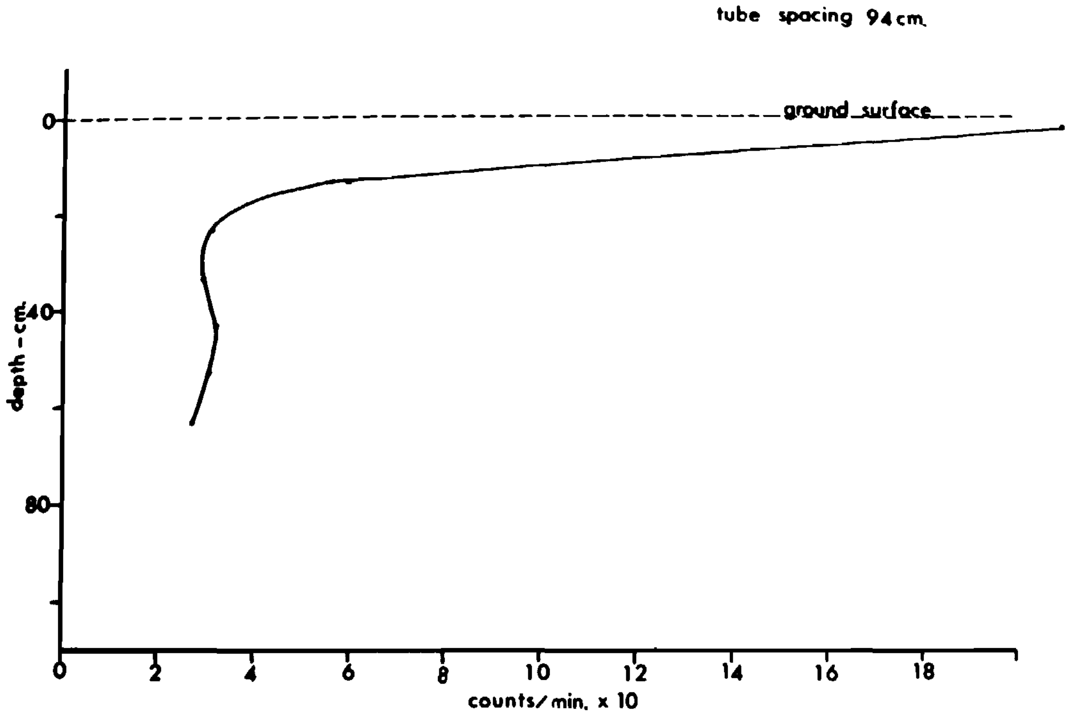



FIG. 3
DENSITY METER –
SOURCE AND DETECTOR IN
PARALLEL



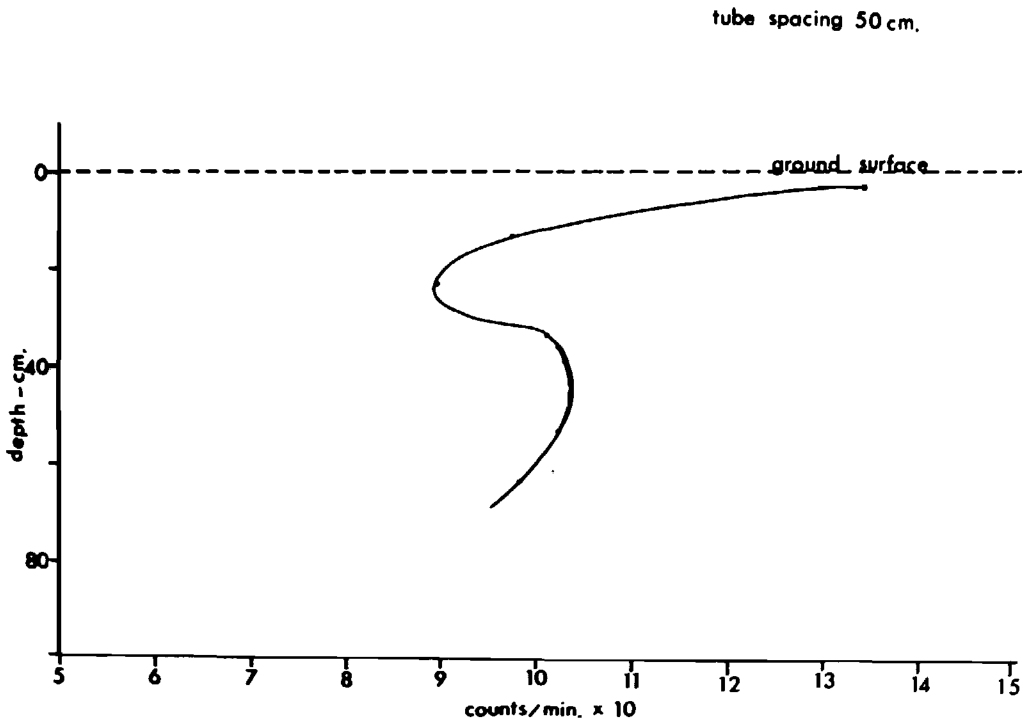




FIG. 4
Peat Density Measurement
Source and Detector in Parallel
Copetown, Ont.

## II.2. PROGRESS REPORT ON THE APPLICATION OF A NEUTRON SOIL MOISTURE METER TO ORGANIC SOIL

R. W. Irwin

Abstract

This report is based on one year of field experience with a neutron scattering device at the Ontario Agricultural College Muck Research Station. The basic problem did not appear to be the bound hydrogen in the organic material, but rather the limiting factor was the calibration of the instrument. It is concluded that additional work is necessary before the neutron scattering method will be of value in the determinations of water content of organic soils.

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## II.2. UN RAPPORT EN COURS SUR L'APPLICATION D'UN APPAREIL A NEUTRONS DANS LA DETERMINATION DE LA TENEUR EN EAU DES SOLS ORGANIQUES

R. W. Irwin

Résumé:

Ce rapport en cours résulte d'une année d'essais sur le terrain avec un appareil à dispersion de neutrons, a la Station de Recherches du College d'Agriculture de l'Ontario. Le problème fondamental ne semble pas être l'hydrogene fixe dans le materiel organique; le facteur de limite fut plutôt la calibration de l'instrument. On conclut qu'un travail additionnel est necéssaire avant que la méthode par dispersion de neutrons soit valable dans la détermination de la teneur en eau des sols organiques.

_ *** _

Soil moisture determinations of organic soil are important for many research uses. Since the neutron moderation theory for measuring soil moisture by volume has been well established on inorganic soils, the author applied this instrument to the organic soils at the Ontario Agricultural College Muck Research Station, Bradford, Ontario. This report is based upon one year of field experience. It should be pointed out that the specific research project involved relative values of soil moisture, not absolute values.

Literature Review: Very little information is available on the use of the neutron scattering method on organic soils. Knight and Wright (1954) reported that organic soil and mineral soil gave results to which a single curve could be fitted. They were criticized at the time for this statement. Church and Smith (1955) showed that the moisture content of sawdust and soil could be fitted with a single curve if the abscissa was total hydrogen. The probe primarily measures unbound hydrogen ions in determining water content and can, therefore, be used in any material when the bound hydrogen content is known or can be established by standard laboratory procedures. Bound hydrogen causes an unwanted background count. If this is constant and not too high, it can be subtracted from the final data; otherwise the two curves should be parallel. If the density of the soil varies, then the background count should be correlated against the density measurements. Clay minerals have a crystalline structure. They are classed according to their lattice structure as kaolinite, montmorillonite, and illite. Each of these groups have hydroxyl ions in their lattices. Kaolinite has the greatest number, the others are about the same. The hydrogen is in chemical combination and is constant, therefore, and not subject to change with change in soil moisture content. These ions may provide enough hydrogen to affect the meter which would indicate more moisture than was actually present. Holmes and Jenkinson (1959) suggest the use of the term "equivalent water" which includes hydrogen in the clay lattice and in the organic matter. Soils with chlorine, cadmium, carbon, lithium and boron affect the accuracy of the moisture probe and require a special calibration curve. Holmes and Jenkinson (1959) reported that changes in soil density change the slope of the calibration curve. The hydrogen ion content of organic soil is difficult to determine and the literature contains few references to its determination. Townsend and MacKay (1963) state that a raw peat from Nova Scotia contained 49.1 per cent carbon and 6.3 per cent hydrogen. Waksman (1938) reported that humus contained 50.8 per cent carbon, 5.4 per cent hydrogen and 2.6 per cent nitrogen by weight. The balance would be largely oxygen. Water contains 11 per cent hydrogen by weight.

The probe measures a semi-spherical volume which changes in volume with the number of hydrogen ions contained in it. Moisture in this volume affects the count rate inversely as the square of the distance from the source. When a soil is wet, the volume measured is low. The count rate is linear with water content. Holmes and Jenkinson (1959) proved that the water content as measured, though representing an extended volume, is not the arithmetic mean, but a weighted average of the soil moisture. The water content closer to the tube has a greater effect. The drying influence of the access tube may affect the calibration.

Lawless (1963) showed the probe was inaccurate at abrupt changes in soil moisture and at shallow depths the results were always negative as the tendency to underestimate was due to the air-soil interface and loss of neutrons to the air. In wet soils, this was not so important but could be as high as one inch of water and corrections should be applied. Lawless also showed that increments of depth of one, three and six inches gave the same reading and that 12-inch increments gave readings six times greater than the lesser values. McHenry (1963) found the effective sensitive length of the P-19 probe to be 10 inches, that is, the minimum length of layer where it alone influences the moisture control. He also pointed out that stones or air reduced the neutron flux to give an apparent low moisture content. The effect of the bottom of the tube is such that the probe must be lifted four inches off the bottom which places the source eight inches off the bottom before the influence is not noticed in calibration.

Apparatus: The instrument used in this study was a Nuclear-Chicago Model P-19 Depth Moisture Gauge with a Model 2800 Portable Scaler. The access tube used was 1-5/8 inch O.D. welded tubing. The principle of operation of this instrument is based upon the neutron moderation theory that fast neutrons lose kinetic energy in elastic collision with low atomic weight nuclei. These neutrons of reduced energy are called thermal neutrons and are subject to scatter and reflection due to the collisions. In soils, the hydrogen nuclei, found largely in water, constitutes nearly all the low atomic weight nuclei. Since the mass of a neutron is almost the same as the mass of a proton in the hydrogen ion, the transfer of energy is very efficient and hydrogen makes a good moderator (Nuclear-Chicago, 1963). The rate of slowing down is also dependent upon the probability that collisions will occur which is greater for hydrogen than any other element. A radium-beryllium (Ra-Be) 4.3-millicurie source provides a constant, fast, neutron emission rate. This alpha-neutron source has proved to be the most popular because beryllium has the highest yield of all elements when bombarded with alpha particles. Radium has a long half-life (1620 years) which ensures a constant neutron emission with time. Boron trifluoride ($BF_3$) gas is used as a sensitive detector of thermal neutrons. The alpha-particles are counted by electronic circuity. The neutron count is an integration of the number of neutron collisions with hydrogen in free water, adsorbed or bound water, organic matter, hydroxyl ions in clay lattices and other minerals less the number of thermal neutrons absorbed by boron, chlorine and other elements.

Method: The calibration curve supplied for the P-19 Moisture Depth Probe is for inorganic soils whose hydrogen content is primarily that of the free water molecule. The method of procedure for determining the moisture content has been set forth by the American Society of Testing Materials (1960) and Sartz and Curtis (1961). Their method of field calibration was followed. Burn (1961) points out the determination of moisture content from field borings is not accurate enough to use as a standard against which to calibrate since there is no control over moisture content in the field and moisture content of natural soils vary so much. A field determination was used in this study since it represents the conditions as they exist in nature. An access tube five feet long was installed June 1, 1964. Weekly observations were taken in this tube to determine any trend in soil moisture movement. On June 29, 1964 readings were taken in the tube at three-inch intervals. Four soil cores (3"x3") were taken in a spoke-like fashion at each depth a distance of six inches from the access tube. These were weighed, dried in an oven, and the water content determined. The average value per sampling layer by depth was calculated and a vertical moisture gradient with depth was established. The results of this survey are shown in Table 1. The dry bulk density was calculated based upon the wet volume of the soil core taken and corrected for water content.

TABLE 1

Soil Moisture Calibration Data, June 29, 1964
Bradford, Ontario

| Depth Range (inches) | Water Content (% by wt.) | Water Content (% by vol.) | Dry Density (g./cc.) |
|---|---|---|---|
| 8-11 | 487.4 | 71.2 | 0.146 |
| 15-18 | 675.0 | 81.8 | 0.121 |
| 21-24 | 662.5 | 80.4 | 0.121 |
| 27-30 | 642.9 | 79.7 | 0.124 |
| 36-39 | 750.8 | 80.0 | 0.107 |

Ash Content 7% ave. S.G. 1.5 ave.

Duplicate two-minute readings were taken at each probe position and are presented in Table 2. In order to establish a correction factor for shallow depths, a second set of readings were taken in the 21 to 27-inch depth after the first 15 inches of soil had been removed. Normally the depth probe is not suited for measuring moisture at shallow depth because of the loss of neutrons at the air-soil interface. The meter tends to overestimate the actual water content and the loss varies with the water content and density. This phase of the study proved to be of little value since the wetness of the soil showed that a six-inch depth was not affected by the air-soil interface.

TABLE 2

Example of Neutron Meter Counts, Bradford, 1964

| Depth of Observation (inches) | Counts averaged over one minute | | | | | |
|---|---|---|---|---|---|---|
| | June 1 | June 8 | June 15 | June 22 | June 29 | June 29 A |
| 6 | | | | | 13,126 | |
| 9 | 14,359 | 14,017 | 14,560 | 14,321 | 14,572 | |
| 12 | 15,206 | 15,368 | 15,499 | 15,018 | 15,628 | |
| 15 | 16,434 | 16,526 | 16,634 | 16,512 | 16,765 | |
| 18 | 16,691 | 16,906 | 16,947 | 16,712 | 16,627 | |
| 21 | | 16,521 | 16,211 | 16,409 | 16,428 | 16,336 |
| 24 | 15,932 | 15,556 | 15,406 | 15,498 | 15,028 | 15,631 |
| 27 | | 16,210 | 16,300 | 16,001 | 15,935 | 15,400 |
| 30 | 16,798 | 16,543 | 16,647 | 16,378 | 15,959 | |
| 33 | | 16,572 | 16,704 | 16,598 | 16,713 | |
| 36 | 16,776 | 16,780 | 17,135 | 16,789 | 16,801 | |
| 39 | | 17,008 | 17,079 | 16,901 | 16,877 | |
| 42 | 17,096 | 16,915 | 16,880 | 16,937 | 16,965 | |
| Standard | | | | | 4,104 | 4,111 |

A - This column is counts after 15 inches of soil had been removed from the surface.

TABLE 3

Summary of Soil Moisture Observations, Bradford, 1964

| Date | Previous Week's Precipitation | Average Water Level | Per cent moisture by volume at depth shown (inches) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 6 | 9 | 12 | 18 | 24 | 30 | 36 |
| May 19 | 0.64 | 36 | | 55 | 66 | 87 | 86 | 92 | 90 |
| 25 | 0.66 | 34 | | 61 | 74 | 85 | 90 | 81 | 90 |
| June 1 | 0.41 | 38 | | 51 | 64 | 90 | 90 | 90 | 90 |
| 8 | 0.46 | 39 | | 79 | 66 | 90 | 85 | 90 | 90 |
| 15 | 0.15 | 42 | | 52 | 64 | 85 | 83 | 90 | 90 |
| 22 | 0.45 | 41 | | 55 | 67 | 90 | 83 | 90 | 90 |
| 29 | 0.29 | 44 | | 49 | 61 | 87 | 85 | 90 | 92 |
| July 6 | 0.00 | 45 | | 50 | 61 | 85 | 82 | 90 | 90 |
| 13 | 2.12 | 34 | | 71 | 81 | 89 | 85 | 90 | 88 |
| 20 | 0.58 | 37 | | 51 | 64 | 85 | 85 | 90 | 90 |
| 27 | 0.36 | 41 | 44 | 50 | 63 | 85 | 82 | 90 | 90 |
| Aug. 7 | 1.33 | -- | 43 | 50 | 61 | 83 | 84 | 85 | 90 |
| 11 | | 42 | Meter faulty | | | | | | |
| 18 | 0.42 | 44 | 43 | 50 | 62 | 84 | 84 | 89 | 91 |
| 25 | 1.68 | 32 | 46 | 54 | 68 | 86 | 85 | 90 | 90 |
| 31 | 0.68 | 35 | 48 | 52 | 65 | 87 | 85 | 91 | 91 |
| Sept. 9 | 0.05 | 41 | 43 | 49 | 61 | 85 | 83 | 90 | 90 |
| 14 | 0.20 | 44 | 43 | 49 | 63 | 83 | 81 | 89 | 91 |
| 21 | 0.00 | 45 | Meter faulty | | | | | | |
| 28 | 0.20 | 45 | 42 | 50 | 63 | 85 | 86 | 89 | 91 |

(cont'd)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Oct. 5 | 0.15 | 47 | 43 | 48 | 62 | 85 | 84 | 90 | 89 |
| 13 | 0.24 | 47 | 43 | 50 | 61 | 86 | 82 | 87 | 90 |
| 19 | 0.00 | 47 | 42 | 49 | 61 | 85 | 83 | 89 | 91 |
| 26 | 0.36 | 48 | 44 | 50 | 62 | 85 | 83 | 87 | 91 |
| Nov. 2 | 0.21 | 49 | 48 | 50 | 63 | 85 | 84 | 89 | 90 |

Results and Discussion: The average counts per minute were estimated from Table 2 for the three-inch depths shown in Table 1. A few points on the calibration curve were calculated. These points scatter about a trend line (Fig. 1) extrapolated from the factory calibration curve for inorganic soil and ending at pure water. A calibration conducted in 1961 on disturbed samples of this soil is also shown in Figure 1.

A record of water content by volume as measured by the neutron moisture probe as well as groundwater level and precipitation was maintained from May 19 to November 2, 1964. These data are summarized in Table 3. Each value is the mean of three access tubes. Data from Table 3 is plotted in Figure 2. It is noted that the measured increase in water content appears linear to a depth of 18 inches where near saturation is recorded. It is probable that the meter is overestimating the water content in the 18 to 24 inch range due to proximity to the water table effect. Seasonal variation in the water table does not appear to have a noticeable effect on the recorded values.

Figure 3 shows a plotting of count rate against time for one access tube for depths of 9, 12 and 15 inches. Variations occur due to rainfall, but generally there is no apparent seasonal trend. The variation for all access tubes are shown for the 15-inch depth.

Conclusions: Additional work is necessary before the neutron scattering method will prove to be of value in the determinations of water content of organic soils. There is also need for additional work in finding a procedure suitable for determining moisture change with time.

The high count rates introduce a higher absolute error into the measurements. The theory forecasts this to be proportional to the square root of the moisture content. The problem does not appear to be the bound hydrogen in the organic material, but rather the calibration of the instrument is the limiting factor. It is doubtful if other techniques such as gamma ray methods would be superior.

- * -

## REFERENCES

A.S.T.M. Measurement by nuclear means of moisture and density in soils. Tentative Method. Committee E 10. A.S.T.M. 1960.

Burn, K. N. Design and calibration of a neutron moisture meter. NRC-DBR Res. Paper 129, 1961.

Church, G. R. and Smith, D. B. Instrument for measurement of hydrogen content of soil. A.E.R.E. Int. Rep. 1687. Harwell, G.B. 1955.

Holmes, J. W. and Jenkinson, A. F. Techniques for using the neutron moisture meter. Jnl. Agr. Eng. Res. 4:100-109. 1959.

Knight, A. H. and Wright, T. W. Soil moisture determination by neutron scattering. Radioisotope Conf. Oxford. 1954.

Lawless, G. P. et al. Soil moisture interface effects upon reading of neutron moisture probe. Soil Sci. Soc. Amer. Proc. 27:502-507. 1963.

McHenry, J. R. Theory and application of neutron scattering in the measurement of soil moisture. Soil Science 95:294-307, 1963.

Nuclear-Chicago Instruction Manual. Model P-19 Depth Moisture Gauge. 1963.

Sartz, R. S. and Curtis, W. R. Field calibration of a neutron-scattering soil moisture meter. Lake States Forest Exp. Sta. Paper 91. 1961.

Townsend, L. R. and MacKay, D. C. Effect of cropping on some chemical properties of a sphagnum peat soil. Cdn. Jnl. Soil Sci. 43:171-179, 1963.

Waksman, S. A. Humus. 2nd ed. Williams-Wilkins. Baltimore. 1938.

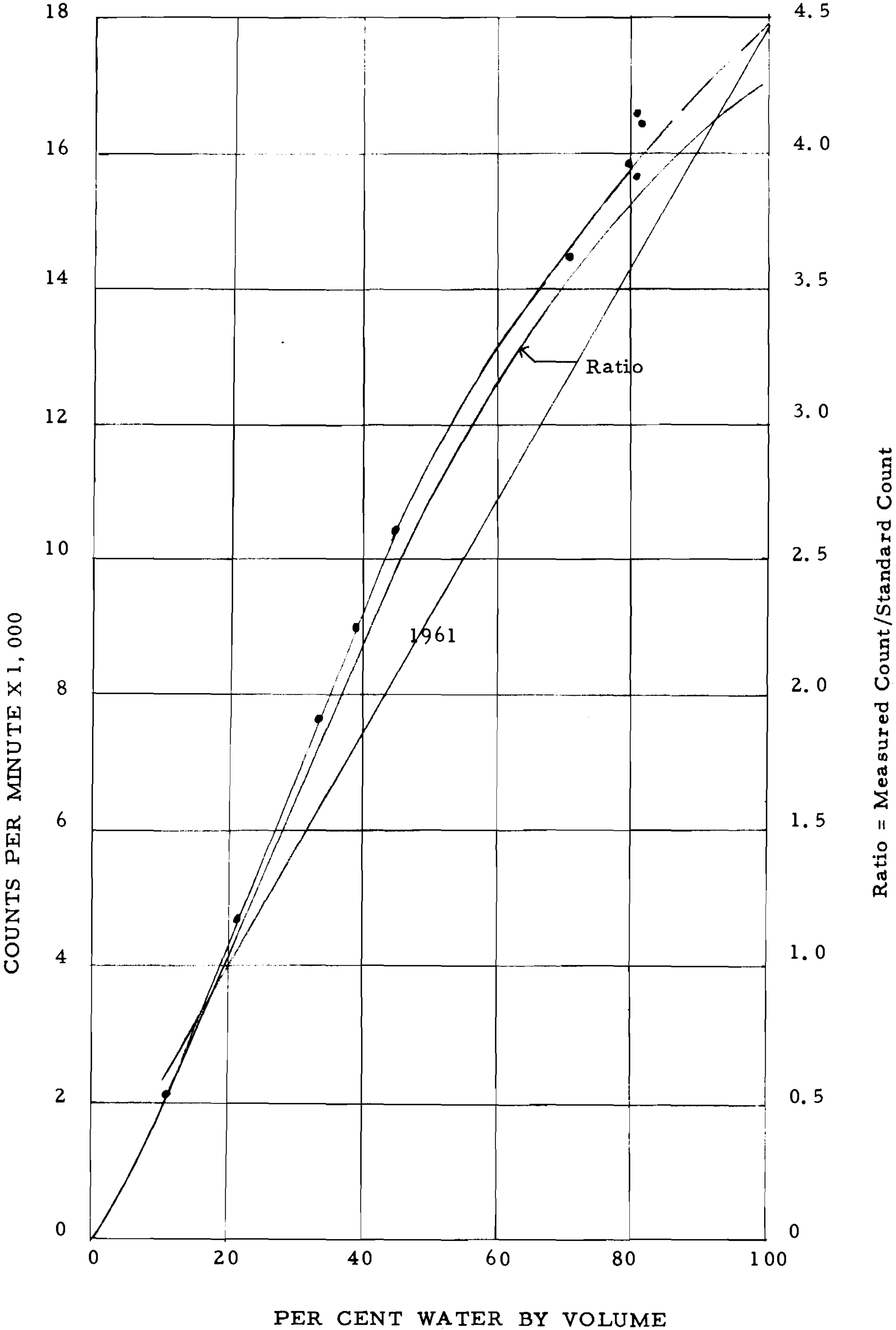


Figure 1. Calibration Curve for P-19 Probe

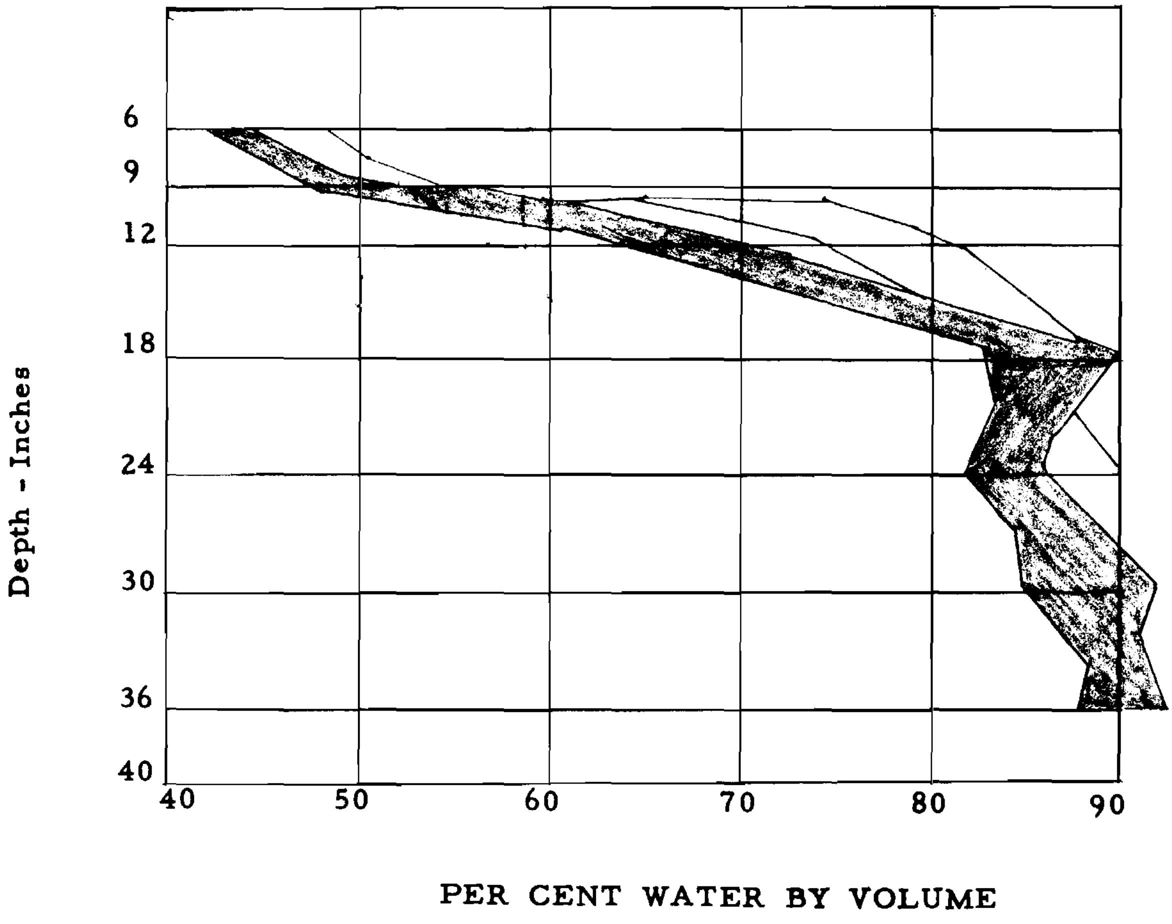


Figure 2. Variation of Soil Moisture with Depth

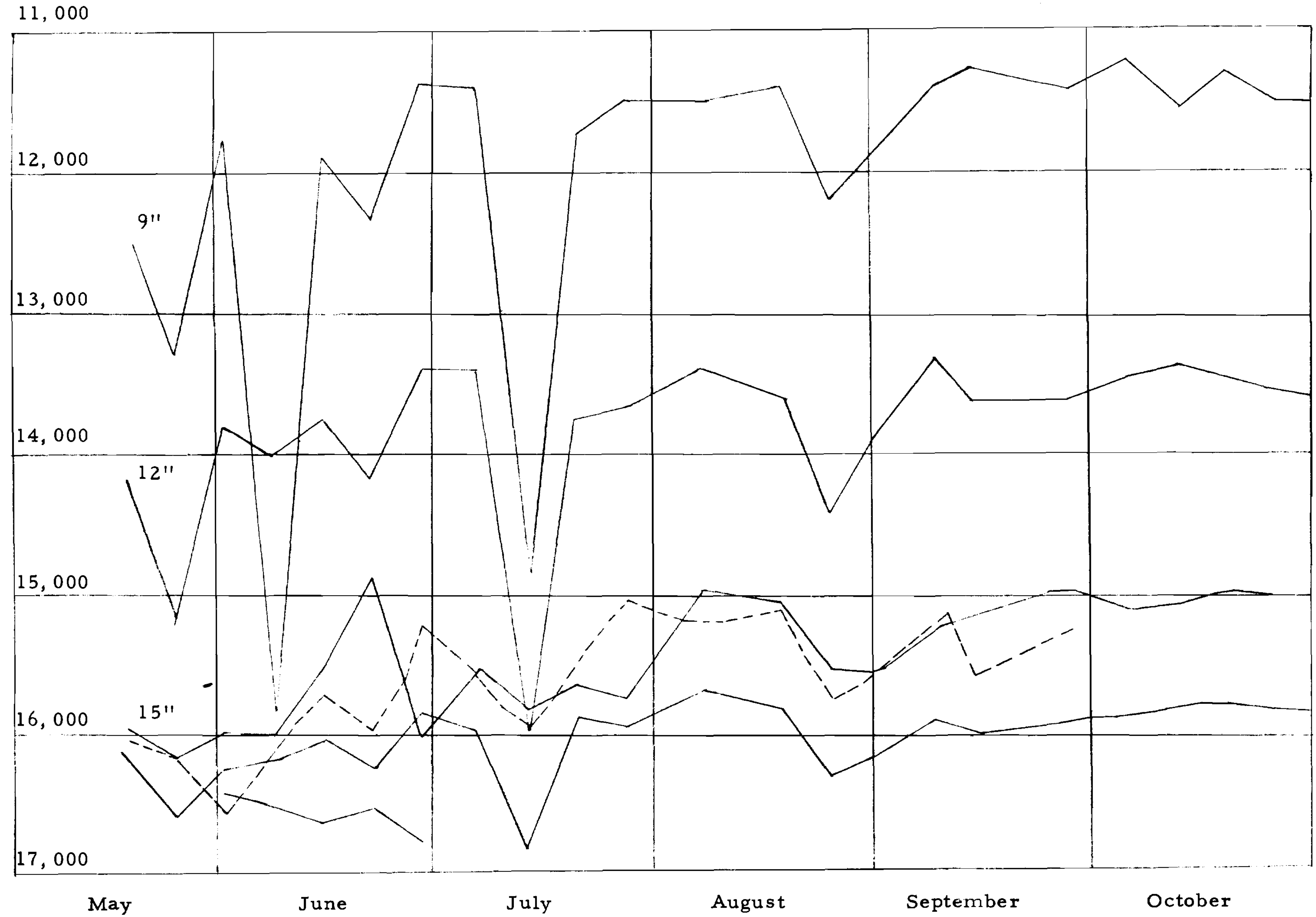
11,000
12,000
13,000
14,000
15,000
16,000
17,000
9"
12"
15"
May
June
July
August
September
October

Figure 3

## II.3. PERCENTAGE OF LATEWOOD AND RATE OF GROWTH OF BLACK SPRUCE OF SELECTED ORGANIC AND MINERAL SOIL SITES

Miss L. Usik

Abstract

The production of latewood in terms of percentage of radial growth was investigated for black spruce in relation to radial growth rate and to site quality. No significant difference in the percentage of latewood produced was found for trees with different growth rates and in different organic and mineral soil sites.

The formation of latewood was related to intrinsic factors of growth similar to those which initiate cambial activity in the spring. The extent to which the latewood develops in character is thought to depend upon the extrinsic factors of the environment.

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## II.3. POURCENTAGE DES DERNIERES POUSSES ET TAUX DE CROISSANCE DE L'EPINETTE NOIRE DANS DES SOLS ORGANIQUES ET MINERAUX

Miss L. Usik

Résumé:

On a étudié, en termes de pourcentage de croissance radiale, la production des dernières pousses de l'épinette noire en rapport avec le taux de croissance radiale et la qualité du site. On ne trouve pas de différence significative dans le pourcentage de production des dernières pousses pour des arbres à différents taux de croissance dans des sols organiques et minéraux.

On a établi une relation entre la formation des dernières pousses et les facteurs intrinsèques de croissance semblables aux facteurs qui amorcent l'activité au printemps. On a pensé cependant que le développement auquel les dernières pousses aboutissent dépend des facteurs intrinsèques d'environnement.

The importance of black spruce (Picea mariana (Mill) B.S.P.) as a pulpwood tree and as a tree indigenous to the organic soils of confined and unconfined areas of muskeg has produced an increasing need for the understanding of its growth behaviour. Diameter growth of trees is of particular interest in relation to site productivity and the proportions of early- and latewood have important effects upon the quality of wood produced.

Growth rings vary in width in trees in relation to species, age and growing conditions. Necessarily correlated with the variation in total ring width are changes in the widths of the early- and latewood portions.

"Using mostly subjective methods some investigators have found that the proportion of latewood increases as the ring narrows" (Studhalter et al,1963). Priestly and Scott (1936) explained that in softwoods, "if wide and narrow annual rings are compared, the difference in width will be found to consist mainly in a varying proportion of thin-walled springwood". Lodewick (1933) reported for southern yellow pine that the maximum percentage of summerwood, at least in crowded stands, occurred only in the narrowest rings.

Latewood production in forest trees has also been investigated in terms of wood density, which is then related to the weight and strength of the wood. The general conclusions have been that slow growing trees have high densities. Hale and Fensom (1931) have found that the specific gravity of white spruce continued to increase up to the maximum number of rings encountered, which in the stock they used was 40 per inch. Rochester (1931) showed by a series of curves that a definite correlation exists between optimum growth expressed in terms of a minimal and a maximal number of growth rings per inch, and the strength of several Canadian softwoods. Hale and Prince (1940) found that the slowest growing white and black spruce had the highest densities.

The situation has been summarized by Brown, Panshin and Forsaith (1956) as follows: "within reasonable limits of ring width, the denser summerwood consisting of thick-walled tracheids is less affected volumetrically by changes in the width of the growth increments, i.e., by big changes in the growth rate, than is the springwood". Latewood production, in terms of annual radial increments, is therefore regarded as relatively stable by all these investigators.

This paper reports the investigation of latewood production in terms of percentage of radial growth. It deals with examples of black spruce growing in selected organic and mineral soil sites and having different radial growth rates.

Location and Description of Tree Sites

The trees of this investigation grow in a bog in the Parry Sound District of Ontario. The bog, numbered Area 9 in connection with other investigations by the Muskeg Laboratory at McMaster University, Hamilton, is approximately 12 miles north of Parry Sound and a quarter of a mile west of Highway 69.

Area 9 is a peat-filled trough about three-quarters of a mile long and one-eighth of a mile wide. The tree distribution in the bog offers several different tree sites according to the Radforth Classification System (Radforth,1952), Figure 1. Three rock outcrops rising 1 to 4 feet above the bog level are situated in the northern half of the bog and support black spruce on their mineral soils.

The northern and southern outcrops were selected as the mineral soil sites because of their different soil types. These sites were designated as N-M and S-M respectively. Most of the spruce in the N-M site grow on a glacial deposit of sand with large pebbles and boulders, which is 2 to 3 feet deep. On the southern outcrop the spruce grow on a coarse skeletal soil, formed from the underlying rock, 4 to 9 inches deep.

Both sites are predominantly black spruce with a few larch (Larix laricina Mill.). The understorey is sparse in both sites and consists of a few scattered shrubs of Viburnum (Viburnum cassinoides L.). The ground cover when present occurs as patches of Hypnum moss, blueberry (Vaccinium angustifolium Ait.), bunchberry (Cornus canadensis L.) and wintergreen (Gaultheria procumbens L.).

The bog tree sites ADI, AEI-D, BEI and BFI are situated around the southern outcrop. The selection of these sites was based upon the differences in plant association, peat depth, and distance from mineral margin.

The ADI site extends as a band 20 to 30 feet around the outcrop. The D element is dense and consists mainly of mountain holly (Nemopanthus mucronata (L.) Trel.). Sphagnum of the acutifolia group blankets the peat and forms loose mounds at the bases of the trees. The depth of peat is 1 to 3 feet.

The AEI-D site lies to the southeast of the outcrop and extends as a band along the length of the bog. The second element in the vegetation is the low shrub cover which consists mainly of leatherleaf (Chamaedaphne calyculata (L.) Moench), with some labrador tea (Ledum groenlandicum Oeder) and bog laurel (Kalmia angustifolia L.). The tall shrub mountain holly, however, occurs frequently in large clones.

The I element is entirely the acutifolia _Sphagna_ which form high loose mounds with the ericaceous shrubs. Peat depth is between 3 and 4-1/2 feet.

North and east of the outcrop in the central portion of the bog are the BEI and BFI sites. The BEI site is a relatively small area just to the east of the outcrop. The average depth of peat in these sites is 6 feet.

The E element of the BEI site consists mostly of leatherleaf with a large admixture of labrador tea and bog laurel which grow as high as 2 feet. These shrubs together with pale laurel (_Kalmia polifolia_ Wang), bog rosemary (_Andromeda glaucophylla_ Link) and _Vaccinium_ species are also present in the BFI site. They are greatly reduced in density, however, branching, and particularly in stature. The F element, which consists of sedges, such as cottongrass (_Eriophorum_ spp.) is the second important vegetal cover in the BFI site. The _Sphagna_ of the BFI site belong to the cymbifolia group which gives the site a fairly flat topography. The acutifolia _Sphagnum_ is mainly present in the BEI site and forms large mounds similar to those in the AEI-D site.

The results of 7 sectioned trees sampled from the large ADI and AEI sites, which are found in the northern end of the bog, have been included in this report as a group. The depth of peat here is 5 to 7 feet.

## Tree Sampling and Growth Analysis

Analysis of radial growth and latewood percentage was made on increment cores and on cross-sectional discs from trees in each site. A certain amount of selection was used in the sampling in order to eliminate diseased and injured trees. Also, the effect of age upon growth rates was reduced by sampling trees of a similar age group for all sites. The number of trees sampled for each site was partly determined by the distribution of the trees and by the size of the site. Mean heights, age and d.b.h. of the trees are shown by site in Table 1. The trees of the BFI site were divided into two age groups: $BFI_1$ - trees 30 to 50 years old and $BFI_2$ - trees 60 to 120 years old.

At least one tree was sectioned from each site. The sections were obtained from the stump, and from a quarter, a half, and three-quarters of tree height. From the analyses of the measurements made on six to eight radii on the cross sections, it was decided that at least three cores taken on different radii between stump and breast height would give a representative measurement of radial growth for any tree as well as an accurate age of the tree.

TABLE 1

Mean Height, Age and D.B.H. for Black Spruce by Site

| Site | No. of Trees Sampled | Age (yr.) | | | Height (ft.) | | | Mean d.b.h. (in.) |
|---|---|---|---|---|---|---|---|---|
| | | Mean | s | V | Mean | s | V | |
| N-M | 15 | 41.8 | 2.93 | 7.00 | 37.7 | 4.45 | 11.71 | 5.12 |
| S-M | 22 | 41.7 | 5.00 | 11.99 | 27.5 | 4.08 | 14.84 | 3.72 |
| ADI | 22 | 38.8 | 5.07 | 19.74 | 21.7 | 4.25 | 19.55 | 3.11 |
| AEI-D | 20 | 38.0 | 3.44 | 9.06 | 20.5 | 3.45 | 16.85 | 3.01 |
| BEI | 10 | 41.8 | 7.21 | 17.26 | 16.7 | 3.13 | 18.72 | 2.60 |
| $BFI_1$ | 10 | 41.9 | 8.48 | 20.24 | 14.3 | 2.31 | 16.15 | 2.22 |
| $BFI_2$ | 20 | 88.9 | 19.43 | 21.86 | 21.9 | 5.70 | 26.03 | 3.06 |
| ADI+AEI* | 7 | 40.0 | - | - | 23.0 | - | - | 3.30 |

s = standard deviation; V = coefficient of variation;
* Trees from nothern bog sites.

The upper surface of each section was prepared for measurement of ring and latewood widths by fine sanding and/or by careful shaving with a scalpel. Each core was trimmed to produce a longitudinal flat surface. The widths of the annual rings and of the latewood portion of each ring were measured with an ocular micrometer in a binocular microscope to 0.01 mm.

Mean ring width and percentage of latewood were then calculated for each tree and also for all the trees of each site. Tables 2 and 3 show mean ring widths (mm/yr) and mean latewood percentages respectively with their standard deviations and coefficients of variation for each site. The tables also show data for the two BFI site age groups. The older group is further subdivided so that growth behaviour in the first and last 40-year periods may be examined separately.

TABLE 2

Radial Growth Rates (mm/yr) for Black Spruce by Site

| Tree Site | N.M | S.M | ADI | AEI-D | BEI | BFI | $BFI_1$ Total Age | $BFI_2$ First 40 yr | $BFI_2$ Last 40 yr | ADI + AEI |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of Trees Sampled | 15 | 22 | 22 | 20 | 10 | 20 | 20 | 20 | 30 | 7 |
| Mean Growth Rate (mm./yr) | 1.53 | 1.14 | 1.08 | 1.01 | 0.86 | 0.63 | 0.47 | 0.55 | 0.58 | 1.29 |
| s | 0.22 | 0.18 | 0.18 | 0.13 | 0.08 | 0.13 | 0.13 | 0.20 | 0.18 | 0.23 |
| V (%) | 14.38 | 15.81 | 16.52 | 13.23 | 9.18 | 20.33 | 27.25 | 36.86 | 32.70 | 18.52 |

TABLE 3

Percentage of Latewood for Black Spruce by Site

| Tree Site | N-M | S-M | ADI | AEI-D | BEI | $BFI_1$ | $BFI_2$ Total Age | $BFI_2$ First 40 yr | $BFI_2$ Last 40 yr | AEI + ADI |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of Trees Sampled | 15 | 22 | 22 | 20 | 10 | 10 | 20 | 20 | 20 | 7 |
| Mean Percentage Latewood | 28.94 | 27.11 | 25.94 | 27.59 | 29.19 | 27.86 | 23.34 | 24.14 | 23.85 | 24.39 |
| s | 6.46 | 5.27 | 4.62 | 4.13 | 3.36 | 5.44 | 6.25 | 7.47 | 3.28 | 2.76 |
| V | 22.30 | 19.45 | 17.86 | 14.96 | 11.49 | 19.53 | 26.79 | 30.94 | 13.75 | 12.47 |

The mean percentage of latewood was found for all the trees sampled and a frequency distribution was plotted. A normal curve was fitted to the distribution and is shown in Figure 2. The chi-square test for goodness of fit gave $\chi^2 = 5.59$, and $P = 0.50$, with $N = 9$.

The normal distribution curve shows that 126 trees sampled from different sites represent a population of trees whose mean percentage of latewood is 26.97 ± 5.21%.

The t-test for significance of differences between site means and population mean (Table 4) shows that all sites are samples of a tree population whose mean percentage latewood was 26.97 ± 5.21% and that the differences between means may arise through sampling. Level of confidence used was $P < .001$.

TABLE 4

P Values for t-test for Significance of Difference between Site Means and Population Mean of Percentage of Latewood where $\bar{X}_p = 26.97 \pm 5.21\%$

| Site | Percentage Latewood | P = |
|---|---|---|
| N-M | 28.94 | .142 |
| S-M | 27.11 | .897 |
| ADI | 25.94 | .667 |
| AEI-D | 27.59 | .596 |
| BEI | 29.19 | .177 |
| $BFI_1$ | 27.86 | .589 |
| $BFI_2$ | 24.25 | .193 |
| $BFI_{1\&2}$ | 25.45 | .112 |
| AEI + ADI | 24.39 | .190 |

The t-test was also applied to determine significance of differences between site mean radial growth rates (Table 5). The northern outcrop spruce have the highest growth rate and this is significantly different from those of all other tree sites.

The southern outcrop spruce growth rates are similar to those of the ADI and AEI-D sites and significantly higher than those of the BEI and BFI sites.

There is a significant difference between the BEI and BFI growth rates.

TABLE 5

P Values for t-test for Significance of Difference between Site Means of Radial Growth Rate (mm/yr)

| Sites Compared | P | Sites Compared | P |
|---|---|---|---|
| N-M - S-M | <.001 | ADI - AEI-D | ≈.10 |
| N-M - ADI | <.001 | ADI - BEI | =.001 |
| N-M - AEI-D | <.001 | ADI - $BFI_1$ | <.001 |
| N-M - BEI | <.001 | ADI - $BFI_2$ | <.001 |
| N-M - $BFI_1$ | <.001 | | |
| N-M - $BFI_2$ | <.001 | AEI - BEI | ≈.005 |
| | | AEI - $BEI_1$ | <.001 |
| S-M - ADI | ≈.200 | AEI - $BEI_2$ | <.001 |
| S-M - AEI-D | ≈.01 | BEI - $BFI_1$ | <.001 |
| S-M - BEI | <.001 | BEI - $BFI_2$ | <.001 |
| S-M - $BFI_1$ | <.001 | | |
| S-M - $BFI_2$ | <.001 | | |

Discussion

The sites chosen for investigation typify organic terrain conditions that recur throughout Canada and other temperate regions of the world. The results obtained from this investigation are, therefore, considered to be not only valid for disclosure of growth rates and latewood production behaviour of black spruce in one area, but useful in formulating hypotheses applicable to all spruce growing in an organic terrain environment.

It is seen (Table 5) that growth rates of black spruce in organic terrain sites vary significantly from those obtaining for spruce growing upon an open-textured mineral soil of moderate depth. Where mineral soil is shallow, growth rates are similar to those of trees growing close to mineral soil margins, on peat of moderate depth and in association with shrubs. Lower growth rates are found in trees growing farther from mineral soil margins and on peat of greater depth. The widest range and lowest values of growth rates occur in spruce growing in the central BFI site.

Factors such as drainage, soil temperature, water movement and nutrient supply are not discussed in this report, but may be associated with the expressions of site quality used, i.e., vegetal formulae, peat depth and distance from mineral soil margins.

In all sites latewood production expressed as a percentage of radial growth is found to be relatively constant. This is contrary to the general conclusions, reached by the investigators mentioned in the introduction, that latewood proportions vary widely.

The increase in the thickness or diameter of trees is produced by a self-perpetuating unicellular layer of cambial initials, or the cambium. Factors which control activity in this region have been considered in attempts to determine reasons for differences in growth characteristics and growth behaviour of the early and latewood portions of the annual wood increments.

A review of the investigations of cambial activity has been given by Studhalter *et al*. (1963). Most of the investigators have concluded that the stimulus responsible for the initiation and basipetal progression of cambial activity in the Spring was not associated with food reserves or food production, but was produced by growth hormones proceeding from the opening buds and developing leaves. Snow (1935), Brown and Cormack (1937), and Fraser (1949, 1952) have shown experimentally that the application of a growth hormone, heteroauxin, stimulated cambial activity and the continued production of earlywood elements.

Studhalter *et al*. (*loc*. *cit*.) also refer to several investigators who have related the time of latewood formation to the condition of leaves and next year's buds. A period of 'rest' or cessation of cambial activity was observed by Brown (1915) for white pine and by Lodewick (1925) for white ash. The latter explained that this period of cambial inactivity could not be correlated with any external factors and that it occurred "between the formation of the springwood and summer-wood elements" (*loc*. *cit*.). Therefore, the distinction between the early and the latewood was not to be associated with the season at which it was formed, but rather with some internal growth developments.

Through an examination of the structure and development of latewood in several hardwood trees, Priestly and Scott (1936) concluded that "the later formed wood of branches and trunk thus has its inception in the differentiating members of the buds". Therefore, like the earlywood, the production of latewood was associated with bud activity. However, they point out that the stimulus "initiates later growth activity rather than necessarily that characteristic structurally of summerwood" (loc. cit.).

Differences between early and latewood are found in the number, size, and structural features of the wood elements. Latewood is characterized structurally by a smaller lumen to the wood element and a thicker lignified cell wall. Also, the cells are more numerous. It has generally been accepted that the large, thin-walled cells of the earlywood are primarily conductive and formed during the flush of rapid growth at the beginning of the season when large quantities of water and sap are transported within the tree. The elements of the latewood are believed to be best adapted to ensure strength to the stem and probably do not participate in sap conduction to the same extent as earlywood (Brown, Panshin and Forsaith, 1949). The smaller lumen also suggests that, at the time these elements differentiate, less water is available to the tree. Priestly and Scott (loc. cit.) further explained that the wall thickening and lignification of the latewood elements may be related to the supply and distribution of food material within the tree at this time. Bannan (1963) reported that, for black spruce, there was an increase in the number of cells towards the end of a growing season that is "characteristic of slow growth and probably indicates a nutritional or hormonal relationship".

## Conclusions

Results of this investigation show that there is reason to suggest that differences in growth rates of black spruce are indexed by a system of cover designation for muskeg. That is, differences in cover type give expression to extrinsic factors governing growth rates.

The production of secondary wood or growth in diameter of trees is a result of the complex interaction of both external and internal factors. The extent to which either early or latewood may develop, i.e., size of cells, thickness of cell walls and degree of lignification may be related to environmental factors, but other factors appear to influence the formation of latewood.

A relatively constant proportion of latewood was produced by black spruce growing in a localized area where climate may be regarded as affecting all trees more or less equally and where differences in growth rate may be related to site quality.

Formation of latewood in all likelihood may be related to growth activities within the tree in a manner similar to that involved in earlywood formation. While the initiation of earlywood is reported to be stimulated by growth hormones from the opening buds, the latewood formation may be related to the development of the following year's buds.

Reasons for differences in latewood or earlywood growth behaviour for trees with different growth rates and from different sites must, therefore, be sought in the more detailed investigation of the character of the wood elements.

Acknowledgments

This work has been made possible through the sponsorship of N. W. Radforth and through the support of the Ontario Research Foundation and the National Research Council of Canada. The author also thanks K. Ashdown for his advice and assistance.

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REFERENCES

Bannan, M. W. Cambial behaviour with reference to cell length and ring width in Picea. Can. Jour. Bot., 41:811-822, 1963.

Brown, A. B. and Cormack, R. G. Stimulation of cambial activity locally in the region of application and at a distance in relation to a wound by means of heteroauxin. Can. Jour. Res. C., 15:433-441, 1937.

Brown, H. P. Growth studies in forest trees. II. Pinus strobus L. Bot. Gaz., 59:197-241, 1915.

____________, Panshin, A. J. and Forsaith, C. C. Textbook of wood technology. Vol. 1. McGraw Book Co.,Inc., 1949.

Croxton, F. E. and Dudley, D. J. Applied general statistics. Prentice-Hall, Inc., 1956.

Fernald, M. L. Ed. Gray's manual of botany. American Book Co.,1950.

Fraser, D. A. Production of springwood with b-indole acetic acid. Nature, 154:542, 1950.

____________. Initiation of cambial activity in some forest trees in Ontario. Ecol., 33, No. 2:259-273, 1952.

Hale, J. D. and Fensom, K. G. The rate of growth and density of white spruce. Can. Dept. Int., For. Serv. Cir. 30, 1931.

____________ and Prince, J. B. Density and rate of growth in the spruces and balsam fir of eastern Canada. Can. Dept. Mines & Res., For. Serv. Bull., 94:1-43, 1940.

Lodewick, J. E. Growth studies in forest trees. III. Experiments with the dendrograph on Fraxinus americana L. Bot. Gaz., 79:311-323, 1925.

________________. Some summerwood percentage relationships in the southern pines. Jour. Agr. Res., Vol. 46:543-554, 1933.

Priestly, J. H. Studies in the physiology of cambial activity. III. The seasonal activity of the cambium. New Phytologist, 29:316-354, 1930.

________________ and Scott, L. I. A note upon summerwood production in the tree. Leeds Phil. & Lit. Soc. Proc., 3:235-248, 1936.

Radforth, N. W. Suggested classification of muskeg for the engineer. Engineering Journal 35, II, 1952.

Rochester, G. H. The mechanical properties of wood. Can. Dept. Int., For. Serv. Bull. 82, 1931.

Snow, R. Activation of cambial growth by pure hormones. New Phytologist, 34:347-360, 1935.

Studhalter, R. A., Glock, W. S. and Agerter, S. R. Tree growth. Bot. Rev., 29, No. 3:245-365, 1963.

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Discussion (J. M. Robinson)

The Canadian pulp and paper industry is based on the large percentage of dense long-fibre wood found in our slow-growing spruce and balsam fir plus the fact that these species contain little resin and can be processed with a minimum of effort.

Though Hale and Prince (1940) point out that faster-grown wood contains more fibre for a given growth cycle, the fact remains that some Canadian pulp and paper companies freely admit that transportation costs from their regions are so high that only the superior quality of their pulp permits them to stay in business.

Hale and Prince (1940) find the densest wood in a bog near Lake Superior and the large number of samples which they had collected indicated that slow growth meant dense wood except peculiarly in the narrow rings at the outer edge of mature and overmature trees. They simply stated this as a fact but gave no reasons and it is possible that it is the key to Miss Usik's problem. Keith (1961) came to the same general conclusions as Hale and Prince.

(Continued on Page 68)

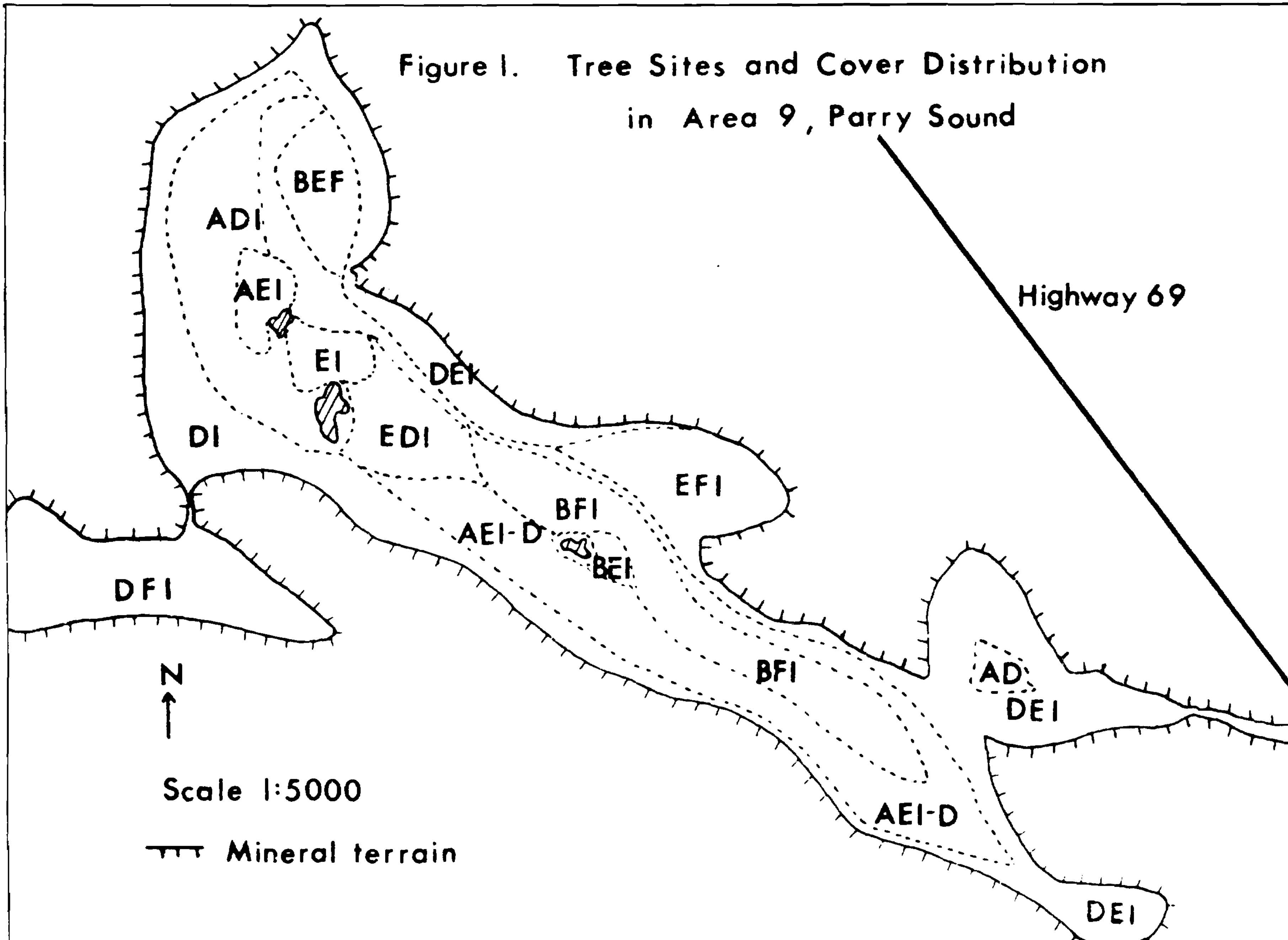


Figure I. Tree Sites and Cover Distribution in Area 9, Parry Sound

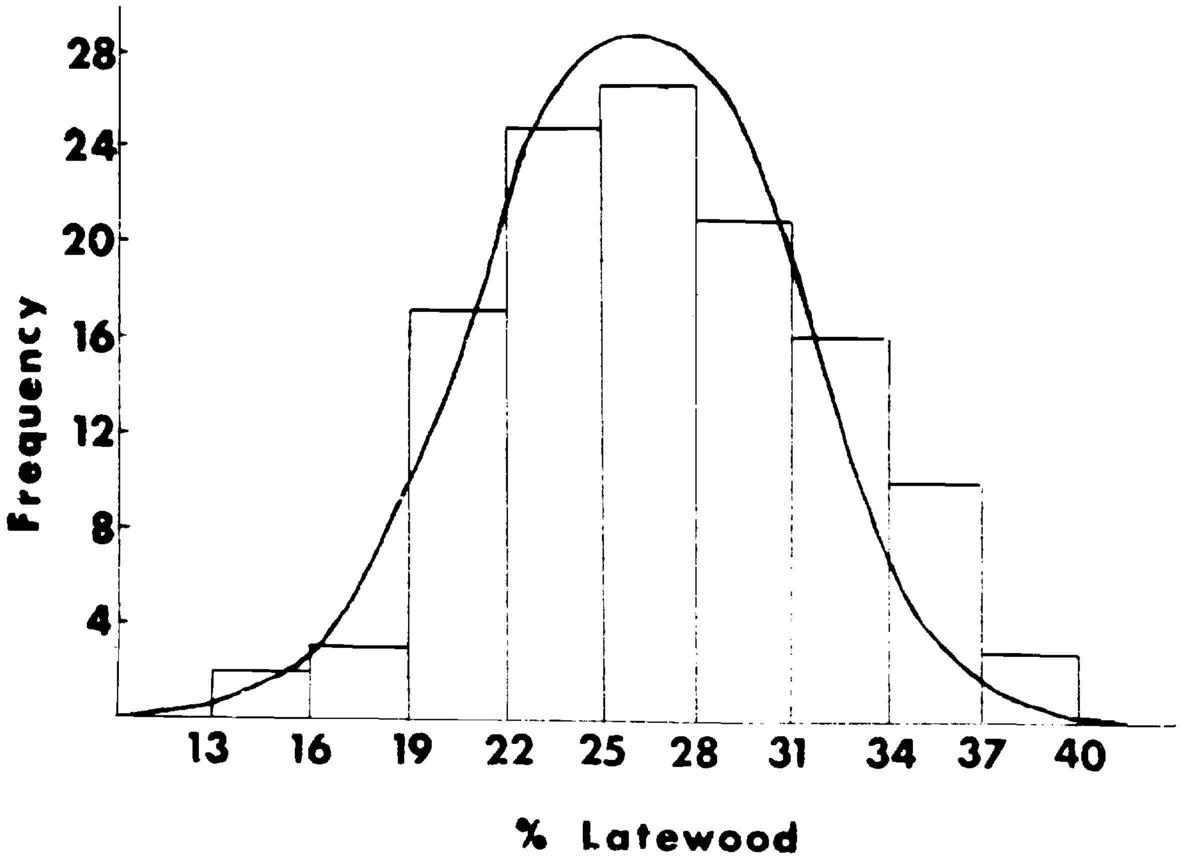


Figure 2. Frequency Distribution of Percentage of Latewood for Black Spruce

Miss Usik found no significant difference resulting from the number of annual rings per inch in her tests and from the care with which her work was done the results are definitely valid. But Hale and Prince were also very careful research officers so that their results should be equally valid.

Though a forest management officer deeply interested in the uses of the wood products, I am not a specialist in wood anatomy and any explanations of this apparent anomaly are simply conjectures.

It is reported that white pine (Pinus strobus) grown in tropical areas is valueless because it grows so fast that the boards either fall apart on drying or at least lack strength. It appears, therefore, that fast growing wood is thin-celled and that slow growing wood of the same species has thicker cell walls and thus greater density. If this is true, the springwood would be denser in a slow-growing tree than that of a fast-growing one but the summerwood could be of relatively equal density. In this way the percentage of spring- to summerwood might be relatively the same in both cases but the density of the slow-growing wood much greater. It is realized that this does not account for the low density of the outer rings of overmature trees but it does provide a factor for further research work.

Again Miss Usik's subdivision of her forest sites by peat depth and indicator plants is very interesting. In light of work by Lowery (1964) and Weetman (1962) at the Pulp and Paper Research Institute, Montreal, and by Peterson (1964), then of the Federal Forestry Department at Fredericton, New Brunswick, chemical analyses of the peat and moisture studies might afford some explanations of the differences in rate of growth.

Quite frankly, I am curious as to why bogs such as the Mer Bleue near Ottawa and the one Miss Usik describes exist. In this climate they should be cedar swamps not northern black spruce bogs. The reasons for the development of these bogs would throw much light on their management and prevention.

In conclusion, the management and prevention of forest moss development is one of the most serious long-range problems in Canadian forestry. Miss Usik is to be congratulated on her addition to the information on this important subject, and especially on her proof that, as this problem is very complex, further research is required to answer the questions which she has raised.

## REFERENCES

Hale, J. D. and Prince, J. B. "Density and Rate of growth in the spruces and balsam fir of eastern Canada". Can. Dept. Mines & Res., For. Serv. Bul., 94:1-43, 1940.

Keith, C. T. "Characteristics of annual rings in relation to wood quality in white spruce". Forest Products Lab., Can. Dept. Forestry, Ottawa, March, 1961.

Lowery, G. L. "Forest soil site studies. I. Objectives, sampling, preliminary results on black spruce". Woodlands Research Index No. 154, Pulp & Paper Res. Inst. Can., Aug. 1964.

Peterson, E. B. "Inhibition of black spruce primary roots by a water soluble substance in Calmia angustifolia". Project 64-M-11, Canada Dept. Forestry Preprint. May 1964.

Weetman, B. F. "Nitrogen relations in a black spruce stand subject to various fertilizer and soil treatments". Woodlands Research Index No. 129, Pulp & Paper Res. Inst. Can., March 1962.

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## General Discussion

Mr. McEwen asked about going underground and looking at the root development of these sites. He reported that he has been looking at some good and some poor sites. In both areas there is the same pattern of death in the roots. There is a growth of moss, an excess of moisture, a dying off of the roots, then a new branching. This is the cause of new growth in black spruce and points to the matter of drainage.

Miss Usik replied that she has looked into this matter but has yet to report on it.

## II.4. A STUDY OF FOREST SITE DETERIORATION

A. B. Vincent

Abstract

The likelihood of site quality deterioration in black spruce peatland areas is pointed out, and its probable sequence described. An area in which to study this problem has been selected, and work by the Department of Forestry and Geological Survey of Canada is underway. Few results are available yet, but preliminary $C^{14}$ dating indicates a maximum age of peat exceeding 7,000 years. This suggests net accumulation rate of about one inch per 100 years.

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## II.4. UNE ETUDE SUR LA DETERIORATION FORESTIERE DANS LES TOURBIERES

A. B. Vincent

Résumé:

On montre la vraisemblance de la détérioration d'un site d'épinettes noires dans les tourbières et on en décrit les étapes successives probables. En vue d'étudier ce problème de détérioration un site a été choisi et le Ministère des Forêts et des Relevés Techniques du Canada y a commencé son travail de recherches. Peu de résultats sont disponibles présentement, mais le datation préliminaire au carbone 14 indique un age maximum dépassant 7000 ans pour la terre noire, ce qui indique un taux d'accumulation net de un pouce par 100 ans.

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Information from the Ontario Department of Lands and Forests indicates that black spruce forms 29 per cent of the forest resource of the province. During the ten years preceding 1963 it contributed about 47 per cent of the total revenue derived from all wood cut. Since black spruce is also our best raw material for pulp and paper and much of it grows on peat, foresters must have a very considerable interest in muskeg or peatlands. They build roads over it, conduct logging operations on it and (this is where the author comes in) must grow trees on it.

In a paper presented to the Eastern Muskeg Research Meeting, Johnston and Hills (1956) expressed concern about good spruce sites becoming poor spruce sites and poor spruce sites becoming unmerchantable. That this concern is warranted is soon apparent to anyone who examines the evidence. Most of our black sprucestands on peatlands are overmature. Trees are dying or being windthrown, and the stands are becoming more open. This is accompanied by a rising water table and Sphagnum invasion of the normal feather moss ground cover. The Sphagnums decompose very slowly and hinder the mineral nutrition of trees as well as aggravating unfavourable moisture conditions. One can see many areas with the current crop composed of trees obviously smaller than the sizes attained in the previous rotation.

This appears to be a stepwise process which in the past was frequently interrupted by nature's "use" of fire, but which forest fire protection is now promoting. Harvesting the tree crop increases the problem. The process appears to proceed somewhat as follows. A stand of black spruce on peat becomes overmature and gradually breaks up. The "pump" has been removed so transpiration decreases and the water table rises. Sphagnums replace or partially replace the normal ground cover, lowering the tree growth potential. There is a long regeneration period, but eventually the new stand is sufficiently dense to allow the feather mosses to again replace the Sphagnum. This stand matures and there is a period during which site quality remains relatively constant. Later the stand breaks up and deterioration again takes place. The site will eventually become incapable of producing trees of merchantable size unless there occurs a fire in a year dry enough to permit a "burn out" of much of the peat. This rejuvenates the area and the entire process of site degradation repeats.

The author believes that this factor of site deterioration or degradation is one of our most important problems in the production of black spruce for the pulp and paper industry. This, and the desirability of rehabilitating sites already below par, have led the Ontario Department of Lands and Forests to undertake peatland drainage studies. The Department of Forestry of Canada has undertaken a project with the stated purpose of "studying a peatland area in which there appears to be site deterioration, apparently brought on by past physical, biotic, and climatic occurrences and aggravated by cutting of the tree stand, and to investigate whether there appears to be a reasonable possibility of developing procedures by which the trend of site deterioration might be halted or reversed". They have been fortunate in securing the cooperation of the Geological Survey of Canada, with Dr. J. Terasmae acting as liaison officer between our two groups. This greatly broadens the scope of the study and should accomplish a much more thorough investigation than if fewer disciplines were involved.

The study area is on the limits of the Abitibi Pulp and Paper Company, Limited, in Heighington Township, 34 miles north of Iroquois Falls (at approx. 80° 35' W, 49° 10' N). It is approximately 160 acres in size, and has peat ranging in depth from about six inches to just over eight feet. The merchantable stand was cut nine years ago. The tree stand ranged from sub-merchantable on the deeper peat to approximately 40 cords per acre where site quality was better on shallower peat or where telluric water was available. Shrubs and herbs are typical of clay belt peatland conditions, and the mosses on the better sites are feather mosses invaded by *Sphagnum*. In poor sites with deeper peat, *Sphagnums* are predominant.

A detailed surface contour map of the area has been prepared, and two baselines intersecting at right angles near the centre have been cut across the area. Wells for checking water table levels are spaced at 5-chain intervals along these lines. Two lines with 40 randomly spaced quadrats cross the area. Vegetation and seedbed conditions on these have been recorded, and tree reproduction has been identified for following growth rates. Six black spruce root systems have been excavated and mapped and more of this is scheduled. Crude peat stratigraphic profiles along the baselines have been plotted.

Four $C^{14}$ dates are available from preliminary investigations by Dr. Terasmae. These are:

| | | | |
|---|---|---|---|
| At bottom of peat 1' thick: | 270 ± 130 | (GSC - 305) | years |
| " " " " 3' " : | 5,880 ± 140 | (GSC - 308) | " |
| " " " " 8' " : | 7,150 ± 140 | (GSC -309A) | " |
| At bottom of 1' layer of lacustrine sediments beneath 8' of peat : | 7,600 ± 140 | (GSC -309B) | years. |

The age of the 1-foot layer indicates an accumulation rate of four inches per 100 years, that of the 3-foot layer about one inch per 100 years, and the 8-foot deep peat has apparently accumulated at the rate of 1.3 inches per 100 years. The one-foot thick lacustrine sediments added 2.4 inches per 100 years. The deeper peat appears to have accumulated at a relatively constant rate in this area. The accumulation of one foot of peat within a period equal to less than two stand rotations may indicate the true current rate of accretion, or it may merely indicate the rate of an intermediate stage of peat formation. If the latter, decomposition and compaction have yet to reduce the accumulation rate to that of older peat. Whether peat accumulation has been affected by fire has yet to be determined.

Weekly measurements of rainfall and water table levels from early June to mid-September 1964 indicated that one inch of rain weekly will maintain the water table here at a constant level. Average depth among wells of the water table below the surface during the period ranged from 0.1 foot to 1.2 foot (Table 1).

TABLE 1

Water table depths below soil surface from June 4 - September 14, 1964

| Well No. | Peat depth (feet) | Avg. depth water table (feet) | Range in depth during period (feet) | Week during period | Rainfall (inches) |
|---|---|---|---|---|---|
| 1 | 1.0 | 1.0 | 0.5 - 1.6 | 1st | 1.14 |
| 2 | 1.9 | 1.1 | 0.8 - 1.3 | 2nd | 0.64 |
| 3 | 1.8 | 0.5 | 0.2 - 0.7 | 3rd | 3.31 |
| 4 | 3.8 | 0.5 | 0.3 - 0.6 | 4th | 0.27 |
| 5 | 4.5 | 0.7 | 0.4 - 0.9 | 5th | 0.72 |
| 6 | 5.6 | 0.1 | 0 - 0.3 | 6th | 0.16 |
| 7 | 1.1 | 0.8 | 0.5 - 1.1 | 7th | 1.99 |
| 8 | 0.6 | 0.9 | 0.3 - 1.1 | 8th | 0.61 |
| 9 | 1.7 | 0.6 | 0.3 - 0.7 | 9th | 0.12 |
| 10 | 2.2 | 0.6 | 0.4 - 0.5 | 10th | 1.39 |
| 11 | 7.7 | 0.4 | 0.2 - 0.5 | 11th | 0.78 |
| 12 | 6.5 | 0.2 | 0 - 0.3 | 12th | 1.10 |
| 13 | 5.5 | 1.1 | 0.9 - 1.1 | 13th | 0.34 |
| 14 | 1.8 | 0.7 | 0.3 - 0.9 | 14th | 0.40 |
| 15 | 2.0 | 1.1 | 0.8 - 1.4 | 15th | 0.21 |
| 16 | 1.6 | 1.2 | 0.8 - 1.3 | Total | 13.18 |

The least fluctuation for the period in any one well was 0.2 foot, the greatest was 1.1 foot. The water table surface fell below the peat in only two wells. An analysis of the data from the wells is being done by Dr. P. Meyboom of Geological Surveys.

It was found when the root systems were excavated that all the roots tended to follow the more or less horizontal plane marking the juncture between moderately well decomposed peat below and the dead undecomposed raw material above. Even the various root strata of trees with multiple-root systems approached this level within a few feet of the trunk; thus the root mat is usually rather thin vertically. The manner in which the roots occupied the hummocks on which the trees supposedly often grow indicates that the hummocks actually have grown up about the stems. This is supported by other evidence where Sphagnums can be seen mounding about the trees.

Not all the data collected to date have been analyzed, and much work in the area still remains to be done. However, the author is confident that we will add considerably to the knowledge of peatlands and advance towards a solution of the problems pertaining to forestry. The author's work in the study area will continue, and it is hoped this year to have the services of a forest ecologist to look into the ecological aspects. The Geological Survey of Canada is planning various investigations. Palynological and paleobotanical studies will be underway this year, a study of the groundwater regime is expected to commence, and the area will become part of an extensive geophysical and geochemical program extending from Cochrane to about Moose River Crossing.

This has been only a brief account of what we are doing or are attempting to do, but it is hoped that it has brought out the fact that muskeg poses serious problems to the forester as well as to the engineer and geologist. The author believes that many of the problems can best be solved by co-operation among the various disciplines.

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REFERENCE

Johnston, R. N. and Hills, G.A. The need for rehabilitation of organic terrain in Ontario with special reference to reforestation. Proc. Eastern Muskeg Res. Meeting, NRC-ACSSM Tech. Memo. No. 42, 1956.

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Discussion (J. Terasmae)

A large number of products are put out by the pulp and paper industry. Black spruce is very important in this regard and is not an unlimited resource. To prevent it from becoming completely used up, we have to know more about it, what reserves we have, and so on. Consequently, better forest management is important. Mr. Vincent's research is a significant step in this direction. The whole question of controlling the environment is important and also the use of muskeg as a resource, not only for black spruce but as a source of chemical derivatives, etc. Mr. Vincent is to be congratulated for the work he has undertaken.

General Discussion

Mr. McEwen referred to forest drainage in other countries such as the USSR and Scandinavia. All have drained huge areas, whereas in Canada we have drained only about 10 acres.

Mr. Robinson recognized the fact of the cool climate and a shady area (caused by the trees) on the moss cover, and wondered if the black spruce was there because of the muskeg or the reverse. Mr. Vincent replied that the black spruce was there because of the muskeg. Miss Usik stated that in her Area 9 the older tree growth is in the centre of the bog, in the deeper peat. The younger growth is in the margin. Mr. Vincent said that in his area there is almost 1 foot of lake sediments beneath the deepest part of the peat. He believed that the black spruce is there by default; no other species will grow successfully in this area.

Dr. Brown remarked that the rate of peat accumulation is very slow. He asked if there were any figures available on a means of detecting the rate of deterioration from year to year; for example, due to air temperature changes. Mr. Vincent replied that he did not know of any studies to that effect. The rate of growth in any given year could be recorded. One problem, however, is that the installation of instrumentation will upset the regime. Mr. McEwen stated that in Northern Ontario the rate of growth of sphagnum peat may be up to one inch per year. What controls the growth of sphagnum is "half light" - as soon as trees cast a shadow over the area the sphagnum grows very quickly. Miss Usik remarked that the rate of accumulation of peat has been studied by examining the root systems of black spruce. The trees have layered root systems and, as the peat accumulates, different root layers are sent out and can be correlated with the rings. Mr. Vincent said that it will all depend to a certain extent on what one means by peat. He thought that as the sphagnum grows very thick, the tree sinks into the peat.

Dr. Radforth suggested that we need to understand the growth relationship of trees in relation to the crop and to clearing. In this case, the crop and the terrain can hardly be separated. The sinking phenomenon mentioned by Mr. Vincent is an interesting one. It is perhaps pertinent to consider that the mounds which develop around the trees contain ice knolls which last well into the summer. A recapitulation of the structure of a forest gives us continuity in the microstructure of peat. This is related to the drainage of peat. Dr. Radforth referred to a peat bog area on the west coast in an area where the tide comes in and erodes the peat face. The surface cover is BEI, and a 12-foot deep section is exposed. It is interesting that all through the depth of the profile, right to the bottom, one can observe tree stumps and roots (woody erratics). Therefore, it is possible to give this peat type a designation which would obtain right throughout its depth. In smaller areas, one gets less constancy with depth, for instance in the confined muskeg in southern Ontario.

## II.5. THE MUSKEG FACTOR AS IT APPLIES IN NORTHERN ONTARIO

Prior to introducing Mr. W. Luke, Mr. W. R. Thompson reviewed his own interest in muskeg. He started work in Northern Ontario in 1919 with the Department of Northern Development and in his 15 years with that organization had considerable experience in building roads over muskeg. In this regard he was involved in the construction of the original Ferguson Highway. Mr. Thompson does not believe that muskeg is as bad as it is made out to be. Up until the 1930's, the peat was left in place in building roads over muskeg in Northern Ontario.

In the 1940's and early 1950's there were efforts to utilize peat for fuel, but this did not prove to be economically feasible and the idea was dropped. In the 1950's the development associations were organized throughout Ontario. In the Sudbury area there is a Northeastern Development Association. Its purpose is to utilize the resources of the area. In 1960 the Ontario Economic Council was formed. One of the subjects which came up was peat. A study was undertaken to see if it was an economic resource which could be utilized. This study was carried out by the Ontario Research Foundation, which gave a negative answer. Nevertheless, the study did bring out some interesting things, one of which will be discussed by Mr. Luke.

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## DESCRIPTION OF KENNEDY BOG INVESTIGATION

L. W. Luke

Abstract

A preliminary examination of a peat bog in Kennedy Township, District of Cochrane, was undertaken in 1962. The chief interest at that time was utilization of the bog for horticultural peat moss. This was subsequently incorporated into a much wider study of the economic potential of Northern Ontario, carried out by the Ontario Research Foundation. This study produced a negative answer to the question of economic feasibility of the Kennedy Bog utilization. More recently, studies have been undertaken to investigate the possible use of this peat as a binder in pelletization of iron ore, to replace bentonite which is now being used. The possibilities for this utilization are quite favourable.

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# DETAILS SUR L'ETUDE DE LA TOURBIERE KENNEDY

L. W. Luke

Résumé:

Un examen préliminaire de la tourbière de la commune de Kennedy, dans le district de Cochrane, fut entrepris en 1962. A cette époque, le principal intérêt était l'utilisation de la tourbière pour la production horticole de la tourbe. Ce projet fut incorporé subséquemment à une étude beaucoup plus vaste du potentiel économique de la région nord de l'Ontario, étude entreprise par l'"Ontario Research Foundation". Cette étude a donné une réponse négative à la possibilité de l'utilisation économique de la tourbière Kennedy. Plus récemment, des études ont été entreprises en vue d'examiner l'usage possible de cette terre noire comme liant dans le traitement du minerai de fer, en remplacement de la bentonite qui est utilisée présentement. En ce qui regarde cette utilisation, les possibilités sont favorables.

## History

Early in 1962 a preliminary examination of a peat bog, and its contents, in Kennedy Township, District of Cochrane, Ontario, was undertaken by the Industrial Development Department of Northern Ontario Natural Gas Co., at the request of Mr. Albert Boisvert, a resident of Cochrane.

## Market Potential

Interest at that time lay in the potential use of material from the bog as horticultural peat moss which would be offered on the rising market which was then apparent in both the United States and Canada. The primary source of peat moss for the U.S. market, prior to World War II, was Western Europe. During the war, this source was unavailable and the demand was met by Canadian producers, mostly in the Maritimes and in British Columbia. After the war, these Canadian producers were successful in retaining this market and in expanding it. This expansion was due, primarily, to the creation of suburbia around the large urban centres during the great post-war residential building boom which swept both the U.S. and Canada. Many of these subdivisions were located in poor agricultural soil and, as the owners all wanted lawns and gardens, a demand was created for peat moss to improve this soil. This demand is still rising and last year Canada produced some $10 million worth of horticultural peat, 90% of which was offered on the U.S. market.

Material Analysis

With the assistance of the Department of Mines and Technical Surveys in Ottawa, a number of analyses were done and these reports indicated that the peat moss of the Kennedy bog was of horticultural grade. Attention was then directed to a more detailed market survey and a feasibility report which would estimate capital outlay required, production costs, operating capital required, etc.

O.R.F. Report

Several things happened at this point which have somewhat diverted our primary objectives. The Northern Ontario Committee of the Ontario Economic Council in 1963 retained the Ontario Research Foundation to carry out a number of technomic studies in Northern Ontario. Perhaps because of our interest in developing Northern Ontario peat, peat moss was included in this list of studies and we worked with the O.R.F. in the preparation of their report. The report was published in March, 1964. It is well done and the author agrees with much they have to say. They do concede that we have peat moss of horticultural grade in Northern Ontario but they say that, because of our location, we can not compete in the U.S. markets with the Maritime or B.C. producers - or with the producer at Rivière du Loup, in Quebec. With the distances involved, and the freight rates now available from the Ontario Northland Railway, the author strongly disagrees and considers that Northern Ontario peat could command a preferred position on much of the U.S. market.

Pelletization

During this study, by the Ontario Research Foundation, their economist, Mr. A. T. Wren, drew the author's attention to a paper published in 1961 by the University of Minnesota which showed a possible use of peat moss as a binder in the pelletization of iron ore. Realizing the potentialities of such use, we were immediately very interested - and so were they. Subsequently, Mr. R. L. Cavanagh, of the O.R.F., carried out some extensive research on this subject and gave an up-to-date report on his findings to the Ontario Select Committee on Mining, in Toronto, on November 5th of last year. The Chairman of that Select Committee, Mr. Rene Brunelle, M.P.P., is in attendance at this conference. Mr. Cavanagh's research, so far, has been most encouraging and present indications are that it might be entirely feasible to replace bentonite by peat moss in the pelletization of iron ore.

Iron Ore Pellets

Please permit a word about iron ore pelletization.

This has introduced a new era in iron ore production and in blast furnace operation. Direct shipment high grade iron ore has about 55-58% iron content. Beneficiated, pelletized iron ore contains 65-68%. It is uniform in content, contains no fines and is easily handled. Because of these factors, the capacity of a blast furnace can be increased by 25% by charging it with pellets, rather than with direct shipment ore. The steel makers want pellets and, as they are the customers, that is what they are going to get. The two producers in Northwestern Ontario, Caland and Steeprock, are both building pellet plants. Jones and Laughlin, at Kirkland Lake, is pelletizing, as is INCo at Copper Cliff and Lowphos Ore at Capreol. The new Sherman mine of Cleveland Cliffs and Dofasco, at Temagami, will be a pellet operation. Iron Ore Co. of Canada is installing an enormous pellet plant for their production. Northeastern Ontario, by 1968, will be producing 3.6 million tons of pelletized iron ore and, in 1980, just 15 years from now, Canada will be exporting 80 million tons of iron ore per year to the U.S. - 70% of which will be pelletized.

Bentonite

The present binder used is a swelling clay - bentonite - and all of Canada's supply presently comes from Wyoming. It is possible that commercial deposits of bentonite exist in Alberta, but they have not yet been defined. Canada used 60,000 tons of bentonite in 1963, at an average cost of $60.00 per ton - a $3.6 million market - 60% of which represents freight costs.

Use of Peat as Binder

Mr. Cavanagh examined peat from our Kennedy bog, from the Port Colborne area of Southern Ontario, from the Maritimes and from Ireland. His findings indicate that peat from Northern Ontario is most suited for use as a binder. The binding agent, incidentally, is the humic acid in the peat. As it requires about 20 lbs. of peat per ton of concentrate, by 1968 Northeastern Ontario alone would offer a potential market for 36,000 tons of peat - and this peat does not have to be of horticultural grade, the humic acid content being the chief consideration. The value of this market - in terms of bentonite replaced - would be $811,800.

Development Potential

With the great quantities of peat available in the North, right alongside our iron ore, it can be seen what an exciting potential this proposition offers - and what the economic impact would be on the Northern areas by reason of this new industry. It is hoped that the Kennedy bog, which is the property of Mr. Boisvert, can be worked as a combined operation - sending peat moss of horticultural grade to that market and producing moss for binder purposes, from the lower grades in the bog, in a continuing 12-month operation.

Conclusion

Obviously, the most significant information mentioned is that concerning pelletization. We are presently making processed samples of peat moss from the Kennedy bog available to the Ore Research Laboratory of Jones and Laughlin Steel Corporation, in Negaunee, Michigan, where they will conduct their own investigation. The author does not know where the Ontario Research Foundation project stands at present; it is hoped that it is being carried to completion.

In conclusion it is suggested that there is a very real possibility that, within the next year or two, peat moss will be used as a binder in the pelletization of iron ore in Canada. Should this take place, a substantial and important new industry will have been created which will have a significant economic impact on our Northern areas. It will also provide a new and important economic reappraisal of our vast deposits of peat. Let us hope that this bright prospect will be realized.

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Discussion

Mr. Ehrlich questioned the statement that no bentonite was mined in Canada, stating that there is a small mine at Borden, Manitoba. Mr. Luke regretted conveying any wrong impressions but said that he had been quoting from official government reports.

Mr. MacFarlane enquired about the Ontario Research Foundation reports referred to by Mr. Luke. He wondered if they are private reports or were they available to the general public. Mr. Luke replied that, so far as he knew, they are available to anyone who requests them from O.R.F. They are dated March 31, 1964 and November 4, 1964. Mr. Thompson mentioned that the O.R.F. is preparing a report for the Department of Mines, to be released shortly. The gist of it is that the use of peat is favourable and that an economic study will be undertaken to see how it compares in cost with bentonite.

Dr. Radforth reported that he has completed the first preliminary test on the humic acid content of the peat from the Kennedy Bog and confirmed that one can be optimistic with regard to its application. He had not seen the bog in question, but suggested that the predominant cover is largely EI and that there would be a tremendous amount of this kind of peat, consistently of one type. Dr. Radforth then asked Mr. Rene Brunelle, MPP for Cochrane North, if he would speak on the effect of muskeg in Northern Ontario.

Mr. Brunelle referred to the size of his riding: 80,000 square miles, a large proportion of which is muskeg. He expressed his intense interest in northern development. He mentioned the need of a road to Moosonee, emphasizing the importance of roads as a key to development. A road is scheduled to be constructed from Smooth Rock Falls to Fraserdale. Ontario Hydro now has a service road to Little Long Lac and to Kipling. He thought that a link to Moosonee would have a very salutary effect on that area. Mr. Brunelle referred also to the immense mining development now underway in Northern Ontario and expressed his belief that this would not only continue, but expand.

## III.1. SOME MICROMETEOROLOGICAL OBSERVATIONS OVER SPHAGNUM MOSS

G. P. Williams

Abstract

Heat balance measurements and air temperature observations were made in the 1964-65 fall and winter season over the Mer Bleue, a peat bog located near the City of Ottawa. Daily air temperatures were compared to air temperatures recorded at a standard meteorological station located about 8 miles southwest of the Mer Bleue. The results from these micrometeorological measurements are analyzed, and the implications of the large observed air temperature differences are discussed.

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## III.1. QUELQUES OBSERVATIONS MICROMETEOROLOGIQUES DES SPHAIGNES

G. P. Williams

Résumé:

Durant l'automne et l'hiver de 1964-65, des mesures de l'équilibre thermique et des observations de la température de l'air furent faites dans la Mer Bleue, une tourbière située près de Ottawa. Les températures journalières de l'air ont été comparées avec celles enregistrées à une station météorologique située à 8 milles au sud-ouest de la Mer Bleue. Dans la présente communication, on analyse les résultats de ces mesures micrométéorologiques et on discute de la portée des grandes différences observées dans la température de l'air.

In ground surface heat exchange studies (Brown, 1965) carried out in connection with the occurrence of permafrost at Norman Wells, N.W.T., difficulties were encountered in measuring with available instruments the exchange of heat and water vapour between the ground surface and the atmosphere. Because of these difficulties, the problems of measurement were investigated at Ottawa where better facilities for maintenance and supervision were available. The results from the heat balance observations made at Ottawa and comments concerning apparatus and techniques were presented at a recent conference (Williams, 1965). Much of the information presented herein is based on the micrometeorological observations made during this heat balance study.

The measurements on heat balance and air temperature were made in the 1964-65 fall and winter season over the Mer Bleue, a peat bog located about 6-8 miles southeast of Ottawa. The bog lies in a depression of a former river channel. It has an area of about 5,000 acres, and a maximum depth of about 16 feet. The principal vegetation form is sphagnum moss but other forms of vegetation usually associated with a peat bog are present, with large portions of the bog covered by blueberry bushes, spruce and tamarack.

In August, 1964, a metal tank, 4 feet in diameter and 2 feet in depth, was filled with sphagnum moss (disturbed as little as possible) and installed about 300 feet from the edge of the Mer Bleue. The tank was installed so that the surface was level with the surrounding organic terrain. The moss was maintained in a saturated condition and heat balance measurements and calculations were made over the tank for the period August 15 to November 15, 1964.

A hygrothermograph was installed in August, 1964, in a Stevenson screen, 4 feet above the moss surface, at the site. Maximum and minimum daily air temperatures recorded at this site during the fall and winter of 1964-65 were compared with those recorded at a standard meteorological station at Uplands Airport, located about 8 miles southwest of the Mer Bleue.

Figure 1 shows the general location and topography of Mer Bleue relative to Uplands airport and the city of Ottawa. Figure 2a shows the installation of the metal tank with the peat bog in the background.

## Heat Balance Measurements

In this study the following components of the heat exchange at the moss surface were measured or calculated:

(1) The heat gained or lost from the surface by net radiation which combines the net long-wave radiation and net short-wave radiation terms;

(2) the heat used in evaporation or gained by condensation;

(3) the heat used to cool or warm the subsurface moss; and

(4) the heat gained or lost from the surface by convection or turbulent exchange. At any instance or over any period of time the algebraic sum of these components must equal zero. When these heat exchange components are put into equation form, it is called a heat balance equation.

Details of the measurement and calculations used to determine the components of the heat balance over saturated sphagnum moss have been outlined previously (Williams, 1965). Net radiation was measured with a net radiometer positioned about 12 inches above the saturated moss. The radiometer was connected to a small battery-powered recorder. (Figure 2b shows the radiometer in position over the tank.) Evaporation was measured about 3 times a week, by the same general technique used by the Canadian Meteorological Branch to make standard evaporation pan measurements. Changes in heat storage were estimated from changes in temperature measured 8-10 inches below the moss surface, assuming a specific heat for saturated moss equal to 1.0 cal/gm°C and a saturated density of 1.1 gm/c.c. The convective term was not measured but was obtained by solving the heat balance equation.

The results of heat balance measurements and calculations over the saturated moss from August 15 to November 15 are as follows:

| | Accumulated Heat calories/sq.cm | Per cent of Net Radiation |
|---|---|---|
| Evaporation | - 16,600 | 148 |
| Net Radiation | + 11,200 | 100 |
| Heat Storage Decreases | + 500 | 4.5 |
| Convection | + 4,900 | 43.5 |

Although the accuracy of the measured and calculated components of the heat balance can not be stated, there is no reason to suspect the results. An analysis of measured evaporation indicated consistent results. The radiometer had proved reliable in the past and its calibration had recently been checked. Because the changes in heat content was less than 5 per cent of the recorded radiation, this term could have quite a large percentage error without affecting appreciably the balance obtained.

## Air Temperature Measurements

The air temperature readings recorded by the hygrothermograph at the site were checked frequently using standard maximum and minimum thermometers. These readings were then compared with air temperature recorded at Uplands Airport. Large differences were noted between air temperature recorded at Mer Bleue and those recorded at Uplands Airport. During the fall months for clear conditions, the night-time minimum air temperatures were 10-20 F° lower at the Mer Bleue site, and daytime maximum air temperatures were up to 10 F° lower. During cloudy conditions the differences were less, with differences of 5-10 F° for maximum air temperatures. Monthly average air temperatures during September and October were 5-6 F° lower over the bog.

Figure 3 shows the differences between minimum daily air temperature from September, 1964 to April 1, 1965. Large temperature differences were noted during the winter months with differences as large as 20 F° occurring during the cold period in February. During the snow melt period in March, recorded differences in minimum air temperature were much less.

## Discussion of Results

In discussing the results, it should be emphasized that these micrometeorological measurements were made for part of one season over part of one peat bog, and thus it would be unwise to make sweeping generalizations. During the observation period, conditions were unusually dry and thus the heat balance measurements would not be representative of a year with average or above average moisture conditions. In addition, the heat balance measurements were made over saturated moss whereas in the surrounding bog the water table was several inches below the surface. It is considered, however, that despite the limited data it will be useful to discuss the implications of the large observed temperature differences.

It has been known for many years that night-time minimum temperatures are usually lower over agricultural peat lands than adjoining mineral soils (Bouyoucos and McCool, 1922), but there does not appear to be many records in Canada of air temperature measured over virgin peat bogs. Brown (1965) in one of the few published records, noted that air temperatures measured over sphagnum moss at Norman Wells were significantly lower than those recorded at the nearby standard meteorological station. Rigg (1947) reported freezing air temperatures 4 feet above the surface of a sphagnum bog on the Pacific coast every month of the year except August.

There are several reasons why air temperatures might be lower at the Mer Bleue bog than at the Uplands weather station. First, as the heat balance studies show, the heat used in evaporation is relatively great, particularly when the water table is near the surface. A high rate of evaporation from wet moss would tend to keep the moss surface temperature lower than the temperature of drier sand or grass surfaces. Second, because moss is a poor thermal conductor, the relatively small amount of heat stored in the moss during the day can not be readily returned to the air during night-time cooling. The result is that the ground surface and the adjacent air layers cool rapidly. Under similar atmospheric conditions, the surface temperature of grass or sand-covered terrain would not fall as much.

Finally, part of the air temperature difference may be attributed to topography, as the Mer Bleue is a low-lying area in comparison with Uplands (Figure 1). The fact that air temperatures were significantly lower over Mer Bleue during late winter when the grass at the airport and the moss were snow-covered, would suggest that air drainage is probably a significant factor causing these large temperature differences.

## Conclusions

Accepting the proposition that air temperature measured over low-lying peat land will probably be lower than air temperature measured, under similar atmospheric conditions, over mineral soil, one can come to several conclusions:-

1. Because most standard meteorological stations are located at urban centres or airports, air temperatures over the extensive peat lands in Canada will probably be lower than air temperatures normally available for analysis. These differences might be of practical significance for those who use available air temperature records in studies relating climatic factors to the rate of freezing of peat land or to the growth of different types of vegetation in a peat bog.

2. The fact that the air over peat land might be colder than over surrounding mineral soil, perhaps for several months of the year, coupled with the fact that sphagnum moss is a good insulating material, suggests that buried ice would tend to last much longer in this type of terrain. Field studies on the occurrence of sporadic permafrost tend to confirm this conclusion (Brown, 1965).

3. Finally, the colder air temperature found over peat lands might be of a significance in bog formation. Gorham (1957) in a paper on the development of peat land notes "the astonishing ability of some plants to persist in unfavourable habitats, and to exhibit what may be described as 'biological inertia'. That is, once having colonized an area they may continue to exist there long after the conditions suitable for their establishment have disappeared. The question arises: does a bog speed up the formation process by creating its own "local" climate and does this "local" climate persist long after the general climate in the region no longer favours bog formation and growth?

It is hoped that this paper and the questions raised by it will encourage more micrometeorological observations to be made over the extensive peat lands of Canada.

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## REFERENCES

Bouyoucos, G., McCool, M. M. A study of the causes of frost occurrence in muck soils. Soil Science, 14 n.2 pp.383-389, July-December, 1922.

Brown, R. J. E. Some observations on the influence of climatic and terrain features on permafrost at Norman Wells, N.W.T., Canada. Canadian Journal of Earth Sciences, Vol. 2, p.15-31, February, 1965. (reprinted as NRC 8213).

Gorham, E. The development of peat lands. Quarterly Review of Biology, Vol. 32, p.145-166, 1957.

Rigg, C. B. Soil and Air Temperatures in a Sphagnum Bog of the Pacific Coast of North America. American Journal of Botany 34:452-469, 1947.

Williams, G. P. Heat Balance over Saturated Sphagnum Moss - to be published in the Proceedings of the First Canadian Conference on Micrometeorology - held in Toronto, April, 1965.

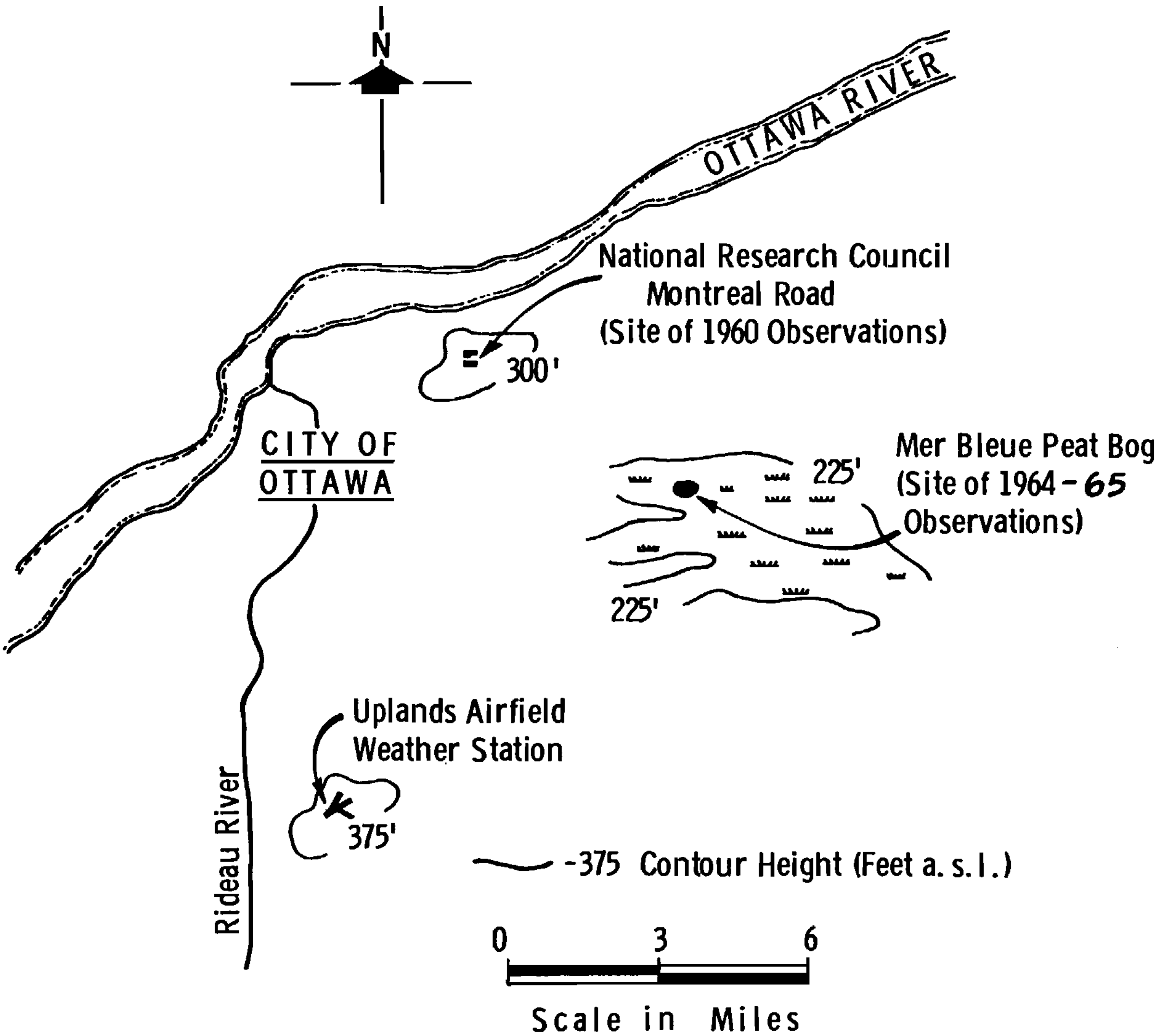


FIGURE 1

LOCATION OF OBSERVATION SITES

BR 9337-1


Figure 2(a). Installing tank, Mer Blue in background.

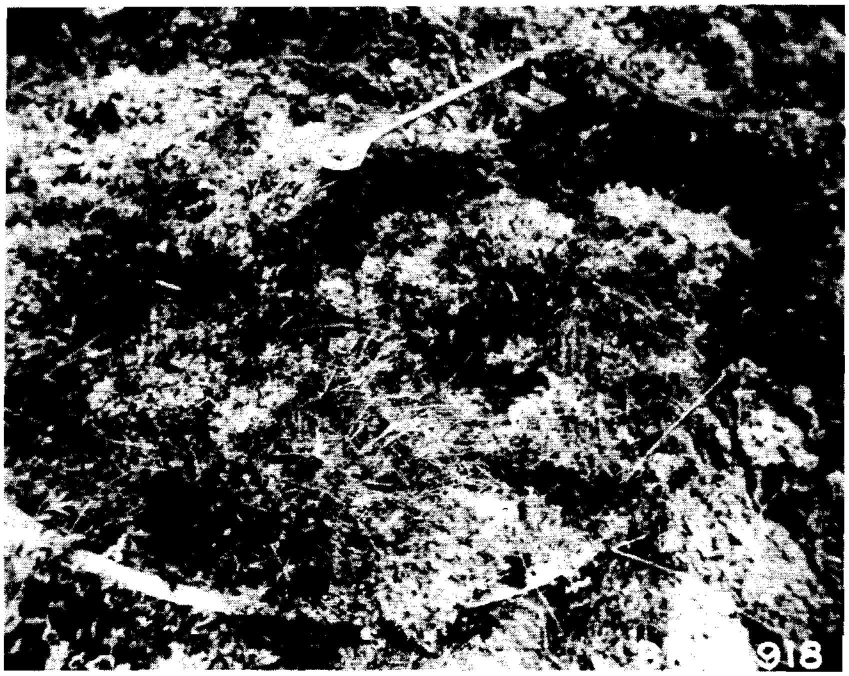


Figure 2(b). CSIRO radiometer over saturated tank.

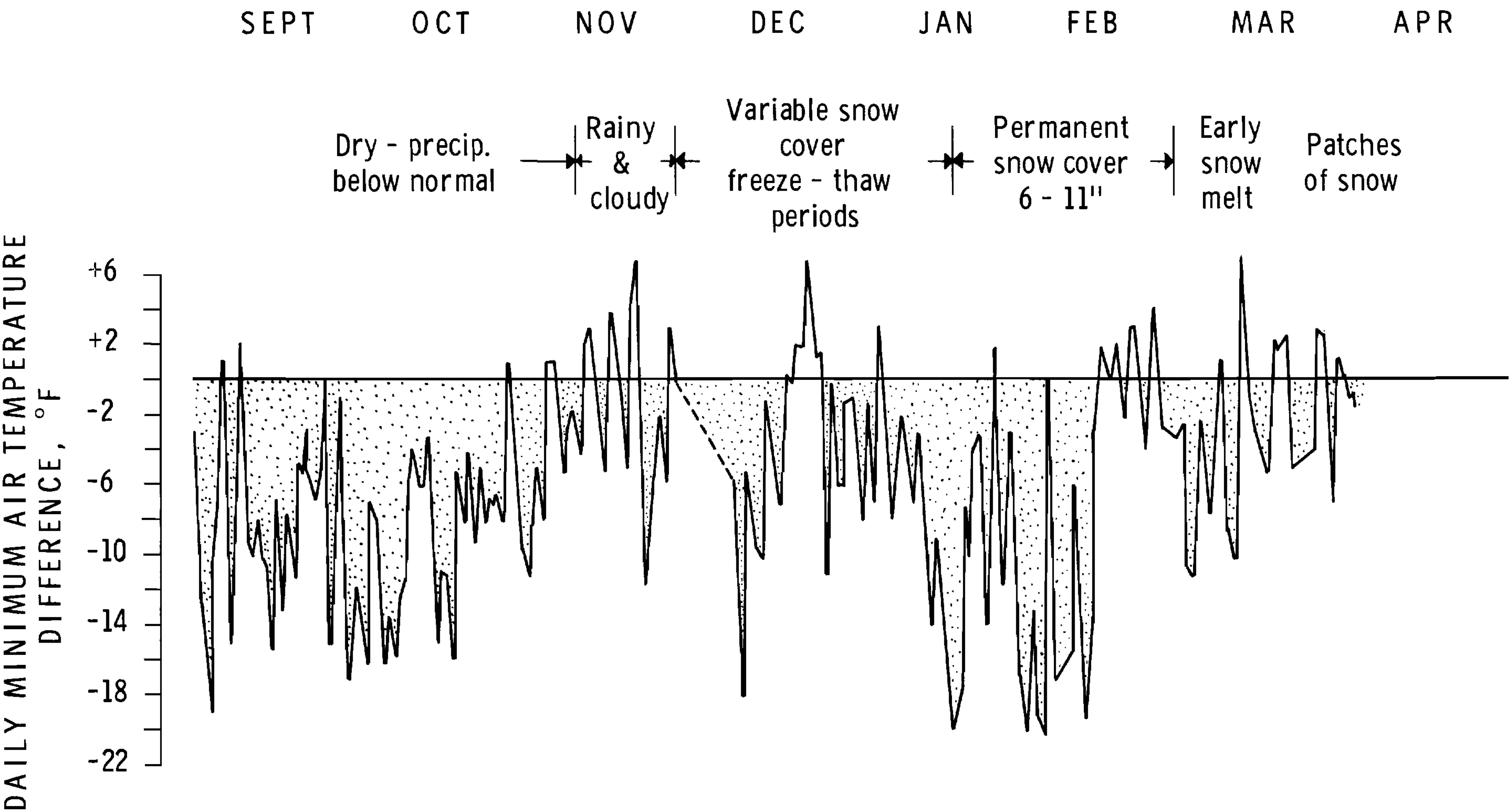


FIGURE 3

DAILY AIR TEMPERATURE DIFFERENCES
MER BLEUE PEAT BOG AND UPLANDS AIRPORT

BR 3386

Discussion

Dr. Terasmae noted that studies such as this have wide application to those who are interested in environment.

Mr. Robinson wondered if there is any way to drain the air from the Mer Bleue Peat Bog, since it is an old section of the Ottawa River. Mr. Williams replied that economics would dictate this since moving large quantities of air is likely to be very expensive and rather difficult. Mr. Robinson asked if there has been any infra-red sensing on peat bog areas. Mr. Williams believed that some has been done by the Defence Research Board, but that he had not yet seen any published results.

Professor Irwin mentioned the practical value of a theoretical study of this type. Yesterday the conference heard of the difficulty of drying peat for fuel. Now, if we could reduce the evaporation term, then more heat would be available to warm up the peat. If a peat bog could be drained, the water table would be lowered, with consequent higher temperatures and more drying effort. Mr. Williams said that he has not seen many studies of the thermal effects of drainage. In Finland, however, in agricultural areas they have apparently placed a layer of sand over peat to reduce evaporation and increase surface temperatures.

Mr. Williams was asked at what distance above the surface of the bog the air temperature was measured. He replied that it was measured at the 4 foot level, in a Stevenson scale. He was asked further if there was any gradient in the air temperature up to this level, but Mr. Williams replied that this was not measured.

## III.2. DEUX EXEMPLES-TYPES DE CONSTRUCTION DE ROUTES SUR MUSKEGS AU QUEBEC

G. Tessier

Résumé:

L'auteur décrit les deux constructions de routes sur muskegs à Napierville et à Saint-Elie d'Orford. Il situé les savanes, donne une description détaillée de chacune, montre les profils stratigraphiques, les sections transversales avec la position des instruments de contrôle, et donne les détails sur la composition de la vieille chaussée dans chacune des savanes. La classification Radforth est donnée pour chacune des savanes.

A Napierville, deux solutions ont été envisagées pour l'amélioration de la route 9 dans les savanes:

1) Elargir de chaque côté de la route 9 existante en employant une surcharge pour bien consolider la partie excédant les accotements actuels,

2) Construire une chaussée séparée à environ cinquante pieds à l'est de la première.

Les raisons qui ont motivé la construction d'une chaussée séparée sont:

1) L'uniformité du sol sous le remblai,

2) Une diminution appréciable des quantités,

3) Les problèmes dus à la formation d'un couloir dans le cas de l'élargissement de la première chaussée sont éliminés.

A Saint-Elie d'Orford, la construction dans la savane se divise en deux parties:

1) La construction d'un remblai jusqu'à deux pieds au-dessus de la vieille route de gravier, de 454 + 00 à 465 + 00,

2) La construction d'un remblai jusqu'au profil final, sans surcharge, de 465 + 00 à 5 + 00.

L'auteur fait des commentaires sur les essais au scissomètre vane "in situ" avant et après la pose du coussin initial, sur l'échantillonnage, sur les essais de laboratoire et les courbes de consolidation; il établit un parallèle entre les résultats de laboratoire obtenus pour Napierville, Saint-Elie d'Orford et Orsainville et ceux de la Colombie Britannique. Il parle des instruments de contrôle, de la

présence et de la position des fossés sur les savanes; il explique les tassements et les déplacements obtenus sur chacune des savanes et donne les raisons des ruptures qui se sont produites dans le remblai sur la savane I à Napierville. Les deux causes principales de ces ruptures sont l'argile molle sous la terre noire et la présence d'un fossé du côté est.

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## III.2. TWO EXAMPLES - TYPES OF ROAD CONSTRUCTION ON MUSKEGS IN QUEBEC

G. Tessier

Abstract

The author describes the road constructions at Napierville and at St. Elie d'Orford. He locates the muskegs encountered, gives a description of each in detail, shows the soil profiles, the cross-sections, the position of the testing instruments, and describes the old roadway built in each case. The Radforth classification of each muskeg is given.

At Napierville, two methods were considered in the design of the new road in the muskeg areas:

1) Widening on both sides of the old road using a surcharge to consolidate the part exceeding the shoulders of the old road,

2) Building a new roadway some fifty feet east of the existing Highway 9 by the surcharge method.

The second method was adopted for the following reasons:

1) The conditions under the embankment are uniform,

2) Less material is required,

3) The problems of snow clearing and visibility caused in the first case (widening of the old road) are eliminated.

At St. Elie d'Orford, the final design specified:

1) An embankment two feet above the grade of the old gravel road, from 454 + 00 to 465 + 00,

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(English translation of this paper is available, on request, from Associate Committee on Geotechnical Research.)

2) An embankment to the final grade without surcharge, from 465 + 00 to 5 + 00.

The author comments upon "in situ" vane tests before and after the first layer of fill, sampling, laboratory tests and consolidation curves. He compares the results from laboratory tests obtained for Napierville, St. Elie d'Orford, Orsainville and those from British Columbia. He comments upon the testing instruments and the distance of the ditches from the toe of the embankment. He gives an explanation of the settlements and the lateral displacements observed in each muskeg and gives the causes of the failures that occurred at Napierville. The main causes were soft clay underneath the peat and the ditch too near the embankment.

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Depuis quelques années déjà, les succès remportés par la méthode de surcharge dans la construction de routes sur muskegs ont incité le ministère de la Voirie du Québec à l'utiliser pour les routes importantes. Dans le Québec, la première application de cette méthode a eu lieu à Orsainville en 1960. Depuis, d'autres constructions de routes sur muskegs ont été réalisées dans notre province, plus particulièrement sur la route transcanadienne à Villeroy et à Notre-Dame-du-Bon-Conseil, sur la route 9 à Napierville et sur le chemin de Montréal-Est a Saint-Elie d'Orford.

Dans cette communication, j'ai choisi de présenter les cas de Napierville et de Saint-Elie d'Orford pour trois raisons:

1) La nature de chacune des savanes. A Napierville, nous avons des savanes relativement étendues dont la couche sous-ja-cente est constituée d'argile molle; à Saint-Elie d'Orford, nous avons une savane confinée dont la couche sous-jacente est constituée de sable.

2) Le type de construction. A Napierville, on a construit une chaussée séparée avec un terre-plein de trente-deux pieds; à Saint-Elie d'Orford, on a élargi de chaque côté de la vieille route de gravier.

3) Le parallèle entre les résultats obtenus dans les deux cas. En observant les tassements et les déplacements obtenus dans chaque cas, on pourra tirer d'intéressantes conclusions à propos du nombre et de la pose des instruments de contrôle, des cotes de sécurité pour le genre de savane considéré, de la présence et de la position des fossés, ainsi que du pourcentage du tassement par rapport à l'épaisseur de la terre noire.

## Localisation des Savanes

Les savanes de Napierville sont situées à environ 35 milles au sud de Montréal, sur la route 9, près de la frontière des États-Unis. Il s'agit en réalité de trois savanes distinctes. Cependant, pour les besoins pratiques, on a divisé ces savanes en quatre parties, soient S-1 (de 50 + 00 à 125 + 00) et S-2 (de 237 + 00 à 284 + 00) dans le comté de Saint-Jean, ainsi que S-3 (de 0 + 00 à 128 + 00) et S-4 (de 152 + 00 à 206 + 00) dans le comté de Napierville. La figure 1 indique l'emplacement de ces savanes. Les chainages sont croissants dans la direction de Montréal. Le point 0 + 00 dans le comté de Saint-Jean est situé à la frontière des États-Unis. La distance totale dans les savanes est de 5.75 milles. Entre le début de S-1 et la fin de S-4, la distance est de 12.1 milles.

La savane de Saint-Élie d'Orford est située à environ 75 milles au sud-est de Montréal ou 14 milles à l'ouest de Sherbrooke. Le chemin en construction doit relier Saint-Élie d'Orford à Stukely Nord et est parallèle à la route 1 reliant Magog à Montréal. La figure 2 montre l'emplacement de cette savane.

## Descriptions et Observations

### A) Napierville

La figure 3 montre les profils stratigraphiques dans S-1 et dans S-2. S-1 comprend en général une couche de terre noire variant de 5 à 11 pieds sur de l'argile molle (CL). La table d'eau est en moyenne à 12 pouces de la surface. On remarque au début et à la fin de cette savane une couche de matériaux assez variés (sable argileux ou silteux, gravier et même argile) sur la terre noire et dont l'épaisseur moyenne est de 4 pieds. Cette couche de matériaux large de 40 pieds existe depuis 1941, alors qu'en construisant la première chaussée, on avait prévu la construction future d'une seconde à l'est de la première, avec un terre-plein de 40 pieds. S-2 contient une couche de terre noire de 3.5 pieds d'épaisseur sur de l'argile molle et de l'argile plus compacte en profondeur (CL).

La figure 4 montre les profils stratigraphiques dans S-3 et dans S-4. La savane 3 est la plus longue et la plus profonde. On y trouve une couche de terre noire variant de 5 à 11 pieds sur de l'argile très molle (CL et CH) jusqu'à une profondeur de 30 pieds sous la surface. On note aussi la présence d'une couche d'argile sur la terre noire entre les chaînages 0 + 00 et 45 + 00. Cette couche d'argile, d'une largeur de quelque 40 pieds et d'une épaisseur moyenne de 5 pieds, fut, comme dans le cas de la savane 1, posée en 1941 en prévision de la construction d'une seconde chaussée. S-4, qui n'est en réalité que le prolongement de S-3, est constituée d'une couche de terre noire variant de 4 à 10 pieds sur de l'argile molle (CL).

On a noté, dans les quatre savanes, la présence de fossés à quelque 80 pieds à l'est de la chaussée construite en 1941. Ce drainage a contribué à former une croûte de surface un peu plus résistante à l'endroit de la future chaussée. D'un autre côté, la position de ces fossés par rapport au remblai a créé des difficultés lors des récents travaux, plus particulièrement dans la savane 1. Au chaînage 45 + 00 dans S-3, la rivière Montréal, creusée en 1941, a également contribué à consolider la croûte de surface. Une grande partie de S-3 et de S-4 était boisée à l'emplacement de la chaussée en construction. Dans les quatre savanes, la végétation dominante est constituée de bouleau, d'érable, d'épinette, de fougère et de mousse. La terre noire est en grande partie fibreuse. Risi a donné une description détaillée de S-3 et de S-4 (Risi et al, 1955).

Disons un mot de la construction de la chaussée ouest en 1941, dans la savane 3. La figure 5 donne le profil stratigraphique suivant la ligne de centre de cette chaussée. En 1941, il n'était pas question d'enlever la terre noire sous les remblais, on a alors construit par-dessus. On peut diviser cette première construction de la route 9 en deux parties:

(a) De 0 + 00 à 45 + 00, où les matériaux de remplissage sont de l'argile et du gravier,

(b) De 45 + 00 à 128 + 00, où le remplissage a été fait avec de la pierre et des matériaux granulaires (gravier silteux).

Pour déterminer les différentes couches de matériaux sous la route, nous avons fait des sondages tous les 400 pieds de part et d'autre du pavage avec une tarière mécanique et un appareil électrique. En plus, nous avons fait des sondages suivant des sections transversales. Nous avons constaté qu'il n'y avait pas eu de glissement latéral du matériel de fondation d'un côté ou de l'autre de la route. Il y a eu un tassement de la terre noire sous les matériaux de remblai. Il y a eu, par la suite, un autre tassement moins accentué, qui s'est produit depuis la fin de la construction de cette chaussée et qui a occasionné des bris dans le pavage et dans les accotements (ondulations, fissures). On a dû, à quelques reprises, apporter des corrections au profil de la route. On a constaté, entre autre, dans la section au nord de la rivière Montréal, un affaissement de la dalle de béton de l'ordre de 4 pouces.

B) <u>Saint-Élie d'Orford</u>

La figure 6 montre le profil stratigraphique de la savane de Saint-Élie d'Orford ainsi que celui de la vieille route de gravier qui est dans l'enlignement du nouveau traçé. La partie de la route projetée qui traverse la savane suit en quelques endroits la vieille route puis s'en éloigne au point d'en être séparée entre les chaînages 465 + 00 et 5 + 00. Il s'agit donc de deux types différents de construction:

(1) Un élargissement de la vieille route, de 454 + 000 à 465 + 00,

(2) Une chaussée séparée, de 465 + 00 à 5 + 00.

La savane est traversée par un cours d'eau et le terrain est submergé de un à trois pieds à proximité du ponceau (460 + 00). Nous avons fait des sondages sous la vieille route pour en déterminer les différentes couches de matériaux qui sont du sable silteux, du gravier et de la pierre. La pierre est surtout localisée aux abords du ponceau.

La figure 7 montre le profil stratigraphique à 35 et à 75 pieds à droite de la ligne de centre, dans la partie où la vieille route doit être élargie. C'est la partie la plus profonde de la savane qui est composée de terre noire d'une épaisseur variant de 6 à 13 pieds sur de sable silteux (SM). La terre noire est surtout amorphe-granulaire. Dans la partie de la savane où on doit construire une chaussée séparée, on trouve une couche de terre noire dont l'épaisseur varie de 3 à 7 pieds sur de l'argile silteuse (CL-ML). Dans cette partie de la savane, l'eau est légèrement au-dessus du terrain naturel (de 0 à 6 pouces).

<u>Classification Radforth</u>

D'une façon générale, on a divisé le terrain en trois zones:

(1) Zone à proximité de la route,

(2) Zone éloignée où la végétation est plus dense,

(3) Zone intermédiaire où la végétation passe de la zone 1 à la zone 2.

A) Napierville

Rappelons que les savanes ont été divisées en S-1, S-2, S-3 et S-4 bien que cette dernière soit le prolongement de S-3. Nous avons classé chacune de ces savanes comme suit:

S-1: F et EF entouré de AF et de ADF avec DEF dans la zone intermédiaire. Arbres dominants: érable et frêne.

S-2: F entouré de AF et de AD avec BF et FD dans la zone intermédiaire. Arbre dominant: bouleau.

S-3: F et FI entouré de AFI et de ADI avec AFD et BFD dans la zone intermédiaire. Arbres dominants: épinette et bouleau.

S-4: F et FC entouré de AF et de DFI avec BFI et DFI dans la zone intermédiaire. Arbres dominants: épinette, bouleau et érable.

Plusieurs parties de terrain ont été défrichées depuis 1941. On a cependant tenu compte de ce facteur en faisant notre classification Radforth.

B) Saint-Élie d'Orford

CF et AF entouré de AFI avec DFI dans la zone intermédiaire. Arbres dominants: bouleau et érable.

## Types de Construction

A) Napierville

Le but de nos premiers sondages sur le terrain était de déterminer, aussi exactement que possible, la section transversale et le profil stratigraphique de la chaussée construite en 1941 afin de connaître le comportement et les conditions actuelles de cette chaussée dans les savanes. Nous avons fait aussi des sondages de part et d'autre de la route afin de bien établir le profil de la terre noire et la nature de la couche sous-jacente.

Deux solutions ont été envisagées pour l'amélioration de la route 9 dans les savanes:

(1) Élargir de chaque côté de la route en employant une surcharge pour bien consolider la partie excédant les accotements actuels,

(2) Construire une chaussée séparée à quelques 50 pieds à l'est de la première.

En adoptant la première solution, nous avons pensé que le tassement différential produit de chaque côté des accotements aurait pu occasionner des fissures longitudinales dans les futurs accotements aux joints entre la vieille plate-forme de la route et son prolongement. Les conditions auraient été différentes sous les futurs accotements. Cependant, il faut admettre que la nouvelle dalle de béton aurait reposé entièrement sur la vieille plate-forme; seuls, les nouveaux accotements auraient été à l'extérieur. De plus, les quantités auraient été plus considérables dans le cas de l'elargissement que dans celui d'une chaussée séparée. En tenant compte de la rareté des matériaux granulaires dans la région des travaux, ce facteur prenait une grande importance dans nos considérations. Un troisième facteur entrait en ligne de compte. Avec les surcharges de chaque côté de la vieille route, celle-ci aurait formé un couloir et nous aurions eu deux problèmes à résoudre: un problème de déneigement et un problème de visibilité pour les automobilistes durant la saison hivernale. En adoptant la solution de la chaussée séparée, nous avons éliminé tous ces problèmes. La couche de matériaux posée sur la terre noire en 1941 était également avantageuse pour cette deuxième solution. Rappelons que cette couche de matériaux existe dans certaines parties des savanes 1 et 3. De plus, il y avait quantité moindre d'instruments de contrôle et un contrôle plus facile du fait que la terre noire à cette distance de la vieille route n'avait pas été remaniée. La figure 8 montre une section transversale dans la savane 3, comprenant la vieille route et la surcharge projetée, à un chaînage choisi (68 + 00). La position des instruments de contrôle par rapport au remblai est indiquée.

La figure 9 montre, suivant une section transversale, la surcharge avec les différentes couches de matériaux utilisés, le tassement probable et le profil final de la nouvelle chaussée. Nous avons essayé de prévoir le tassement dans les savanes. Cependant, à l'époque, les échantillons prélevés étaient quelque peu remaniés étant donné que nous n'avions pas d'échantillonneur à piston. Nous avons référé a Brawner (1961) et à Paré (Paré and Brochu 1964). D'après l'épaisseur de la terre noire, nous avons assumé un tassement de l'ordre de 3 1/2 à 4 pieds. Étant donné la rareté des matériaux dans la région des travaux, nous avons adopté les trois couches de matériaux représentées sur la figure 9, soient: 3 pieds de sable, 3 pieds de gravier et 3 pieds de sable. Nous avons accepté 15% passant le tamis 200. Pour un tassement de l'ordre de 4 pieds, en donnant au profil final de la route une hauteur de 4 pieds au-dessus du terrain naturel, nous assumions un agencement adéquat des quantités pour l'enlèvement de la surcharge et la pose des fondations.

B) Saint-Élie d'Orford

Étant donné les deux genres de construction, la hauteur de la table d'eau, l'épaisseur de la terre noire et la disponibilité des matériaux d'emprunt dans la région, nous avons opté pour la construction d'un remblai jusqu'à deux pieds au-dessus de la vieille route de gravier dans la première partie de la savane (de 454 + 00 à 465 + 00) et la construction d'un remblai jusqu'au profil final, sans surcharge, dans la deuxième partie (de 465 + 00 à 5 + 00). La figure 10 montre des sections transversales dans les deux parties de la savane, à 459 + 00 et à 0 + 00, ainsi que la position des instruments de contrôle.

L'an dernier, le budget accordé n'était pas suffisant pour compléter le remblai sur toute la savane. Les autorités ont alors décidé d'interrompre les travaux à l'équation de chaînage suivant 468 + 04.8 = 0 + 00, c'est-à-dire à la limite de la municipalité de Saint-Élie d'Orford. Comme le remblai se trouve encore sur la terre noire, on a établi une transition de 50 pieds de part et d'autre de ce chaînage dans la pose du remblai. Ainsi, dans la reprise du chargement, une partie de la terre noire sera consolidée à cet endroit.

Essais au Scissomètre Vane

Pour chacune des savanes, nous avons déterminé le profil stratigraphique, nous avons fait des essais au scissomètre vane à chaque pied dans la couche molle et nous avons prélevé des échantillons que nous avons étudiés en laboratoire. Nous avons utilisé deux types d'appareil vane: un appareil vane avec torquemètre et sans tuyau-enveloppe, et un appareil vane suédois avec tuyau-enveloppe pour enlever l'effet de friction le long des barres. Cependant, dans la terre noire et l'argile molle, la force de cisaillement étant faible, la friction développée le long des barres est considerée comme étant négligeable. Les résultats obtenus avec les deux types d'appareil vane (ayant des palettes de mêmes dimensions) sont à peu près les mêmes pour des épaisseurs allant jusqu'à 20 pieds dans ces savanes. L'appareil vane sans tuyau-enveloppe est donc suffisant pour l'étude de nos savanes. Il a l'avantage d'être plus rapide d'opération et il est plus pratique dans certains cas. Par ailleurs, MacFarlane a déjà noté des résultats différents avec des palettes de dimensions différentes dans la terre noire et dans l'argile molle (4). Nous nous proposons de faire une étude complémentaire du même genre dans certaines parties de nos savanes et nous pourrons donner une étude comparative lors d'une prochaine publication. A Napierville, nous avons fait une deuxième série d'essais au scissomètre vane sous une certaine couche de remblai (4 à 5 pieds). Nous avons constaté une augmentation appréciable de la force de cisaillement pour la partie de terre noire située de 0 à 8 pieds sous le remblai. Les figures 11, 12 et 13 montrent, pour les savanes de Napierville et de Saint-Elie d'Orford, les résultats des essais au scissomètre vane "in situ".

On constate qu'à Napierville, ce sont les savanes 1 et 3 qui ont les valeurs les plus basses pour la force de cisaillement. La force de cisaillement la plus faible est rencontrée dans la couche d'argile molle immédiatement sous la terre noire. Cette argile molle est susceptible de causer autant sinon plus de dommage que la terre noire. Dans S-2 et dans S-4, la force de cisaillement augmente plus rapidement avec la profondeur. Nous nous proposons, pour de futures constructions dans les savanes, de faire plusieurs essais au scissomètre vane lors de la pose des différentes couches de matériaux, et plus particulièrement pendant la première journée de la pose du coussin initial, au moment où la pression d'eau atteint son maximum dans les piézomètres. A Saint-Elie d'Orford, les essais au scissomètre vane que nous avons effectués dans la première partie de la savane mettent en évidence des alternances de zones faibles et de zones plus résistantes dans la terre noire (fig. 13). Ces essais ont été effectués à proximité de la vieille route.

Essais en Laboratoire

Dans les savanes de Napierville, des échantillons n'ont pu être prélevés qu'à de faibles profondeurs à cause du manque d'outillage adéquat au début de nos études sur ces savanes. Depuis, nous avons fait l'acquisition de l'échantillonneur à piston suédois qui s'est avéré un excellent outil pour ces types de sol. Nous l'avons utilisé pour la savane de Saint-Elie d'Orford. Les essais de laboratoire sur les échantillons provenant de Saint-Elie d'Orford ont été effectués de la même façon que sur ceux provenant de Orsainville et de Napierville. Une table donnant les résultats des essais en laboratorie pour Napierville et Saint-Elie d'Orford suit (Table I). Une partie des valeurs apparaissait dans la publication de Paré et Brochu (1964).

La figure 14 montre le rapport entre l'indice des vides et la teneur en eau. Pour Saint-Elie d'Orford, nous avons trouvé une relation linéaire, la droite se rapprochant passablement de celle de Orsainville. Elle se situe entre la droite pour Napierville et celle de Cook (1956) (Paré et Brochu, 1964). Les courbes présentées dans les figures 15, 16 et 17 donnent les rapports entre le coefficient de compressibilité et l'indice des vides. Encore là (fig. 17), on voit que la courbe donnée pour Saint-Elie d'Orford est près de celles données pour Napierville et Orsainville et par Brawner et Fenco. Avant de se servir de telles courbes pour l'évaluation des tassements, il serait bon cependant d'en

Table I

Caracteristiques de la terre noire

| | Napierville | Saint-Élie d'Orford | Commentaires |
|---|---|---|---|
| Profondeur - pieds | 5 - 11 | 3 - 13 | Fibreuse et amorphe |
| Teneur en eau - % | 300 - 650 | 200 - 890 | 24 h. à 100° C. |
| Cendres - % | 40 - 15 | 13 - 7 | 24 h. à 300° C. |
| Matiéres org. - % | 60 - 85 | 87 - 93 | 2 comb. (2h. à 750° C.) |
| Poids spécifique | 1.30 - 1.75 | 1.40 - 1.53 | Flacon Lechâtelier |
| Poids spécifique | 1.68 - 1.98 | 1.66 - 1.80 | Basé sur % mat. org. |
| Poids spécifique | 1.90 - 2.68 | 1.90 - 2.70 | Pycnomètre (cendres) |
| $p^H$ | 5 - 7 | 6 - 7 | Papier tournesol |
| Indice des vides | 7 - 11 | 5 - 16 | A 100% saturation |
| Poids unitaire | 64.6 - 66.7 | 58.1 - 64.1 | Poids total |
| Poids unitaire | 9.2 - 12.1 | 5.9 - 9.5 | Poids sec |
| Résist. au cisail. | 140 - 190 | 120 - 300 | Scissomètre vane |
| Sensibilité | 3.5 - 4.5 | 2.5 - 3.5 | Scissomètre vane |

établir pour chaque catégorie de terre noire et de bien coordonner les résultats obtenus.

Des essais de consolidation ont été effectués sur les échantillons prélevés à Napierville et à Saint-Elie d'Orford. Nous n'avons pas tenté de calculer le tassement de la terre noire d'après ces essais pour les raisons suivantes: les échantillons prélevés à Napierville étaient quelque peu remaniés et ils avaient été prélevés trop près de la surface.

Les figures 18 et 19 montrent les courbes tirées des essais de consolidation sur les échantillons de Napierville et de Saint-Elie d'Orford. Dans nos essais, les charges appliquées étaient trop grandes pour pourvoir donner des valeurs suffisamment justes dans la prédiction du tassement. Sur un échantillon de dimensions restreintes tel que ceux utilisés pour l'essai, une grande partie de la consolidation a lieu très rapidement et il devient assez difficile de prendre la lecture du consolidomètre avec une précision suffisante. En l'espace de quelques secondes, nous atteignons 90% de la consolidation primaire. En employant les charges et les accroissements de charges réels (i.e. ceux du remblai), nous aurons plus de chance de prédire correctement le tassement et le temps à l'aide des relations $t/t' = H^2/H'^2$ et $s/H = s'/H'$ (Cook, 1956; Risi, Brunette et Girard, 1955). Nous aurions des résultats plus conformes à la réalité en faisant les essais de consolidation sur des échantillons beaucoup plus gros. Il faudrait alors un équipement qui n'est pas standard et un échantillonneur à piston plus gros. Il est important aussi de prendre les échantillons dans la partie de terre noire libre de racines et à une profondeur adéquate.

Instruments de Contrôle

Nous avons utilisé des piézomètres à pierre poreuse. A Saint-Elie d'Orford, pour les poser plus facilement dans les endroits très mous et où il y avait de l'eau en surface, nous avons ajouté des cages en tôle perforées de 4 pouces de diamètre et de 5 pieds de longueur. A quelques endroits, dans l'argile molle, nous avons utilisé des piézomètres de type "Geonor". Ces piézomètres ont l'avantage d'être récupérables en tout temps. Les piézomètres ont été posés à tous les 800 pieds dans les savanes de Napierville et aux endroits les plus critiques dans celle de Saint-Elie d'Orford où à deux endroits particuliers, nous avons posé deux piézomètres sur une même section transversale et à des profondeurs différentes (voir fig. 10). Nous avons posé des plaques de tassement à tous les 400 pieds dans les savanes de Napierville et a tous les 200 pieds dans celle de Saint-Elie d'Orford. Nous avons également installé des indicateurs de déplacement latéral à tous les 200 pieds et distancés de 7 et 18 pieds du remblai à

Napierville et de 20 et 30 pieds a Saint-Elie d'Orford (voir fig. 8 et 10). La table II donne les quantités d'instruments de contrôle dans les savanes.

Table II

Instruments de contrôle

| | Napierville | Saint-Élie d'Orford |
|---|---|---|
| Piézomètres | 29 | 7 |
| Plaques de tassement | 74 | 9 |
| Indicateurs de déplacement | 286 | 17 |

Les figures 20 à 24 donnent les courbes de tassement, de pression d'eau et de déplacement latéral en fonction de la hauteur du remblai et du temps.

Pressions d'eau

Nous avons considéré comme cote maximum pour la durée des travaux le niveau maximum atteint dans les piézomètres pendant la première journée de la pose du coussin initial. Cependant, l'eau atteint ce niveau très rapidement et elle se dissipe aussi très rapidement. Une lecture dans les piézomètres pendant la première journée de la pose du coussin initial n'est past suffisante pour enregistrer correctement la courbe de la pression d'eau durant ce laps de temps. Il sera sûrement intéressant de prendre plusieurs lectures durant la première journée de la pose du coussin initial et durant la première journée de la pose de chacune des couches subséquentes, de comparer ces pressions d'eau maximum entre elles et avec celles prises quelques jours plus tard. Nous sommes d'avis, à l'instar de Lea et de Brawner (1959), que la cote maximum de pression d'eau avant tout chargement subséquent ne doit pas dépasser 30% de la pression totale due au remblai à ce stage de la construction. À Napierville, nous avons eu de la difficulté avec certains de nos piézomètres. À cause de la construction simultanée des remblais sur les quatre savanes, de la quantité considérable d'appareils de contrôle à surveiller et du nombre restreint de techniciens à notre disposition, nous n'avons pu enregistrer dans plusieurs des cas qu'une lecture des pressions d'eau durant la première journée des travaux. Durant l'hiver qui suivit le début des travaux, plusieurs de nos piézomètres ont gelé malgré la pose d'antigel. À Saint-Élie d'Orford, nous n'avons pas pris de lecture durant l'hiver.

Tassements

À Napierville, les tassements ont été variables dans les quatre savanes, avec une différence marquée entre ceux dans S-1, S-2 et S-4 et ceux dans S-3 où on a enregistré les tassements maximums. À Saint-Élie d'Orford, les tassements ne furent pas considérables si on juge que la hauteur du remblai variait de 8 à 17 pieds.

Déplacements latéraux

Tout comme les tassements, les déplacements latéraux enregistrés sont les valeurs moyennes représentatives de toutes les savanes. A certains endroits de la savane 3 à Napierville, les déplacements latéraux ont ete considérables (plus que un pied). Nous avons arrêté les travaux pour de longues périodes. Nous avons ajouté des bermes pour consolider le remblai et pour éviter des glissements. Nous sommes d'avis que ces incidents furent causés par la couche d'argile molle immédiatement sous la terre noire. C'est d'ailleurs dans cette zone que la force de cisaillement était le plus faible.

Comportement des Remblais

De façon générale, les savanes de Napierville ont subit des tassements plus considérables pendant la pose du coussin initial. C'est ce que démontre la figure 25. Nous y avons placé le rapport Tc/Hc (tassement du coussin/hauteur du coussin) en regard du rapport Tr/Hr (tassement du remblai/ hauteur du remblai). La droite moyenne obtenue indique le rapport suivant: Tc/Hc sur Tr/Hr = 2/3. Pour Orsainville, la droite moyenne donnait la valeur 1/2. Cependant, Paré avait alors considéré l'épaisseur de la couche molle et non pas uniquement celle de la terre noire (Paré et Brochu, 1964).

La figure 26 montre le rapport entre la valeur Tc/Hc (tassement du coussin/hauteur de coussin) et l'épaisseur de la terre noire. Nous avons établi ce rapport pour chacune des quatre savanes de Napierville et nous constatons que la droite représentative de la savane 3 s'écarte sensiblement de celle des trois autres savanes. Le tassement du coussin initial et du remblai est beaucoup plus considérable dans la savane 3. Ceci est démontré par la figure 27 sur laquelle nous avons placé les tassements en regard de l'epaisseur de la terre noire pour chacune des savanes 1, 2, 3 et 4. Le tassement était pour un remblai maximum de 9 pieds et pour une période de 400 jours. Pour les savanes 1, 2 et 4, le rapport Tr/Hp (tassement du remblai/épaisseur de terre noire) donne des valeurs variant de 0.25 à 0.45 avec une moyenne de 0.33. Autrement dit, les savanes ont subi un tassement moyen équivalent au tiers de l'épaisseur de la terre noire. Cependant, cette valeur est dépassée dans le cas de la savane 3. Les grandes valeurs de tassement pour S-3 peuvent s'expliquer en partie par le fait qu'à plusieurs endroits, la savane a jadis été endommagée par le feu, ce qui a certainement affaibli la croûte de surface. De plus, quelle partie de ces tassements s'est effectuée dans l'argile molle? Les déplacements latéraux excessifs enregistrés à certains endroits ont aussi contribué pour une certaine part à ces tassements en brisant la croûte de surface.

Pendant la construction des remblais à Napierville, trois incidents sont survenus:

(1) Pendant la pose du coussin initial dans la partie de la savane 3 située au nord de la rivière Montréal, des tassements et des déplacements latéraux importants ont brisé la croûte de surface. Les travaux ont été interrompus et une berme a été ajoutée du côté est pour servir de contre-poids. Deux causes possibles sont: marche trop rapide des travaux et outillage trop lourd.

(2) Un glissement est survenu dans le remblai de la savane 1, sur une longueur de 1100 pieds. Une des causes principales était que les couches subséquentes du remblai avaient été posées trop rapidement, l'autre cause étant la présence d'un fossé à une distance d'une trentaine de pieds du remblai. Durant l'hiver, nous avons profité du gel pour remplir le fossé, poser une berme et réparer le remblai.

(3) Au printemps suivant, un autre glissement s'est produit dans le même remblai, sur une longueur de 300 pieds à la suite du premier glissement. Nous pensons que dans ces glissements la couche d'argile molle a joué un rôle très important, car la grande partie du tassement dans la terre noire avait été accomplie.

À Saint-Élie d'Orford, où la savane est composée de terre noire sur du sable (SM), aucun incident n'est survenu bien qu'à certains endroits le remblai a une hauteur supérieure à dix pieds.

La figure 28 donne la valeur du tassement sous le remblai en regard de l'épaisseur de la terre noire dans la partie de la savane 3 où il y avait une couche de CL sur la terre noire (de 0+00 à 45+00). Le tassement immédiat dû au coussin initial est minime (droite de l'ordre de 2%), tandis qu'après 400 jours, le tassement du au remblai de 9 pieds est beaucoup plus considérable (droite de l'ordre de 25%). D'autre part, la couche de CL posée en 1941 a dû consolider en grande partie la terre noire à cet endroit.

Conclusion

D'après notre expérience passée, il nous semble raisonnable de ne tolérer aucun fossé à moins de 50 pieds du remblai dans les savanes contenant de la terre noire sur du sable ou de l'argile compacte; par contre, pour les savanes composées de terre noire sur de l'argile molle, on ne devrait pas faire de fossé à moins de 90 pieds du remblai. La position des instruments de contrôle sera déterminée en fonction de l'étude préliminaire (i.e. étude pédologique, essais au scissomètre vane). En ce qui concerne les indicateurs de déplacement latéral, les distances de 20 et 30 pieds du remblai semblent être adéquates. On pourra toutefois faire une étude complémentaire aux endroits les plus critiques dans de futures constructions de routes sur muskegs pour des distances variant de 15 à 50 pieds du remblai.

Cette communication ne donne toutefois pas une conclusion définitive aux savanes de Napierville et de Saint-Élie d'Orford. Une prochaine communication pourrait contenir, en plus d'une courbe montrant la relation entre les tassements du remblai et l'épaisseur de la couche molle (i.e. terre noire et argile molle) des données complémentaires au sujet des tassements sous la première chaussée de la route 9 construite en 1941, dans le savanes 1 et 3, une comparaison entre ces tassements et ceux survenus lors de la présente construction, ainsi que des résultats de futurs essais au scissomètre vane avec des palettes de différentes dimensions. Nous pourrons en plus fournir des renseignements provenant des calculs de stabilité pour les parties des savanes où il y a eu des ruptures dans le remblai. Nous ferons une comparaison entre la résistance au cisaillement calculée et celle donnée à l'aide des essais au scissomètre vane.

Ce rapport nous donne clairement la marche à suivre dans nos futures constructions sur muskegs:

(a) Une étude plus approfondie des savanes comprenant: classification Radforth, catégories de terre noire, essais au scissomètre vane, prélèvement de nombreux échantillons.

(b) Des essais de consolidation en utilisant des accroissements de charges réels pour prédire le tassement et le temps.

(c) Avec les résultats de futurs travaux sur muskegs, on pourra certainement établir des relations du genre de celles données aux figures 25 et 26 et prédire pour telle catégorie de terre noire, les tassements immédiats et finaux, avec une assez bonne précision.

Nous avons donc besoin de renseignements plus complets par une étude plus poussée de toutes les savanes rencontrées et par des essais de laboratoire plus précis afin d'éliminer le plus d'erreur possible dans nos prédictions.

Remerciements

Je remercie les autorités du ministère de la Voirie du Québec qui m'ont permis de présenter cette communication au onzième congrès annuel sur le muskeg. Je remercie en outre M. G. Robert Tessier, Chef du Service des Sols et Matériaux, pour son encouragement, sa révision du texte et ses judicieuses remarques, M. J. J. Paré, de l'Université de Sherbrooke, pour sa révision du texte, ses commentaires et ses précieux conseils, M. Benoit Deshaye, Conseiller Technique à la Voirie, pour l'excellente correction du texte anglais, M. Claude Bernard, du Service de l'Information, pour la préparation des nombreuses copies anglaises et françaises et mes collègues de la Division de la Géotechnique qui ont fourni une aide precieuse lors de la préparation du texte et des figures, notamment MM. Rosaire Pépin, Paul Brochu, Luc Tanguay et Jean Normand.

- * -

## REFERENCES

Brawner, C. O. "The Practical Application of Preconsolidation in Highway Construction over Muskeg", Proceedings Sixth Muskeg Research Conference, NRC-ACSSM Tech. Memo. 67, Ottawa, 1961, p. 13-31.

Cook, P. M. "Consolidation Characteristics of Organic Soils". Proceedings, Ninth Canadian Soil Mechanics Conference, NRC-ACSSM Tech. Memo. 41, Ottawa, 1956, p. 82-86.

Lea, N. D. and Brawner, C. O. "Foundation and Pavement Design for Highways on Peat". Proceedings, 40th Convention, Canadian Good Roads Association, Vancouver, 1959, p. 406-420.

MacFarlane, I. C. "Evaluation of Road Performance over Muskeg in Northern Ontario". Proceedings, Sixth Muskeg Research Conference, NRC-ACSSM Tech. Memo. 67, Ottawa, 1961, p. 38-48.

Paré, J. J., et Brochu, P. A. "Construction de Routes sur Tourbières dans la Province de Québec". Proceedings, Ninth Muskeg Research Conference, NRC-ACSSM Tech. Memo. 81, Ottawa, 1964, p. 74-108.

Risi, J., Brunette, C. E., et Girard, H. "Étude Chimique des Tourbes du Québec, X; Tourbière de Napierville, comté de Napierville, R.P. no. 306, Québec, 1955.

- * -

<u>Discussion</u> (C. O. Brawner)

Mr. Tessier's paper provides a detailed account of the engineering investigation, construction program and field experience for several areas where highways are being constructed on peat in the province of Quebec.

The program utilized was generally similar to those that have been used in other areas of Canada during the past four to five years. Of particular interest is a comparison of the data and experience on the projects reported by Mr. Tessier and other projects in Canada.

Some of the more notable comparisons are as follows:

(a) In the Napierville area the peat is underlain by soft clay which the author indicates lead to more severe stability problems than occurred with the peat. This agrees with experience encountered during the construction of the four-lane Burnaby Freeway in Vancouver, where soft sensitive clay occurred directly under the peat. (Lea and Brawner, 1963).

This emphasizes the importance of evaluating the clay in detail and in particular considering shear strength and stability at comparable strain.

(b) The shear strength of the peat as measured by the vane apparatus increased over 200 per cent as a result of the application of fill load. This agrees with experience in British Columbia (Brawner, 1959)(Lea and Brawner, 1959).

(c) The void ratio vs. moisture content comparison of the Quebec peat agrees favourably with data from British Columbia (Cook, 1956; Brawner, 1959; Lea and Brawner, 1959, 1963).

**(Continued on Page 138)**

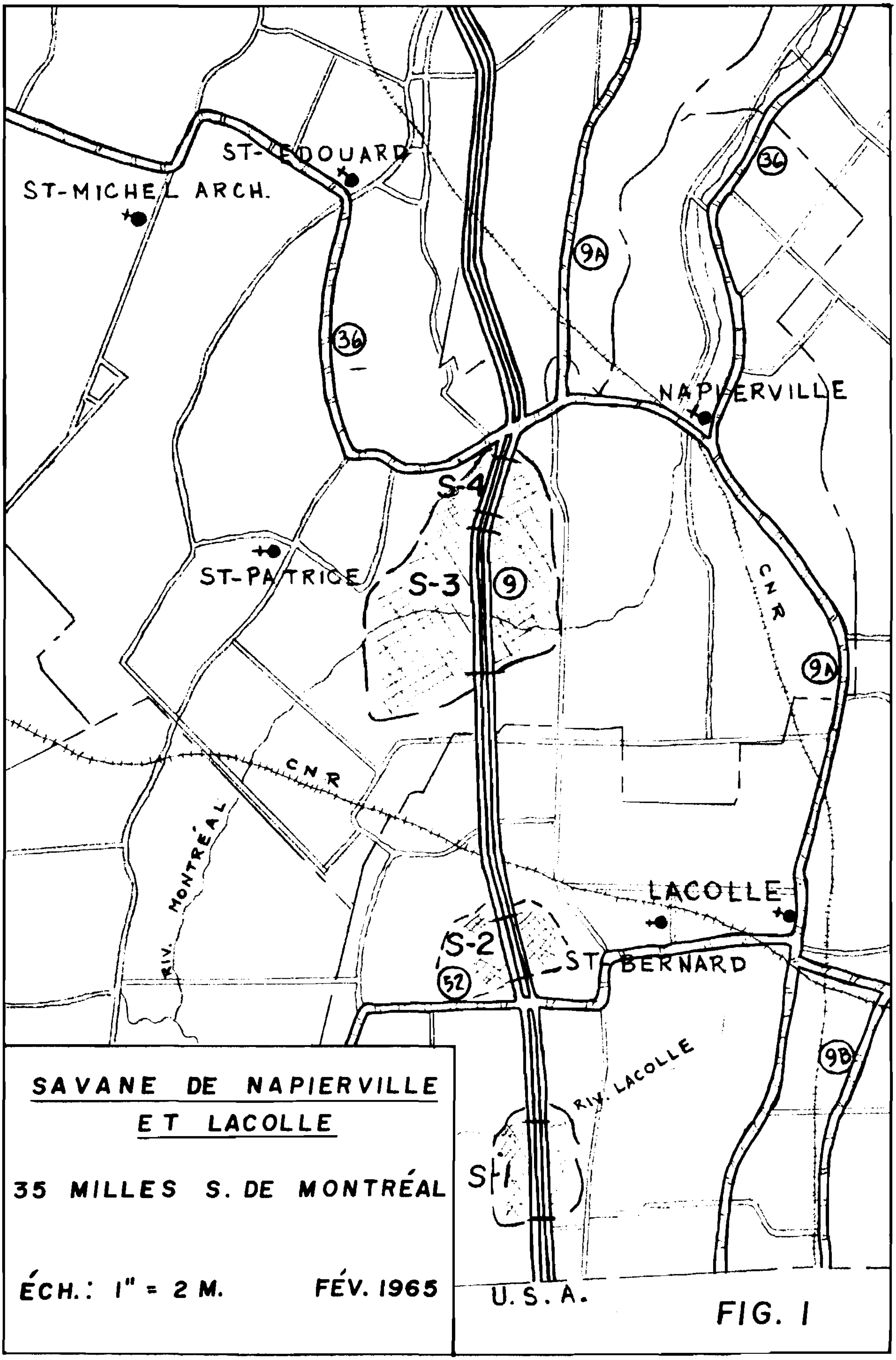
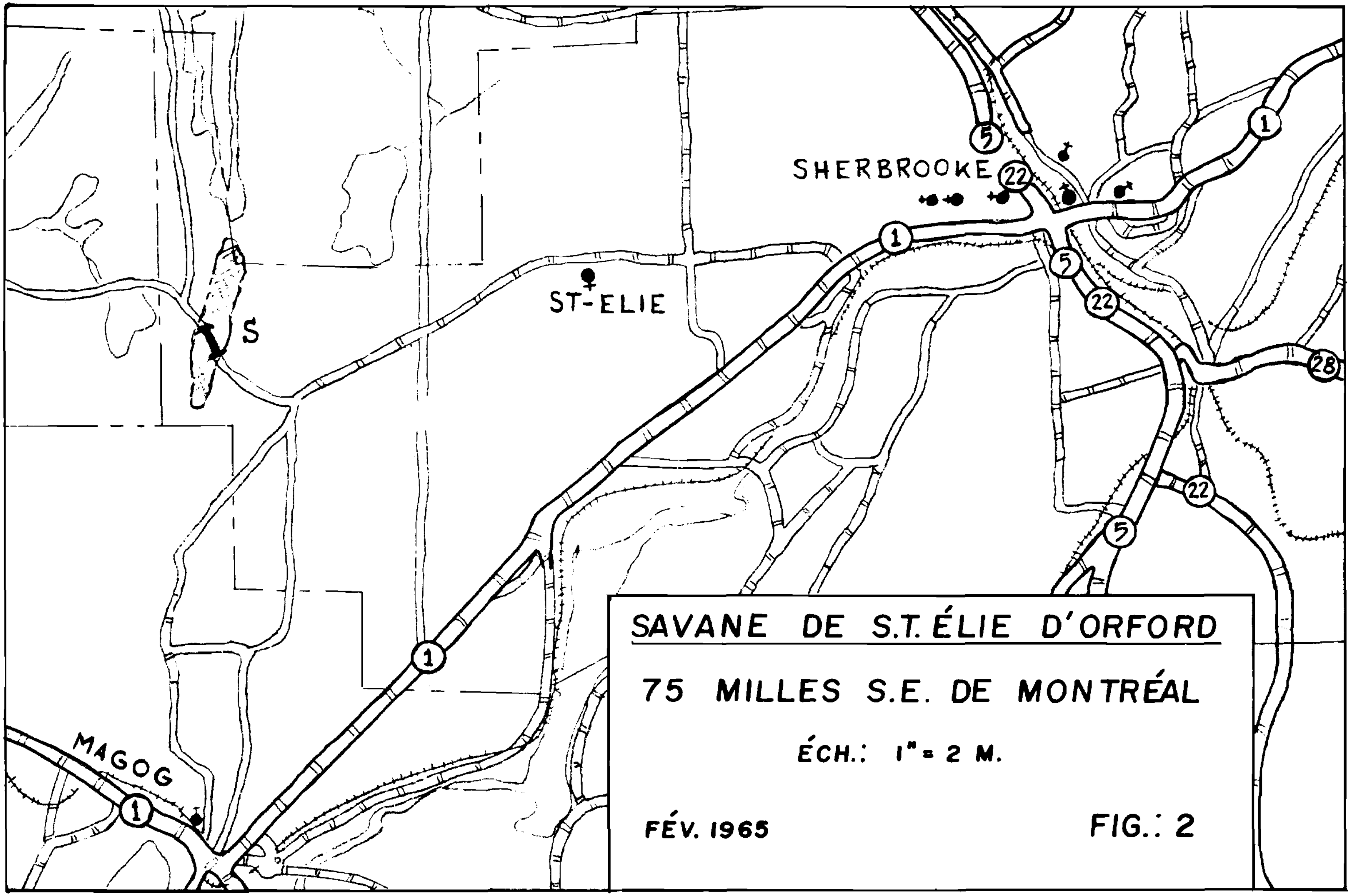

ST-EDOUARD
ST-MICHEL ARCH.
NAPIERVILLE
ST-PATRICE
S-4
S-3
9
36
9A
9B
52
CNR
RIV. MONTRÉAL
LACOLLE
S-2
ST BERNARD
RIV. LACOLLE
S-1
U.S.A.
SAVANE DE NAPIERVILLE
ET LACOLLE
35 MILLES S. DE MONTRÉAL
ÉCH.: 1" = 2 M.
FÉV. 1965

FIG. 1



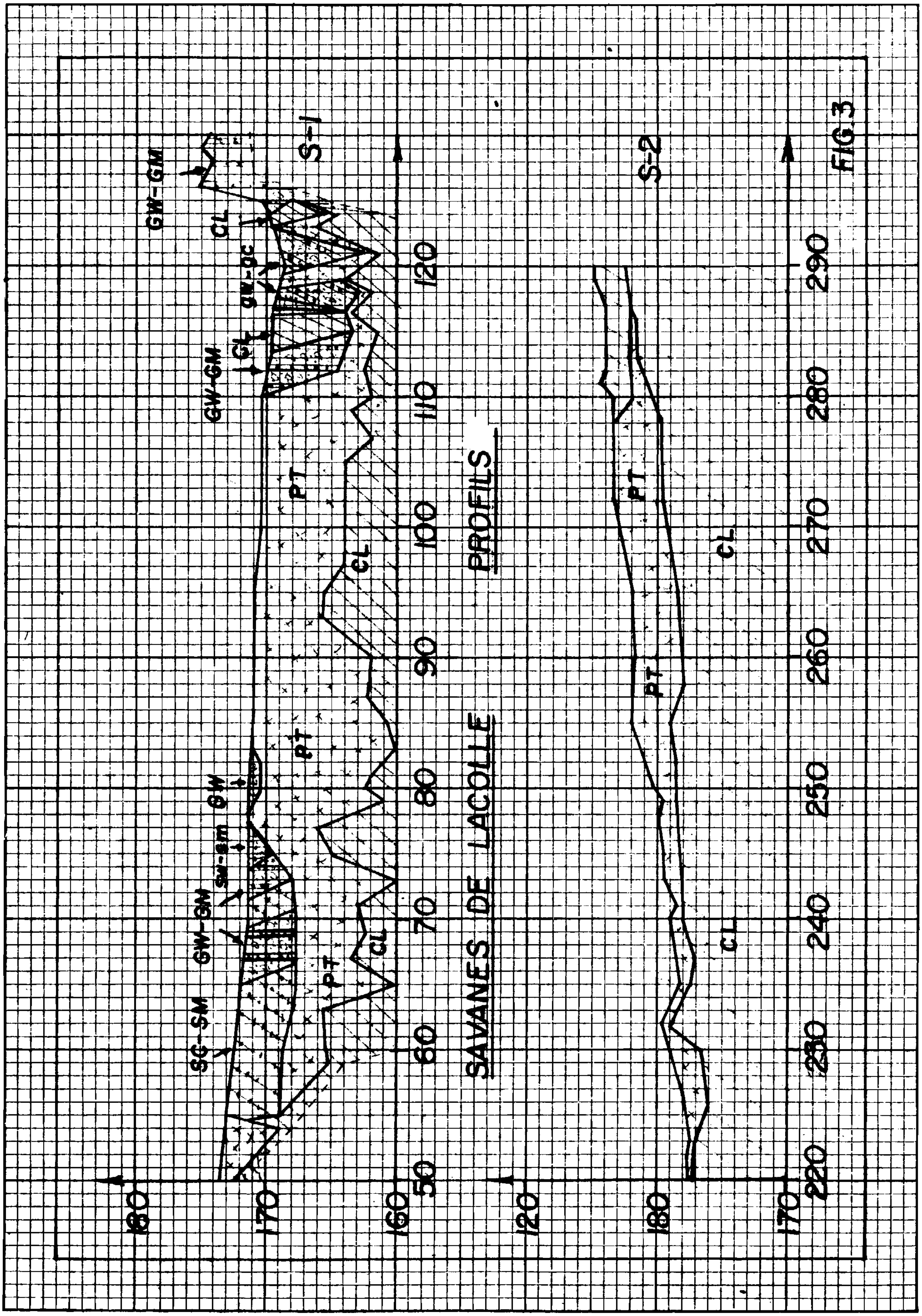

SAVANE DE S.T. ÉLIE D'ORFORD

75 MILLES S.E. DE MONTRÉAL

ÉCH.: 1" = 2 M.

FÉV. 1965

FIG.: 2


SAVANES DE LACOLLE
PROFILS
FIG.3
S-1
S-2
GW-GM
CL
GW-GC
PT
SC-SM
SW-SM
GW
50
60
70
80
90
100
110
120
160
170
180
220
230
240
250
260
270
280
290

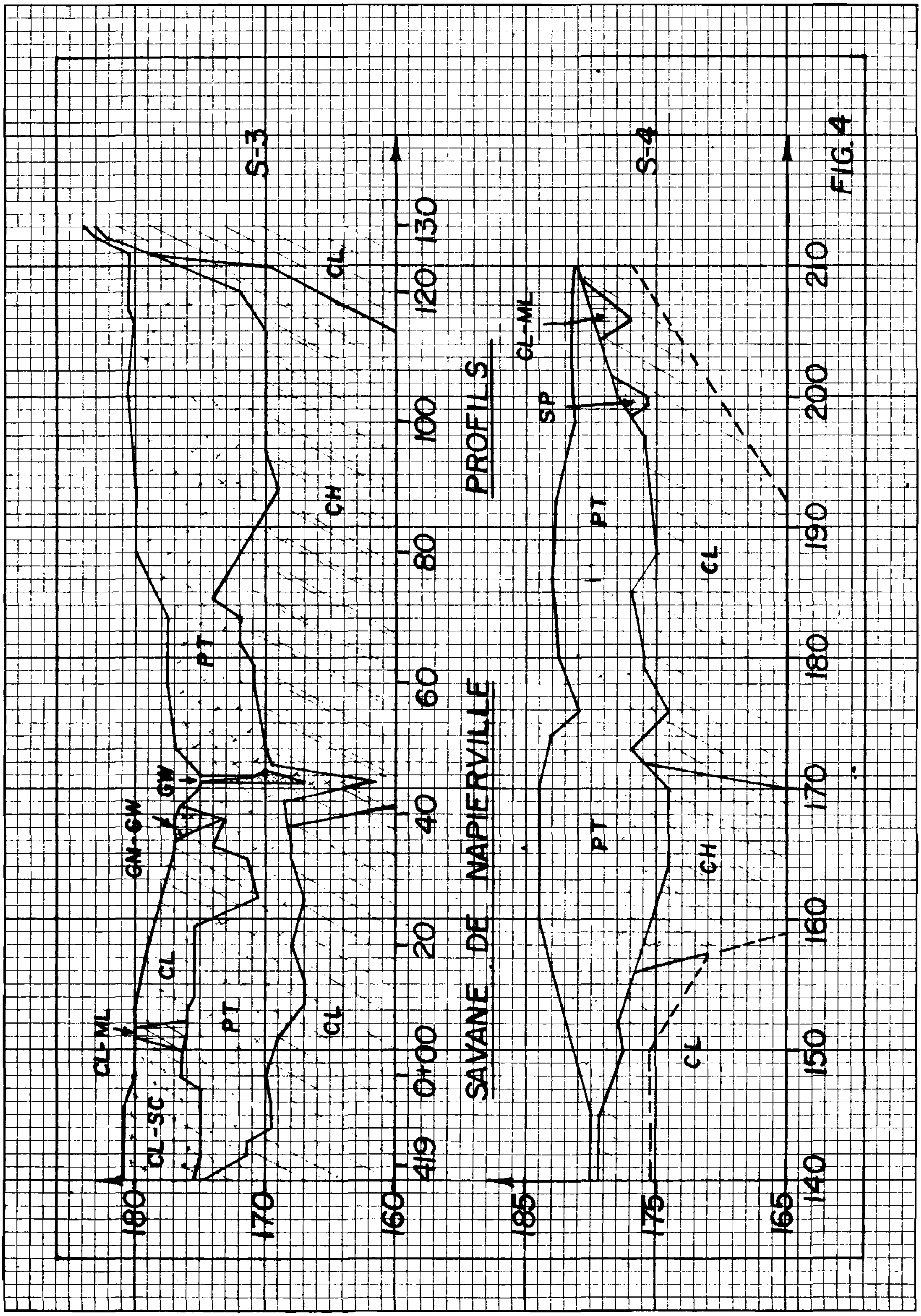

SAVANE DE NAPIERVILLE
PROFILS
S-3
S-4
CL-ML
CL-SC
CL
PT
GM-GW
GW
CH
SP
180
170
160
185
175
165
419
0+00
20
40
60
80
100
120
130
140
150
160
170
180
190
200
210

FIG. 4

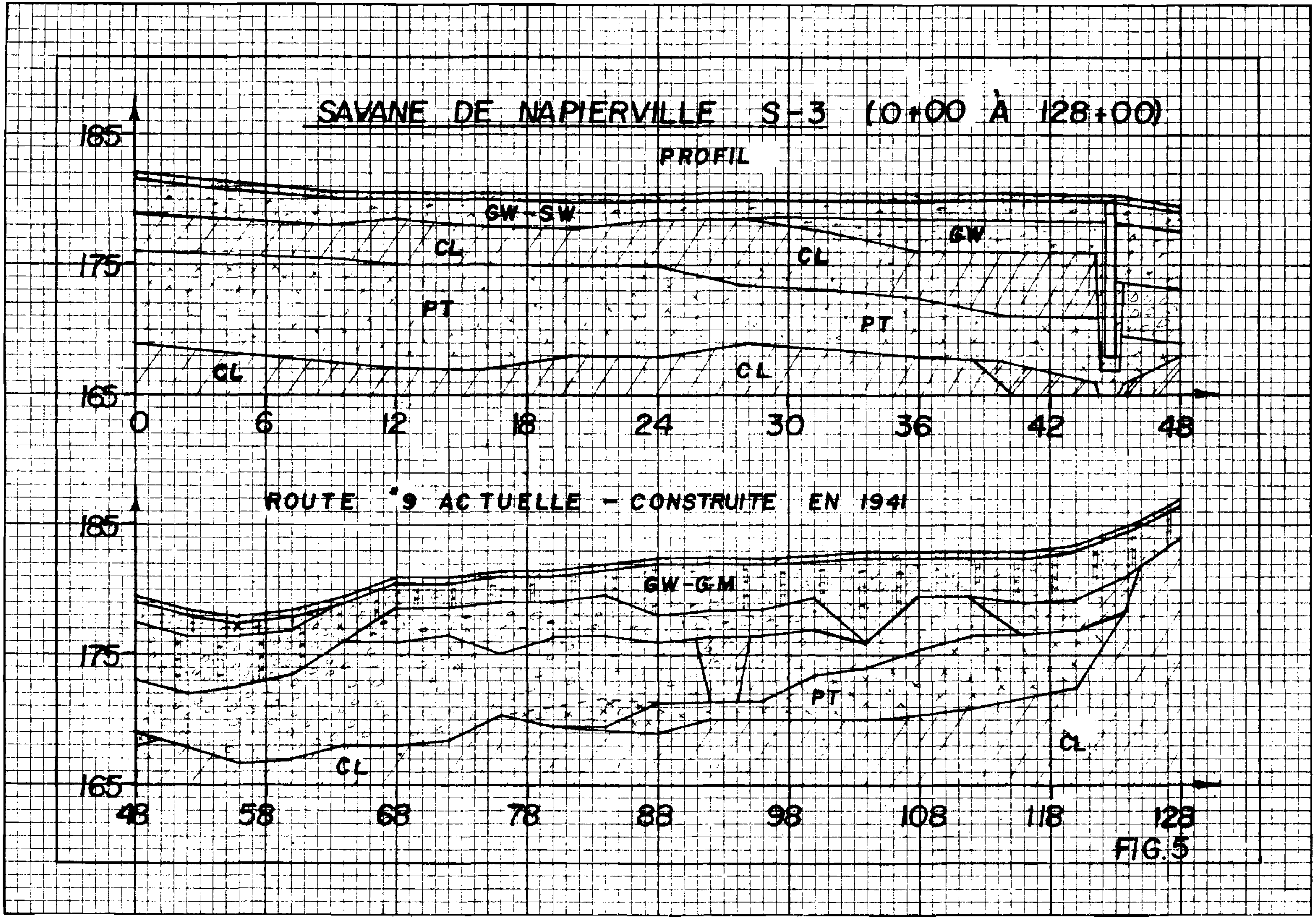

SAVANE DE NAPIERVILLE S-3 (0+00 À 128+00)
PROFIL
185
175
165
GW-SW
GW
CL
CL
PT
PT
CL
CL
0
6
12
18
24
30
36
42
48
ROUTE "9 ACTUELLE - CONSTRUITE EN 1941
185
175
165
GW-GM
PT
CL
CL
48
58
68
78
88
98
108
118
128

FIG.5

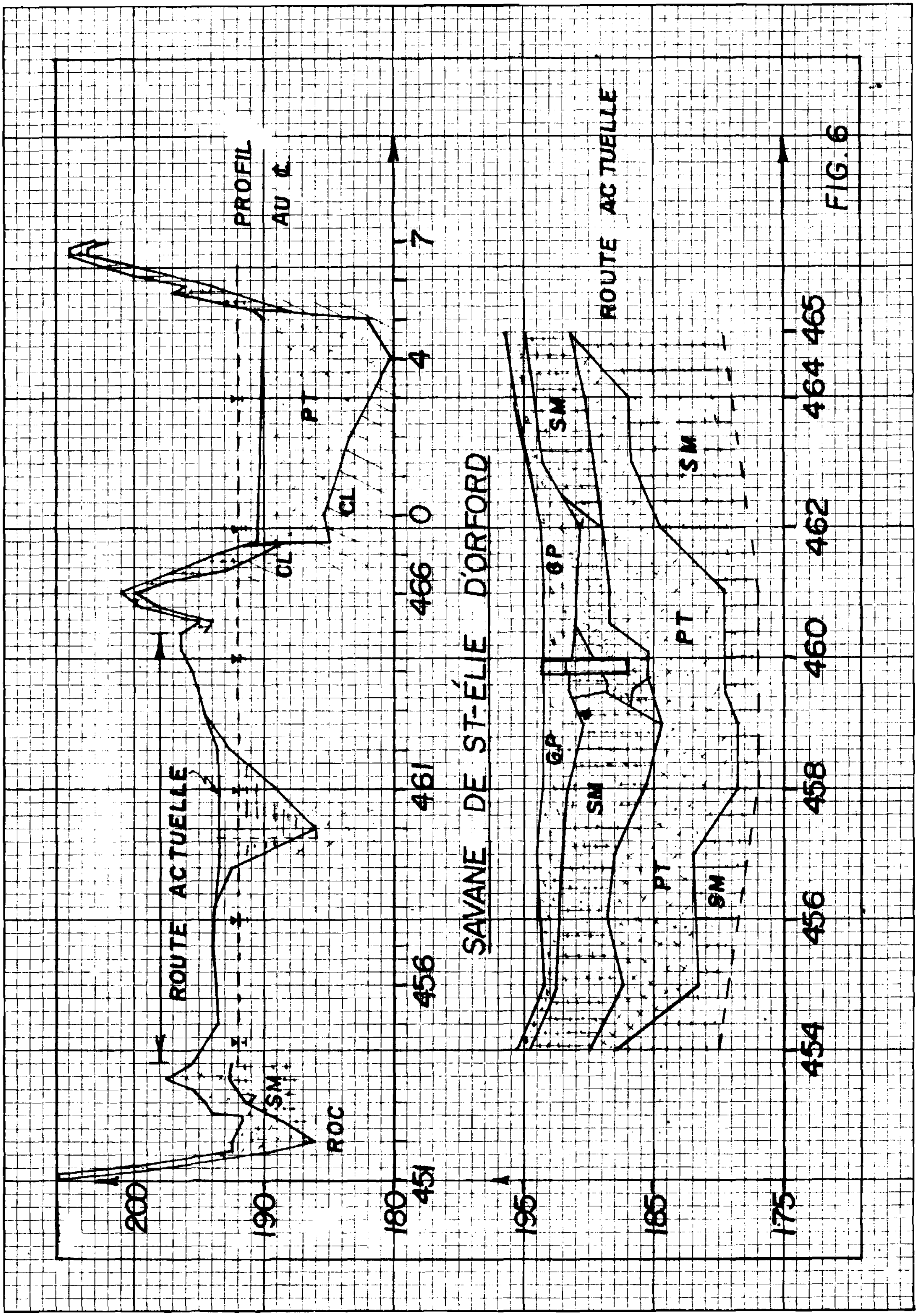

SAVANE DE ST-ÉLIE D'ORFORD
PROFIL AU ℄
ROUTE ACTUELLE
ROUTE ACTUELLE
ROC
SM
CL
CL
PT
GP
GP
SM
SM
PT
PT
SM
SM
200
190
180
195
185
175
451
456
461
466
0
4
7
454
456
458
460
462
464
465

FIG. 6

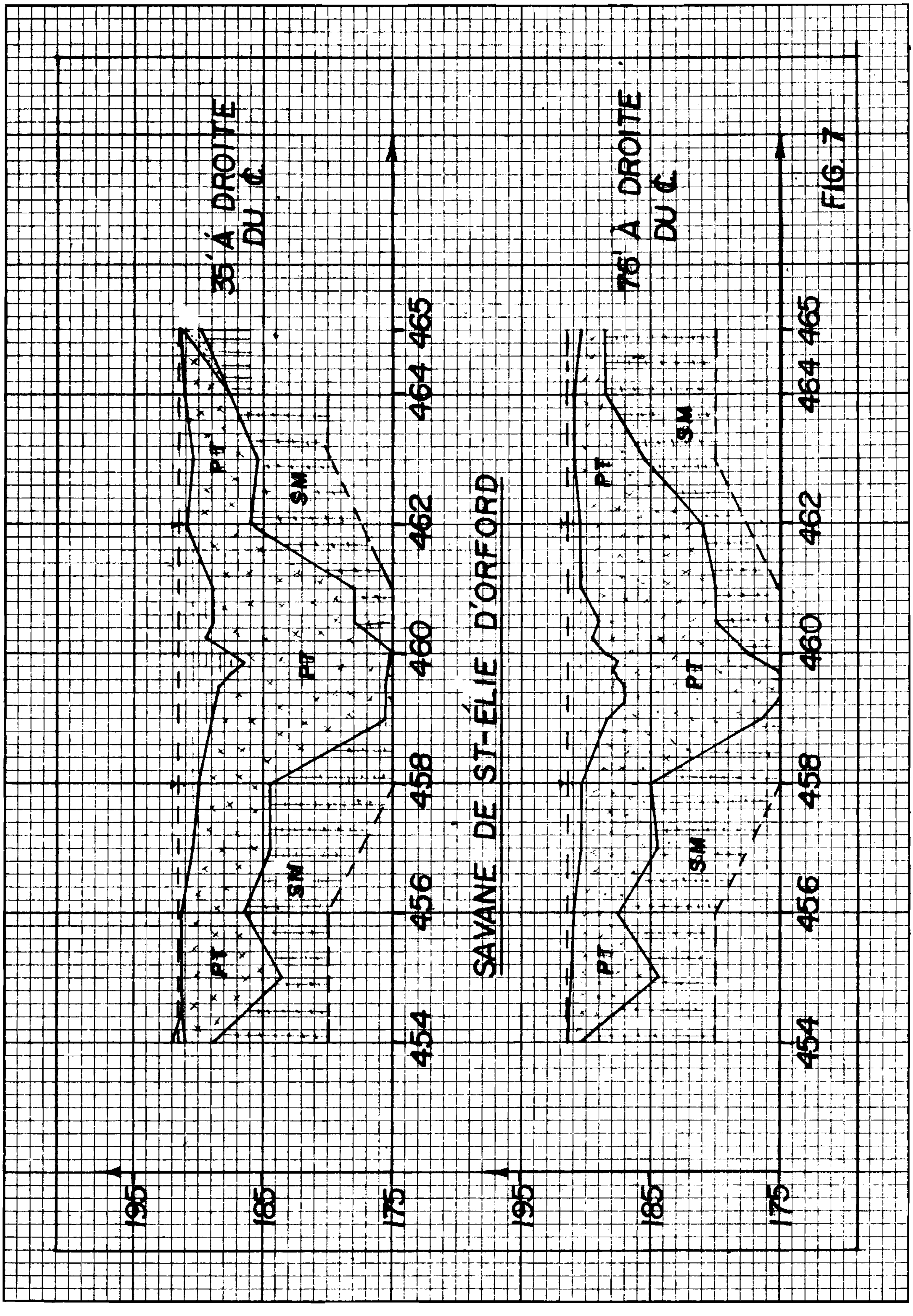
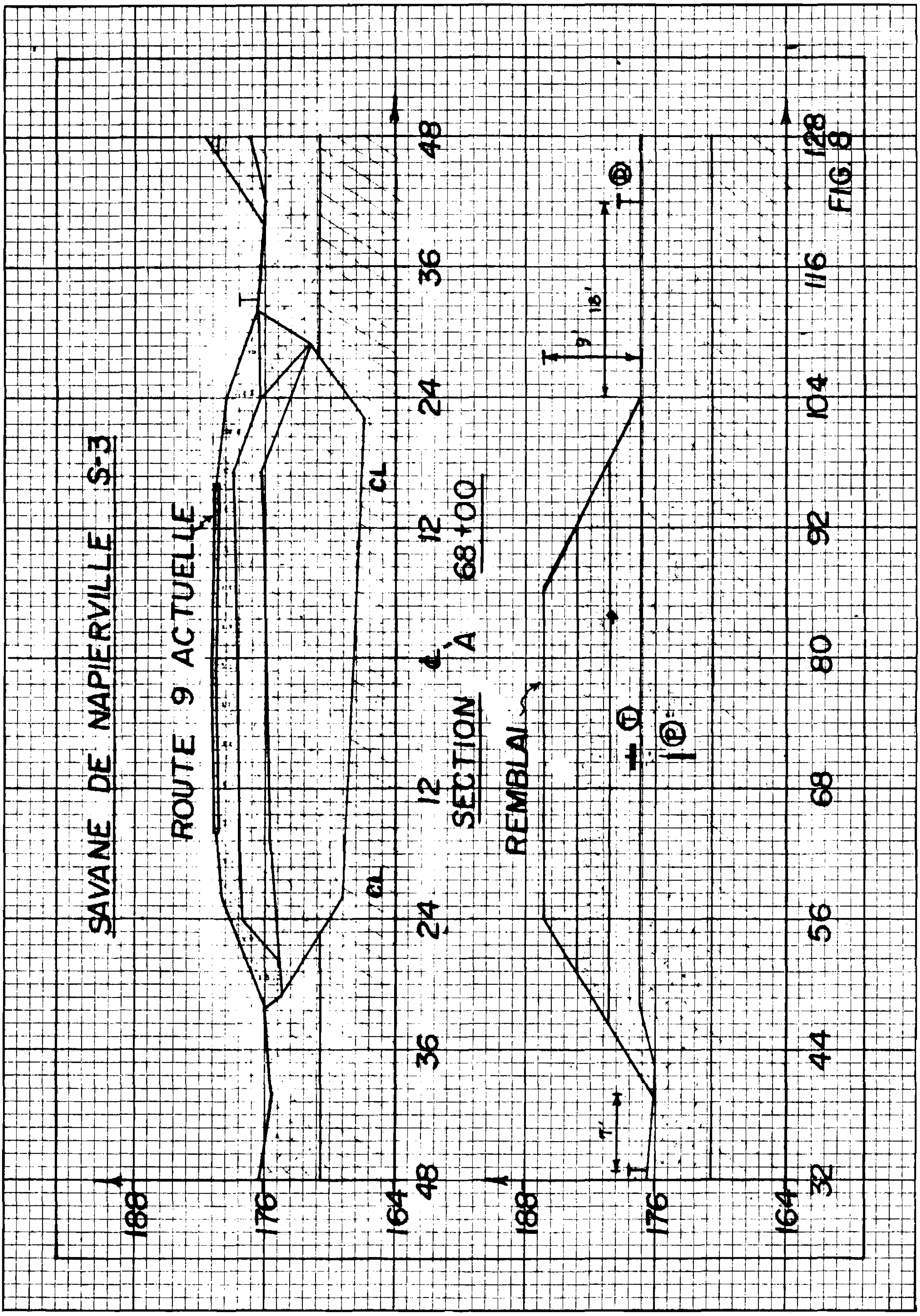
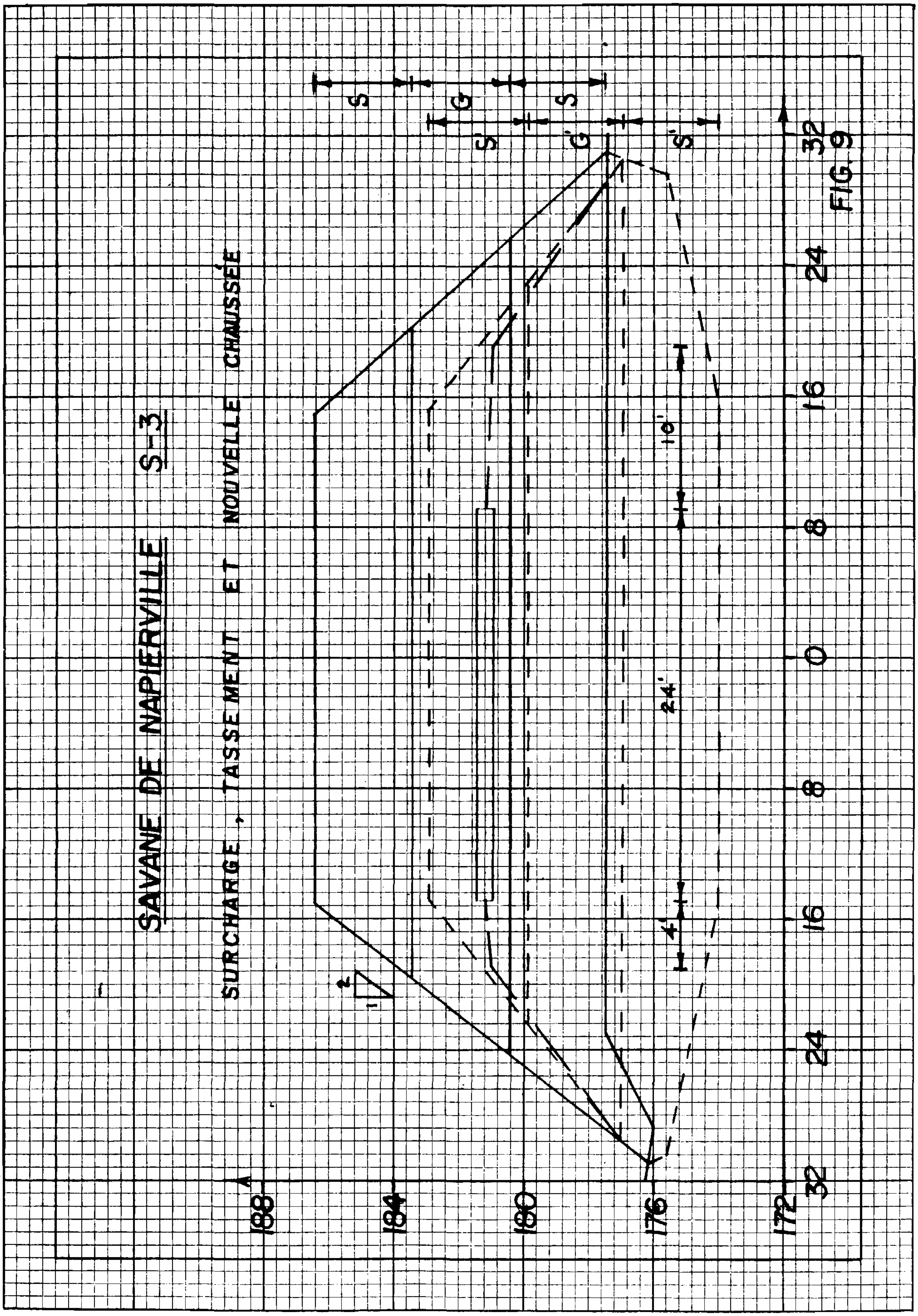

SAVANE DE ST-ÉLIE D'ORFORD
35' À DROITE DU ℄
75' À DROITE DU ℄
PT
SM
454
456
458
460
462
464
465
175
185
195

FIG. 7

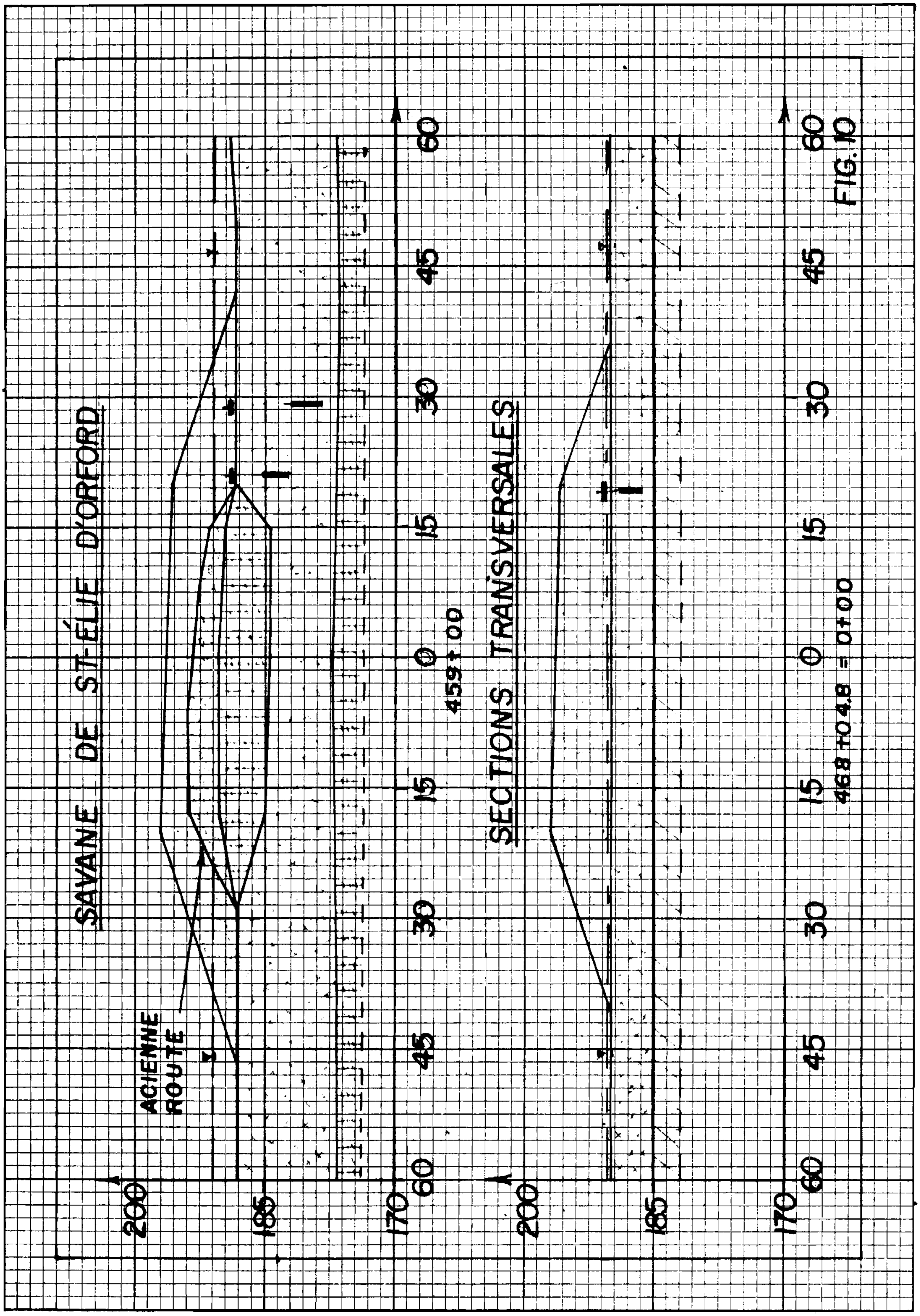


SAVANE DE NAPIERVILLE S-3
ROUTE 9 ACTUELLE
SECTION A 68+00
REMBLAI
CL
CL
9'
18'
7'
188
176
164
188
176
164
48
36
24
12
12
24
36
48
32
44
56
68
80
92
104
116
128
FIG 8



SAVANE DE NAPIERVILLE S-3
SURCHARGE , TASSEMENT ET NOUVELLE CHAUSSÉE
S
G
S
S'
G'
S'
10'
24'
4'
2
1
188
184
180
176
172
32
24
16
8
0
8
16
24
32


FIG. 9


SAVANE DE ST-ÉLIE D'ORFORD
SECTIONS TRANSVERSALES
ACIENNE ROUTE
459+00
468+04,8 = 0+00
200
185
170
60
45
30
15
0
FIG. 10

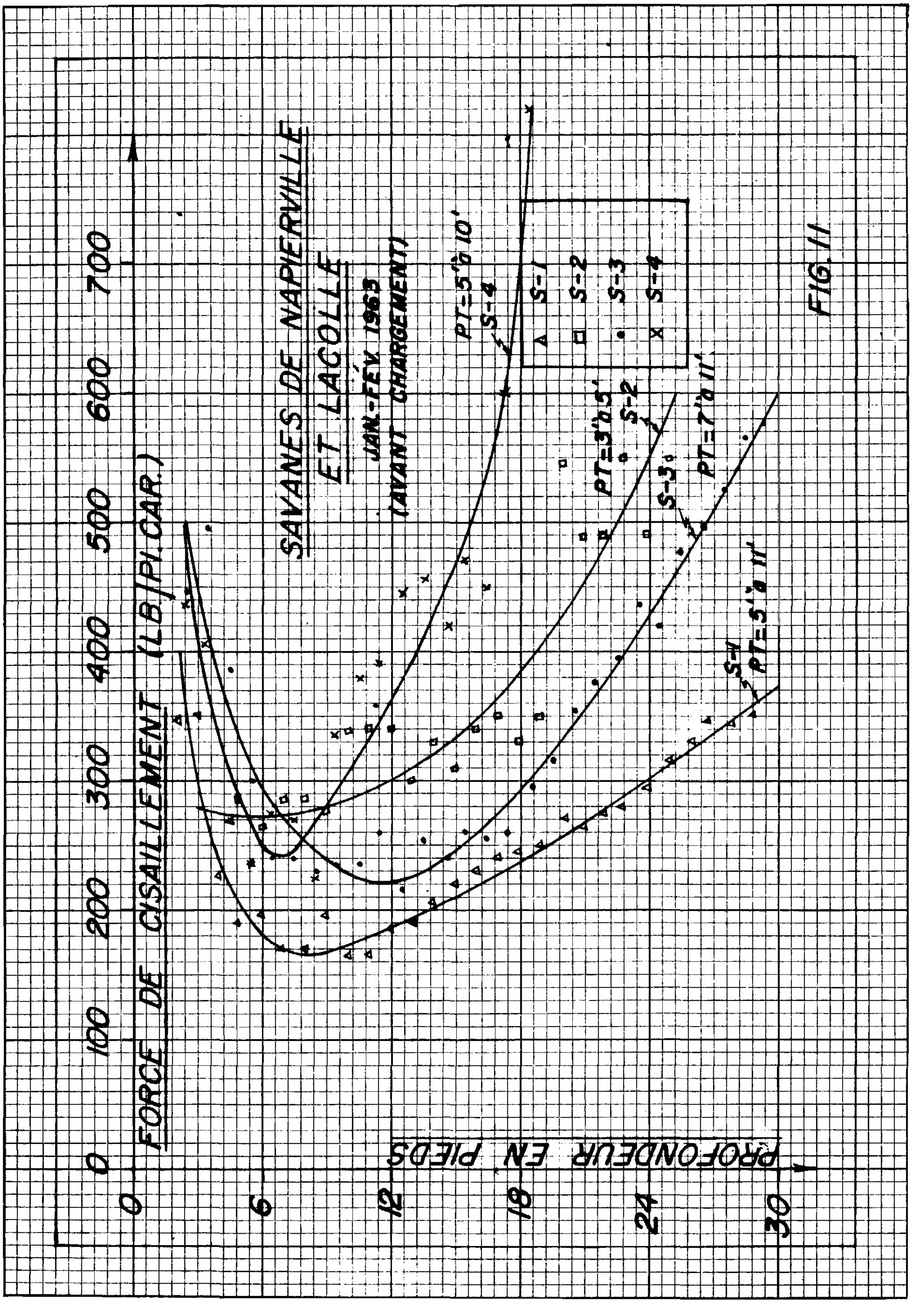

SAVANES DE NAPIERVILLE
ET LACOLLE
JAN-FÉV. 1963
(AVANT CHARGEMENT)
FORCE DE CISAILLEMENT (LB/PI.CAR.)
PROFONDEUR EN PIEDS
0
100
200
300
400
500
600
700
0
6
12
18
24
30
Δ S-1
□ S-2
• S-3
X S-4
PT=5' à 10'
S-4
PT=5' à 5'
S-2
PT=7' à 11'
S-3
PT=5' à 11'
S-1

FIG. 11

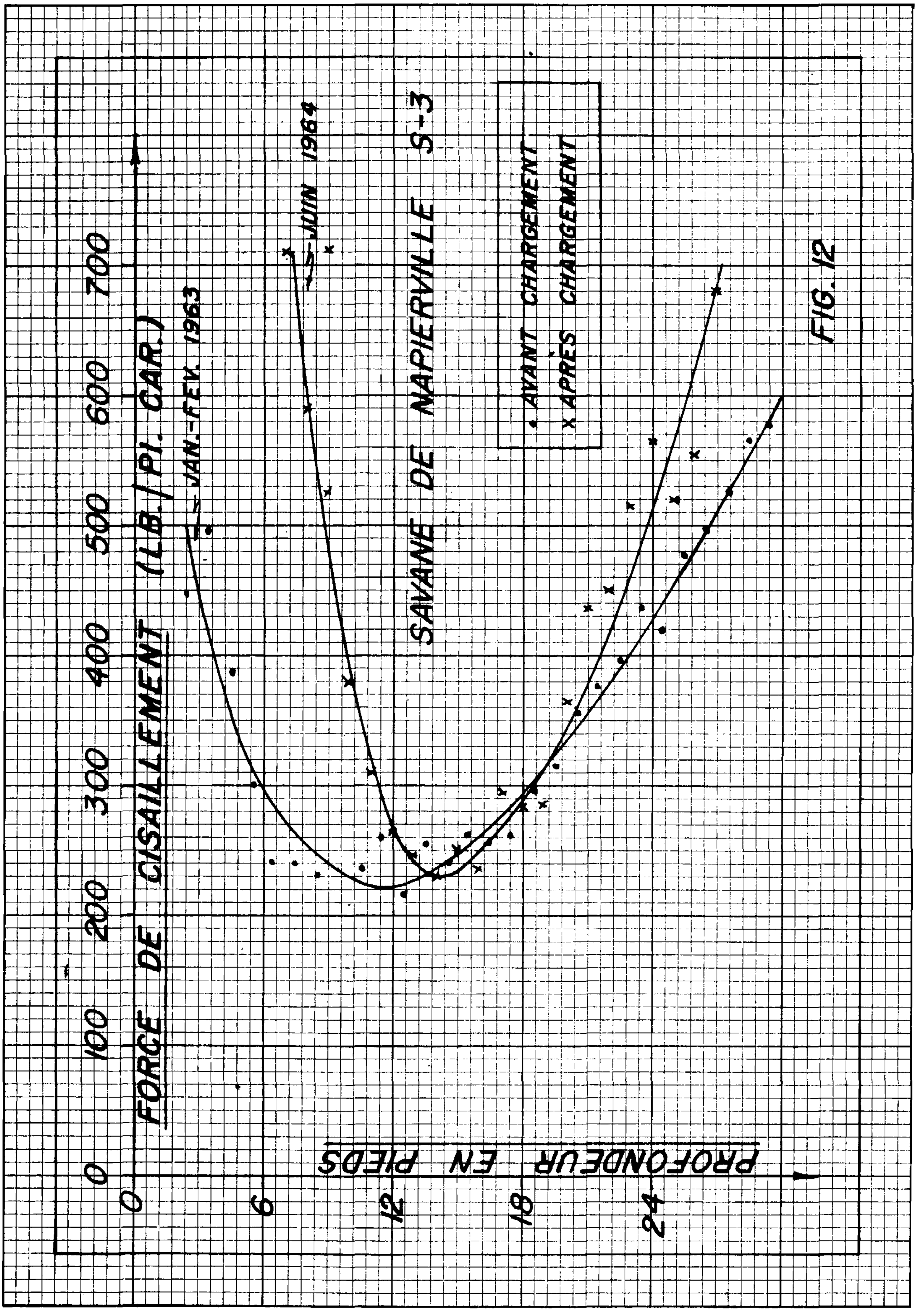
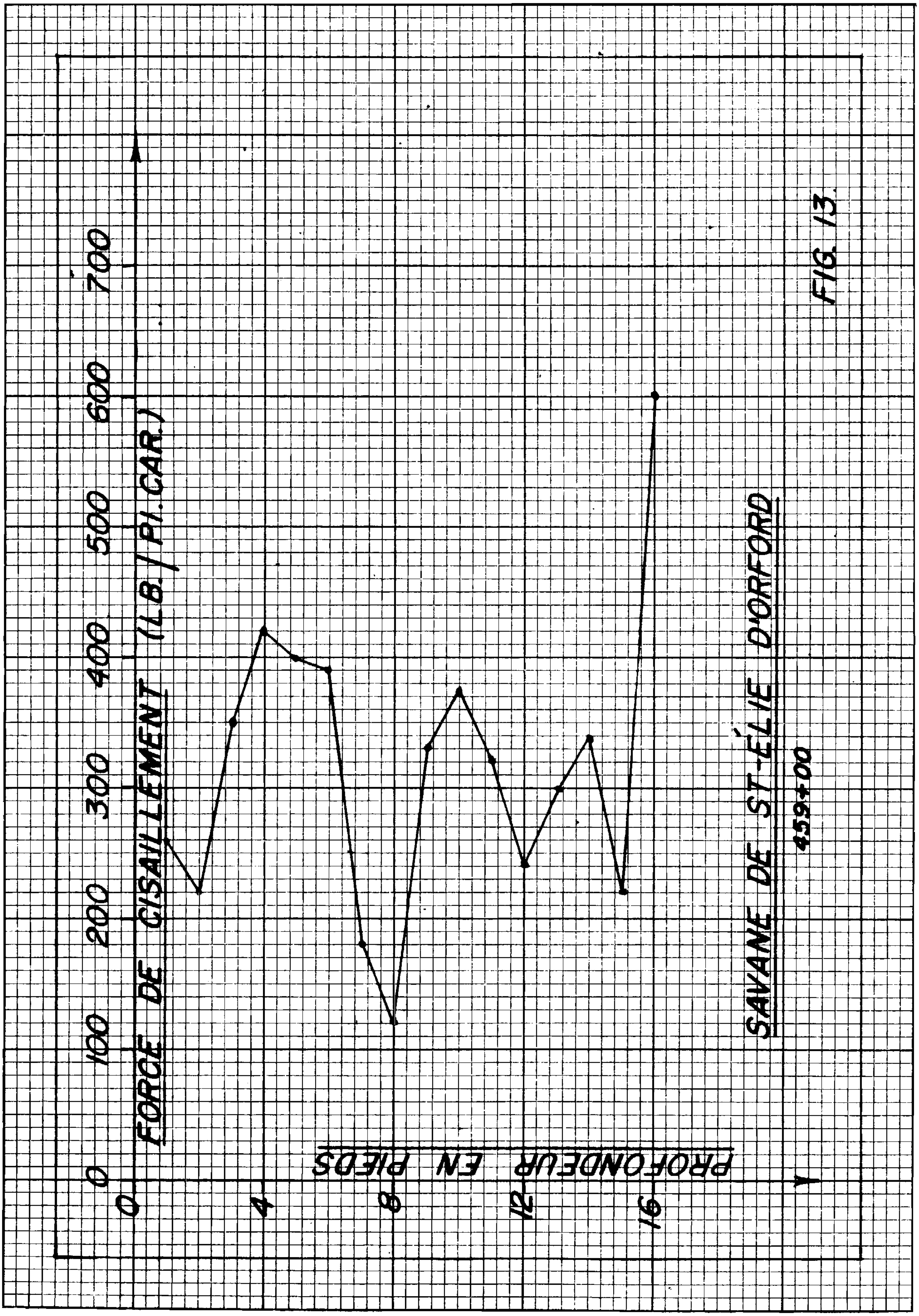

FORCE DE CISAILLEMENT (LB./PI. CAR.)
0
100
200
300
400
500
600
700
JAN.-FEV. 1963
JUIN 1964
SAVANE DE NAPIERVILLE S-3
• AVANT CHARGEMENT
x APRÈS CHARGEMENT
PROFONDEUR EN PIEDS
0
6
12
18
24

FIG. 12


FORCE DE CISAILLEMENT (LB. / PI. CAR.)
0
100
200
300
400
500
600
700
PROFONDEUR EN PIEDS
0
4
8
12
16
SAVANE DE ST-ÉLIE D'ORFORD
459+00
FIG. 13

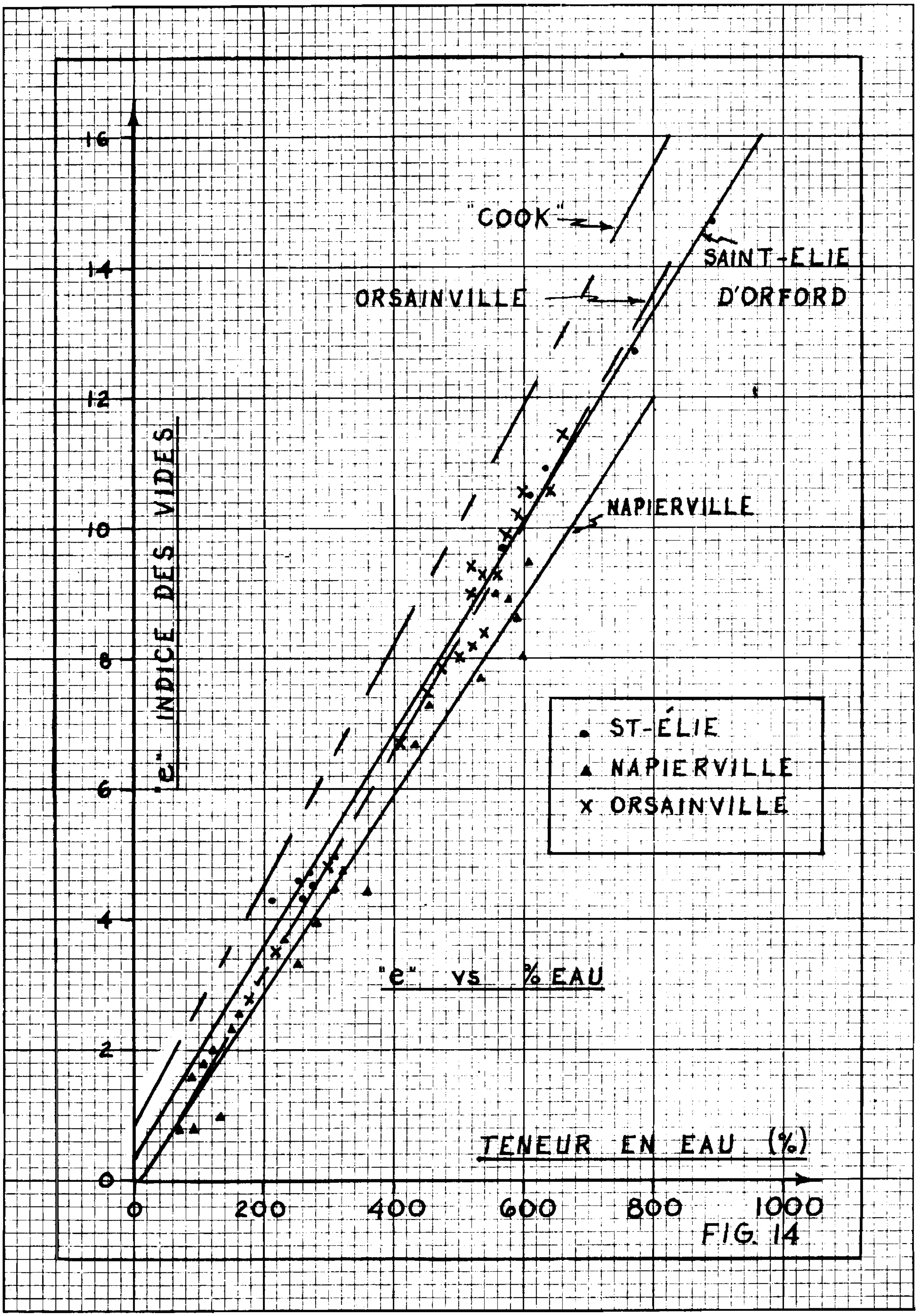
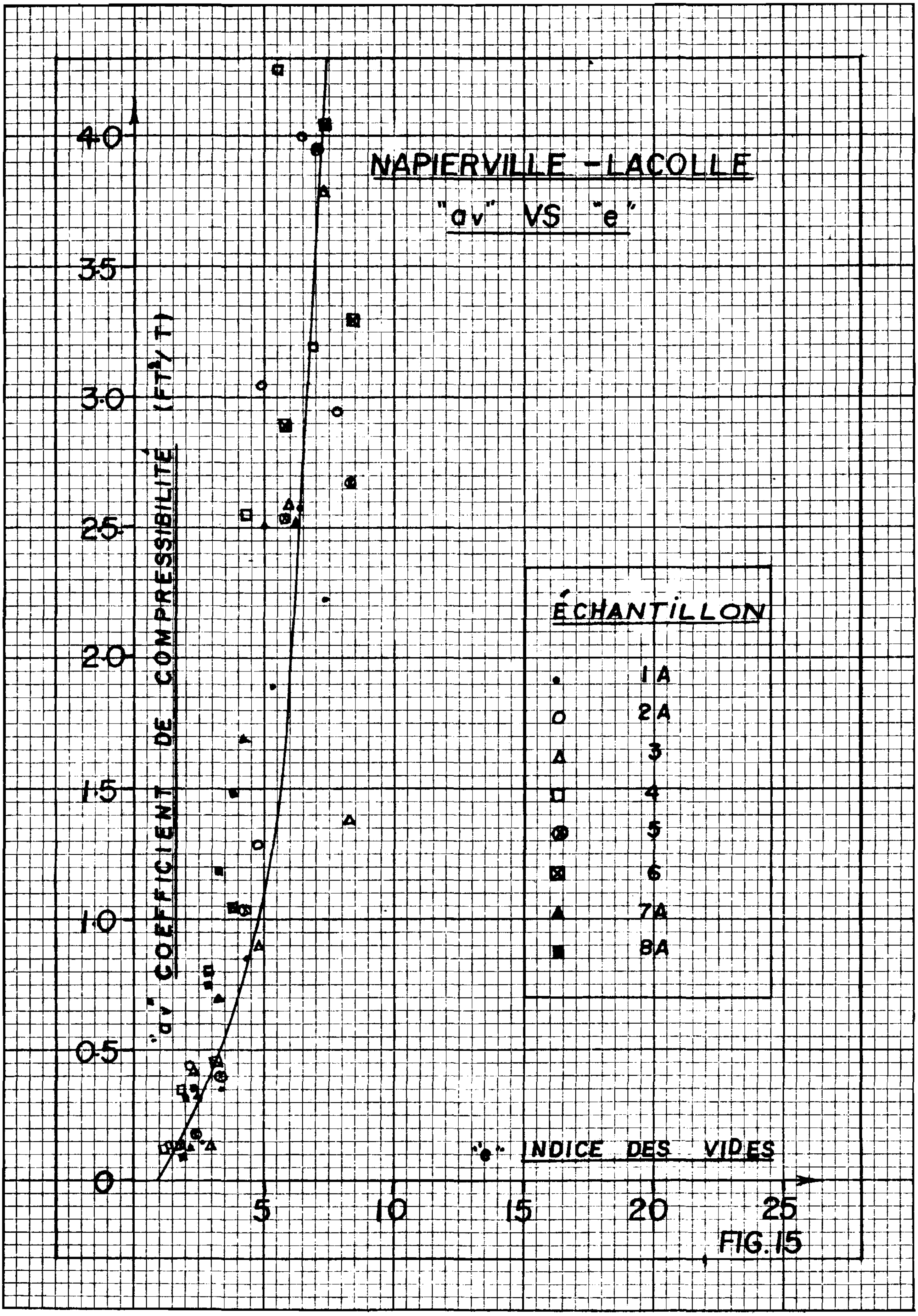
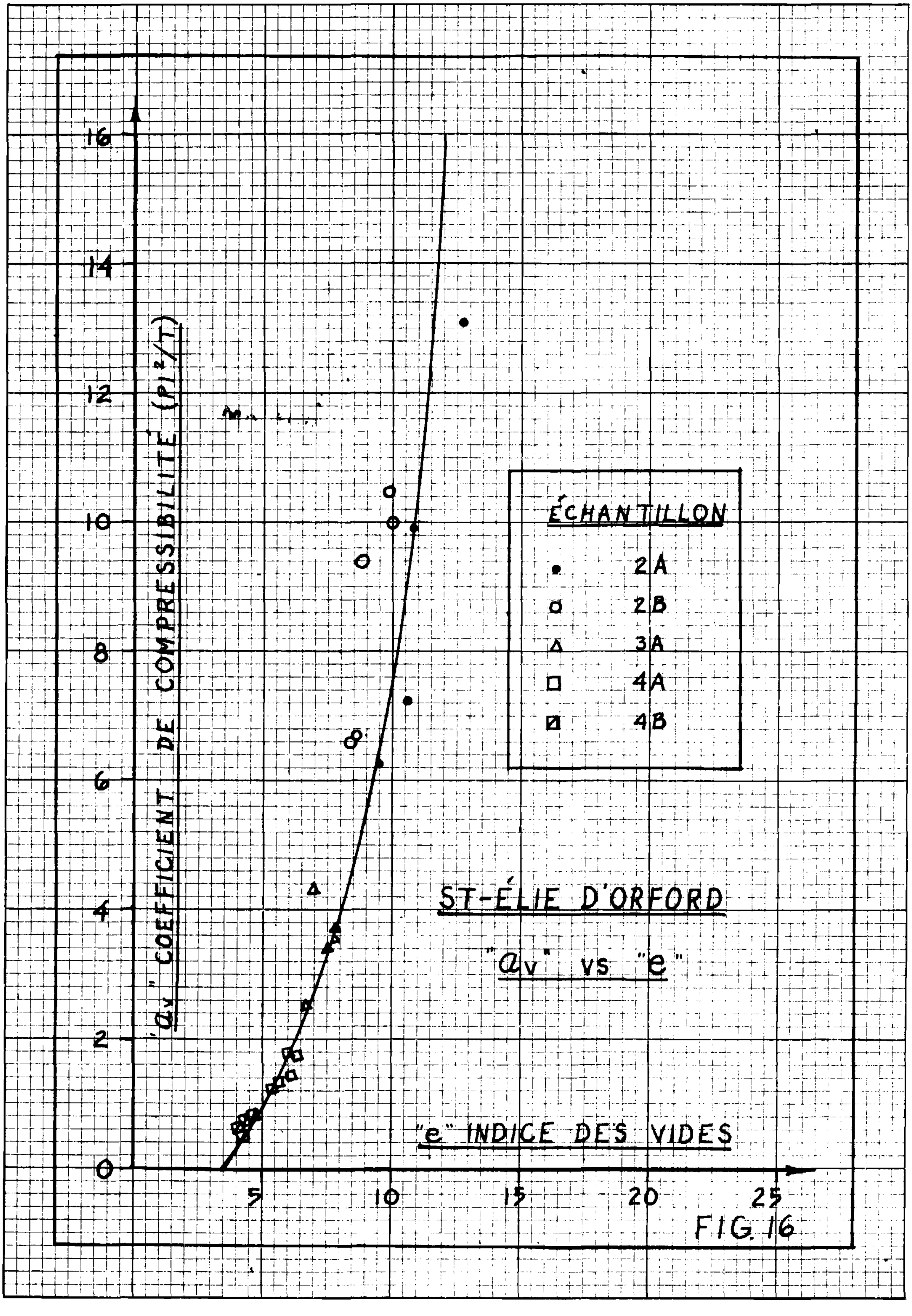

"COOK"
SAINT-ELIE D'ORFORD
ORSAINVILLE
NAPIERVILLE
"e" INDICE DES VIDES
ST-ÉLIE
NAPIERVILLE
ORSAINVILLE
"e" vs % EAU
TENEUR EN EAU (%)
0
2
4
6
8
10
12
14
16
0
200
400
600
800
1000

FIG. 14



NAPIERVILLE - LACOLLE
"av" VS "e"
"av" COEFFICIENT DE COMPRESSIBILITE (FT²/T)
"e" INDICE DES VIDES
ÉCHANTILLON
1A
2A
3
4
5
6
7A
8A
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
5
10
15
20
25


FIG. 15


"$a_v$" COEFFICIENT DE COMPRESSIBILITÉ (PI²/T)
16
14
12
10
8
6
4
2
0
5
10
15
20
25
"e" INDICE DES VIDES
ÉCHANTILLON
2A
2B
3A
4A
4B
ST-ÉLIE D'ORFORD
"$a_v$" vs "e"
FIG. 16

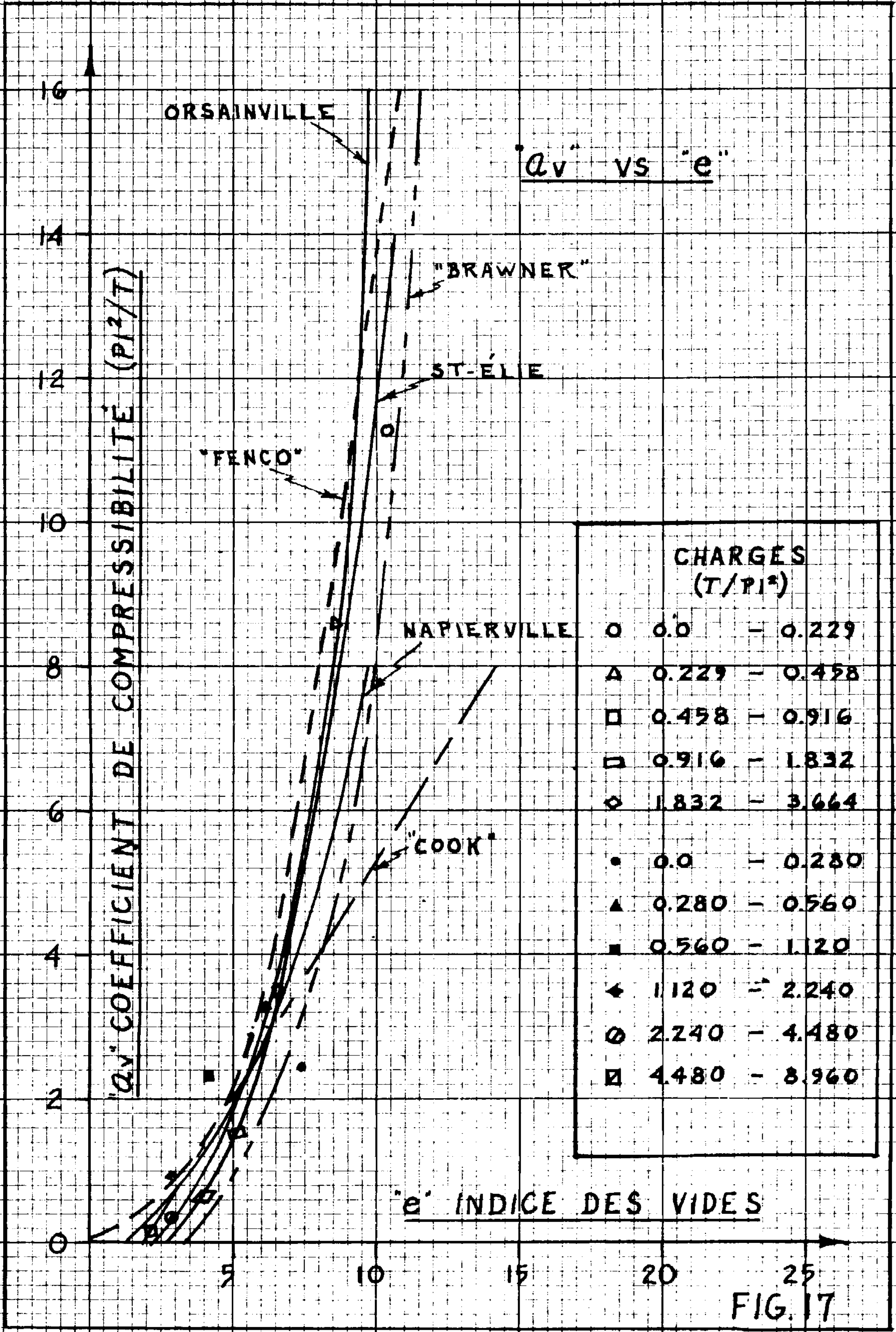
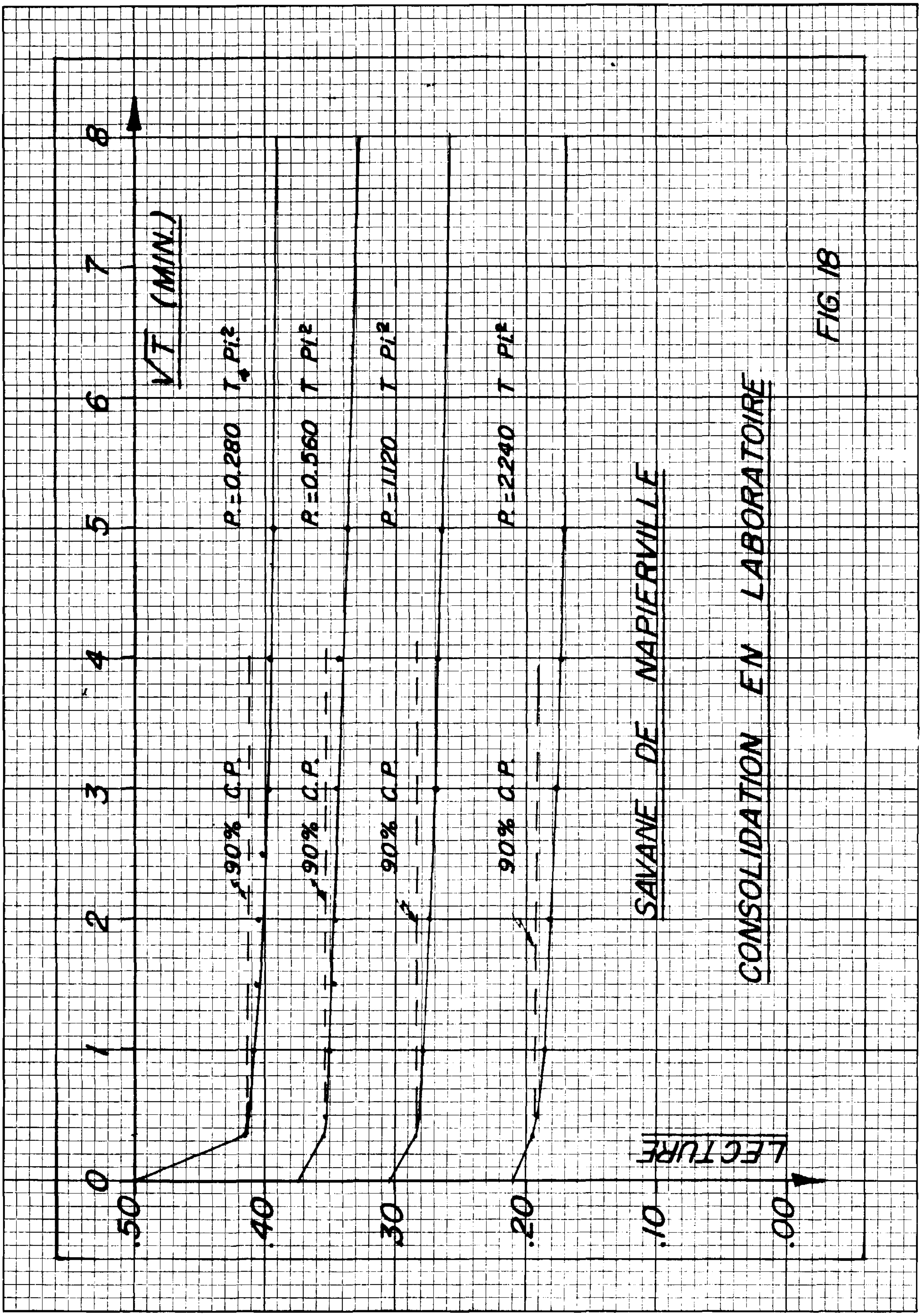

"av" vs "e"
ORSAINVILLE
"BRAWNER"
ST-ÉLIE
"FENCO"
NAPIERVILLE
"COOK"
CHARGES (T/PI²)
0.0 - 0.229
0.229 - 0.458
0.458 - 0.916
0.916 - 1.832
1.832 - 3.664
0.0 - 0.280
0.280 - 0.560
0.560 - 1.120
1.120 - 2.240
2.240 - 4.480
4.480 - 8.960
"av" COEFFICIENT DE COMPRESSIBILITÉ (PI²/T)
"e" INDICE DES VIDES
0
2
4
6
8
10
12
14
16
5
10
15
20
25

FIG. 17




SAVANE DE NAPIERVILLE

CONSOLIDATION EN LABORATOIRE

FIG. 18

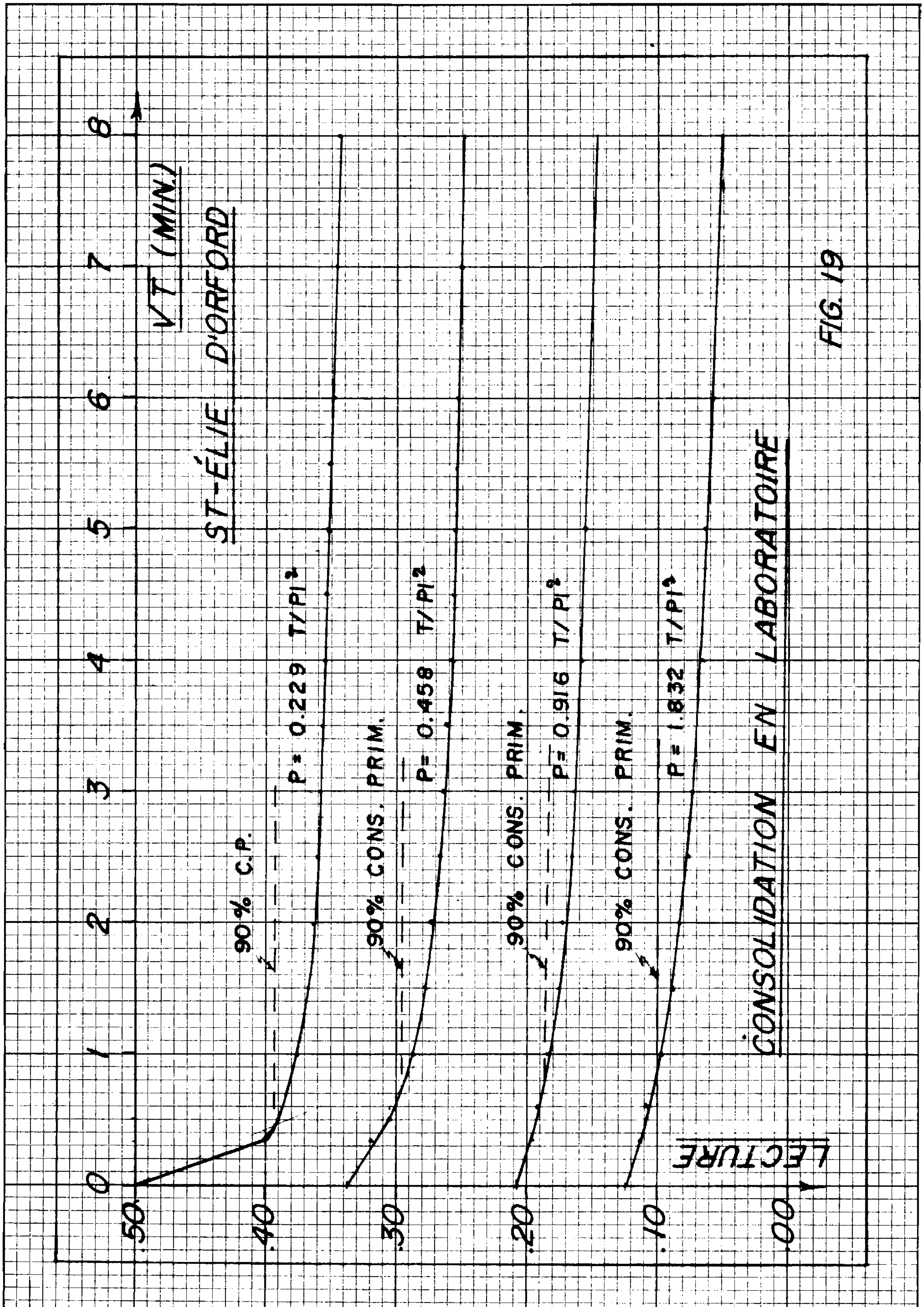

ST-ÉLIE D'ORFORD
√T (MIN.)
0
1
2
3
4
5
6
7
8
.50
.40
.30
.20
.10
.00
LECTURE
P = 0.229 T/PI²
P = 0.458 T/PI²
P = 0.916 T/PI²
P = 1.832 T/PI²
90% C.P.
90% CONS. PRIM.
90% CONS. PRIM.
90% CONS. PRIM.
CONSOLIDATION EN LABORATOIRE

FIG. 19

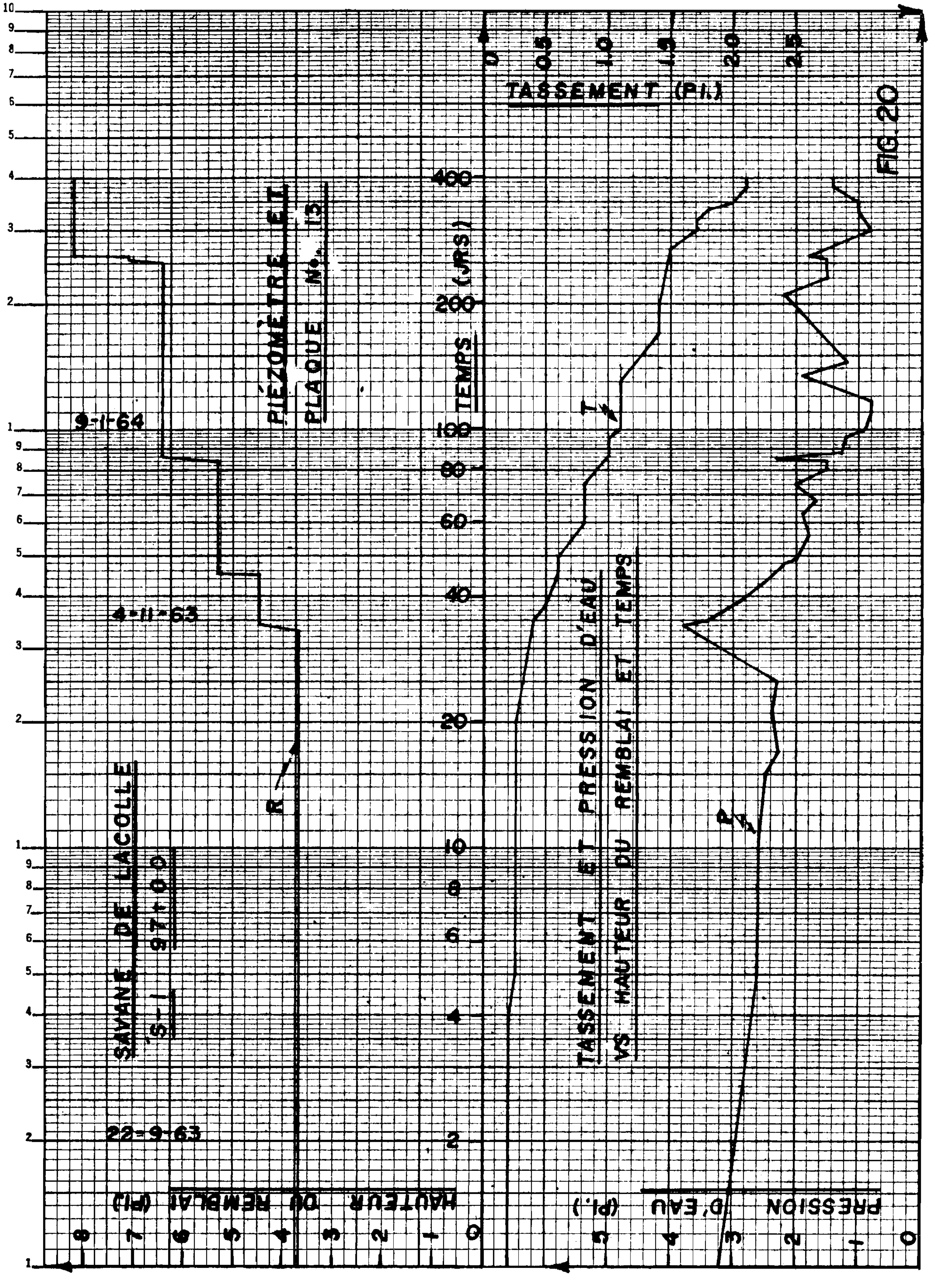
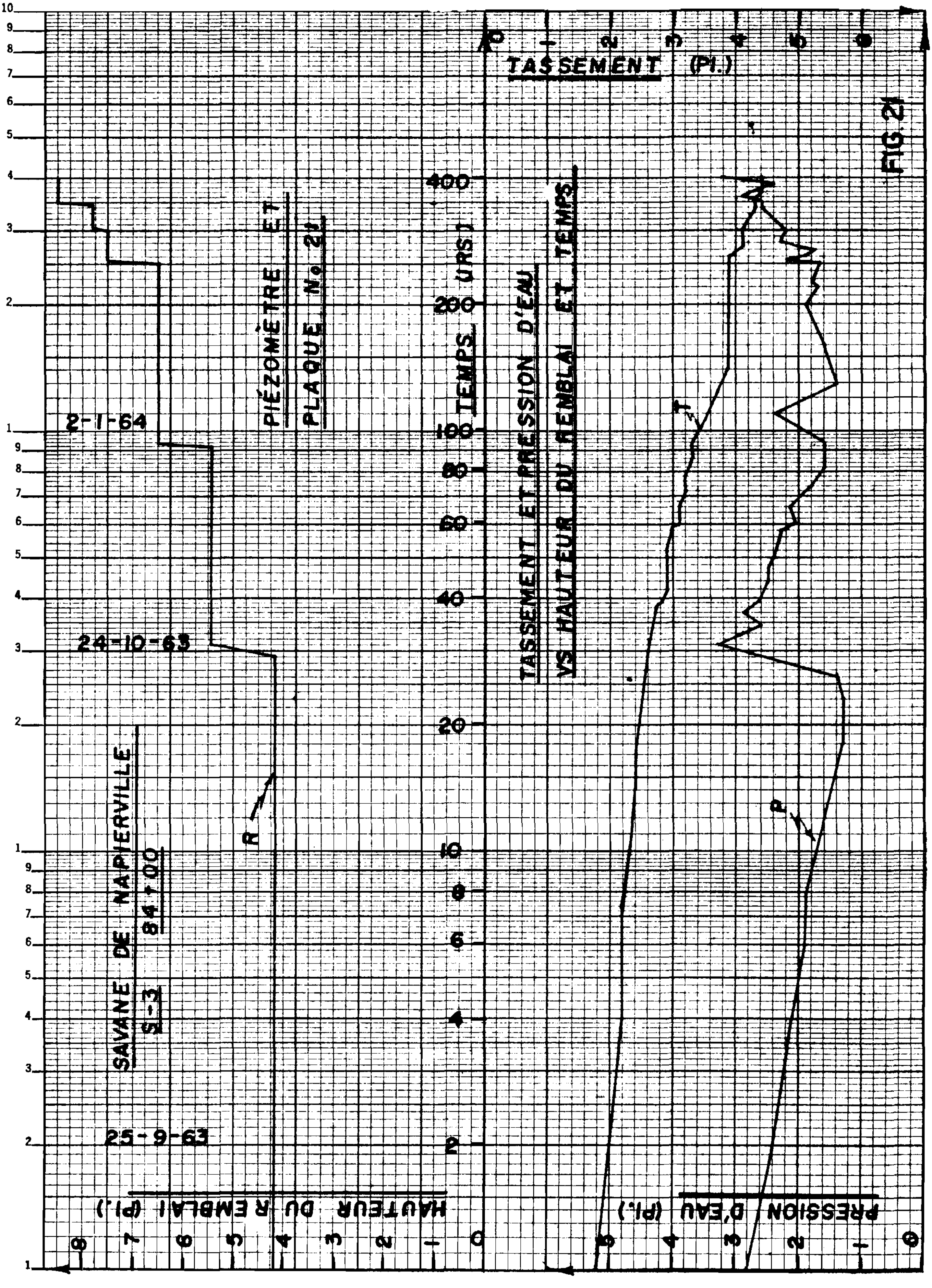
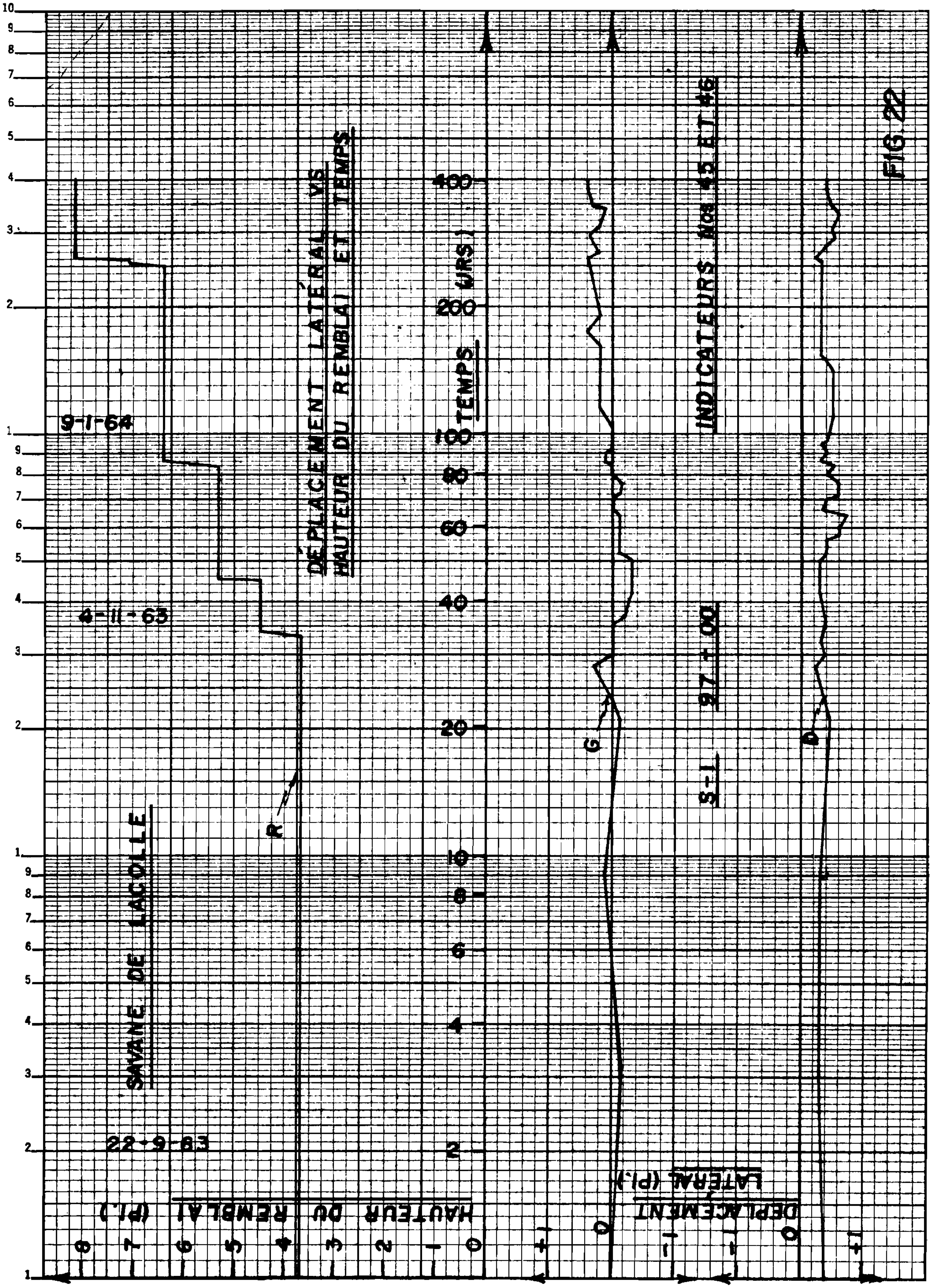

TASSEMENT (Pi.)
0 0.5 1.0 1.5 2.0 2.5
TEMPS (JRS)
PIÉZOMÈTRE ET
PLAQUE No. 13
SAVANE DE LACOLLE
S-1 97+00
TASSEMENT ET PRESSION D'EAU
VS HAUTEUR DU REMBLAI ET TEMPS
9-1-64
4-11-63
22-9-63
T
P
R
HAUTEUR DU REMBLAI (Pi)
PRESSION D'EAU (Pi.)

FIG. 20


TASSEMENT (Pi.)
PIÉZOMÈTRE ET
PLAQUE No 21
TEMPS (JOURS)
TASSEMENT ET PRESSION D'EAU
VS HAUTEUR DU REMBLAI ET TEMPS
2-1-64
24-10-63
25-9-63
SAVANE DE NAPIERVILLE
S-3 84+00
HAUTEUR DU REMBLAI (Pi.)
PRESSION D'EAU (Pi.)
FIG. 21


DÉPLACEMENT LATÉRAL VS
HAUTEUR DU REMBLAI ET TEMPS
TEMPS (HRS)
INDICATEURS Nos 45 ET 46
S-1 97 + 00
SAVANE DE LACOLLE
9-1-64
4-11-63
22-9-63
HAUTEUR DU REMBLAI (PI.)
DÉPLACEMENT LATÉRAL (PI.)
FIG. 22

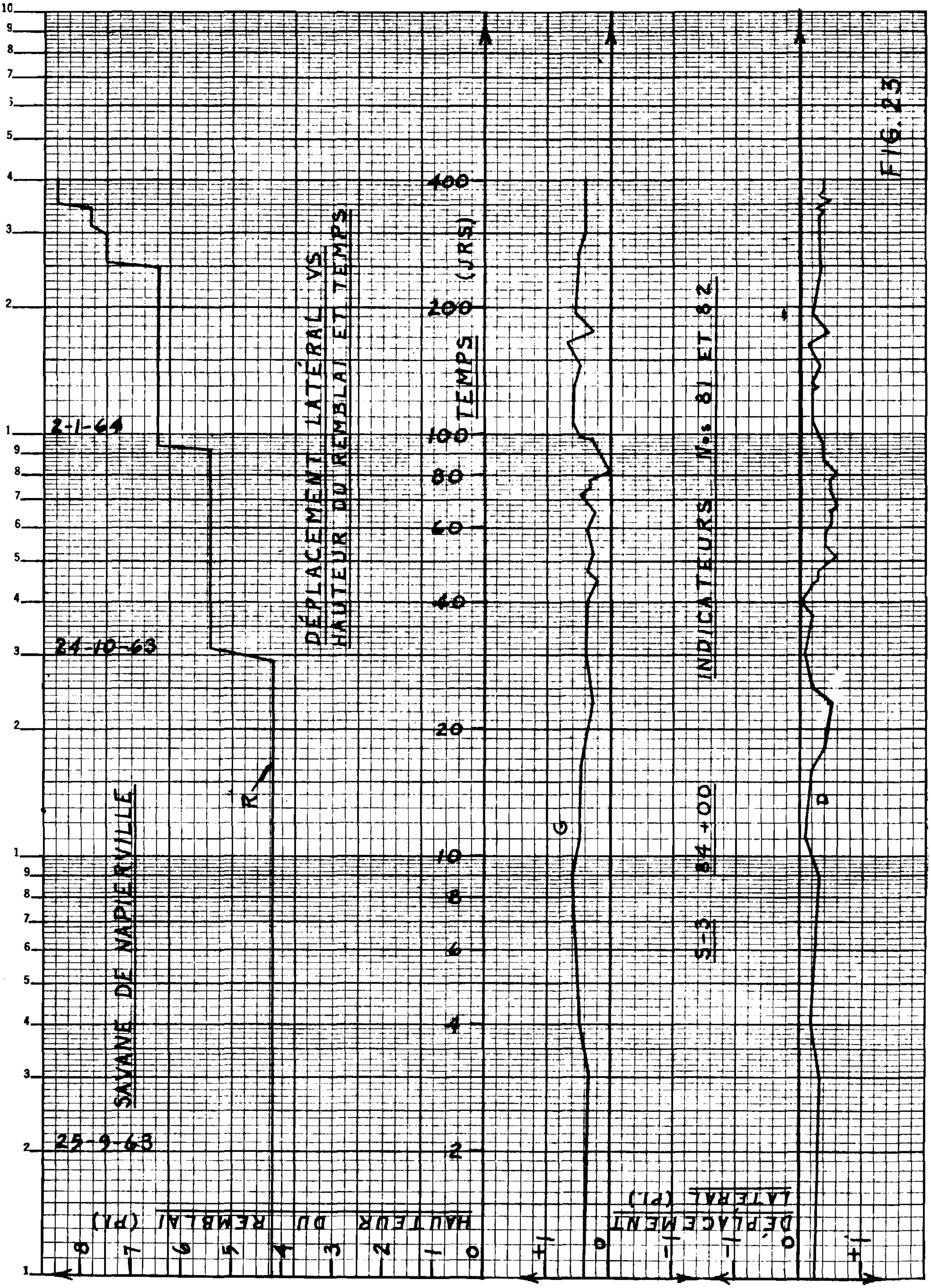

DÉPLACEMENT LATÉRAL VS
HAUTEUR DU REMBLAI ET TEMPS
TEMPS (JRS)
INDICATEURS N.os 81 ET 82
S-3 84+00
SAVANE DE NAPIERVILLE
2-1-64
24-10-63
25-9-63
R
G
D
HAUTEUR DU REMBLAI (PI)
DÉPLACEMENT LATÉRAL (PI)

FIG. 23

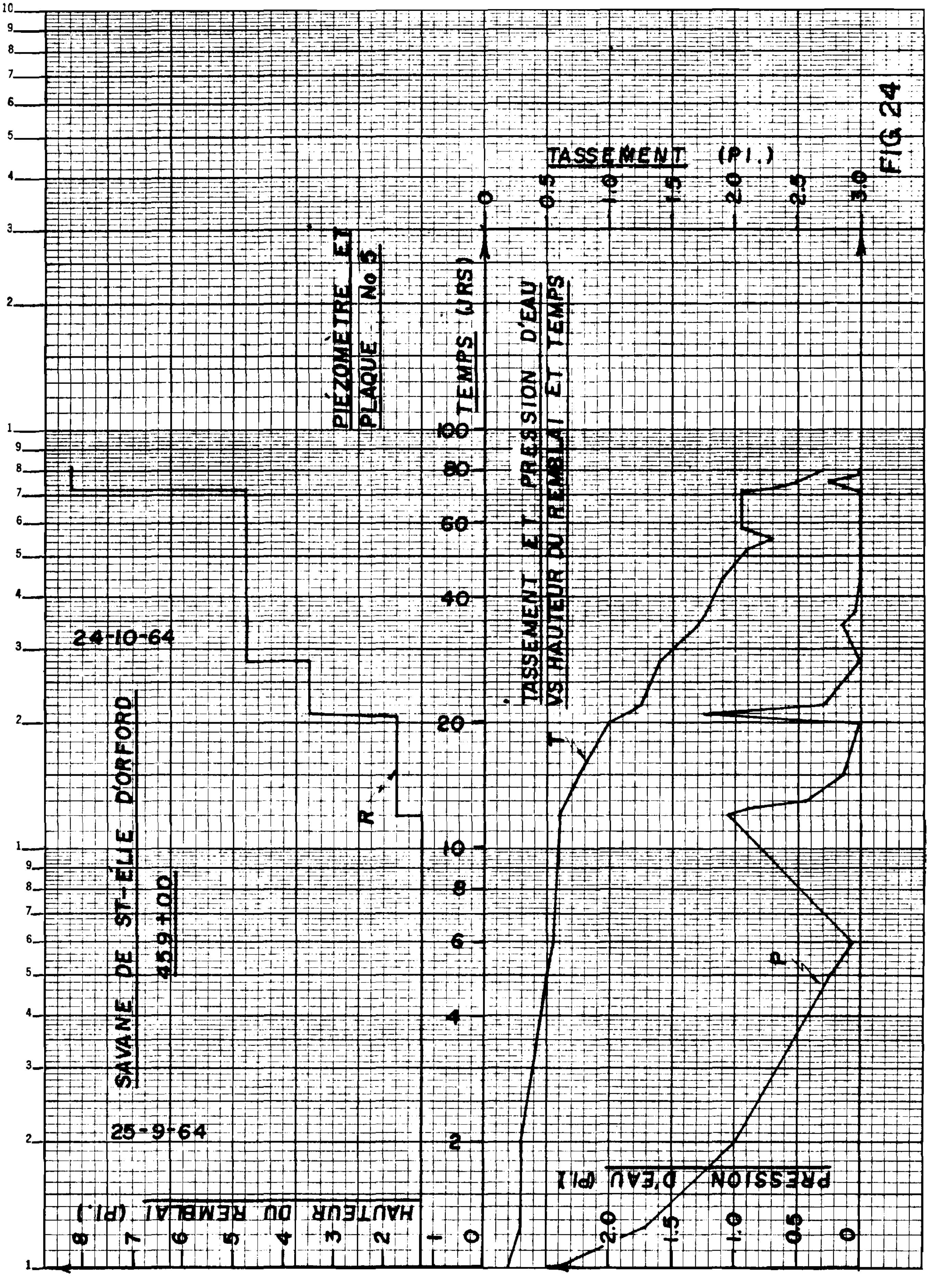
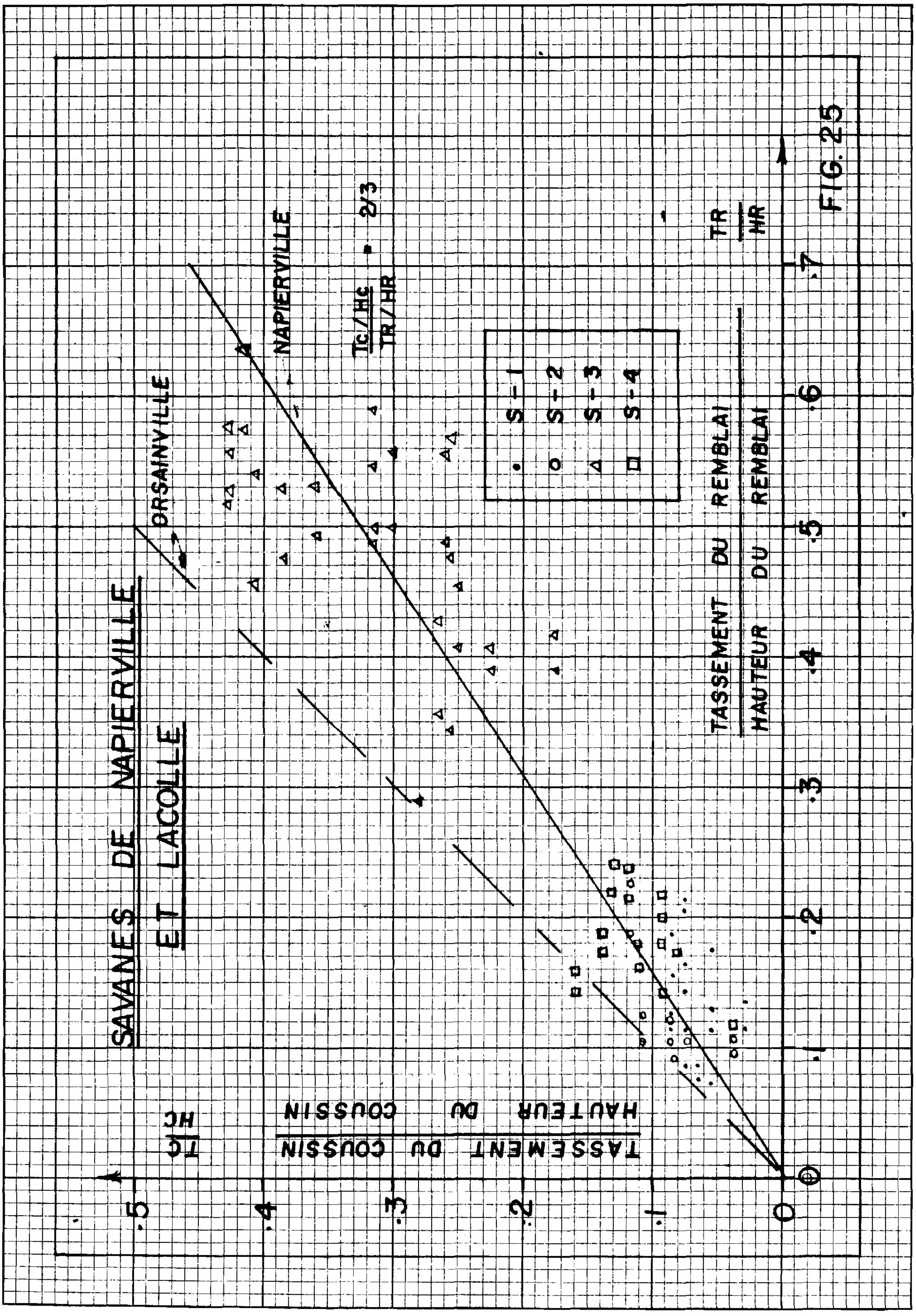


FIG 24
PIÉZOMÈTRE ET
PLAQUE No 5
TASSEMENT ET PRESSION D'EAU
VS HAUTEUR DU REMBLAI ET TEMPS
SAVANE DE ST-ÉLIE D'ORFORD
459+00
TASSEMENT (PI.)
TEMPS (HRS)
PRESSION D'EAU (PI.)
HAUTEUR DU REMBLAI (PI.)
24-10-64
25-9-64
R
T
P


SAVANES DE NAPIERVILLE
ET LACOLLE
ORSAINVILLE
NAPIERVILLE
Tc/Hc / TR/HR = 2/3
S-1
S-2
S-3
S-4
TASSEMENT DU COUSSIN / HAUTEUR DU COUSSIN
TC/HC
TASSEMENT DU REMBLAI / HAUTEUR DU REMBLAI
TR/HR
0
.1
.2
.3
.4
.5
.6
.7
FIG. 25

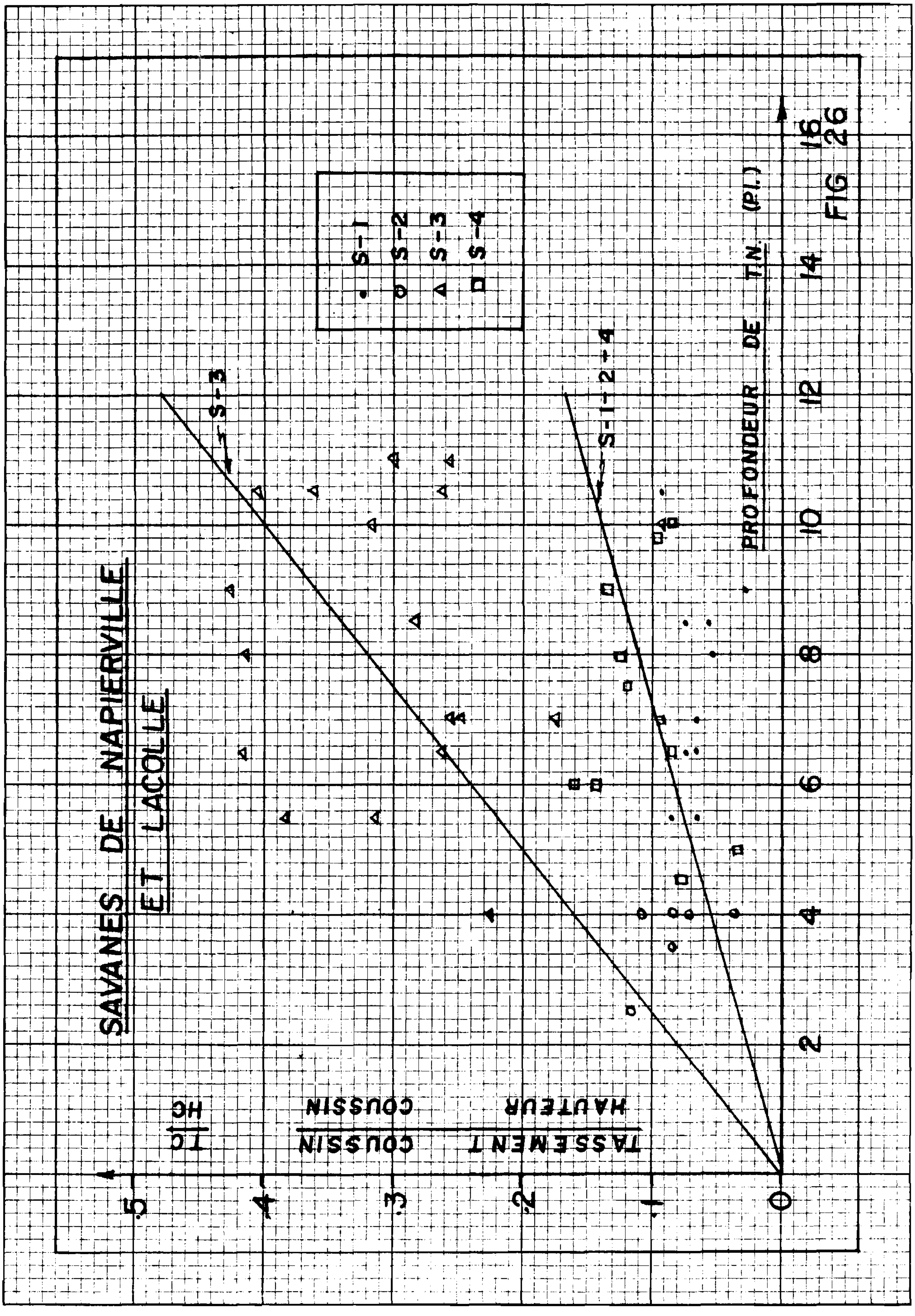

SAVANES DE NAPIERVILLE
ET LACOLLE
S-1
S-2
S-3
S-4
S-3
S-1-2-4
TASSEMENT COUSSIN
HAUTEUR COUSSIN
TC
HC
0
.1
.2
.3
.4
.5
2
4
6
8
10
12
14
16
PROFONDEUR DE T.N. (PI.)

FIG 26

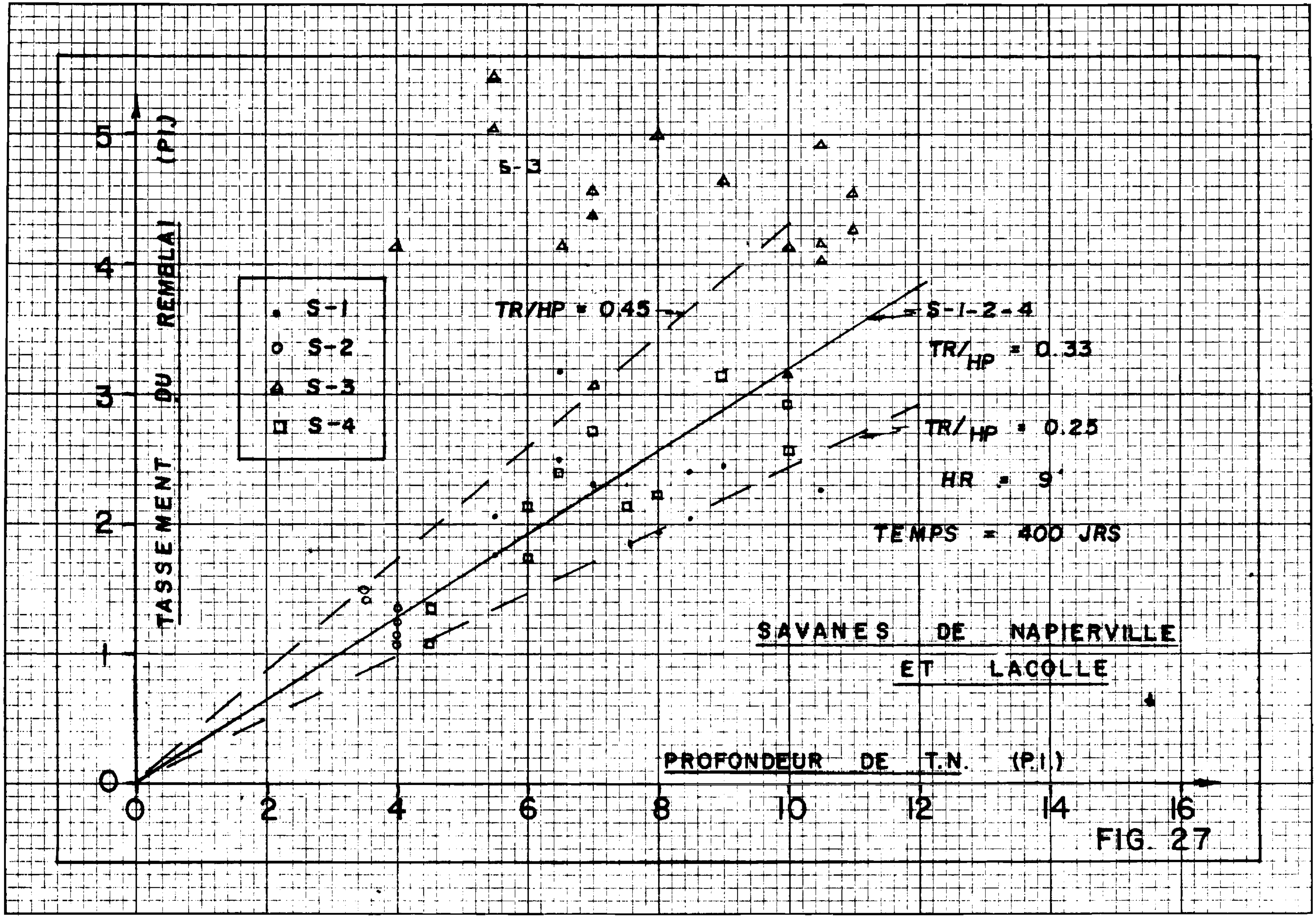

TASSEMENT DU REMBLAI (P.I.)
PROFONDEUR DE T.N. (P.I.)
S-1
S-2
S-3
S-4
S-3
TR/HP = 0.45
S-1-2-4
TR/HP = 0.33
TR/HP = 0.25
HR = 9'
TEMPS = 400 JRS
SAVANES DE NAPIERVILLE
ET LACOLLE
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16

FIG. 27

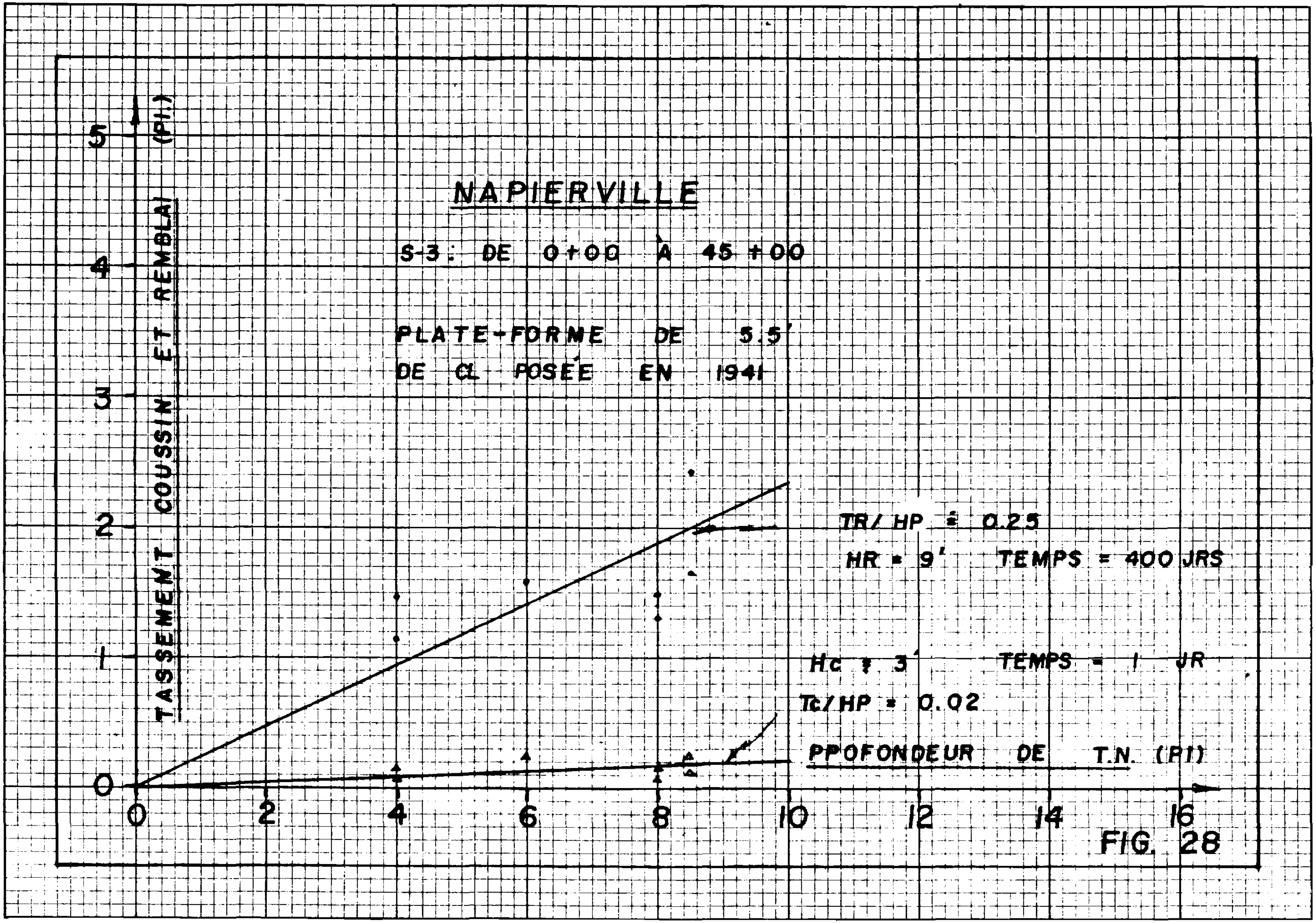

NAPIERVILLE
S-3: DE 0+00 À 45+00
PLATE-FORME DE 5.5'
DE CL POSÉE EN 1941
TR/HP = 0.25
HR = 9' TEMPS = 400 JRS
Hc = 3' TEMPS = 1 JR
Tc/HP = 0.02
PPOFONDEUR DE T.N. (PI)
TASSEMENT COUSSIN ET REMBLAI (PI.)
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16

FIG. 28

(d) The void ratio coefficient of compressibility comparison of the Quebec peat agrees favourably with the data from British Columbia (Brawner, 1959; Lea and Brawner, 1963).

The similarity of experience and test data in these two widely separated areas gives hope that the similarity of physical and mechanical properties of peat may extend and be applied beyond local areas. A great number of case histories have been presented at the Muskeg Conferences and elsewhere. It is suggested that the time may be opportune for a detailed evaluation and comparison of these case histories to determine whether relationships and/or empirical rules can be established.

It is acknowledged that some variation in data can be attributed to a difference in test methods employed by various investigators. This further suggests that some recognized agency consider the merits of preparing specific methods of test, at least for the more common tests.

With Mr. Tessier's paper covering 5 separate muskeg areas, it is obviously not possible to provide complete details of test data in a single paper. There is some further information which would be of interest and possibly Mr. Tessier could provide these details.

(a) Was the accuracy of the electrical resistivity profile survey checked by borings? If so, what degree of accuracy was obtained?

(b) Was the peat strength determined under the old fill placed in 1941? If so, how did it compare to the results obtained where no fill had been placed?

(c) Vane shear test results with and without casing to a depth of 20 feet were said to be comparable. Would it be possible to have the comparison data made available?

(d) Were any tests performed to determine the gas content of the peat?

(e) Were detailed identification tests performed on the clay? If so, could this data be made available in summary form?

(f) Was settlement data obtained only from settlement plates on top of the peat or were settlement plates also installed at the peat clay contact?

(g) Could the soil profile be shown for the locations represented by Figures 12, 20, 21, 22 and 24?

Regarding the actual construction, it may be useful to emphasize a few specific points. Field instrumentation is installed to provide specific information and therefore should be installed at the locations that will provide the necessary data. For example, lateral movement gauges are placed beyond the toe of the applied fill to indicate horizontal movement of the peat. They are useless, however, for the purpose of evaluating movement underlying clay strata unless very elaborate installation methods are used. Settlement plates should be installed wherever total or differential settlement data is required. Where accurate data on settlement of the peat is necessary, settlement plates must be installed at the bottom of the peat layer unless rock or dense soil occurs at that depth. Piezometers installed to provide data on pore pressure buildup for analysis of stability must be installed along the shoulder where the failures occur. They are of little use under the road centerline.

If the accuracy of settlement estimates is expected to be good, fill materials can be placed selectively so that base gravel placed during the initial construction will ultimately be located at the desired location. This approach was apparently used successfully at Napierville.

The location of drainage ditches is very important. Mr. Tessier has suggested that several failures occurred which were possibly influenced by the close proximity of ditches parallel to the highway. Parallel ditches near the toe of the fill where the fill exceeds about 5 feet should be discouraged.

Care must be taken in plotting settlement and piezometer data. Readings should always be taken within 24 hours prior to placing further fill and sufficiently often to define the shape of the curve.

Many investigators are reporting test data using height of fill as a measure of load. As settlement takes place, the applied effective load reduces. Also the unit weight of fill materials may vary by 25 percent. It is suggested that a more accurate presentation of test data would be provided by using applied effective pressure instead of height of fill. When computing the vertical settlement the amount of lateral movement must be considered. If the lateral movement is large, the total vertical settlement will be exaggerated.

Mr. Tessier has plotted settlement vs depth of peat in Figure 27. This is a useful approach. It is suggested that this idea be extended with per cent settlement $(\frac{\text{final depth of peat}}{\text{initial depth of peat}} \times 100)$ plotted against applied effective pressure and void ratio on a three variable graph.

The results of the paper are not final. It is hoped that a follow-up paper will be prepared.

The review of Mr. Tessier's paper and the preparation of this discussion has suggested certain further research projects may be worthy of consideration at this time. These include:

(a) Review all case histories of highway construction to determine possible correlation of physical properties of peat and evaluate validity of empirical limits previously suggested to control construction.

(b) Review present test procedures, prepare specific procedures and attempt to have these accepted as standard by organizations which test peat.

(c) The gas content of peat has largely been ignored to date. This condition must have some effect on moisture content, compressibility, permeability, etc. It is suggested that research be directed toward an evaluation of this property.

(d) Obtaining good undisturbed samples of peat is still a major technical problem. Further research is urgently required in this field. One possible avenue to explore is a hollow bit with a split flush stationary liner with a very high speed circular rotating cutting edge.

- * -

## REFERENCES

Brawner, C. O. "Preconsolidation in Highway Construction Over Muskeg". Roads and Engineering Construction, Vol. 97, No. 9, 1959.

Cook, P. M. "Consolidation Characteristics of Organic Soils". Proc. 9th Canadian Soil Mechanics Conference, Tech. Memo. 41, National Research Council, Ottawa, 1959.

Lea, N. D., and Brawner, C. O. "Foundation and Pavement Design for Highways on Peat", Canadian Good Roads Association, 40th Proceedings, 1959.

———————————— "Highway Design and Construction Over Peat Deposits", Highway Research Board Proceedings, Washington, D.C., 1963.

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Closure (G. Tessier)

The author thanks Mr. Brawner for his valuable and interesting discussion. No doubt the similarities of experience and test data in Quebec and in British Columbia should urge us to do a detailed investigation of all the case histories presented at the Muskeg Conference and elsewhere: the author is willing to contribute to this particular work. He will answer (with appropriate details) all the questions which have been asked concerning the cases of Napierville and St. Elie d'Orford in a paper he hopes to present at the next Conference. Mr. Brawner's accurate evaluation of what has been done at Napierville and his suggestions are helpful for further research in road construction over muskeg. Further investigation is being done at Napierville and new data will be available in the near future.

## III.3. AERIAL PHOTOGRAPHIC INTERPRETATION OF MUSKEG CONDITIONS AT THE SOUTHERN LIMIT OF PERMAFROST

E. Korpijaakko and N.W. Radforth

Abstract

One of the requirements for wider application of aerial photographic interpretation is the development of a system to predict subsurface ice conditions in muskeg. This paper reports on efforts to develop such a system, based on a careful study of aerial photographs. It is suggested that there are factors which can be used as indicators in the interpretation of subsurface ice conditions in muskeg, relative to the distribution of permafrost and climafrost, particularly in the prediction of the southern limit of permafrost. One such indicator may be the muskeg "H-factor", although any direct correlation is difficult to make at the present stage of the investigation.

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## III.3. INTERPRETATION DES CONDITIONS DU MUSKEG A LA LIMITE SUD DU PERMAFROST A L'AIDE DE LA PHOTOGRAPHIE AERIENNE

E. Korpijaakko et N. W. Radforth

Résumé:

Développer une méthode de détecter les conditions de la glace en profondeur dans le muskeg constitue une des conditions pour une plus grande application de la photographie aérienne dans ce domaine. Cette communication parle des efforts en vue de développer une telle méthode, basée sur une étude élaborée de la photographie aérienne. On suggère la possibilité de facteurs qui peuvent être employés comme indicateurs dans l'interprétation des conditions de la glace en profondeur dans le muskeg, relativement à la distribution du permafrost et du climafrost, particulièrment dans la detection de la limite sud du permafrost. Un tel indicateur peut être le facteur H du muskeg, bien que toute corrélation directe est difficile à établir au stade actuel des recherches.

The permafrost and vast muskeg areas in northern Canada necessitate special engineering treatment for problems pertaining to development of the North. This is revealed when roads, railways or other constructions are to be planned for the northern areas. Even muskeg alone sometimes creates limiting difficulties to construction. Permafrost, in addition to this, further complicates the problems connected with the building of roads etc., by requiring the creation of new ways to install foundations. A drawback to surveying and construction in these areas has been, and still is, the lack of roads and of off-road vehicles which could be used economically.

Fortunately the development of air traffic and aerial photographic technique has helped decisively especially where development is absent. Aerial photographic interpretation of mineral terrain has been used successfully for a long time, for instance in geology, but the use of aerial photographs in the interpretation of muskeg (organic terrain) conditions is quite a new application. Actually it has been initiated in Canada for accessibility studies on the large muskeg areas in the North and the first publications on the aerial photographic interpretation of organic terrain are two handbooks by Radforth (1955, 1958).

During the development of systems for aerial photographic interpretation of organic terrain, attention has been directed also towards the possibilities of predicting from aerial photographs the subsurface ice conditions in muskeg areas. Prediction of the southern limit of permafrost is especially important and challenging because of the suspected presence of physical differentials although permafrost does not always mean presence of ice in mineral soils,whereas in muskeg it generally does. Thus, when the basis for the aerial photographic interpretation of organic terrain is laid, the study and development of a system to predict from aerial photographs subsurface ice conditions in muskeg will be one of the requirements towards wider application of aerial photographic interpretation. The development of interpretation systems for the prediction of the southern limit of permafrost and, if possible, for the prediction of the distribution of climafrost from aerial photographs, will be of great significance. If this can be done, it will help greatly the surveying and planning of construction in the North. Among other benefits it will probably lead to refinements in prediction of subsurface temperature and ice conditions in the permafrost and thus afford better route selection for off-road vehicles. It will be a basic help to efficient planning for land-use and road location.

Relative to these needs, and on the basis of existing knowledge, the authors have selected airphotos of organic terrain for some cases where genesis of ice is predominantly due to long-term factors, for others, where shorter term climate or regional influence prevails and in still others where ice is a seasonal climate or a regional phenomenon. These photographs are at present under comparative study. Certain observations, mostly geomorphic and already revealed, are now submitted for consideration.

## Observations of Special Muskeg Features Associated with Sub-surface Ice-conditions

During the development of techniques for aerial photographic interpretation of muskeg conditions, it has been noticed that there are some characteristics which are associated with the distribution of ice in the organic terrain and which can be seen on aerial photographs. One of these characteristics, now frequently referred to as the "H-factor", exists basically because of the lichenaceous cover of muskeg (Radforth, 1952). It has been observed that in general direct aerial survey the amount of this cover on the muskeg often increases from the south to the north. In the south, out of the reach of permafrost cover, may be FI and EI (Radforth, 1962) but in aerial traverses towards the north the cover first appears as FEH and then EH and eventually HE (ibid). It has been suggested that the appearance of the "H-factor" has some relationship to the southern limit of permafrost (ibid). This phenomenon could be regarded in part as a working hypothesis in the attempt to interpret, locate, and predict sub-surface ice-conditions in the muskeg.

Towards the south on probable climafrost areas the "H-factor" is localized often near the boundary between confined muskegs and mineral terrain and is patterned according to a "crumbly" appearance and is still rather inconspicuous (Fig. 1). This "crumbliness" which on the ground is polygonal (Fig. 2) has been compared by Hustich (1954) with patterned ground and attributed to frost action, but it is probably a result of the natural process of lichen growth or of desiccation (Fraser, 1956).

Farther to the north "the H-factor", following more detailed examination, becomes the main cover on muskeg, conforming to generalized observations made from the air, and is the primary cause of the light tone of photographs (Fig. 3). This photograph gives a good indication of the frequency of H-cover in the north and typifies it. This photograph also shows that the main air-form pattern here is "Marbloid". It is a high altitude photographic pattern which gives an image of polished marble (Radforth, 1958). The photograph shows that the terrain is also patterned by polygons. It has been recorded that climafrost is the cause of this pattern in some parts of Manitoba (Radforth, 1962) but in these more northerly areas permafrost is also present.

This polygonal pattern is often an intermediate between "Marbloid" of 30,000 ft. and "Polygoid" pattern of 5000 ft. (Radforth, 1958).

The increase in frequency of the "Marbloid" airform pattern with more severe ice conditions might profitably augment the working hypothesis. Also the distinct linear orientation of the "Polygoid" units (which corresponds with drainage direction) is a factor which could be used with other drainage pattern characteristics in the prediction of subsurface ice presence and form. This, in Fig. 4, is a clearly seen phenomenon. It recurs from locality to locality and has some relationship with existence of permafrost.

In addition, the great number of small lakes and ponds and the fact that their position, shape and size can change from year to year, indicates imperfect drainage (Jenness, 1949) and thus long presence of permanently frozen ground. Differential thaw of seasonal frost thus presents a pattern that is dynamic with respect to season.

These comprise the main observations (seen or derived) with which this paper is concerned but there are certain accessory factors which have relative importance and these also require some evaluation.

## Collateral observations

The above-mentioned observations pertaining to Canada are not unique to North America. Figures 5 and 6 are other examples from northern Finland of the occasions in which lichen cover and frozen terrain (climafrost) occur together. Figure 5 (Ruuhijärvi, 1960) is a diagram of a so-called "pounu" profile showing how the lichens have concentrated upon the "pounu" formations (peat-, moss-, or bog-ridge I). The ice is conserved in these mounds sometimes through several years. They are of peat throughout and rise up from the surrounding "flarke" areas and they are situated in areas without permanently frozen ground. Permafrost, in its usual generic connotation, is not a feature of Finnish terrain and in this sense the frozen state (Fig. 5) can not be construed as a discontinuity of a condition that does not exist. In this case, the designation climafrost is more appropriate generally and less misleading geomorphologically. Figure 6 is a diagram of a peat formation called "palsa" (ibid). The structure is more than 200 yards wide and 20 - 25 ft. high at greatest. Briefly, "palsa" is a large ice-centered peat mound. These formations are old and indefinitely frozen although they are far out of the permafrost area. The frozen core of "palsa" is composed mainly of frozen sedge-peat (derived from FI, FEH cover) and ice which often are in separate layers. This core is covered by about 1 - 2 ft. thick layers of sphagnum peat which will thaw every summer. From this diagram (Fig. 6) one can see how the lichens and shrubs completely cover this formation. But in the environment this cover is insignificant. The "palsa" images are large enough as such to be distinguished in high altitude photographs and are a certain indication of presence and prediction of ice conditions.

Figures 7 and 8 are from a "raised" bog in central Finland. These photographs were taken in August and yet, at that time, ice was encountered in the ridges also seen in the figures. Note how the lichens are concentrated on these ridges. This kind of peat ridges and mounds in which ice may be conserved through all the year is encountered in many areas beyond the permafrost. This feature therefore also signifies association between the "H - factor" and subsurface ice conditions and for some areas the possibility of predicting the appearance of climafrost by means of the "H - factor".

Discussion

The apparent inevitability of the "H - factor" as associated with the ice-factors remains to be explained. What are the reasons for the great abundance of lichens on permafrost at climafrost areas? The frozen state as a feature of environment, if significant, is not the sole cause. On the other hand, in Finland it has been observed that the cold has some control. It has been observed that the heather (Calluna sp) and lichens thrive well on the same ridges forming a cover of EH (Drury, 1956) but, if the ice-conditions in the ridges become more severe, the cover is changed into HE (Drury, 1956) and finally heather disappears entirely. This has been attributed to the low cold resistance of more southern heather (Ruuhijärvi, 1960).

The appearance of lichens on the mounds and ridges in Finland has been attributed to dryness of these microtopographic features, and this renders them more suitable as a habitat for lichens. This dryness (which is revealed in the physical state of the plant itself) is caused indirectly by the ice conserved in the ridges. Dryness, in part, is contributed to by upheaval to which the ice-core also contributes. Onset of dry environment also encourages shrubs and establishment of a sphagnum species (*S. fuscum*) which are encountered together with drought-loving lichens on the mounds and ridges. The higher the ridges and mounds (initiated by frost-heaval) the greater the water run-off and the greater the predominance of this "H factor".

Water run-off might also generally be better on certain kinds of topography when the underlying permafrost table provides a virtually impermeable base.

Frost heaval actuated roughness in the topography of peat soils will increase desiccation especially in climafrost regions. The wind would be incident on elevated surfaces which often would be exposed more effectively to the sun. Ensuing desiccation would insulate the core of the mounds and ridges from the heat of summer, thus preserving the ice. In the winter the winds would keep promontories snow-swept thus facilitating early heat loss and localized relatively low freezing temperatures conforming to terrain contour. Reasoning explains the onset of drought in temperature differentials in the terrain and thus accounts for the genesis of lichenaceous environment as well as for the origin of the low temperature condition. The latter, incidentally, is distinct and secondary from that kind of cause commonly understood as having promoted permafrost and which is more widespread and massive in implication.

The lichens themselves in the last analysis will increase the degree of drought still more by further facilitating run-off. This situation is already acknowledged by Fraser (1956) in his studies of the lichen woodlands of the Knob Lake area of Quebec - Labrador.

Thus the H-factor (as one index) points to existence of subsurface ice.

The implications of the appearance of "Marbloid" air-form pattern and the linear drainage orientation within "Polygoid" pattern is a far more difficult problem. In any case, the condition is distinctive and repetitive. It implies and delineates the existence of relationship between drainage pattern, "Marbloid", and occurrence of surface ice.

The hope now is to correlate results of air photo interpretation with field investigation in which predictability will be tested and geobiological explanation evaluated where possible by experimental means.

Summary

From the preceding discussion the following points are apparent:

1. Connected with the distribution of climafrost and permafrost there are factors which could be used as indicators in the interpretation of the subsurface ice conditions in muskeg.

2. The factors could be applied to predict the southern limit of the ice condition mentioned.

3. One can, however, always assert that the 'H-factor' and permafrost have no significant connection with each other.

4. It must be remembered that the 'H-factor' is only one factor in this problem.

5. Additionally, it is a biological entity and so any too direct and strict conclusions should be avoided.

6. It should be realized that the interactions are indirect.

7. There are many interfering factors which can seemingly confuse and muddle the possibilities to use, for instance, the 'H-factor' in the interpretation of ice conditions.

8. Such interfering factors could be, for instance, edaphic, local climatic changes, etc.

9. If their existence can be realized, they can be taken into consideration and in many cases probably used as auxiliary information with the 'H-factor', drainage pattern, etc., in the interpretation.

10. To these possibilities are linked others, too. For instance, Jenness (1949) refers to the slight possibility of using aspen in the north to predict ice conditions from aerial photographs.

11. All these factors should be included in some kind of system of patterns which they create on aerial photographs. These systems should form a reference which could be used in future interpretation.

12. Additionally, the interpretation of drainage pattern and its origin could be greatly enhanced using, for example, isotopes in the studies of rather unknown movement of water and peat and peaty soils. This refers to varieties of studies of economic and scientific importance in the development of the northern country, problems which are waiting for solution.

## REFERENCES

Drury, William, H. Bog Flats and Physiographic Processes in the Upper Kuskokwim River Region, Alaska. Contributions from the Gray Herbarium of Harvard University No. CLXXVIII, 1956.

Fraser, E. Morton. The Lichen Woodlands of the Knob Lake Area of Québec-Labrador. McGill Sub-Arctic Research Papers, No. 1, Dec. 1956.

Hustich, I. The Lichen Woodlands in Labrador and their Importance as Winter Pastures for Domesticated Reindeer. Acta Geographica XII, No. 1, 1954.

Jenness, John, L. Permafrost in Canada. Origin and Distribution of Permanently Frozen Ground, with Special Reference to Canada. Arctic (Journal of the Arctic Institute of North America) Vol. 2, No. 1, 1949.

Radforth, N. W. Suggested Classification of Muskeg for the Engineer. Engineering Journal 35, II, 1952.

————————— Organic Terrain Organization from the Air (Altitude less than 1000 ft.). Handbook No. 1, Defence Research Board, DR No. 95, 1955.

————————— Application of Aerial Survey over Organic Terrain. Roads and Engineering Construction Magazine, NRC-ACSSM Tech. Memo No. 42, 1956.

————————— Organic Terrain Organization from the Air (Altitudes 1000 to 5000 ft.). Handbook No. 2, Defence Research Board, DR No. 124, 1958.

————————— The Ice Factor in Muskeg. Proceedings, First Canadian Conference on Permafrost, NRC-ACSSM Tech. Memo No. 76, 1963.

————————— Organic Terrain and Geomorphology. The Canadian Geographer VI (3-4), 1962.

Ruuhijärvi, Rauno. Über die regionale Einteilung der Nordfinnischen Moore. Ann. Bot. Soc. 'Vanamo', Tom. 31, No. 1, 1960.

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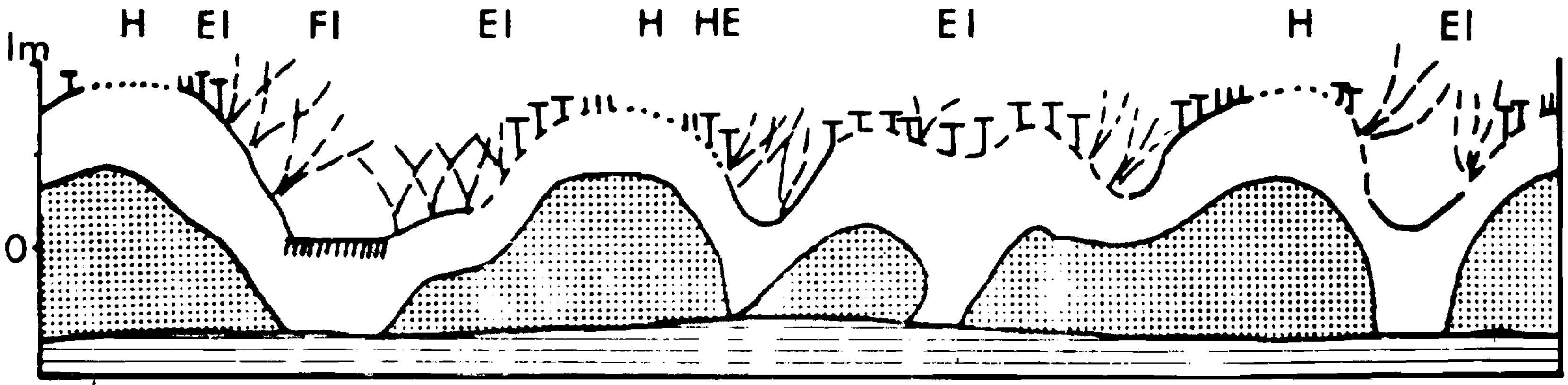
Note:

Figures 1 - 4 and 7 and 8 were not available at the time of publication.




Betula nana (E)

Sphagnum fuscum (I)

Rimpi

Ledum palustre (E)

Pleurozium Schreberi (I)

Mineralboden

Empetrum (E)

Flechten (H)

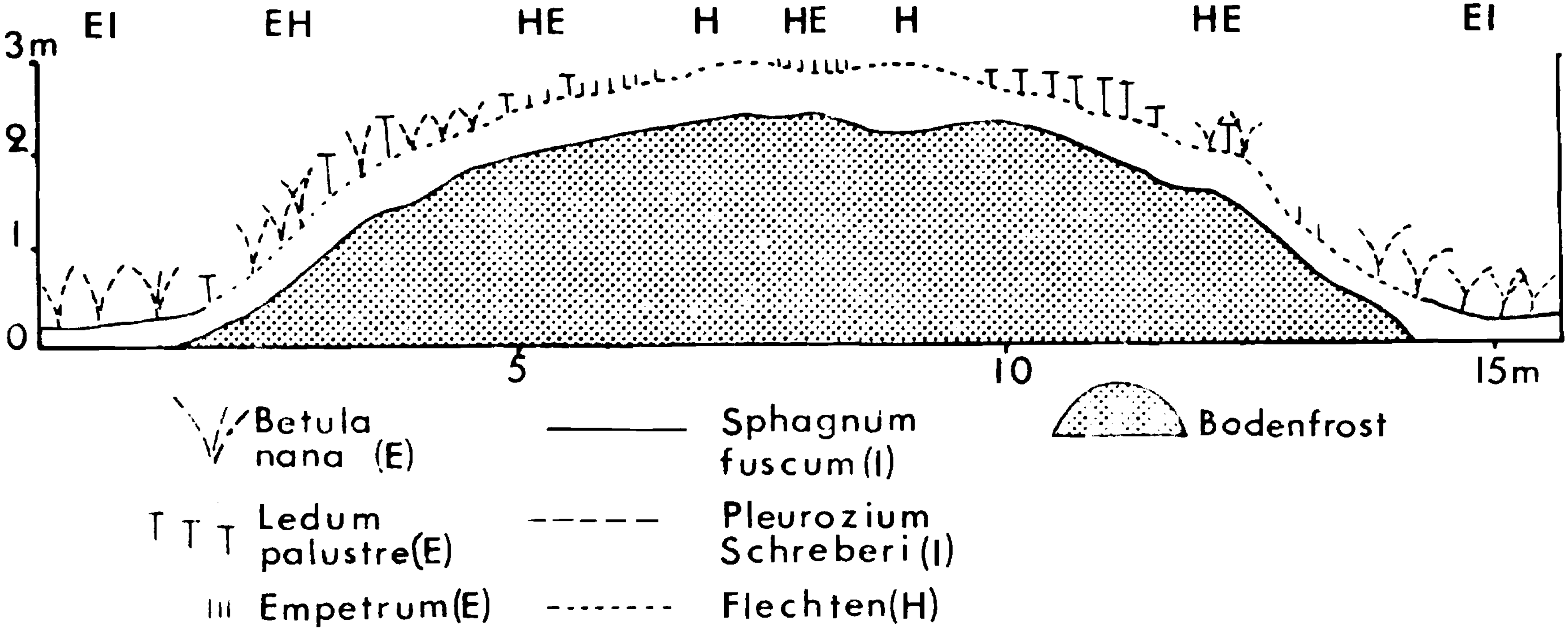
Bodenfrost

Ruuhijärvi, R., 1960, Über die regionale Einteilung der Nordfinnischen Moore. Ann. Bot. Soc. 'Vanamo', Tom. 31. N:o l.

(Slightly modified).

Pounikkoprofil.

FIGURE 5




Profil eines Palsas. Ruuhijärvi, R., 1960. Über die regionale Einteilung der Nordfinnischen Moore.- Ann. Bot. Soc. 'Vanamo', Tom. 31. N:o1. (Slightly modified).

FIGURE 6

Discussion (R.J.E. Brown)

I am greatly concerned by the authors' attempts to create a purely artificial and arbitrary division between so-called "climafrost" and permafrost. It is virtually impossible to make a distinction and there is no practical reason for doing so. I know of no other authors who make this division.

It is stated in their paper that "permafrost in its usual generic connotation is not a feature of Finnish terrain . . ." Actually, there is permafrost in northern Finland, as there is in northern Sweden and Norway, being a westward extension of the permafrost in the Kola Penninsula of the U.S.S.R.

In stating that the features known as palsas, lie outside of the permafrost region, the authors run counter to all current opinion. For example, H. Sjörs is only one of numerous investigators who state categorically that palsas are situated in the permafrost region. "Spruce islands are found in Alaska and the interior of Canada. At the southern margin of the area of discontinuous permafrost, where the climatic conditions for tree growth are still good, the islands are often quite extensive, though moderately high, and covered by unusually dense stands of black spruce. This species is well adapted to grow on peaty permafrost hillocks." (Sjörs, 1961-p.223) "There is little doubt that these black spruce islands have raised cores of permafrost . . . . Farther north . . . knolls of a different type, which also have cores of permafrost were found . . . . In some bogs, these numerous small but fairly high knolls are of a type quite similar to the palsas of subarctic Europe. Only scattered small black spruce and tamarack grow on these palsas . . . ." (Sjörs, 1959-p. 15 and 16).

There are several other statements in the paper which deserve detailed comment:

1. "Among other benefits, it [air photo interpretation] would probably lead to refinements in prediction of subsurface temperature . . . ." It is very unlikely that refinements in prediction of subsurface temperatures could be obtained from studying air photos. Only precise ground temperature observations on thermocouples or thermistors would provide such information. In any case, careful measurements under different types of vegetation show a range of temperatures which could not possibly be predicted from air photos.

2. ". . . where genesis of ice is predominantly due to long-term factors, for others where shorter term climate or regional influence prevails and in still others where ice is a seasonal climate or regional phenomenon." What are long term factors? What are shorter term climate or regional influences? Does regional mean terrain? It is frequently impossible to distinguish between the influences of climate and terrain on the formation and existence of frozen ground.

3. "Towards the south on probable climafrost areas the H factor is localized. . ." Figure 1 to which this statement pertains is an air photo of the Thompson area in northern Manitoba. From the air, this area is one of "probable climafrost" - i.e. "no permafrost". Although the H factor is localized, detailed field observations over three years by the National Research Council revealed considerable permafrost at Thompson (Johnston et al, 1963). Individual islands of permafrost vary in extent from a few feet to several acres, and in thickness from 2 to 50 feet. It can be calculated on the basis of simple conduction theory that a body of permafrost 50 feet thick would require more than a century to form. This hardly fits into the authors' definition of climafrost.

4. "In addition, the great number of small lakes and ponds and the fact that their position, shape and size can change from year to year indicates imperfect drainage and thus long presence of permanently frozen ground". The term "permanently" frozen ground is outdated. It is now universally recognized that permafrost is perennial not permanent. Although the authors seem to treat this statement as fact, it is actually indicated in the original reference as being only a supposition. "Throughout this intermediary region [between Wabowden and Gillam in northern Manitoba] . . . the drainage pattern may be changing, due in part to the permafrost that lies so close to the surface, and in part to the flatness of the topography. [This] theory could be readily checked by means of an aerial and ground survey . . ." (Jenness, 1949 p. 26).

5. "Figure 5 is a diagram of a so-called pounu profile showing how the lichens have concentrated upon the pounu formations (peat-moss or bog-ridge I). The ice is conserved in these mounds sometimes through several years . . . ." If the ice is conserved through several years, then it is permafrost. Does the lichen disappear when the ice disappears? If not, then it can hardly serve as an indicator of ice.

6. "This feature therefore also signifies association between the H factor and subsurface ice conditions and for some areas the possibility of predicting the appearance of climafrost by means of the H factor . . . ." This statement assumes that the thermal regime in a lichen area is different from other areas. We need more observations such as those reported from the Mer Bleue peat bog at Ottawa before a definite opinion can be made on this matter (Williams,1965). There is evidence now, however, that the thermal situation in a lichen-covered area is not significantly different from areas with other types of vegetative cover. I will discuss this in my paper which follows.

7. "The apparent inevitability of the H factor as associated with the ice factor remains to be explained. What are the reasons for the great abundance of lichens on permafrost at climafrost areas? The frozen state as a feature of environment, if significant, is not the sole cause. On the other hand, in Finland it has been observed that the cold has some control . . . ." Is it the cold in the ground or the air which has some control? Actually Fraser, to whom the authors refer, states that lichens can withstand extremes of heat as well as cold. "They [lichens] can survive extreme heat and cold, and by suspending active metabolism, they can withstand desiccation for a period of months - a necessary condition for life in a plant dependent on precipitation for moisture. Nevertheless, they are not xerophytic. They grow best in an atmosphere which is fairly, though not constantly, humid . . . ." (Fraser, 1956 p. 6) Thus lichens can grow in a range of environmental conditions not necessarily those encountered only in permafrost regions. The southern limit of permafrost does not correspond with the southern limit of the H factor. Field observations show that the southern limit of permafrost corresponds to some degree with the 30°F mean annual air isotherm. At the southern limit, permafrost occurs in peatlands because of the presence of the peat with its peculiar thermal properties. In other types of terrain in this region, there is no permafrost near the surface although isolated bodies of relic permafrost may occur undetected at depth.

8. "This dryness [of microtopographic features] (which is revealed in the physical state of the plant [lichen] itself) is caused indirectly by the ice conserved in the ridges. Dryness, in part, is contributed to by upheaval to which the ice core also contributes . . . ." There is no evidence that the dryness of microrelief (not "microtopographic") features such as peat hummocks and ridges is related to the presence of ice. During the summer, the top few inches of peat become dry whether or not there is ice beneath the surface. Ice lensing does in fact cause desiccation in

the surrounding soil as water is drawn by suction to the freezing plane but this is entirely unrelated to the surface drying to which the authors refer. The two processes occur at at different seasons, the drying during the summer and the heaving during the late fall and winter.

9. "The lichens themselves in the last analysis will increase the degree of drought still more by further facilitating run-off. This situation is already acknowledged by Fraser in his studies of the lichen woodlands of the Knob Lake area of Quebec-Labrador . . . ." In Fraser's paper, it is stated, "The surface network of podetia protects the damp lower layers from direct evaporation. In the lower layers, and particularly in the basal layer, water accumulates and seeps downhill so that there is constant saturation there of around 400% by dry weight, throughout the summer" (Fraser 1956 p.5). Fraser does state that water seeps downhill in the basal layer but field measurements show that the moisture content of the basal layer is as high on hilltops, and the summits of hummocks and ridges, as it is in both macro- and micro-depressions.

10. "Thus the H factor (as one index) points to existence of subsurface ice . . . ." There are many peat areas in the permafrost region where there is H factor and no ice and peat areas where there is ice and no H factor.

The following comments refer to the points itemized in the summary:

1. This is essentially correct but the factors are complex and closely interrelated. Their use as indicators of permafrost usually requires qualifications.

2. Investigators have been searching for years for indicators of the southern limit of permafrost and there are virtually no clear-cut answers to this problem.

3. One can indeed assert this because H factor and permafrost do have no significant connection with each other.

4. to 9. In the paper, the authors attempted to build a case for the H factor indicating the presence of permafrost. In Items 4 to 9 of the summary, they backtrack to the point of admitting that the H factor is only one of a complex combination of factors in the permafrost environment. There is an unfortunate tendency in the paper to place the H factor at the top of a pyramid which is out of all perspective to the real situation.

10. The possibility of using aspen in the north to predict ice conditions from aerial photographs is repudiated by Jenness. "Most of the species of trees that grow within the forested part of the permafrost zone can be differentiated on the air photographs that now provide the basis for nearly all northern maps; but because the same trees thrive also on ground that is not permanently frozen, it would hardly seem possible . . . to use their distribution for defining the areas that are underlain by permafrost. It is conceivable that aspen might be used for the purpose if . . . it is intolerant of frozen ground; but unfortunately, it is neither a climax species nor is it easy to distinguish from balsam poplar either from the air or in air photographs. While the type of forest can certainly give a clue to the amount of moisture in the ground and the nature of the soil, so far at least it has not provided any satisfactory guide for the delimitation of permafrost itself". (Jenness, 1949 - p. 24) It would be to the authors' advantage to study the large body of literature which has been written since 1949 on the relations between vegetation and permafrost.

In conclusion, there are two main objections to this paper:

1. The authors' attempts to delineate a so-called "climafrost" region and separate it from the permafrost region.

2. The attachment of so much importance to one element of the permafrost environment - the H factor - as an indicator of permafrost. The permafrost environment is not as simple as the authors apparently wish it to be. It is rather a complex dynamic system. Studies by the National Research Council at Thompson, Manitoba, referred to previously, showed this to be true. Thompson is located in the southern fringe of the permafrost region and the permafrost situation there is representative of the southern fringe and limit. Many islands of permafrost occur in the drier areas of peat bogs and sloping edges of these depressions where the combination of peat and relatively good drainage is conducive to the formation and existence of permafrost. Other islands of permafrost were encountered which at first defied explanation on the basis of air photo or field examination. Eventually, it was realized that the ground surface at these locations had an almost imperceptible north-facing slope of about 1° or less. These slopes were detected only on a 2 ft interval contour map and a very accurate and sensitive stereo plotter - but not on air photos using a pocket stereoscope or standing on the ground. The difference in net radiation between a north-facing slope of even 1° and a horizontal surface is very small. Over a period of decades or centuries, however,

the total difference is sufficient in the southern fringe of the permafrost region to permit the formation and existence of permafrost in the sloping areas but not in the horizontal areas. There are other islands of permafrost which lack explanation and are caused possibly by factors no longer in existence. Thus there are changes in space and time for which the H factor cannot be used as an indicator.

Several points in this discussion are also dealt with in my paper which follows.

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## REFERENCES

Fraser, E. M. "The Lichen Woodlands of the Knob Lake Area of Quebec-Labrador", McGill Sub-Arctic Research Papers No. 1, December 1956, 28 pp.

Jenness, J. L. "Permafrost in Canada", Arctic Vol. 2, No. 1, May 1949, p. 13-27.

Johnston, G. H., R. J. E. Brown and D. N. Pickersgill, "Permafrost Investigations at Thompson, Manitoba, - Terrain Studies", National Research Council, Division of Building Research Technical Paper No. 158, October 1963, 51 pp.

Sjörs, H. "Bogs and Fens in the Hudson Bay Lowland", Arctic, Vol. 12, No. 1, March 1959, p. 2-19.

———— "Surface Patterns in Boreal Peatland", Endeavour, Vol. XX, No. 80, October 1961, p. 217-224.

Williams, G. P. "Heat Balance over Saturated Sphagnum Moss", First Canadian Conference on Micrometeorology, Toronto, April 1965, 17 pp.

General Discussion

Dr. Radforth, in commenting on the reference to Sjörs said that what Sjörs calls "permafrost", he calls "climafrost". However, the concept is there.

Mr. McEwen in commenting on the slides shown following Mr. Korpijaakko's paper, remarked that the late fall pools had a changing aspect from year to year. Dr. Radforth warned of something which arises in degree in raised bog pools. These have one sloping side and one steep side. He suggested that they may be migrating. The pools of which Mr. Korpijaakko spoke, characterizing huge areas of northern organic terrain, may contain high moor and may not migrate on a year-to-year basis. However they do migrate in contemporary times, say, in a 10-year interval.

# III.4. PERMAFROST, CLIMAFROST AND THE MUSKEG H FACTOR

R. J. E. Brown

Abstract

The terms "climafrost" and "H factor" (lichen) were formulated in the course of the muskeg investigations carried out by N. W. Radforth and his co-workers at McMaster University. "Climafrost" was introduced in 1953, redefined in 1955, and has been defined a third time in 1962 as frozen ground which occurs perennially for two to several years but is not considered as permafrost. This paper objects to all three definitions, but particularly to the most recent one. It is argued that in both fundamental and engineering studies it is virtually impossible and unnecessary to separate so-called "climafrost" from permafrost. Several practical reasons are stated for including frozen ground of several years' duration, which Radforth terms "climafrost", in the permafrost region. Radforth has stated several times in recent years that the muskeg "H factor" is an indicator of the southern limit of permafrost. This paper shows that field observations of the southern limit of all permafrost does not correspond with the southern limit of the "H factor". Attempting to use this or any other single factor as an indicator is oversimplifying the complex and dynamic nature of permafrost and its environment.

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# III.4. PERMAFROST, CLIMAFROST ET LE FACTEUR H DE MUSKEG

R. J. E. Brown

Résumé:

Les termes "climafrost" et "facteur H" (lichen) furent formulés au cours des recherches effectuées sur le muskeg par N. W. Radforth et ses assistants à l'Université McMaster. "Climafrost" fut introduit en 1953, redéfini en 1955 et a été défini une troisième fois en 1962 comme étant le sol qui reste gelé durant deux ou plusieurs années mais qui n'est pas considéré comme permafrost. Cette communication s'objecte aux trois définitions, plus particulièrement à la dernière, en soutenant que dans les études fondamentales et dans les études techniques, il est virtuellement impossible et il n'est pas nécessaire de séparer "climafrost" de "permafrost". On mentionne plusieurs raisons pratiques pour inclure dans le permafrost la définition suivante que Radforth appelle climafrost: le sol qui reste gelé durant

plusieurs années. Radforth a déclaré à plusieurs reprises depuis quelques années que le facteur H de muskeg indique la limite sud du permafrost. Cette communication montre, par les observations sur le terrain, que la limite sud du permafrost ne correspond pas toujours à la limite sud du facteur H. L'utilisation de ce facteur H ou de tout autre facteur unique donne une représentation trop simple de la nature complexe et dynamique du permafrost et de son environnement.

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In recent years the increasing economic developments in northern Canada have been accompanied by a continual expansion of fundamental and engineering studies of the two vital terrain features, permafrost and muskeg. These investigations have resulted in the formulation of new concepts and new terminology. Permafrost has become recognized not as a static body but as a dynamic system resulting from the interaction of climatic and terrain factors. Muskeg is considered not merely as a poorly-drained peat-filled depression but a three-dimensional system composed of vegetation above the ground, topographic features along the ground, and organic and mineral matter in the ground. Terms such as "thermokarst", "ice wedge" and "pingo" have become universally accepted in permafrost nomenclature as have "organic terrain" and its attendant classification symbols in muskeg nomenclature.

In muskeg research, N.W. Radforth and the Organic and Associated Terrain Research Unit at McMaster University have led the way in fundamental and engineering studies. The Radforth muskeg classification system is used widely and successfully by engineers and others who have to operate in organic terrain. Through the continued efforts of Radforth and his co-workers, the popular idea of muskeg as a chaotic arrangement of features has been changed to an ordered system.

Two terms which were formulated in the course of the muskeg investigations at McMaster University are "climafrost" and "H factor". In recent years the author has become increasingly disturbed by the use of these terms in connection with permafrost. The purpose of this paper is to show some of the difficulties which arise in employing these terms in a permafrost context.

## Definition of Permafrost

Permafrost, or perennially frozen ground, is defined exclusively on the basis of temperature, referring to the thermal condition of earth materials (mineral and organic soils, and rock) whose temperature remains below 32°F continuously for a number of years (Sumgin, 1940; Müller, 1945; Shvetsov, 1959; Pihlainen, 1963). Thus permafrost includes ground which freezes in one winter and remains frozen through the following summer and into the next winter. This is the minimum limit for the duration of permafrost; it may be only a few inches thick. At the other end of the time scale is that permafrost which is thousands of years old and hundreds of feet thick. The mode of formation of such old and thick permafrost is identical to that of permafrost only one year old and a few inches thick. In the case of the former, a thin layer is added to the permafrost each winter resulting in a layer hundreds of feet thick after several thousands of years have elapsed.

Climafrost

The term "climafrost" was introduced in 1953 (Radforth, 1953 - p.51). It is stated that "... Though it has not been emphasized in the literature, the influence of permafrost is probably due to the properties of its active layer for which the term 'climafrost' is in use in our laboratory ..." A footnote adds that the term was suggested by a research assistant at McMaster University to designate that part of the permafrost affected by seasonal climatic factors.

Two years later climafrost was defined as "... that part of the permafrost affected by seasonal climatic factors". (Radforth, 1955 - p.18).

The term was used next in 1962 (Radforth, 1962 - p.168). "...Another condition of frozen ground also occurs perennially but from two to several years, not indefinitely. Temperatures arranged on this order of time produce the condition designated by the author as 'climafrost'. Obviously climafrost and permafrost can occur together but it is significant that the former may occur in permafrost-free country ..."

More recently in a paper discussing the ice factor in muskeg, "... Climafrost is a frozen condition existing temporarily but for more than one year within the terrain." (Radforth, 1963a - p.69).

In reviewing the definitions given above, it appears that the concept of climafrost has changed since its inception. Referring first to the definition proposed in 1953, problems arise if it is used synonymously with "active layer". Although possessing some shortcomings, "active layer" has been a commonly employed and useful term in both fundamental and engineering studies of permafrost. The use of "climafrost" in this sense implied, first, that the active layer is frozen. This is the situation for only a portion of each year. Secondly, climate is made to appear to be the most important factor, which is not always the case. The thickness of the active layer each year depends not only on climatic factors but also on ground surface features such as vegetation, drainage and snow cover, and subsurface features such as the moisture regime. These non-climatic factors, and their influence on the active layer and permafrost, can vary sufficiently from one year to another so as to override the influence of climate.

In the footnote to the mention of climafrost in the 1953 paper (Radforth, 1953), and in the 1955 paper (Radforth, 1955), climafrost is defined as that part of the permafrost affected by seasonal climatic factors. In the 1953 paper, the footnote actually contradicts the definition because the active layer is not part of the permafrost. Temperature measurements in numerous boreholes in permafrost in North America and the U.S.S.R. show that the influence of seasonal climatic factors extends to depths varying from 30 to 50 feet or greater. At Resolute, N.W.T., for example, where permafrost exceeds 1300 feet in thickness, the annual air temperature cycle causes fluctuations in the ground temperature to a depth of about 70 feet (Cook, 1958). The term "climafrost" could be used to denote that portion of the permafrost lying above the depth of zero annual amplitude but there does not appear to be an urgent requirement for it.

The third and most recent definition of "climafrost" refers to the ground which is frozen for a few years and then thaws. This phenomenon was described first by Soviet permafrost investigators in the 1930's. They introduced the term "pereletok" meaning "through the summer". It is defined as "the frozen layer at the base of the active layer which remains unthawed (frozen) for one or two summers". (Müller, 1945 - p.219). The maximum duration of a pereletok has "... so far not been definitely established but is approximately equal to two, three or five years." (Sumgin, 1940 - p.15).

Experience has shown that there is no requirement for the terms "climafrost" (used in this sense) or "pereletok". There is no attempt in North American permafrost literature to separate frozen ground of a few years' duration from permafrost. The concept of "pereletok" is not even accepted universally by Soviet investigators. The definition of permafrost, which is accepted in the U.S.S.R., states that its duration is two to tens of thousands of years which corresponds with the author's time limits. Thus "climafrost" and "pereletok" are in fact "permafrost" representing the extreme southern limit condition. It is essential to make field observations in September and October when summer thawing has virtually ceased and seasonal frost of the oncoming winter is beginning to form.

If "climafrost" or "pereletok" were used in the sense that is proposed, then an arbitrary decision should be made as to the number of years assigned to their duration above which this frozen ground would be termed "permafrost". Would the number be 2, 3, or 5 as suggested in the U.S.S.R., or 7, 8, or 9 or what number? Soviet investigators presented this term thirty years ago and have not specified an exact number yet. In any investigations concerned with either the fundamental or engineering aspects of permafrost, there is no noticeable or significant difference in characteristics or properties between "climafrost" or "pereletok" that is, say, 5 years old, and permafrost that is 6 years old. Both are permafrost.

The term "climafrost" implies that such perennially frozen ground of a few years' duration is a product of climate. This is true in some instances but many occurrences of so-called "climafrost" are caused by other factors. (The Russian term "pereletok" at least does not include this implication.) The origin of a permafrost island at the southern limit of the permafrost region can be attributed to one or more causes (Brown, 1964; Brown, 1965b). It may be a remnant of the cooler climate of the Pleistocene; it may be several decades in age and formed as a result of air temperatures slightly lower than those prevailing at present; or it may be of a few years' duration, formed as a result of certain combinations of such terrain factors as snow cover, drainage, or vegetation, without a change in the climate. It is even possible for permafrost to be generated by climatic factors and perpetuated by terrain factors, or vice-versa.

Thus many complex combinations of climatic and/or terrain factors are conducive to the formation of permafrost only a few years old. Three examples are described here. First, an island of permafrost one acre in extent and two feet thick could have formed 2000 to 3000 years ago during the colder than present climatic period which followed the post-glacial thermal optimum. Second, another permafrost island of similar dimensions could have formed only a few decades ago in the bottom of a drained lake. A third permafrost island of similar area and thickness could be only two or three years old resulting from several consecutive years of abnormally light snowfall and increased frost penetration. In each of these situations the causes and time factor vary to a marked degree but the physical and engineering properties of the permafrost are similar.

Permafrost is caused by many factors acting in complex combinations and is very sensitive to environmental changes. A minute change in one factor can cause a significant change in the permafrost. For example, there are peat bogs in the southern fringe of the permafrost region where perennially frozen ground occurs in patches only a few feet in diameter beneath individual trees. These patches appear to have formed as the result of a heat deficit in the ground associated with the shading of the ground surface by these individual trees. Although of small extent, these patches may be several decades old. Small patches of permafrost in a peat plateau, or ridge, for example, could be as old as the bog itself - several centuries; or they could be only two winters and one summer in age. Thus there is an infinite number of combinations of climatic and terrain factors which can produce and maintain a perennially frozen condition in the ground. All of the resulting patches and islands of frozen ground which persist through at least one summer come within the definition of permafrost.

A possible use for the term "climafrost" is for reference to permafrost formed by climate. The broad pattern of permafrost distribution is indeed determined by climate. However, terrain causes local variations in distribution of permafrost in the southern fringe and in the thickness of the active layer throughout the permafrost region. Thus the very thick permafrost in the continuous zone resulting from thousands of years of severe climate could be termed "climafrost". For example, it can be calculated, on the basis of simple conduction theory, that at Resolute, N.W.T. about 10,000 years was required for the ground to freeze to a depth of 1300 feet, the present estimated thickness of the permafrost (Brown and Johnston, 1964 - p.67).

If the term "climafrost" could refer to perennially frozen ground formed by climate, there should be a term for perennially frozen ground formed by a terrain condition. The obvious term is "terrafrost". The author suggests that "climafrost" and "terrafrost" are unsuitable terms because it is virtually impossible to ascertain, without detailed studies of several years' duration, whether a particular island of permafrost was formed as a result of climatic and/or terrain factors. If both are involved, it would be necessary to introduce another term. Would it be "climaterrafrost" or "terraclimafrost" or "clerrafrost"? The use of these terms can be extended easily to ridiculous extremes. It is surely more realistic and practical to include all of these occurrences of perennially frozen ground under the permafrost "umbrella". From this starting point, the description of particular islands of permafrost, whatever their duration and mode of formation, can be undertaken.

The H Factor

In the Radforth classification of muskeg for engineers, the H factor refers to lichens which are described as non-woody plants 0 to 4 inches high, having leathery to crisp texture growing mostly in continuous mats (Radforth, 1952 - p.6). In order for a coverage class, such as H, to be included in the description of the plant growth on a particular muskeg, it must comprise a minimum of 25 percent of the total coverage.

During the past three years, it has been stated several times that the H factor is an indicator of the southern limit of permafrost. In 1962 it was stated that "... Aerial inspection on flights from south to north reveal EI changing to EH and finally HE. The latitude at which H makes its appearance is now known to bear some relationship to the southern limit of permafrost". (Radforth, 1962 - p.168).

At the First Canadian Permafrost Conference in Ottawa, 1962, it was stated that "... An analysis of the positions of initial occurrence of HE shows an approximate coincidence with the southern limit of the permafrost condition. The degree of prevalence of Class H in a secondary position in formulae designating the cover condition to the south of the limit suggests the presence of permafrost-free climafrost (e.g. Wabowden, Man.)" (Radforth, 1963a - p.67). (This contradicts the first statement where EH appears to have some relationship to the southern limit of permafrost; in the second statement HE designates the southern limit of permafrost and H in a secondary position, such as in EH, "suggests the presence of permafrost-free climafrost".)

Later in 1963, "... For all conditions the H factor in organic terrain is apparently a sure index of presence of geomorphic peaks in permafrost ice. It disappears near the ice cap front in the north and at the southern fringe of permafrost in the south." (Radforth, 1963b - p.12). (In this statement the H factor indicates "geomorphic peaks in permafrost ice or a thin active layer", the implication being that permafrost with a thick active layer can exist without the H factor.)

At the end of 1963 it was stated that "... The work supported by the Defence Research Board has recently resulted in the disclosure that H as a cover class designates the southern limit of permafrost across the country (Newfoundland excepted)." (Radforth, 1963c - p.40).

The most recent reference to permafrost and the H factor is, "... In this respect it has been observed that the lichens in the muskeg only appear north of the permafrost line except in Newfoundland and Labrador." (Harwood and Radforth, 1964 - p.10). Note in this statement that there is no mention of H factor but only lichens.

Thus to summarize, or to reword the contention, the southern limit of peatbogs or peatlands with 25 per cent or more lichen cover coincides with the southern limit of permafrost. South of this permafrost limit there is no H factor in the cover formula which means that lichens comprise less than 25 per cent of the ground cover.

In the author's opinion, many more field observations and measurements are required before any relation between the H factor and the southern limit of permafrost can be established. (The selection of 25 per cent lichen coverage as a critical value for indicating permafrost seems rather arbitrary and the author is curious to know how this value was obtained.) In the continuing search for surface indicators of subsurface permafrost conditions, Radforth's proposal is interesting and attractive. His statement may hold true in some areas but its use as a generalization is dangerously premature. Why, for example, does this relationship not apply in Newfoundland and Labrador?

An examination of the Radforth muskeg map shows that there is little correspondence between the plotted limit of the H factor and the southern limit of permafrost (Radforth, 1961 - p.10) (Figure 1). This map was a first attempt to show the distribution of muskeg in Canada. Perhaps it is now possible to make significant alterations to the map in the light of recent field observations which bring the southern limit of the H factor more in line with the southern limit of permafrost.

It has been stated that south of the permafrost is a zone of climafrost, which is not permafrost but "permafrost-free climafrost" (Radforth, 1963a). It is the author's opinion, developed earlier in this paper, that the "climafrost zone" is part of the permafrost region. Because of the difficulties already discussed, of determining the location of the boundary between Radforth's permafrost and climafrost, it would be more realistic and easier to examine the relationship between the southern limit of the H factor and the true southern limit of permafrost.

In a recent paper it is stated that "... there appears here to be some peculiar relationship between the occurrence of lichens and the rates of evapotranspiration in various areas; this needs to be explored." (Harwood and Radforth, 1964 - p.10). (Again note the reference to lichens and not H. In other words, there is no minimum coverage requirement. Greater precision is required.) This statement implies that the existence of permafrost is dependent on one or several properties of lichen, or that lichen is an indicator of some condition which permits the existence of permafrost - this condition being able to exist only in the presence of lichen. Conversely, there is the implication that lichen in bogs can not exist without the presence of permafrost.

With regard to the first implication, the vegetation indicates subsurface conditions to a depth of only a few feet (Larsen, 1965 - p.44). The presence or absence of lichens covering more or less than 25 per cent of a muskeg surface would have no relation to bodies of permafrost occurring, say, below the depth of the active layer.

With regard to the second implication, the same lichen species (Cladonia sp., Cetraria sp. and others) which are so prevalent in the H factor comprise virtually 100 per cent of the ground cover in lichen woodlands south of the permafrost limit. These lichen woodlands grow in such widely separated localities as Labrador-Ungava (Fraser, 1956; Hare, 1959), Kapuskasing (Ahti, 1964), and Saskatchewan northeast of Prince Albert (Brown, 1965b). These areas are not muskegs because peat is absent but the lichens grow prolifically without permafrost.

In the author's own field investigations and discussions with botanists[1], climatic and terrain conditions necessary for the existence of permafrost are not necessarily coincident with those required by lichen. Permafrost conditions can change more rapidly than lichen in response to environmental changes. For example, in a wet bog in the southern fringe of the permafrost region, there is no perennially frozen ground. For some reason, such as a change in drainage conditions, the bog dries and a thin layer of permafrost forms immediately. This layer disappears in a few years because of a change in snowfall or rupture of the ground cover due to tree fall or game trails which causes increased thawing. After initial drying of the bog surface, conditions are suitable for lichen growth but it does not move in until several decades have elapsed by which time permafrost may have formed and dissipated (Drury, 1956 - p. 24 and 48).

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[1] Personal communications with R. E. Beschel, Department of Biology, Queen's University, Kingston, Ontario, and W.K.W. Baldwin, National Herbarium, Ottawa, Ontario.

Further to the statement about lichen and evapotranspiration, lichens are actually not vascular plants and can not transpire in the sense that vascular plants do; and their moisture regime has been explored to some extent. It was observed at Norman Wells, N.W.T., that water loss through a lichen cover was lower than through other ground covers for an 80-day period, June 30 to September 17, 1960 - lichen (10.75 cm.), Sphagnum (13.37 cm.), marsh sedge (12.51 cm.), Thornthwaite evapotranspiration site (22.90 cm.) (Brown, 1965a - p. 19). At Schefferville, P.Q., observations carried out for four summers showed that water losses through lichens were much lower than the computed latent evaporation (LE) or potential evapotranspiration (PE) for the region - 39% of LE, 29% of PE in 1956; 55% of LE, 38% of PE in 1957; 51% of LE, 38% of PE in 1958; 69% of LE, 61% of PE in 1959 (Nebiker, 1957; Watts, 1960). If lichens allow less water loss than, say, Sphagnum, it means that less heat is being withdrawn from the ground and the thermal level is higher beneath lichen than beneath Sphagnum. Thus conditions are more conducive for permafrost beneath Sphagnum.

In considering other thermal properties of lichens, it has been postulated that their very light colour, in contrast to the dark greens of Sphagnum, spruce, etc., gives them a high albedo resulting in low net radiation values - low ground thermal level and conditions conducive for permafrost. Extensive aerial and ground measurements in Labrador-Ungava, where lichen is widespread, indicate that their brightness has been overemphasized (Davies, 1962). In localities where lichen grows, the albedo varies from 7 to 20 per cent, the lower value referring to a vegetation condition where lichen is obscured by a shrub cover and the upper value refers to the sparsest open lichen woodland where the ideal value of 20 per cent for lichen alone will be approached. Values of 20 per cent are rarely observed because lichen usually grows in association with other ground vegetation and thus the albedo of the mosaic is somewhat less.

Albedo measurements at the Mer Bleue peat bog near Ottawa gave values ranging from 12 to 16 per cent for various combinations of bog vegetation, a maximum of 16.2 per cent being obtained over bare Sphagnum (Williams,1965 - p.14). These values are similar to those obtained by Davies in lichen woodlands where lichen comprises far more than 25 per cent of the ground cover but is not considered as H factor, and where permafrost does not exist. A higher albedo value of 21.1 per cent was obtained by Davies over sparse brown grass and sedge cover.

Other measurements at Norman Wells, N.W.T., indicate that lichen and Sphagnum have similar thermal properties

(Brown, 1965a). The depth of thaw beneath both plant types was similar whether the lichen was growing on Sphagnum or directly on peat - about 2 feet at the end of September 1960. Hundreds of depth of thaw measurements throughout Canada's permafrost region confirm that there is no difference between adjacent lichen and Sphagnum-covered areas, other factors such as drainage, shading, snow cover and mineral soil type being equal. Ground temperature measurements showed no differences also. Thermocouples spaced at 1-inch intervals beneath lichen and Sphagnum showed similar temperatures and temperature gradients between the air-lichen or air-Sphagnum interface and the permafrost table - the latter being at the same depth beneath both plant types. The mean ground temperature at the 1 foot depth during September 1959 was 32.5°F beneath Sphagnum and 32.6°F beneath lichen.

It appears that lichen, and more specifically H factor in muskegs and other areas, is neither an indicator nor a cause of permafrost. The most southerly occurrences of permafrost in Canada occur in peat bogs or muskegs. This permafrost is induced by seasonal variations in thermal conductivity peculiar to peat (Shvetsov, 1959 - p.400) or it is degrading permafrost which was formerly more widespread. This permafrost, only a few feet thick, occurs in only the better-drained portions of bogs - peat ridges, plateaux (Figure 2) or in sloping areas between peat bogs and surrounding higher areas of mineral soil. Lichen may or may not be present but the presence of well-drained peat appears to be a necessary prerequisite for permafrost.

Investigations have shown that the most marginal permafrost does not occur south of the 30°F mean annual air isotherm. The depth of thaw in peat bogs at the location of this isotherm is little different from that in peat bogs near the treeline where the mean annual air temperature is below 20°F. The peat has such high insulating values (regardless of whether it is covered by Sphagnum or lichen) that differences in thawing indices appear to have little bearing on the depth of thaw. Thawing indices (10-year averages) are: Inuvik - 2300 degree days; Norman Wells - 3000; Mackenzie Highway in Northern Alberta, Prince Albert to La Ronge in Northern Saskatchewan, and The Pas to Flin Flon in Northern Manitoba - 3500 (Thompson, 1963; Brown 1964, Brown 1965b). In all of these areas the depth of thaw in peat varies within the fairly narrow limits of about 1'-9" to 2'-9" averaging about 2'-0" despite the range of 1000 degree days of thawing (Pihlainen, 1962; Brown 1964, Brown 1965b).

During the author's investigations of the southern limit of permafrost in Canada from Hudson Bay to the Pacific

Ocean, the existence of perennially frozen ground and related environmental factors was examined in more than 300 peat bogs and other types of terrain. The occurrence of permafrost was in no way related to the existence of lichen or vice-versa whether coverage was more or less than 25 per cent. All combinations of permafrost and lichen were found: bogs with permafrost and lichen; permafrost and no lichen; no permafrost and lichen; no permafrost and no lichen. Lichen coverage ranged from more than 25 per cent (H factor) to less than 25 per cent (no H factor). The following situation was found:

| | Lichen | No Lichen |
|---|---|---|
| Permafrost | 112 | 35 |
| No Permafrost | 112 | 47 |

The permafrost varied from scattered patches 1 to 2 feet in diameter beneath individual trees, to larger bodies in peat mounds, ridges and plateaux, to islands several acres in extent. The thickness of the permafrost was not related to the areal extent. There were instances of an island of permafrost several acres in size being only 3 feet thick in contrast to a body only 25 feet in diameter in a peat plateau being 20 feet thick (Figures 3 - 5).

Further problems arise with regard to the necessity of lichen or any other plant species comprising more than 25 per cent of the cover to be included in the muskeg coverage formula for permafrost purposes. Plant species may be excluded which in fact are significant indicators of ground thermal conditions. For example, there are bogs with lichen but no permafrost; the moisture content of the peat is sufficiently low to allow lichen growth but too high for permafrost. The ground cover includes remnants of pool vegetation - grasses and marsh sedges - which predominated before the encroachment of Sphagnum and lichen. These remnants survive because the site is still sufficiently moist; it is too moist for permafrost but sufficiently dry for lichen. The grass and sedge comprise less than 25 per cent of the total cover and thus are excluded from the Radforth muskeg classification. In these situations, however, these plants are the key indicators of the permafrost conditions. There are examples of adjacent bogs having identical muskeg classifications, one having permafrost and the other not having it. The cause may be a difference in drainage conditions which is manifested in the presence of certain plant species whose coverage is not sufficient to include them in the classification.

Permafrost will form and persist in a peat bog regardless of the presence of lichen as long as the moss and peat are not disturbed. The lichen may be burned off and regenerate several times during the duration of the permafrost. At Chisel Lake, Manitoba, a fire in a peat bog burned the lichen and charred the top one inch of the Sphagnum. The underlying Sphagnum and peat were not disturbed and the depth of the permafrost table remained unchanged (Figure 6). At Inuvik, N.W.T. the removal of trees and brush did not alter the depth of the permafrost table as long as the moss and peat were not disturbed (Pihlainen, 1962). The permafrost and its environment are both dynamic systems but we rarely see the changes with time except in the case of fire. This is a serious problem in studying permafrost particularly in the southern fringe. The permafrost is dynamic - degrading in some areas and aggrading in other areas in response to macro and micro-climatic and terrain changes. The permafrost that we observe at a particular time is the product not only of present environmental factors but also of past factors not evident now. If lichen is one of these factors, it also changes with time and its use as an indicator is debatable.

## Conclusion

Serious difficulties arise in the use of the term "climafrost" to denote a certain type of frozen ground, and the muskeg H factor as an indicator of the southern limit of permafrost. The author repeats his contention that there are several practical reasons for including frozen ground of several years' duration, which Radforth terms "climafrost", in the permafrost region. This leads to consideration of the H factor and the necessity of examining its relation to the true southern limit of permafrost.

The author supports completely the attempts to relate the southern limit of permafrost to the H factor or any other indicator. One of the prime tasks in permafrost research is to improve the ability of predicting subsurface permafrost conditions from surface features. Because of the complex and dynamic nature of permafrost and its environment, however, the use of any single factor as an indicator must be tested thoroughly before it can be accepted. On the basis of his own field observations, and discussions with botanists and workers in allied fields, the author contends that a detailed assessment of the role of lichen in the permafrost environment is required. Only then will it be possible to make any generalizations.

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## REFERENCES

Ahti, T. "Macrolichens and their Zonal Distribution in Boreal and Arctic Ontario, Canada", Annales Botanici Fennici, Vol. 1, No. 1, 1964, p.1-35.

Brown, R. J. E. "Permafrost Investigations on the Mackenzie Highway in Alberta and Mackenzie District", Division of Building Research Tech. Paper No. 175, June 1964, 27pp. (NRC 7885).

——————— and G. H. Johnston. "Permafrost and Related Engineering Problems", Endeavour Vol. XXIII, No. 89, May 1964, p.66-72 (NRC 7860).

——————— "The influence of Climatic and Terrain Features on Permafrost at Norman Wells, N.W.T", Canadian Jour. of Earth Sciences, Vol. 2, No. 1, February 1965a, p.15-31.

——————— "Permafrost Investigations in Saskatchewan and Manitoba", Division of Building Research Technical Paper No. 193, 1965b, (NRC 8375).

Cook, F. A. "Temperatures in Permafrost at Resolute, N.W.T.", Geographical Bulletin, No. 12, 1958, p.5-18.

Davies, J.A. "Albedo Measurements Over Sub-Arctic Surfaces", McGill Sub-Arctic Research Papers No. 13, July 1962, 86 pp.

Drury, W. H. Jr., "Bog Flats and Physiographic Processes in the Upper Kuskokwim River Region, Alaska". The Gray Herbarium of Harvard University, No. CLXXVIII, 1956, 130 pp.

Fraser, E.M. "The Lichen Woodlands of the Knob Lake Area of Quebec-Labrador", McGill Sub-Arctic Research Papers No. 1, December 1956, 28 pp.

Hare, F. K. "A Photo-Reconnaissance Survey of Labrador-Ungava" Memoir 6, Geographical Branch, Department of Mines and Tech. Surveys, Ottawa, 1959, 83 pp.

Harwood, T. A. and N. W. Radforth. "Northern Landform as it Affects Potential Development in Organic Terrain", Proc. Ninth Muskeg Research Conference, May 21 and 22, 1963, Tech. Memo. 81, NRC Associate Committee on Soil and Snow Mechanics, April 1964, p.7-19.

Larsen, J. A. "The Vegetation of the Ennadai Lake Area, N.W.T.: Studies in Subarctic and Arctic Bioclimatology", Ecological Monographs, Vol. 35, No. 1, Winter 1965, p.37-59.

Müller, S. W. "Permafrost or Permanently Frozen Ground and Related Engineering Problems", Strategic Engineering Study No. 62, U.S. Army, Washington, D.C. August 1945, 231 pp.

Nebiker, W. A. and Orvig, S. "Evaporation and Transpiration from an Open Lichen Woodland Surface". International Union of Geodesy and Geophysics, General Assembly of Toronto, September 3-14, 1957, Vol. III - Surface Waters, Prevision, Evaporation, p.379-384.

Pihlainen, J. A. "Inuvik, N.W.T. - Engineering Site Information", Division of Building Research Tech. Paper No. 135, August 1962, 18 pp. (NRC 6757).

——————— and G. H. Johnston. "Guide to a Field Description of Permafrost", Associate Committee on Soil and Snow Mechanics, National Research Council Tech. Memo. 79, October 1963, 23 pp. (NRC 7576).

Radforth, N. W. "Suggested Classification of Muskeg for the Engineer". Engineering Journal, Vol. 35, No. 11, November 1952, p.1-12.

——————— "Palaeobotanical Method in the Prediction of Sub-Surface Summer Ice Conditions in Northern Organic Terrain". Trans. Roy. Soc. Can. Vol. XLVIII, Series III, Section 5, June 1953, p.51-64.

——————— "Organic Terrain Organization from the Air (Altitudes less than 1000 feet)". Handbook No. 1, Defence Research Board, Dept. of National Defence, DR No. 95, 1955, 49 pp.

——————— "Distribution of Organic Terrain in Northern Canada", Procs. Seventh Muskeg Research Conference April 18 and 19, 1961, Tech. Memo. 71, NRC Associate Committee on Soil and Snow Mechanics, December 1961, p.8-11.

——————— "Organic Terrain and Geomorphology", Canadian Geographer, Vol. VI, Nos. 3-4, Winter 1962, p.166-171.

———————— "The Ice Factor in Muskeg", Procs. First Canadian Conference on Permafrost, April 17 and 18, 1962, Tech. Memo. 76, NRC Associate Committee on Soil and Snow Mechanics, January 1963a, p.57-78.

———————— "The Origin and Significance of Organic Terrain Features", Presented at International Conference on Permafrost, Purdue University, November 1963b, 14 pp.

———————— A Classification System for Organic Terrain, and its Application", Procs. of the Atlantic Provinces Regional Seminars on Organic Terrain Problems, October 1962, Tech. Memo. 77, NRC ACSSM December 1963c, p.37-44.

Shvetsov, P. F. ed. "Osnovy Geokriologii" (Principles of Geocryology), Academy of Sciences of the U.S.S.R., Vol. 1, Moscow 1959, 459 pp.

Sumgin, M. I., S. P. Kachurin, N. I. Tolstikhin and V. F. Tumel. "Obshcheye Merzlotovedeniye" (General Permafrost Studies), Academy of Sciences of the U.S.S.R., Moscow 1940, 337 pp.

Thompson, H. A. "Freezing and Thawing Indices in Northern Canada", Procs. First Canadian Conference on Permafrost, April 17 and 18, 1962, Tech. Memo. 76, NRC Associate Committee on Soil and Snow Mechanics, January 1963, p.18-36.

Watts, D., J. H. Galloway and Z. Grenier. "Evapotranspiration Studies at Knob Lake in the Summer of 1957, 1958 and 1959". McGill Sub-Arctic Research Papers No. 10, June 1960, 32 pp.

Williams, G. P. "Heat Balance Over Saturated Sphagnum Moss". Presented at First Canadian Conference on Micro-meteorology, Toronto, April 1965, 17 pp.

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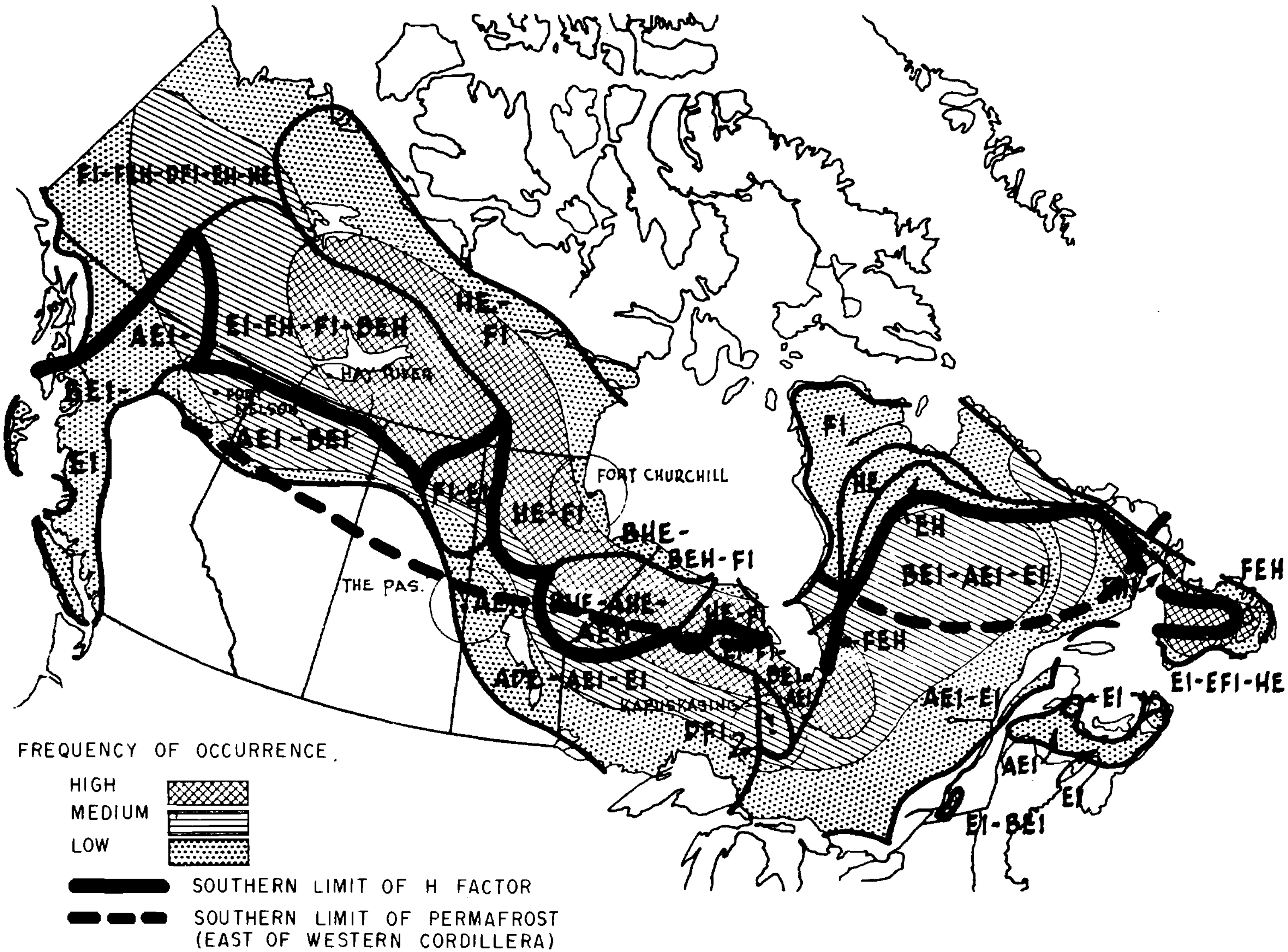


MUSKEG AREAS

SOUTHERN LIMITS OF H FACTOR AND PERMAFROST

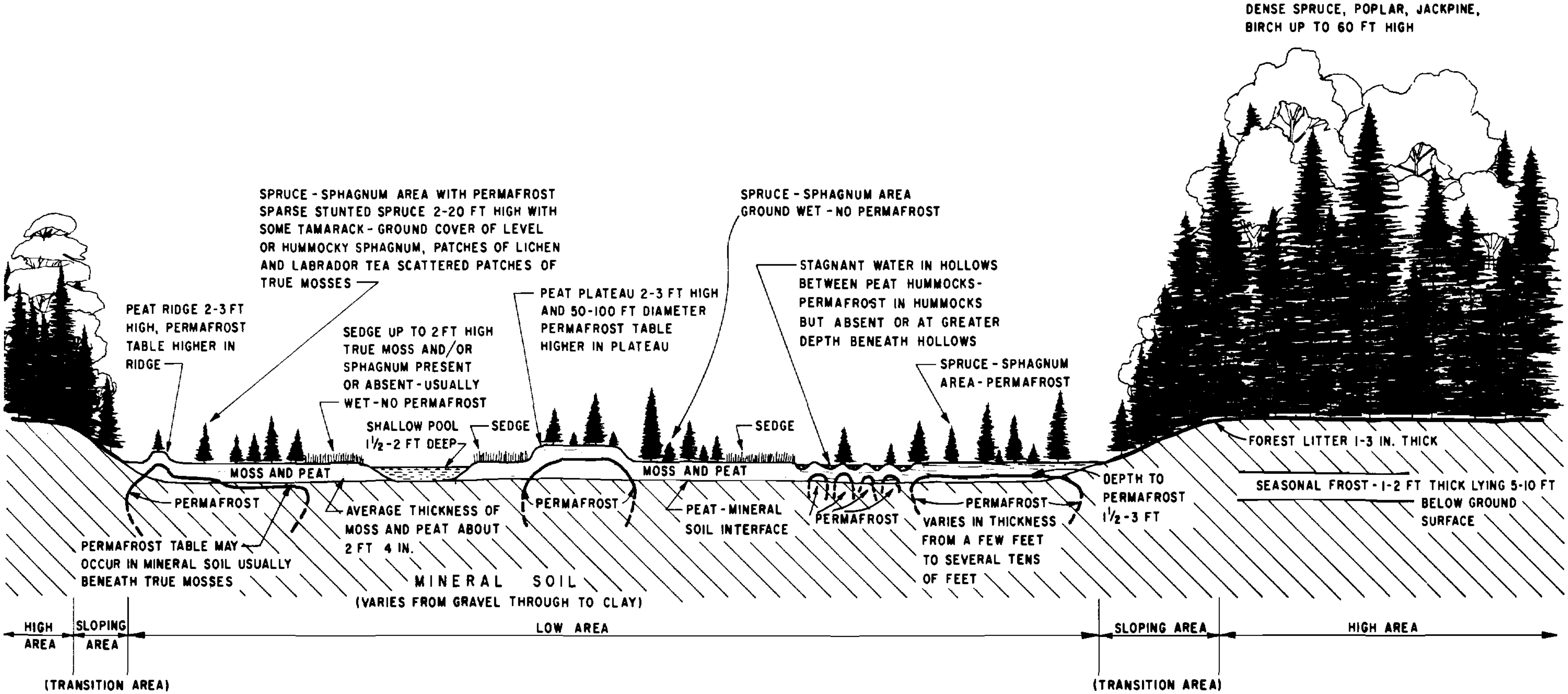


FIGURE 2

PROFILE THROUGH TYPICAL PEAT BOG IN SOUTHERN FRINGE OF PERMAFROST REGION

Figure 3

Bog with lichen about 120 miles southwest of Flin Flon, Manitoba. Peat is 2'-0" thick overlying sand. No permafrost exists here. September 19, 1963 (BRS 2447).

Figure 4

Bog with lichen about 20 miles southwest of Flin Flon, Manitoba. Peat exceeds 6 feet in thickness. No permafrost exists here. September 21, 1963 (BRS 2471).

Figure 5

Bog with no lichen about 25 miles north of LaRonge, Saskatchewan. Peat exceeds 7 feet in thickness. The permafrost table is 1'-6" beneath the ground surface and the permafrost is 1'-5" thick. September 15, 1963, (BRS 2421).

Figure 6

Recently burned bog at Chisel Lake, Manitoba, about 60 miles east of Flin Flon. Trees and Sphagnum surface are charred. Peat exceeds 6 feet in thickness. The permafrost table is 2 feet beneath the ground surface and the permafrost is 4 feet thick. September 30, 1963, (BRS 2524).

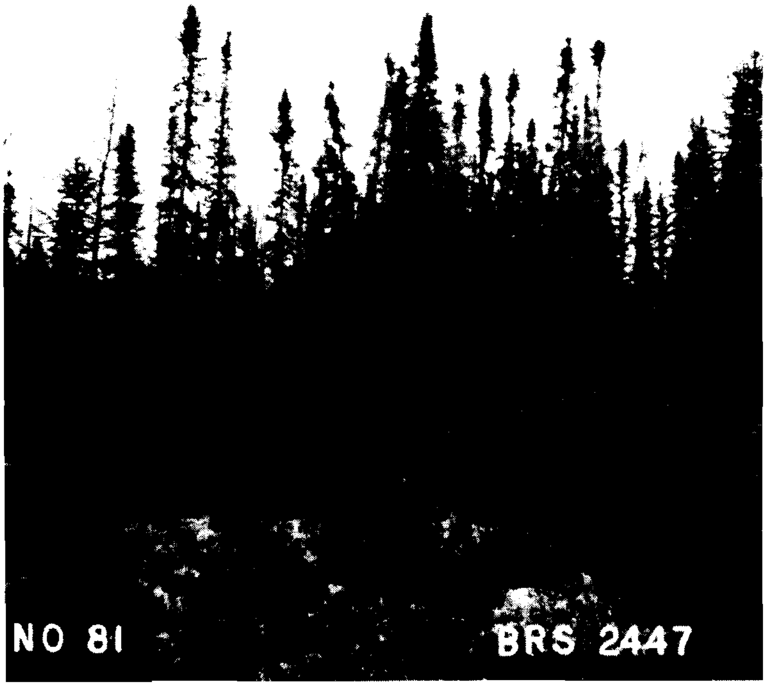


FIGURE 3

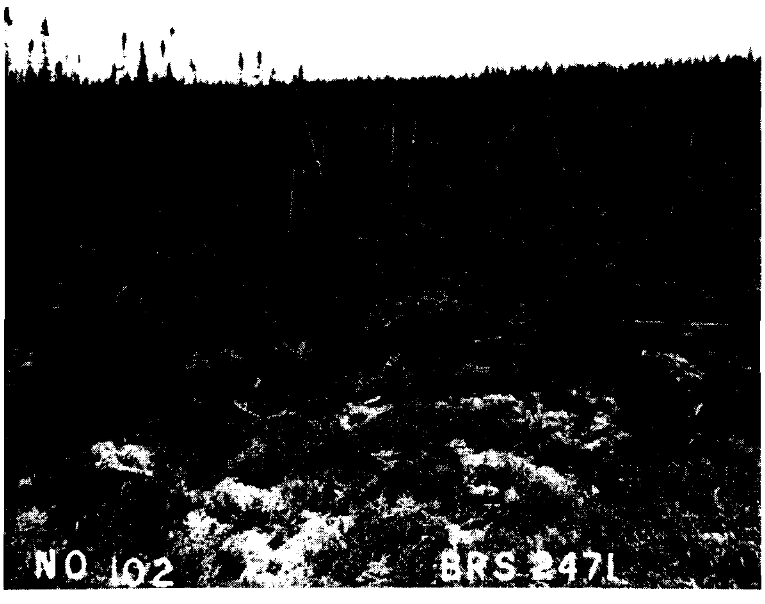


FIGURE 4


FIGURE 5

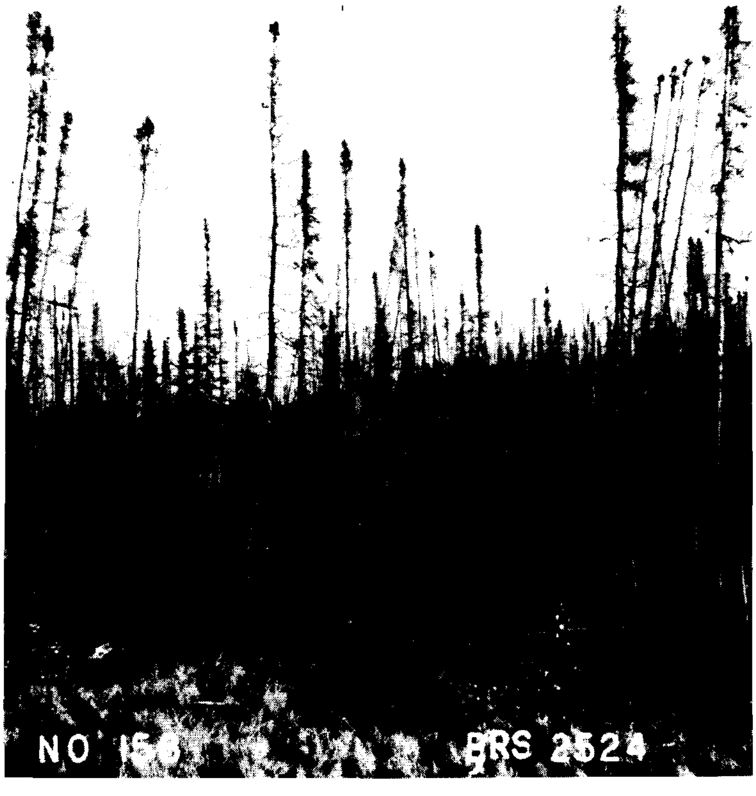


FIGURE 6

<u>Discussion</u> (N. W. Radforth)

I am pleased to respond to a paper most helpful to me. For many years Dr. Brown has carried out preliminary work in connection with permafrost studies in Canada and has now extended this work into aspects of detail. In addition to this, he is one of those individuals we need to keep us on the straight and narrow path! On the other hand, in any study, especially an interdisciplinary study, there is a necessity for discipline on how to use terms. This Committee has long since tried to promote the kind of thing which has happened at this Conference with Dr. Brown's paper. He has been very meticulous; he has gone back through the literature and pulled out those things in accord with the difficulty. If I were to attempt to answer or to respond to all the points raised, there would be no time for any other papers in this session. I am hoping, however, that there can now be some sort of collusion. The ultimate purpose of Dr. Brown and myself is to assure that out of this can come something we can both use. Perhaps the way to resolve our differences is for Dr. Brown and I to write a joint paper!

Now to consider some specific points raised by Dr. Brown, the first of which is the matter of definitions. When one is working - especially in preliminary research - and trying to find out what variables are significant and what are not, one is apt to label features which recur again and again. This becomes a short form of language. If we were to stick only to definitions, the conclusions Dr. Brown makes - as well as Mr. Korpijaakko's paper - could not be served, nor the dissertations from which they came. We would be hidebound by definitions. Definitions are like rules; in one sense they are desirable, in another sense they have to be changed somewhat.

What we have to consider here is the matter of concept. Take, for instance, the idea of permafrost as ground continually frozen over a number of years. There is also the concept of contemporary frozen ground, compared to permafrost going on for thousands of years. When an expression is used, it has to be defined. We have a concept or an idea - which has arisen in two separate areas and without any collusion whatever: "pereletok" and "climafrost". Consequently, there must be a need for something, and if there is a need it should be served.

With regard to the several definitions for "climafrost", in its original usage the author was concerned only with concept; definition was secondary. It was a description of a phenomenon. This condition was conceived as occurring along with permafrost. We wanted to separate the ancient condition, arising from temperature, etc., from contemporary conditions. What are said to be definitions are simply elaborations or extensions - even qualifications - of what was said in the first place. We do not need to apologize for giving a name to a condition which has been observed.

In the engineering sense, suppose that you have two feet of permafrost (or "climafrost"?). Think of it in terms of a foundation of some sort. If you have 8 feet of peat and 2 feet of ice, you must treat it differently if it is going on for only 2 years as opposed to going on indefinitely.

With regard to the H-factor, both Dr. Brown and Mr. Korpijaakko have concluded that more work should be done on this factor, along with other factors. This shows that it needs to be looked at. Here, however, we should not confuse observations with conclusions. Also, it should be pointed out that we do not anywhere state that H factor causes ice.

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General Discussion

Mr. Robinson said that he did not wish to get drawn into the climafrost - permafrost controversy but wished to refer to a paper he heard presented at another conference and which may be of help in interpretation. That paper showed that normal color photography is better than black and white, and that infrared spectrachrome is better than either of these. The latter has been proven to be very effective in topographic mapping.

Mr. McEwen stated that in their maps the permafrost boundary is shown 25 miles south of Hudson Bay. From the forestry standpoint they are interested in it when it affects the growth of trees. Deep frost 10 or more feet down does not affect tree growth and consequently is not permafrost to them. Dr. Brown stated that the southern limit of permafrost is much farther south than 25 miles from Hudson's Bay. It is definitely as far south as 53°N.

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<u>Closure</u> (R.J.E. Brown)

I wish to point out, first of all, that for more than a decade in the Division of Building Research, National Research Council, my colleagues and I have been publishing the results of detailed observations and conclusions of specific studies in various parts of Canada's permafrost region. I can not agree, therefore, that only now has our work been extended into aspects of detail.

Dr. Radforth mentions certain difficulties which arise if we stick to definitions. I submit that definitions form an integral part of the framework of any discipline and the concepts emanating therefrom. Indeed, we have to be hidebound by definitions or our framework disintegrates and we drift aimlessly. One should consider the definitions of "definition" and "concept". The Oxford dictionary defines "definition" as: "stating the precise nature of a thing or meaning of a word". The definition of "concept" is given as: "the idea of a class of objects, general notion". In this context Dr. Radforth's definitions have not been precise, i.e., he has not stated precisely either the nature of "climafrost" or the relationship of "H factor" to permafrost; nor is it possible to do so. Rather, he has dwelt only in general notions, his boundaries being vague or non-existent because of limited field measurements and of the difficulties inherent in these terms.

Dr. Radforth speaks of "the idea of permafrost" and "the concept of contemporary frozen ground". Permafrost is not an idea. It is a physical phenomenon capable of precise definition. If we do not define it and work from the definition, we experience the difficulties in which Dr. Radforth and Mr. Korpijaakko find themselves. The term "contemporary frozen ground" presents problems. Dr. Radforth uses it to refer to permafrost of short duration as opposed to permafrost of long duration. As was pointed out in my paper, there is great difficulty in pinpointing the dividing line between them. Both are under the permafrost umbrella and should be treated as such. The term "contemporary" should not be used because all existing permafrost is contemporary.

It is true that "pereletok" and "climafrost" are terms which were coined independently and without collusion in two separate countries. I repeat the objections stated in my paper that these terms are unnecessary and incapable of definition. The term "pereletok" is used rarely in Russian permafrost literature. The number of years dividing "pereletok" and permafrost has never been stated precisely by the Russians and probably never will be. The features which the users of these terms are trying to describe are actually permafrost of short duration and should not be separated from the permafrost.

I object also to the contention that definition is secondary. If a condition or feature is given a name, the name has to be supported by a definition whether it is descriptive or generic. It is oversimplifying the situation to state that the "ancient condition" arises from temperature (presumably air temperature) as opposed to "contemporary conditions" (by which it is implied that they result from some other factor). Actually the causal factors are many in number and complex in their interrelations. Some so-called "ancient permafrost" was formed by factors other than temperature, and some so-called "contemporary conditions" of frozen ground have arisen from air temperature.

In the definition of permafrost, the important factor is the temperature of the ground, not the duration of this thermal condition or the soil type. If there are 8 feet of peat and 2 feet of ice at a temperature of 31°F, the engineering properties of this ice are no different whether it is 2 years old or 200 years old. In either case, the ice is permafrost but it will melt if disturbed.

With regard to the "H factor", Dr. Radforth states that "we should not confuse observations with conclusions". My contention is that he and Mr. Korpijaakko are creating just such confusion in attempting to correlate the southern limit of permafrost with the "H factor". They have drawn their conclusions on the basis of too few observations and in the face of the fact that in many areas no such correlation exists.

In his discussion, Dr. Radforth denies stating that "H factor" causes ice. I did not say that he stated this, but the implications in his original statements are sufficiently strong to require further comment. In 1964, he stated that "It has been observed that the lichens in the muskeg only appear north of the permafrost line... There appears to be some peculiar relationship between the occurrence of lichens and the rates of evapotranspiration in various areas; this needs to be explored." (Harwood and Radforth, 1964, p.10). Repeating from my paper, "this statement implies that the existence of permafrost is dependent on one of several characteristics of the lichen, or that lichen is an indicator of some other condition which permits the existence of permafrost - this condition being able to exist only in the presence of lichen. Conversely, there is the implication that lichen in bogs cannot exist without the presence of permafrost". In studying the relation between permafrost and the "H factor", Dr. Radforth and Mr. Korpijaakko must not forget that the "H factor" does not stand alone. It must be considered as only one feature of a complex dynamic environment.

I should like to elaborate on my reply to Mr. McEwen's statement. The presently known southern limit of the permafrost region in Ontario occurs as far south as 53°N. Future field observations may in fact reveal that permafrost occurs south of this parallel west of James Bay. The permafrost at the southern limit occurs mostly in the relatively drier portions of peatlands - peat plateaux, ridges and hummocks, spruce islands and palsas. The areal extent of permafrost areas varies from patches of a few feet in size to islands extending over several acres. The depth to the permafrost at these locations varies from as little as 1-1/2 feet to 5 or more feet depending primarily on the thickness of the moss cover. The permafrost may vary in thickness from a few inches to more than 10 feet. In addition to this type of permafrost, there are bodies of erratically distributed relic permafrost occurring at greater depths. The latter type of permafrost may not affect tree growth. The former type near the ground surface probably influences tree growth in peatlands, a situation which would be of significance to the pulp and paper industry. Surely it would be useful to the forester to know the location of the southern limit of permafrost.

## IV.1. TRAFFICABILITY OF ORGANIC TERRAIN

K. Ashdown and N. W. Radforth

Abstract

Trafficability of organic terrain is regarded as a changeable concept, which will vary as off-road vehicles become more sophisticated and efficient. In this regard, the use of wheeled vehicles in certain types of muskeg is now becoming gradually accepted. Trafficability of the terrain is dependent upon certain variables which must be quantitatively assessed: bearing capacity, moisture content and terrain roughness. The degree of humification of the peat is also an important factor in the ability of the terrain to withstand traffic and should be assessed quantitatively.

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## IV.1. LA TRAFFICABILITE DES TERRAINS ORGANIQUES

K. Ashdown et N. W. Radforth

Résumé:

La trafficabilité des terrains organiques est considérée comme étant un concept variable, qui change au fur et à mesure que les véhicules "tout-terrain" deviennent plus compliqués et plus efficaces. A ce point de vue, l'emploi des véhicules sur roues est accepté graduellement pour certains genres de muskeg. La trafficabilité du terrain dépend de certaines variables qui doivent être établies quantitativement: la capacité portante, la teneur en eau et la rugosité du terrain. Le degré d'humidification de la terre noire est aussi un facteur important dans la capacité du terrain à supporter la circulation et devrait être établi quantitativement.

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Off-road mobility of vehicles is a matter of interest to a number of military and commercial organizations concerned with transportation of men and materials in many areas of the world characterized as organic terrain.

Many novel modes of locomotion and vehicle configurations have been introduced in recent years to meet particular requirements or to enhance the versatility of existing vehicles, but routinely successful negotiation of organic terrain, without recourse to route deviation and without risk of immobilization, is not yet possible.

Most innovations have resulted from an increasing qualitative appreciation of the trafficability of organic terrain and the reliability of this basis for development is exemplified by papers presented at this Conference by other members of O.A.T.R.U. One is devoted, in part, to a proposal that certain qualitatively revealed critical terrain factors now be expressed in quantitative terms so that vehicle design can be successfully optimized (Siddall et al, 1965). Another describes development of a density and moisture meter (Radforth and Radforth, 1965) to be used to quantify factors which until now could only be judged qualitatively or at best quasi-quantitatively. However, during the period of development of a "rational empirical approach" to vehicle design or measurement techniques, which also promises to be a period of ever-increasing need for activity on organic terrain, there should also be an expansion and refinement of qualitative methods of assessing trafficability.

Not only will the number of successful applications of less-than-optimum vehicles be improved, but contributions will be made to predominantly quantitative programmes of development by the identification of further problems in need of that kind of research and the emergence of possible extensions of instrumentation procedures already adopted as a result of qualitative observations made in the past.

A number of land factors, cover formulae, 30,000 ft. altitude air form patterns and expected vehicular performance have been tabulated in the course of investigations by O.A.T.R.U. members (Radforth, 1960) and in some cases it is a kind of semantic exercise to determine which are trafficability factors and which are properly dealt with under the heading of vehicle mobility.

Access hazards such as ice or rock inclusions and tree fall render an area less trafficable in proportion to the mobility; ruggedness and 'ride comfort' possessed by a vehicle and failures are either mechanical or the result of inadequate design. Other factors present difficulties which are not only initially bad but grow worse with continued traffic and these are considered here under the heading of trafficability. Some factors in this category, however, may not continue to present difficulty if vehicle design improves.

At present it is obvious that the trafficability of "ponded terrain" is low and that a succinct description of vehicle performance has to be "total subsidence, high deviation rate", but it is conceivable that this kind of terrain might provide few problems for air-cushion, screw-propulsion or cable-operated vehicles.

Trafficability of organic terrain must therefore be regarded as a changeable concept.

As recently as 1959-60 it was possible to cull from the literature such statements as "peat, muck, swamp soils and so on, are practically always impassable for all except light amphibious-type vehicles" (Anon. 1959). "All muskegs, even although only a few inches deep are impassable to wheeled vehicles" (Thomson, 1960) and "conventional off-road wheeled vehicles are, except in extremely rare cases, completely immobilized by six inches of muskeg" (Nuttall and Thomson, 1960).

In 1962 O.A.T.R.U. examined the performance of two light vehicles, the Jiger and the Fisher, both fitted with low pressure tires, the latter vehicle having sixteen wheels attached to rolling tracks, and found that they could traverse all muskeg where brush or trees did not provide hindrance (Radforth, 1962).

In 1963 a large-wheeled, articulated-frame logging vehicle was found to cope so well with conditions (Radforth, 1963) that three such vehicles were tested the following year together with a standard Jeep and a four-wheel drive Volvo utility truck (Radforth, 1965). All vehicles were deliberately immobilized in tests, but the number of accidental immobilizations was surprisingly low and attributable in many cases to poor route selection or terrain assessment on the part of drivers who had had no previous experience of organic terrain.

Because there is advantage in using wheeled vehicles in areas where organic terrain occurs as significant interruptions in the landscape, there is incentive to pursue the successful application of wheeled vehicles to travel on muskeg. Preliminary findings still place driver instruction and proper route selection at the head of requirements, but it is also known, in a qualitative way, that tire size, pressure and tread configuration have some effect upon mobility. If proper changes are made, the ability of muskeg areas to sustain traffic by improved wheeled vehicles will be much different from that which encouraged the views expressed five years ago.

## Bearing Capacity

Most initial studies of trafficability of muskeg commence with some attention to bearing capacity and methods of measuring it. Field and laboratory tests of consolidation (Schroeder and Wilson, 1962), or shear strength (Thomson, 1960), have been made and have been related to vehicle performance, in terms of sinkage or drawbar pull efficiency, with varying degrees of success. Interpretive difficulties imposed by the effect of variations in fibrosity and moisture content are recognized, and it is agreed that the Radforth classification system is useful in providing qualitative appreciation of these factors (ibid), but little has been done to exploit their implications to the full.

It is recognized that the terrain is often a two-layered system and that the success of many vehicles depends upon the strength and integrity of the surface mat (which is composed of living and recently incorporated fibrous vegetal components) or that, if a vehicle possesses adequate 'sinkage tolerance', advantage may be taken of the often-encountered increase of shear strength of peat with depth. Little has been done to ascertain the range of values which may be ascribed to such factors as tensile or shear strength of individual and aggregated fibrous elements, mesh density, and mat integrity in terms of these factors. And apart from initial studies (Radforth and Ashdown, 1962) which reveal that the shear strength of peat does not invariably increase with depth from one horizontal zone to another, ranges of values have not been fully ascertained.

During O.A.T.R.U. tests some vehicles foundered in patches of I in an area of FI. The moisture regime was quite uniform throughout the area and the strengths of fibrous elements of F and I are quite similar, but the orientation, degree of interlock, mesh density and consolidation characteristics of underlying peat are known qualitatively to be quite different.

Moisture content affects the strength of fibres of the mat and the behaviour under stress of underlying peat, but the amount of free water at the surface of muskeg is not always an indication of bearing capacity or trafficability. A flooded condition may be temporary and the permeability of subsurface peat such that its moisture content and consolidation characteristics remain unaffected. A semi-arid surface condition can also be deceptive. Subsurface peat can be relatively wet or dry. Broadly speaking, wet peat remoulds easily, dry peat is friable and compressible, but the extent of either form of response to stress depends upon the kind of peat. Sixteen categories have been suggested (Radforth, 1955) with differences based upon qualitative assessment of degree of fibrosity, woodiness or non-woodiness of fibrous elements and granularity.

If quantitative values of, say, density and moisture content or consolidation characteristics can be reliably related to qualitatively assessed categories, quantification of peat structure need not be attempted.

Terrain roughness is a factor which has received consideration from a vehicle mobility viewpoint (Bekker,1956) that is, consideration of the restrictions on mobility that might arise from lack of climbing ability, inadequacy of track and suspension systems or ride comfort, and also from the point of view of soils trafficability in which the larger forces that have to be imparted to the soil in order to maintain locomotion are considered as having a negative effect. Roughness of organic terrain presents a slightly different problem.

In EI the centres of mounds are firmer than intervening channels and hollows because they are formed of woody concentrations of stems, branches, roots and, in some seasons, ice, while the hollows are generally occupied by mosses, bare peat or water. If mounds are contiguous, a vehicle may span several and the trafficability of the terrain will be that provided by the firm fibrous aggregation.

A similar situation arises in FI and DI where hummocks or tall bushes provide localized firm points. If a vehicle can span these points, or, in the case of DI, break down the brush cover, it may not encounter the soft intrusions.

Usually several passes may be accomplished with slight rolling and pitching in each of these areas, but eventually the trafficability of the hollows will become limiting. The pitching grows, the vehicle impacts upon the softer areas more and more forcibly, remoulding or displacing the peat or moss, and eventually founders.

The surface roughness meter described in another O.A.T.R.U. paper (Siddall et al, 1965) may be used to predict frequency of occurrence of failure by equating irregularities with existing bearing strength differentials or with the likelihood of vehicle-induced differentials.

Vehicle-induced bearing strength differentials may also occur in level areas where the surface mat overlays relatively fluid peat and surface waves precede a vehicle or occur beneath its tracks or wheels. Fibrous elements are alternately flexed and the degree of interlock and mesh density are reduced so that on subsequent passes the vehicle relies more and more on the support, if any, provided by the underlying peat.

Trafficability may be interpreted as an expression of ability to withstand deterioration. As peat, in its natural state, is organic material which has undergone a certain amount of deterioration in structure through microbial or mechanical action, it would seem logical to assess the degree of humification as a trafficability factor. Qualitative and quantitative methods are available and may find application.

All qualitative assessments of trafficability of organic terrain derive from repeated observations of terrain-vehicle relationships and are therefore expressions of probability based upon subjective sampling. If quantitative data are obtained, they will, in many cases, be both susceptible to and in need of statistical treatment before application.

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REFERENCES

Anonymous. Soils Trafficability. Dept. of the Army, TB Eng 37, Washington, D.C. 1959.

Bekker, M. G. Theory of Land Locomotion. U. of Michigan, Ann Arbor, 1956.

Nuttall, C. J. and Thomson, J. G. Design and muskeg operations of the 20-ton payload carrier: The Musk-Ox. S.A.E. San Francisco, 1960.

Radforth, N. W. Range of structural variation in organic terrain. Trans. Roy. Soc. Canada, Series III, Sect. V, Vol. XLIX, 1955.

————————. Land factors and vehicle design in operations on organic terrain. Proc. 1st Int. Conf. on Soil-Vehicle Systems, Turin, 1960.

————————. Small high-mobility vehicles. O.A.T.R.U. Research Report, D.R.B. Ottawa, 1962.

————————. Project 'Timberjack'. O.A.T.R.U. Research Report. H.E.P.C.O. Toronto, 1963.

————————. Project 'Hi-Move'. O.A.T.R.U. Research Report. D.R.B. Ottawa, 1965.

———————— and Ashdown, K. H. Design in organic terrain and its effect on trafficability. I.S.T.V.S. Conf. Durham, 1962.

———————— and Radforth, J. R. The significance of density as a physical property in peat deposits. Proc. XIth Muskeg Res. Conf. Ottawa, 1965.

Schroeder, J. and Wilson, N. E. The analysis of secondary consolidation of peat. Proc. VIIIth Muskeg Res. Conf., Tech. Memo. 74, NRC-ACSSM, Ottawa, 1962.

Siddall, J. N., Newcombe, W. R., Ghosh, K. and Radforth, J. A rational empirical approach to vehicle design. Proc. XIth Muskeg Res. Conf. Ottawa, 1965.

Thomson, J. G. Vehicle mobility performance in muskeg: a second report. Proc. Vth Muskeg Res. Conf., Tech. Memo. 61, NRC-ACSSM, Ottawa, 1959.

————————. Vehicles in muskeg. Eng. Journal, May, 1960.

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Discussion

Mr. Ashdown was asked about the pressure in the low pressure tires of the wheeled vehicles to which he referred. He replied that for the 16-wheeled vehicle it was perhaps 1 to 2 psi, for the Jiger it was 5 psi.

Professor Bayer asked if there was any correlation between the speed of a vehicle and trafficability over a given terrain type. Mr. Ashdown said that speed tests were not carried out to observe the effect on the terrain. Rather, they were carried out to obtain the acceleration characteristics of vehicles. This is a vehicle mobility consideration.

Professor Haas wondered about the effect of seasonal variations on trafficability, i.e. spring versus summer. Mr. Ashdown replied that they are not usually on the ground in any formal way before the end of June. The water table is observed, however, although he believed that the surface water is no indication of trafficability. As yet O.A.T.R.U. have not gone to the extremes of season to determine the trafficability on a year-round basis.

Dr. Radforth referred to the immobilization of the "Water Buffalo" in a muskeg near Parry Sound. Despite the fact that it was down 7-8 feet at the back, it was able to winch itself out. He emphasized the importance of this ability of a vehicle to extricate itself from embarrassing situations. Dr. Radforth stated that when one examines the seasonal factor, he should be aware of thermal factors in the terrain which do not show up in summer. The seasons of the year should actually be considered in the design of a vehicle because certain seasonal factors will limit design.

Professor Niemi remarked that the tractive effort increases with frost. He wondered about the change in tractional effort with depth. Mr. Ashdown said that it has been found by J. Thomson of Imperial Oil Ltd. that there is greater tractive effort with depth. Mr. Nuttall is of the same philosophy. The sinkage tolerances must be designed to enable the vehicle to reach peat with a greater sheer strength. The "Musk-Ox", for example, can travel with a 53-inch sinkage.

## IV.2. A RATIONAL EMPIRICAL APPROACH TO MUSKEG VEHICLE RESEARCH

J. N. Siddall, W. R. Newcombe, J. R. Radforth
and K. K. Ghosh

Abstract

A basic purpose in muskeg vehicle research is the establishment of criteria which will permit the design of optimum vehicles. A rational empirical approach to this problem indicates that a substantial amount of development work is required for adequate instrumentation on all levels of sophistication. The statistical nature of terrain is recognized, although this greatly complicates the amount of measurements that are required. It is suggested that vehicle performance can be predicted on the basis of probabilities. The final and greatest problem is synthesizing the best configuration which will produce an optimum vehicle.

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## IV.2. UNE APPROCHE RATIONNELLE EMPIRIQUE DE LA RECHERCHE SUR LES VEHICLES SUR LE MUSKEG

J. N. Siddall, W. R. Newcombe, J. R. Radforth
et K. K. Ghosh

Résumé:

L'établissement d'un critère qui permettra le "design" des véhicules optimum est le but premier de la recherche sur les véhicules. Une approche rationnelle empirique de ce problème indique qu'un travail substantiel est requis pour développer une instrumentation adéquate à tous les niveaux. La nature statique du terrain est connue, bien que cela complique grandement les nombreuses mesures requises. On suggère que la performance des véhicules peut être assumée par les probabilités. Le dernier et le plus grand problème est de faire la synthèse des meilleures configurations qui produira un véhicule optimum.

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Our basic purpose in muskeg vehicle research is the establishment of criteria which will permit us to design optimum vehicles. An optimum vehicle is one giving maximum value to the user.

Our first difficulty is establishing exactly what the users' values are, just what does he desire in the way of vehicle performance, and what order of priority does he give to design variables such as resistance to immobilization, speed, efficiency, capacity, reliability, manoeuvreability, cost, and other possible important variables.

Assuming we are able to establish values, the next and equally difficult problem is that of predicting the performance of a given design to see if it satisfies the desired values. Given a certain vehicle configuration, what mobility will it have in various types of muskeg, what efficiency will it have, what load carrying capacity will it have, what will its cost be, and so on?

Assuming finally we have established values, and have established means of predicting performances, the final problem, and again a very difficult one, is synthesizing the best configuration which will make possible maximum satisfaction for the customers' desires, or in short, give us an optimum vehicle.

Establishment of users' values

The first thing we must say on this point is that there is no one set of users' values. A logging company, for example, puts different emphasis on various design characteristics than the oil well driller, the electric utility user, the army, the agricultural user, and so on. It is therefore difficult to generalize. There are some variables, however, which most users would agree are dominant variables. Resistance to immobilization, for example, would be the most important variable to most users. Efficiency of operation and high capacity would also be important variables to many users. On the other hand, variables such as high speed might be much more important to the army than to commercial users. The researcher's only practical approach is to examine these variables separately, and attempt to determine the performance of a given vehicle configuration in terms of each variable separately. This is feasible to a considerable extent. There may be some interaction, however, between variables to complicate the problem.

The researcher, then, can, to some extent, ignore the relative importance of major design variables as long as he identifies the important ones. The designer, however, can not take this easy way out, and must make intuitive decisions for each individual application or user as to the relative importance of the major design variables.

Proposed major design variables of concern to the researcher are formally itemized as follows:

(a) Single-pass immobilization on various homogeneous muskeg areas
(b) Multiple-pass immobilization on various homogeneous muskeg areas

(c) Vehicle mobility on associated inorganic terrain
(d) Maximum draw-bar pull
(e) Maximum speed
(f) Vehicle ride
(g) Manoeuverability
(h) Ride
(i) Reliability
(j) Life
(k) Serviceability, or convenience in maintenance and repair
(l) Specific fuel consumption
(m) Capacity
(n) Seaworthiness and manoeuvreability on water

Prediction of vehicle performance

The prediction of vehicle performance may occur at four different levels of sophistication. The lowest level is purely qualitative and is knowledge gained by observation and testing of many different vehicles in many different types of muskeg. Information is most valid if this testing is done in a highly systematic way and correlated, at least qualitatively, with simple quantitative measurements such as cone penetrometer and subsidence readings. This experience can give very valuable insight into the mobility of vehicles in muskeg. The results are limited, however, to relatively few of the dominant variables mentioned above. Principal among these are single-pass immobilization in muskeg, multiple-pass immobilization, and mobility in associated inorganic terrain.

The second level of sophistication in predicting vehicle performance is partly quantitative and empirical. It is a trial-and-error technique using measured terrain properties as a control.

The third level is still empirical but almost wholly quantitative,and uses the techniques of simulation and dimensional analysis.

Perhaps the ideal approach to muskeg vehicle research is implied by the science of terramechanics where sufficient basic information is obtained and physical relationships established so that mathematical models can be set to represent vehicle performance and be used in its prediction. It is the most powerful approach, if it is feasible. The ideal has been reached to a considerable degree in the design of aircraft, spacecraft, and ships. There is considerably less hope of success for land vehicles.

It is probably true to say that only the first level of sophistication in muskeg vehicle research has been reached to date. We shall give below some of the results that have been obtained from this work, presented in a systematic manner. We shall also go into more detail on the approaches that might be used in the higher levels of sophistication.

(1) A Qualitative Prediction of Vehicle Immobilization in Muskeg

This section is an attempt to describe in specific qualitative terms the nature of vehicle immobilization in muskeg. It illustrates clearly how difficult it will be to predict immobilization from a mathematical model. It does, however, provide a useful qualitative basis for design. It deals only with one dominant variable - immobilization. Much additional test work is needed to expand our qualitative understanding of vehicle mobility in different types of confined and unconfined muskeg in different seasons and latitudes.

Terrain Factors Which Can Initiate Immobilization

A. Widespread type factors.
    1. Low ground bearing capacity - usually combined with high water level.
    2. Dense shrubbery, or trees or both.

B. Boundary type factors.
    1. Boundary lagg in confined muskeg, drainage channels.
    2. Mat edge bordering on open water.

C. Local type factors.
    1. Soft spots.
    2. Stumps, sporadic shrub and tree growth.

It is important to note that each of these initiating terrain factors is strongly linked to one or a combination of various aspects of vehicle geometry, weight, ground pressure, behaviour and driver training and experience.

Vehicle Factors Which Can Contribute to Immobilization

1. Weight and power
2. Ground pressure
3. Approach angle
4. Method of steering
5. Articulation or lack of it
6. Track or tire geometry
7. Belly height and width
8. Buoyancy or relation of water line to horizontal centre line of undercarriage
9. Protection of delicate parts
10. Speed
11. Amount of sustained traffic
12. Driver skill

## Interaction of Terrain and Vehicle Factors

### Terrain Factor A

For most vehicles this category is made up of large areas of high probability of immobilization. For A1, critical vehicle features are likely to be ground pressure, method of steering, track approach angle, belly height and width, and amount of sustained traffic. For A2, most critical vehicle factors are weight and power, track approach angle, articulation, and lack of protection for delicate parts. In spite of the very best current vehicle design, immobilizations are frequent and often the only solution is rerouting.

### Terrain Factor B

These are obstacles occurring in a restricted, specialized, characteristic form. Successful negotiation of these obstacles is dependent to a great extent on vehicle geometry. For terrain factor B1, the important vehicle factors are track approach angle, track length, and speed. Driver skill can be a critical factor in B1. With a light vehicle, such as a Weasel*, it is often better to use speed rather than caution in crossing a drainage channel or lagg, as the vehicle's momentum tends to carry it forward where traction is lost. Heavy vehicles, such as the Water Buffalo, may be incapable of sharp bursts of speed, but often have the necessary track length to bridge the gap. When negotiating terrain factor B2, the important vehicle factors are ground pressure, track approach angle and the buoyancy or relation of water line to track height.

### Terrain Factor C

Factor C1 consists of soft spots characterized by I, FI cover and high water level. They can be avoided without too much difficulty if the driver is trained to recognize them. The amount of sustained traffic is an important consideration in negotiating soft spots. Ground pressure is also critical. For terrain factor C2, which consists of stumps and local trees or shrubbery, critical vehicle factors are articulation, ground clearance, and lack of protection for delicate parts. Articulated vehicles, such as the Rat, can be immobilized by a stump between the two sections of the vehicle. When this occurs, the vehicle can move neither forwards or backwards until the stump is removed.

## Where, When and How Vehicles Immobilize in Muskeg

Terrain Factor A1 - initiating factor is low ground bearing capacity.

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* Description of vehicles referred to can be found in Siddall, 1962.

| | | |
|---|---|---|
| Where | Light tracked vehicles on BEI, FEI, EFI, FI, EI, BFI and I* | Heavy tracked vehicles on BEI, FEI, EFI, FI, EI, BFI, I |
| | These areas must be wet enough so that free water comes to the surface when a man stands on the muskeg. | |
| When | Rarely on first pass except on I cover or no cover | Often on first pass in wet I or FI. Sometimes on first pass on others if very wet |

How Vehicle subsides a few inches because of low bearing capacity of soil. Rolling resistance is increased by this subsidence. Greater shear force is exerted by tracks on the mat. The mat begins to break down and slipping of tracks on the mat increases. Once slipping starts, forward progress of the vehicle decreases very quickly. Slipping tracks destroy the mat quickly, ground bearing strength decreases, and the vehicle subsides still more. The Weasel, Rat and other small buoyant vehicles may swim through the muck created, and also through very wet amorphous granular peat. The Water Buffalo makes no forward progress when the top run of tracks sinks below the peat surface.

Terrain Factor A2 - difficulty is dense shrubbery and trees.

| | | |
|---|---|---|
| Where | Light tracked vehicles on DFI, DEI, BDE, ADE, AEI, BFI | Heavy tracked vehicles on ADE and AEI (except Water Buffalo) |

When Always on first pass. If not on first pass, vehicle continues with decreasing difficulty.

How Vehicle does not have sufficient weight or power or both to force its way through the vegetation.

Terrain Factor B1 - obstacle is boundary lagg or drainage channels.

Where On the boundary of confined muskeg or water channels in muskeg.

When Immobilization may occur on the first pass or after several passes.

How Inappropriate track length, height, or approach angle, or both, can cause the vehicle to butt its front end against the bank of the lagg channel, stopping forward movement. On attempting to traverse, the vehicle loses traction and digs itself in. Also after several passes, ruts tend to develop at the crossing point, the vehicle's belly drags, the vehicle loses traction and digs itself in.

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* Cover classifications are found in Radforth, 1952.

Terrain Factor B2 - mat edge bordering on open water.

Where Boundary between open water and soft peat mat, where a sharp drop or bank may occur below the surface of the water.

When First attempt

How Assuming the vehicle is amphibious, it approaches the edge of the mat from open water. The waterline on almost all known tracked vehicles is above the top run of the tracks, and the front of the vehicle body projects beyond the leading edge of the tracks. When the vehicle reaches the edge of the mat, the front of the body butts against the edge of the mat and the tracks fail to reach the mat. It would seem that this type of failure could be consistently eliminated by appropriate vehicle design.

Terrain Factor C1 - soft spots

Where In FEI, and particularly IF.

When Light vehicles on second or third pass. Heavy vehicles on first pass.

How See A1. Heavy vehicles, even with low ground pressure, tend to become immobilized in the immediate vicinity of soft spots, as well as directly in the soft spots.

Terrain Factor C2 - stumps, sporadic shrub and tree growth.

Where In DFI, DEI, BEI.

When On first pass with light articulated vehicles.

How Stumps get caught on between the two sections of light articulated vehicles such as the Rat. The vehicle cannot move forward or backward until the obstacle is removed. This type of failure can be controlled by driver skill and experience.

(2) The Controlled Evolutionary Approach to Prediction of Vehicle Performance

In this approach, only one vehicle parameter at a time is varied and its effect on various vehicle performance variables determined quantitatively. A simple example would be ground pressure on a tracked vehicle. This could be done with either a group of existing vehicles or with a special experimental vehicle. An important aspect of this approach is the use of instrumentation to give control of the test environment. In order to have full control of the testing, one must measure environmental variables such as density, moisture content, roughness and dynamic response of the muskeg surface so that a given test can be consistently repeated and be compared with different future tests in the same environment. It is also necessary to measure

## MATRIX OF MODES OF FAILURE IN MUSKEG TERRAIN FACTORS

| | A1 General low ground bearing capacity, usually associated with high water level | A2 Dense Shrubbery and/or trees | B1 Boundary lagg in confined muskeg and drainage channels | B2 Mat edge bordering on open water | C1 Soft spots I and FI and high water level | C2 Stumps, sporadic shrubs and tree growth |
|---|---|---|---|---|---|---|
| 1. Weight and power | | X | | | X | |
| 2. Ground pressure | X | | | X | X | |
| 3. Track approach angle | X | X | X | X | | |
| 4. Method of steering | X | | | | | |
| 5. Articulation or lack of it | | X | | | | X |
| 6. Track length | | | X | | | |
| 7. Belly height and width | X | | | | | |
| 8. Buoyancy and relation of track height to water line | | | | X | | |
| 9. Protection for delicate parts | | X | | | | X |
| 10. Lack of speed | | | X | | | |
| 11. Number of passes | X | | | | X | |
| 12. Driver skill | | | X | | | |

vehicle performance with similar quantitative consistency. Such measurements would include maximum speed, subsidence, draw bar pull, turning radius, fuel consumption, vehicle pitch, roll and jerk, and possibly many others. This approach is perhaps the highest level of sophistication which is feasible with the present state of the art. It is a relatively powerful approach which requires very exhaustive testing, not only with different parameters, but with different vehicle configurations. The measurements involved in the testing will be on a very large scale and probably require quite sophisticated data processing techniques. The development of instrumentation for measurement of the test environment and the vehicle performance is in itself a major research program. The choice of variables to measure is, at this level of sophistication, largely a matter of intuition. We shall discuss the nature of some of these measurements in more detail in a later section.

(3) Simulation and Dimensional Analysis Approach to Vehicle Performance Prediction

The use of simulation by models has been proposed (Bekker, 1956) and used (Nuttall and McGowan, 1961) to predict the performance of full-scale prototypes operating on conventional soils. This model testing is commonly done in soil bins, analogous to the wind tunnels used in aeronautical work and the towing basins used for testing ship models. Because of the special nature of muskeg and peat, however, it is impractical to set up soil bins with these materials and simulate the performance of models in muskeg. It is even doubtful whether models could successfully be used in field testing in muskeg because of the scale effects of the peat material itself. Simulation and dimensional analysis can, however, still be used successfully by essentially full-scale testing of vehicles in muskeg.

A major difficulty of rational vehicle testing in organic terrain is the multitude of variables involved in trying to generalize relationships empirically. Dimensional analysis is well known as a mathematical tool useful for reducing the effective number of variables, and reducing the number of tests needed to define relationships. It is a means of organizing and rationalizing an empirical approach. This approach could be used as a basis for empirical testing of muskeg vehicles. For illustration, the only vehicle type presently considered will be the tracked vehicle. Also for illustration, we shall consider only two performance characteristics of the vehicle. The first assumes that a given vehicle is not subject to immobilization on a given terrain, and we are interested in predicting its maximum speed, $V_m$. The criterion for maximum speed will be the amount of pitching that the driver and passengers can tolerate. Since this is a subjective criterion, it would be desirable to establish a maximum allowable jerk (rate of change of acceleration) that, say, 90% of persons tested can tolerate. Such a quantity could then be measured with instruments.

The second mode of operation that we might investigate is immobilization. On a given terrain, we wish to be able to predict what maximum ground pressure a given vehicle may have before immobilization occurs. For some vehicles, in some terrains the critical pressure is exceeded even by an empty vehicle, so our prediction will also tell "go" or "no go". This could be extended to immobilization after a given number of passes. Owing to the complexity of the problem, variables must be discarded as ruthlessly as possible. Or, alternately, we must put severe restrictions on the scope of validity of the empirical curves. We must begin by applying judgment based on past experience, and use later tests to verify and modify our judgments.

It is clear that this is a problem in vehicle dynamics, so that the mass and suspension characteristics of the vehicle will be significant. It also seems likely that, uniquely for muskeg, the mass and elastic properties of the terrain are significant. This is indicated by the ground waves observed in muskeg. We let the maximum vehicle speed be $V_m$.

The vehicle design variables or parameters are assumed to be:-

geometric - $l$ = track length
- $b$ = track width

inertia - $M$ = mass of vehicle

suspension - $k_v$ = spring rate

We are neglecting here the following possible significant design features:-

(1) Angle of approach
(2) Location of sprocket
(3) Proportion of mass that is unsprung
(4) Possible effect of shock absorbers
(5) Location of centre of gravity

It may be, for example, that different sets of curves must be used for a vehicle having no angle of approach than for one with an angle of approach. In particular, it is well known that shock absorbers appreciably control pitching. Systematic tests in conjunction with the dimensional analysis approach are a good means for evaluating the significance of these features.

We are also assuming that mass moment of inertia can adequately be expressed in terms of $Ml^2$; and that the suspension moment or pitch spring rate can adequately be expressed in terms of $kl^2$.

The terrain variables are assumed to be:-

geometric - h = mean double amplitude of surface variations in a given terrain

inertia) elastic) $f_t$ - natural frequency of muskeg surface

It is clear that terrain variables are going to be the most difficult to measure and judge for significance. It may be doubted that terrain geometry can adequately be represented by a single quantity. An instrument must be devised that will quickly and easily determine this quantity. Just as doubtful is the representation of the elastic and inertia properties of the muskeg by a single quantity. It may even be doubted that muskeg can be considered completely elastic. Again, a new technique must be devised for measuring the terrain natural frequency. The area included in the measurement should be large enough to average out variations in peat properties to the same degree that the vehicle does. The concept of a terrain natural frequency will be discussed in a later section.

It is recognized that there is more than one maximum speed mode. For example, the limitation may not be due to pitch but rather to drag of trees which must be pushed over. This mode would require a different set of graphs.

The variables to be analyzed dimensionally are then

$$V_m, \ l, \ b, \ M, \ k_v, \ h, \ f_t \ .$$

Following the techniques of dimensional analysis, we could arrange them in the following independent dimensionless groups.

$$\frac{V_m}{l} \frac{M^{1/2}}{k_v^{\ 1/2}} , \ \frac{h}{l} , \ \frac{l}{b} , \ \frac{f_t^{\ 2} M}{k_v}$$

The dependent variable, $V_m$, may be expressed in terms of the others as follows, where f is a function

$$V_m = \frac{l k_v^{\ 1/2}}{M^{1/2}} \ f \left( \frac{l}{b} , \ \frac{h}{l} , \ \frac{f_t^{\ 2} M}{k_v} \right) \qquad (1)$$

Sensitivity of the dimensionless variables is estimated to be in the following order, from greatest to least,

$$\frac{h}{l} , \ \frac{l}{b} , \ \frac{f_t^{\ 2} M}{k_v}$$

On rigid ground, only $\frac{h}{l}$ and $\frac{l}{b}$ would be significant.

The results of test might be plotted as shown in Figure 1.

This one set of curves would be valid for all terrain having the same roughness, mass and elastic characteristics. Note that from testing one vehicle we could get one curve of the above set. But that curve would be valid for <u>all</u> vehicles having the same l/b ratio. Of course, one vehicle might not give the complete range for all vehicles.

Immobilization Mode

We shall assume again that vehicle and terrain dynamics are significant. The velocity of the vehicle will also affect its dynamic behaviour. We thus have all the same significant variables as before. However, velocity will now be fixed at some arbitrary value, say 3 m.p.h. In addition, we must include some variable expressing the strength of the mat. This could be a shear failure or a compression failure. It may be possible to devise a single field test which will yield a quantity proportional to mat strength, and will automatically yield shear strength if it is critical, or compression strength if it is critical. We shall assume this is possible and designate a mat failure stress, s, in p.s.i. It further would seem that we must somehow take into consideration the "softness" of the peat. This softness is closely related to the slope of a load-deflection curve in a localized measurement of the peat strength properties. It will be closely related to the measurement of s. We shall designate this variable $E_t$, a "modulus of elasticity" with dimensions of $lb/in^2$. This concept will be further explored in our discussion of instrumentation in a later section. Since we are now concerned with vehicle weight, which governs ground pressure, we must introduce g, the acceleration due to gravity.

The variables to be analyzed dimensionally in this case now are

$$s,\ l,\ b,\ M,\ k_v,\ h,\ f_t,\ g,\ E_t$$

Using the techniques of dimensional analysis, we can obtain the following dimensionless groups,

$$\frac{gM}{bls}\ ,\ \frac{l}{b}\ ,\ \frac{h}{l}\ ,\ \frac{{f_t}^2\ M}{k_v}\ ,\ \frac{s}{E_t}\ ,\ \frac{k_v}{sl}$$

In this case the dependent dimensionless variable is $\frac{gM}{bls}$, since it contains $\frac{gM}{bl}$, which is ground pressure, the quantity we wish to determine. Thus we let $p = \frac{gM}{2bl}$ = critical ground pressure at which immobilization occurs.

The ground pressure may be expressed in terms of the others as follows

$$p = \frac{s}{2}\ f\left(\frac{l}{b}\ ,\ \frac{h}{l}\ ,\ \frac{s}{E_t}\ ,\ \frac{k_v}{sl}\right) \qquad (2)$$

where f is a function.

We would now get curves of the type shown in Figure 2.

Attempts have been made to correlate one terrain parameter with immobilization of a given vehicle. One approach of this type has been to use the cone penetrometer reading (U.S. Army, no date), a difficult measurement to rationalize. The dimensional analysis approach attempts to take into consideration more terrain parameters, and as well, generalize the tests on one vehicle to be applicable to all vehicles of basically similar configuration. The cone penetrometer tests are usually intended to provide information useful for operation of a given vehicle, in the hope of predicting if it will negotiate a given terrain without immobilization. If the dimensional analysis approach is successful, it will do this, and also be useful for the design of new vehicles.

The above examples of the dimensional analysis approach to prediction of muskeg vehicle performance are for illustrative purposes only - they are not intended to be definitive.

## The Mathematical Model Approach

The topic of this paper is empirical approaches to muskeg vehicle research. We are therefore not concerned here with the rigorous and basic mathematical model techniques of predicting performance. Two comments, however, are in order. First, the approaches currently being used in developing the mathematical model approach to vehicle performance in conventional soils are not likely to be adaptable to muskeg terrain. Secondly, the problem is enormously difficult because of the large number of significant terrain variables of a stochastic nature, and the very many vehicle variables.

## Instrumentation

As the previous discussion indicates, the use of any of these approaches to performance prediction first requires the development of a number of new devices to measure terrain and vehicle variables.

## Terrain Variables

It is clear that some sort of statistical approach is essential in any treatment of terrain. Referring specifically to organic terrain, we can define a rough model for the muskeg. Most types have two layers, a surface mat a foot or more thick containing living plant structure growing in fossilized plants. The mat is significantly stronger than the substrata and acts almost like a membrance on a plastic base. The peat has two types of structural elements in macroscopic scale (Radforth,1952). There are woody and non-woody fibres; and there are amorphous granular particles. The fibres occur in random sizes and orientation. Their size and type depend on the nature of the cover. There appears to be a correlation between cover classification and fibre population. The fibres contribute tensile strength to the peat; the amorphous granular material provides plastic shear strength similar to clay. In addition to these primary elements, there may also occur large woody roots or even logs.

Because the fibres and other woody material occur randomly on a scale significantly large relative to any feasible material property testing technique and to vehicle dimensions, the muskeg must be treated statistically. We propose the following hypothesis:
"Each classification of muskeg, having a given water content, represents a homogeneous stable population in the statistical sense, and each physical property of the population is defined by a consistent probability distribution curve. Any statistical sample of a given classification at a given moisture content approximates this distribution."

What physical properties of the peat are significant relative to vehicle performance? How shall they be measured? We should note that, according to the hypothesis, we are defining a group of consistent materials based on cover classifications. If the hypothesis is valid, we can obtain, once and for all, physical properties as distribution curves corresponding to these materials, just as steel alloys are classified and their properties recorded. These physical properties are as follows:

(a) Water Content and Density

It is well known that water content is a physical property of basic importance. Absolute water content is perhaps not as important as a consistent relative measure of water. Water content has been recognized to occur in soils in three forms (Jumikis,1962): as free gravitational water; as capillary water either inside or outside cells; and as hygroscopic water attached colloidally to granular peat particles. The hygroscopic water can only be removed by heating above 105°C. Thus it must always be present and can, for practical purposes, be treated as dry weight. The other types of water content vary with water regime and climatic conditions.

An instrument for measuring peat density and moisture content in situ is now available (Radforth and Ashdown,1961; Radforth and Radforth,1965).

For density measurement, a probe containing a gamma radiation source and detector is inserted into the ground. Depending on the density of the material surrounding the source, a certain proportion of the radiation emitted from the source is reflected to the deflector in the form of pulses. These pulses are converted to electrical pulses by a scintillating crystal and photomultiplier tube. The electrical pulses are then counted by a scaler, and counts per minute as shown by the scaler are then proportional to peat density.

For moisture content determination, the probe contains a source of fast neutrons which are emitted into the wet peat.

When the fast neutrons collide with hydrogen atoms in the water, they give up part of their energy and become slow neutrons. Some of these are picked up by the detector and are counted in the manner explained above. Thus, theoretically, count rate is proportional to moisture content.

(b) Strength and Load Response Modulus

We should review the basic approach to the strength prediction of any material. Consider, for example, materials treated as perfectly elastic, such as metals. It is possible, by theoretical or experimental mechanics, to predict the stresses and strains in a member in a machine or structure. It is much more difficult to predict the level of stress or strain at which failure will occur. This critical level is not a fixed quantity; it varies with different distributions of stress and strain throughout the member. The approach used is to determine experimentally the critical level in the simplest possible kind of member - a simple tension specimen. This critical value is defined as a property of the material. Various theories are then used to correlate this value with the critical stresses in more complicated members. We must also define strength. In metallic members, the strength may be the critical stress or strain level at which plastic yielding occurs, or when fracture occurs, or sometimes when excessive creep occurs. Strength of a soil is more difficult to define. In fact, it can not be defined in this general way, but only in relation to a specific form of loading of the soil for a specific purpose. For example, the strength of a soil under a building is the bearing stress at which excessive sinkage occurs. This sinkage will be relatively small or the failure may be, in some circumstances, a catastrophic slip of a large body of soil. On the other hand, the strength of a soil under a vehicle is the combined bearing and shear stress at which the vehicle is immobilized or slowed excessively. The sinkage will be relatively large. Furthermore, there is an interaction between the soil displacement and the loading, so that, as a vehicle sinks, the drag or forward motion resistance is increased and the shear loading on the soil must correspondingly increase with more slip and more slip-sink. This sort of interaction occurs occasionally in machine members - examples are column instability and self-excited oscillations. This is an interesting analogy and suggests that vehicle immobilization is an instability phenomenon as well. The analogy also suggests that the load-displacement relationship of the soil is of critical importance rather than some failure stress. Thus it seems important to measure the load-deflection relationship as well as some failure stress. The analogy here is to the modulus of elasticity of a perfectly elastic material.

Now, how shall we measure these things? What simple loading configuration can we devise which will yield measurements which can be used to define the peat properties, and which can be correlated with actual vehicle loadings? An advantage exists here over the analysis of metallic machine members. The number of loading configurations and "member" geometries is limited to only a few. The usual types are illustrated in Figure 3.

Probably the most obvious simple loading configuration to use is a small flat plate loaded normal to the surface for which loads and corresponding displacements have been recorded. Such instruments have been designed for inorganic soils (Bekker, 1956), but they are larger trailer-mounted devices. In muskeg work, it would be desirable to have a small portable device. It is also important in muskeg to explore strength properties below the surface. The cone penetrometer does this but its significance is limited. It presumably gives a measure of the force corresponding to a fixed displacement - one-half the width of the cone. In a sense it gives one point, rather near the origin, on the load displacement curve for the peat. It is proposed that a sort of clamshell be devised which can be thrust to any depth, and then forced open in parallel. Opening load versus displacement would be automatically recorded as a curve on a chart. It would actually be a measure of some combination of normal and shear loading; but this is not necessarily undesirable. As we have seen, the loading configuration which defines strength of a material is arbitrary. This device has been designed and is sketched in Figure 4.

We shall define a load response modulus as a tangent of the load displacement curve at some arbitrary point.

(c) Roughness

Roughness is an important terrain characteristic which we might define as the standard deviation or arithmetic mean deviation of surface irregularities over a sampling distance. This quantity will itself be a random variable for the whole population defined by a muskeg classification.

It is postulated that each type of muskeg as classified by the Radforth system (Radforth,1952) has a typical roughness, and a preliminary investigation (Newcombe and Radforth,1965) is in progress to prove or disprove this postulation. If it is true, the roughness characteristic for each classification of muskeg can be measured once and for all. Again, due to the nature of the surface, this will have to be a statistical determination.

Surfaces in general are very complex in nature, and one needs to define what is to be measured. The surface roughness of muskeg can be defined by direct analogy to the definitions used for metallic surfaces. These are as follows:

Waviness - surface irregularities of considerable wave length of a periodic character.

Roughness- this is composed of the finely spaced surface irregularities which are superimposed on the waviness.

Roughness Height - this is the measure of surface roughness used for metallic surfaces, and it is the arithmetic average height of the irregularities above and below the mean or centreline drawn through the profile. This is a line drawn through the centre of the curve so that the area above the line is equal to the area below the line. The absolute values of the deviations are used.

It is believed that the arithmetic average roughness height of a muskeg surface will give a satisfactory and consistent representation of the roughness. It may be argued that it is necessary to determine the frequency of occurrence of the surface irregularities. As mentioned earlier in the discussion, however, it will be necessary to discard variables as ruthlessly as possible. It is assumed that the frequency of the irregularities will be consistent and that each classification of muskeg will have a typical frequency, whose effect on vehicle performance can be represented by the roughness variable in the dimensional analysis equation.

A simple device for obtaining preliminary roughness data is shown in Figure 5. This device is being used to determine appropriate sampling length, measurement interval and measurement pressure as design parameters for a more sophisticated instrument.

(d) Dynamic Properties of the Muskeg Surface

Although all soils have elasticity, muskeg terrain commonly has it to a much more marked degree. It is a grossly observable phenomena and it is reasonable to assume that there is a dynamic interaction between a vehicle and the muskeg surface. Thus, the elasticity of the muskeg surface as well as its roughness affects the dynamic behaviour of the vehicle. Strictly speaking, this dynamic interaction depends on the inertia properties or mass density of the peat as well.

It seems intuitively reasonable to measure the dynamic characteristics of the muskeg surface by mechanical admittance measurements - a common technique in vibration analysis. In this technique a harmonic or sinusoidally varying force is applied to the muskeg surface, and the corresponding displacement measured. If this response is explored over a continuous range of frequencies, most structures have one or more peak responses, called natural frequencies. Also we may expect the muskeg to have a characteristic natural frequency, which may be used as a measure of its dynamic characteristics.

We have designed a device for measuring mechanical admittance of the muskeg surface. It generates the vertical harmonic force by two contra-rotating eccentric masses driven by an air motor. The horizontal unbalanced forces cancel out, and the vertical components add up. It is sketched in Figure 6, and has the following specifications -

Total machine weight - 200 lbs.
Maximum shaking force amplitude - 190 lbs.
Frequency range - 1-1/2 to 9 cycles/sec.
Force measurement - strain gauge load cells.
Displacement measurement - accelerometer.

Vehicle Variables

We are referring here to variables defining the responce of the vehicle to the terrain

(a) Jerk - It has been shown (Dean Hartog,1956) that driver and passenger comfort is mainly a function of jerk, the rate of change of acceleration. It will therefore be desirable to devise a convenient means of measuring jerk continuously in the moving vehicle.

(b) Pitch and Roll - Angles of pitch and roll are significant variables illustrating the response of the vehicle to the terrain.

(c) Drawbar Pull - This is the useful force remaining after rolling or motion resistance has been overcome. This force is used to accelerate the vehicle, pull loads or to enable the vehicle to climb slopes.

(d) Subsidence - Subsidence is measured by taking the difference in elevations of a muskeg surface before and after a vehicle passes over it. Subsidence increases with the number of passes, and it is a terrain variable as well as being mainly dependent on the vehicle ground pressure.

(e) Turning Radius - It is a well understood fact that cross-country vehicles require a sharp turning radius. This has been provided on many vehicles by articulation. Articulated vehicles making sharp turns on muskeg show a tendency to have greater sinkage on the inside track. This is probably due to a shift of the centre of gravity of the overall unit towards the centre of the turn.

(f) Acceleration - Good acceleration is a requirement for military vehicles and should be a requirement for all muskeg vehicles. The ability of a vehicle to accelerate quickly will aid greatly in negotiating obstacles such as soft spots and drainage channels. Acceleration is proportional to draw-bar pull and vehicle gross weight.

(g) Internal Vehicle Performance Variables - Some additional vehicle variables are significant, specific fuel consumption might be used to measure operating efficiency and could have units of ton mile/gal. fuel. Carrying capacity would be most significant as a ratio of payload to curb weight.

Discussion

It is clear from the outline here of a rational empirical approach to muskeg research that a substantial amount of development work is required for adequate test instrumentation at all levels of sophistication.

It is also clear that we must accept the statistical nature of terrain variables. This complicates the amount of measurement required substantially, but it has an even more important consequence. We can only hope to predict vehicle performance on the basis of probabilities.

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REFERENCES

Bekker, M. G., "Theory of Land Locomotion", University of Michigan Press, 1956.

Cobb, D. E., G. T. Cohran and J. D. Gentry, "Scale Model Evaluation of Earthmoving Tools", First Internl.Conf. on the Mechanics of Soil-Vehicle Systems, Torino, Italy, 1961.

Dean Hartog, J. P., "Mechanical Vibrations", 4th ed. McGraw-Hill, 1956.

Department of the Army, "Soils Trafficability", Hdas. Department of the Army, Washington 25, D.C., Tech. Bulletin 37 (no date).

Jumikis, A. R., "Soil Mechanics", Van Nostrand, 1962, p.179.

Newcombe, W. R. and Radforth, J. R., "The Measurement of Surface Roughness of Muskeg", Proc. Tenth Muskeg Res. Conf., NRC-ACSSM Tech. Memo. 85, 1965.

Nuttall, C. J.,Jr. and R. P. McGowan, "Scale Models of Vehicles in Soils and Snows", First Internl. Conf. on the Mechanics of Soil-Vehicle Systems, Torino, Italy, 1961.

Radforth, N. W., "Suggested Classification of Muskeg for the Engineer", Engineering Journal, Vol. 35, No. 11, 1952.

_______________ and Ashdown, K. H., "The Procurement of Physical and Mechanical Data from Organic Terrain", Proc. Sixth Muskeg Res. Conf., NRC-ACSSM Tech. Memo. 67, 1961.

Radforth, J. R. and Radforth, N. W., "The Significance of Density as a Physical Property in Peat Deposits", Proc. Eleventh Muskeg Res. Conf., NRC-ACSSM Tech. Memo. 87, 1965.

Siddall, J. N., "The Evolution of Muskeg Vehicles", Proc. Muskeg Vehicle Conference, Parry Sound, Ontario, August 15th, 16th, 1962.

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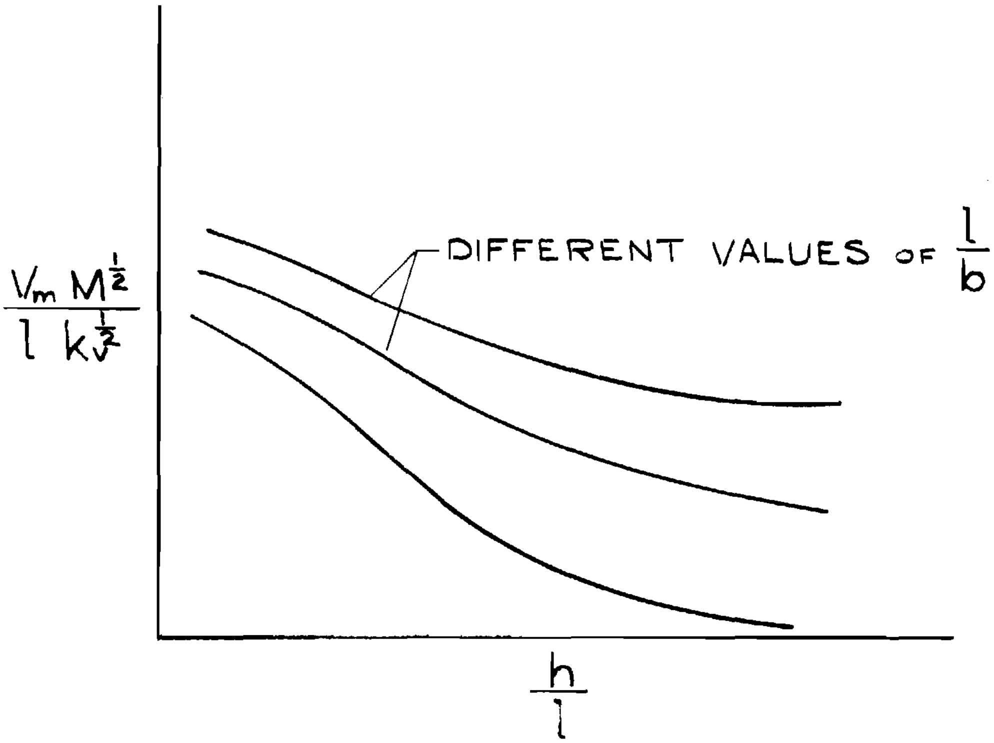


FIG. 1. HYPOTHETICAL DIMENSIONAL ANALYSIS CURVES FOR PREDICTING MAXIMUM VEHICLE SPEED

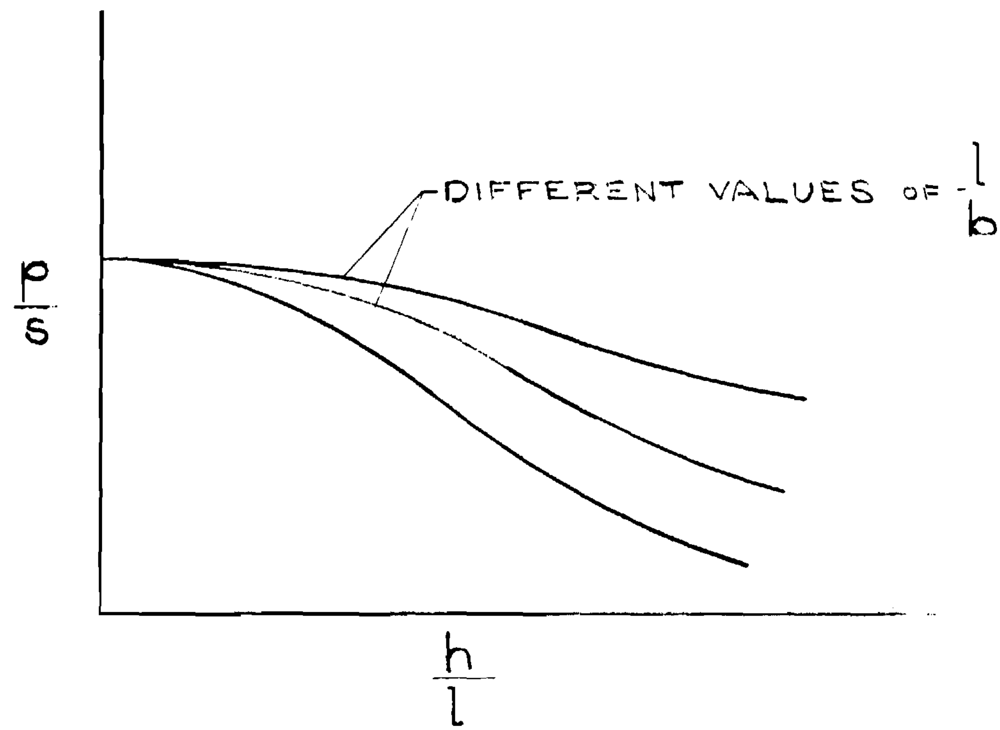


FIG. 2. HYPOTHETICAL DIMENSIONAL ANALYSIS CURVES FOR PREDICTING IMMOBILIZATION OF A VEHICLE IN MUSKEG

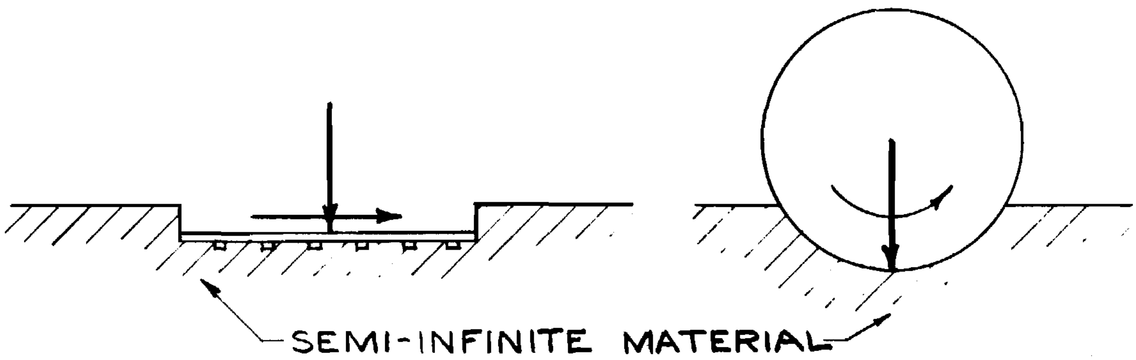


FIG. 3. SOIL-VEHICLE LOADING CONFIGURATION

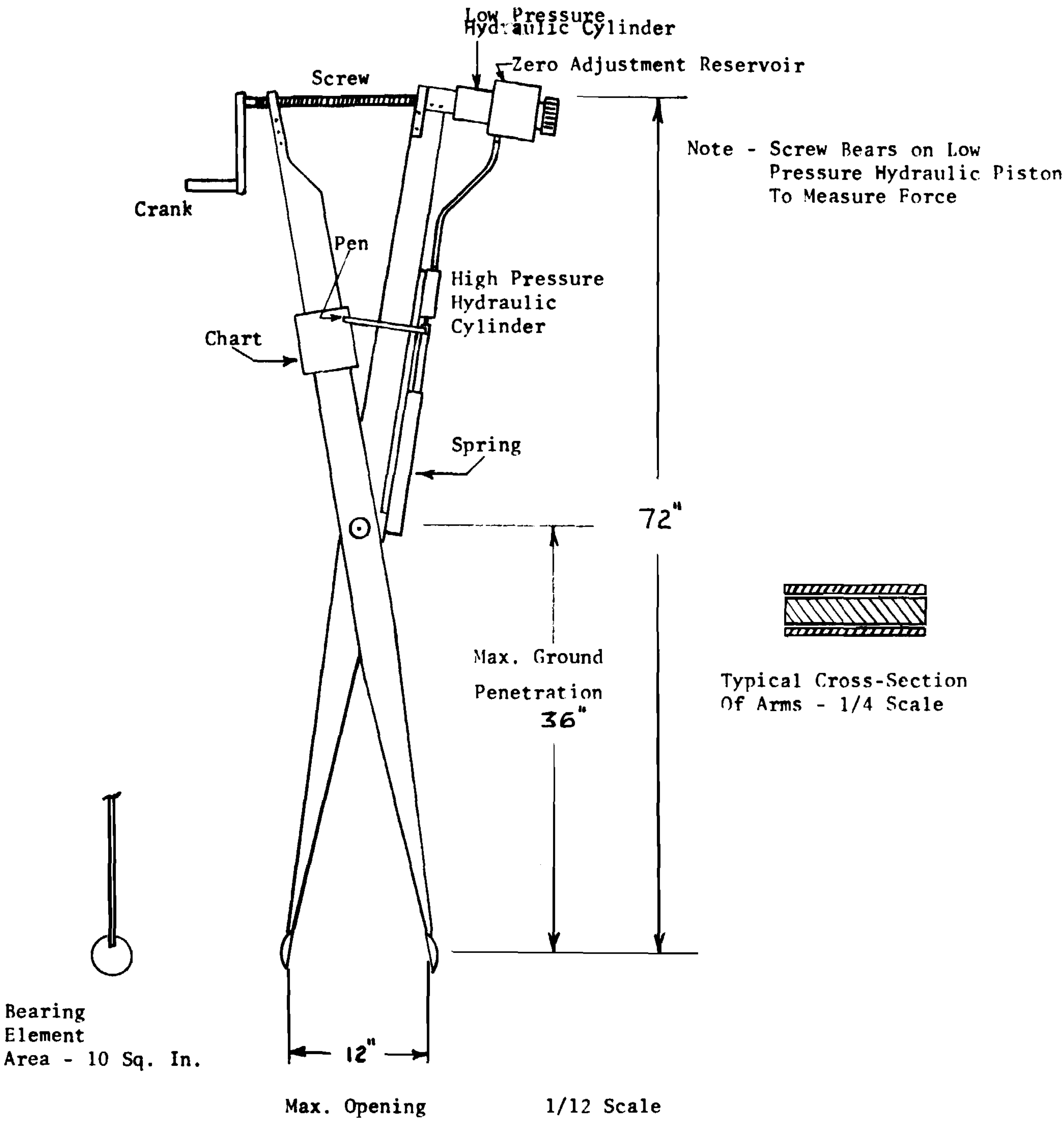


FIG. 4 DIRECT RECORDING PEAT STRENGTH MEASURING DEVICE

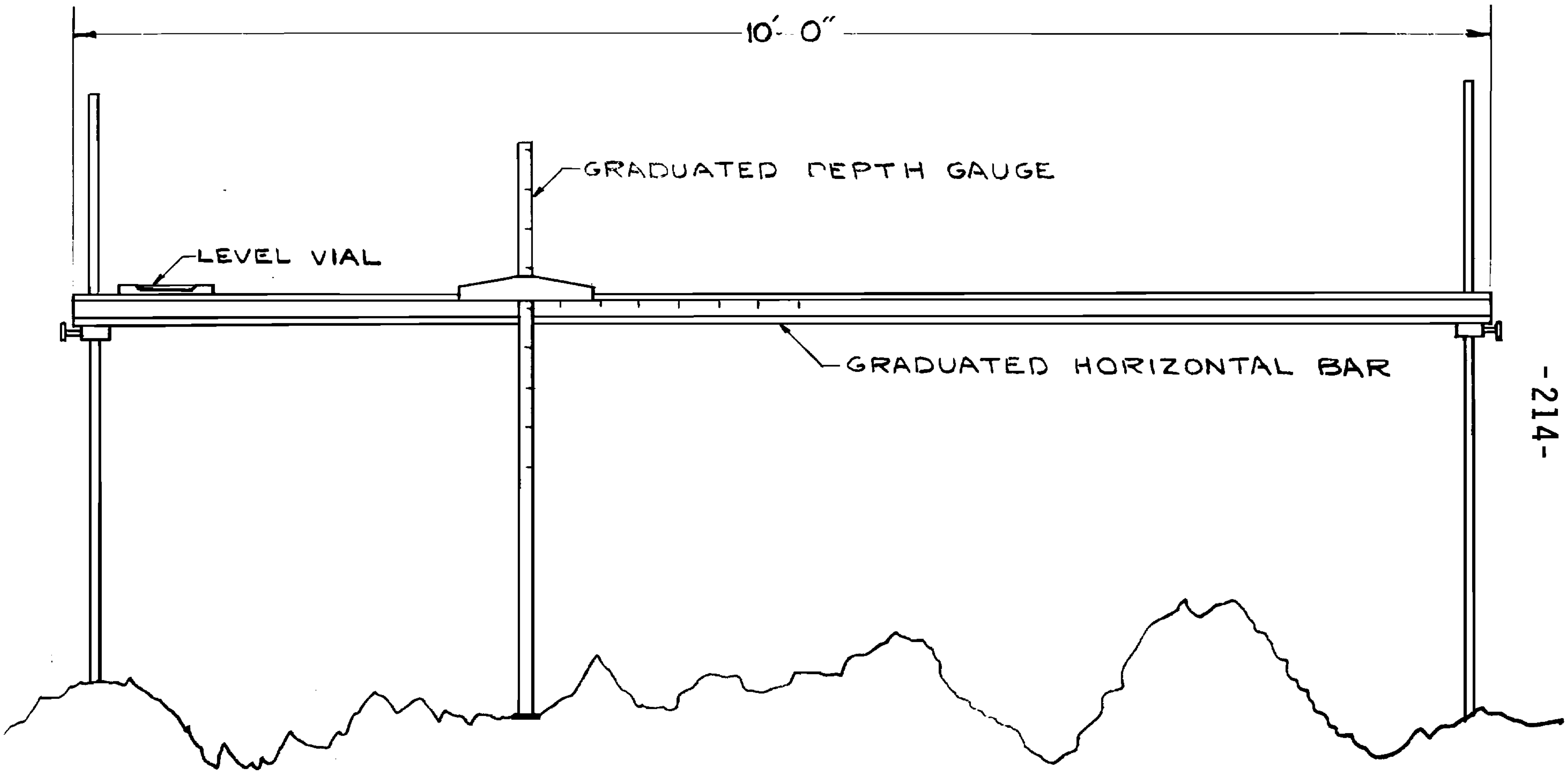


FIG. 5. PRELIMINARY DEVICE FOR OBTAINING SURFACE ROUGHNESS DATA OF MUSKEG

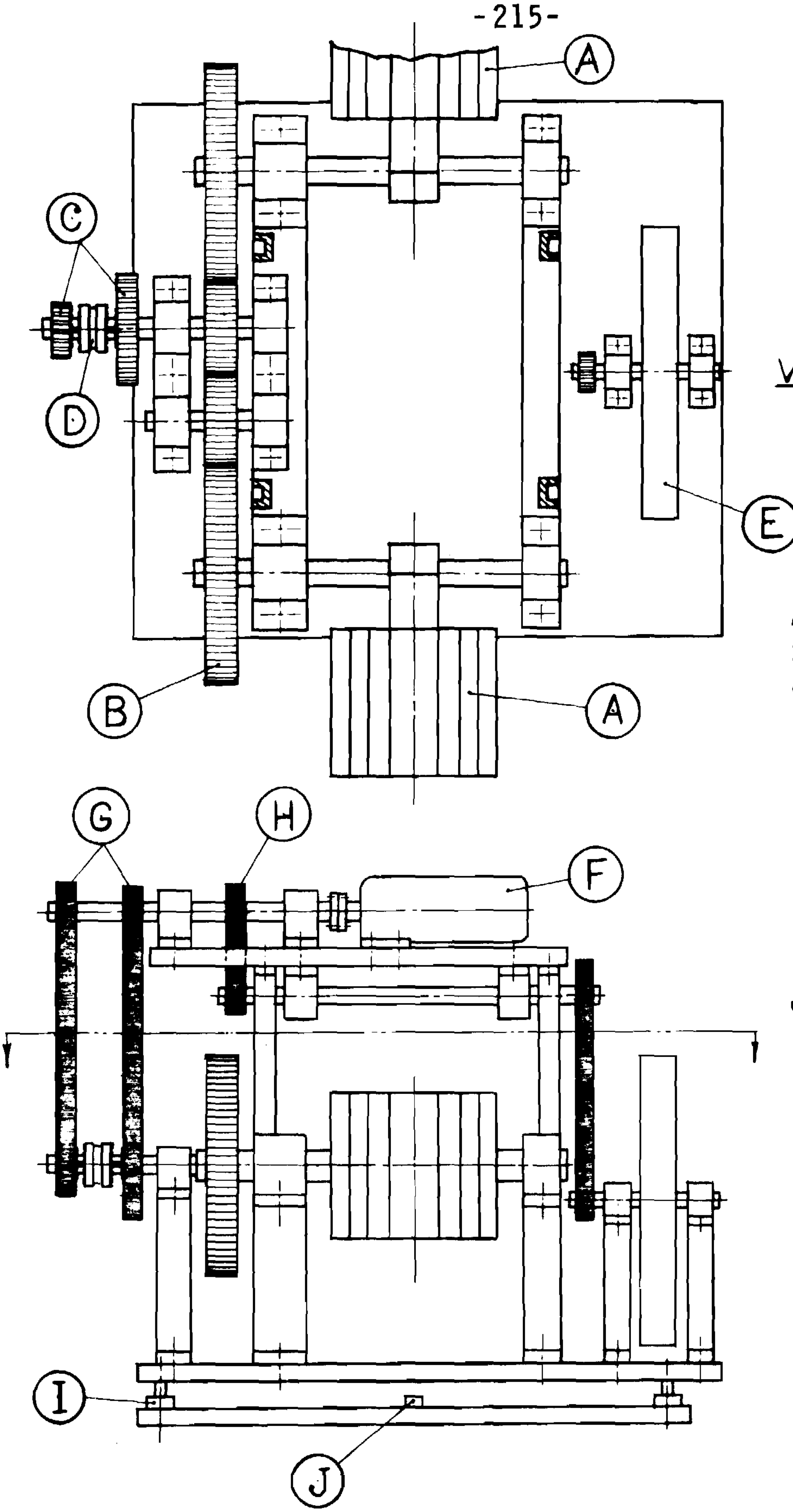


FIG. 6.

REACTION TYPE VIBRATION EXCITER FOR MUSKEG.

LEGEND

A. ROTATING WEIGHTS.
B. GEAR DRIVE.
C. TIMING BELT PULLEYS.
D. SQUARE-JAW CLUTCH.
E. FLYWHEEL.
F. DRIVING MOTOR.
G. TIMING BELT DRIVE TO ROTATING WEIGHTS.
H. TIMING BELT DRIVE TO FLYWHEEL.
I. FORCE TRANSDUCER.
J. ACCELEROMETER.

Discussion (G. H. Schlosser)

I wish to commend the authors on their most informative and welcome paper. I believe this introduces a new phase in muskeg research - the development of criteria for the design of muskeg vehicles. The data obtained in the research will be of invaluable aid to the manufacturers of these vehicles.

The authors have cited twelve factors which contribute to vehicle mobility in various muskeg situations. I would like to include one more - suspension, which influences several of those factors mentioned. The importance of these factors cannot be over-emphasized.

Not all of these features can be incorporated in the design of any one machine. Conversely, no one machine can be designed to operate in all terrain situations, nor to satisfy all job requirements.

The manufacturers of vehicles in other fields of transportation have built vehicles to do specific jobs. Similarly, the manufacturers of muskeg vehicles should be encouraged to produce a type of vehicle to do a specific job in a particular terrain regime.

As an example, on seismic crews in the Oil Industry in Western Canada, a vehicle should have the following features: light weight; low ground pressure; track approach angle; individual track steering; short turning radius; both forward and reverse gears; high belly; flexible suspension, and accessible maintenance features. Other industries and transportation companies would require other features, possibly including long tracks, articulation and buoyancy.

There is a need for the manufacturer to become acquainted with industry's requirements and to consult with the researchers in an endeavour to produce a vehicle which will provide the variables cited by the speaker, such as resistance to immobility, speed, efficiency, capacity, reliability, and manoeuvrability according to a client's need in the particular terrain conditions.

A major breakthrough in muskeg vehicle research has been presented by Prof. Siddall and his colleagues and should be given our fullest support and encouragement.

General Discussion

Lt. Col. Crowley asked if the factors discussed in this paper have been correlated with the McGill University project and their tank tests. Professor Newcombe replied that they had not as yet, but they will eventually.

# IV.3. ASSESSING ORGANIC TERRAIN FOR PEAT UTILIZATION

M. W. Radforth

Abstract

A tabulation is presented of the relationship between proposed uses for peat and a given muskeg cover type. A large number of functions (uses) are listed, together with their probability of success in given muskeg types.

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# IV.3. EVALUATION DES SOLS ORGANIQUES EN VUE DE L'UTILISATION DE LA TERRE NOIRE

N. W. Radforth

Résumé:

On donné une table montrant la relation entre les utilisations proposées de la terre noire et un type donné de couverture (végétation) du muskeg. Un grand nombre de fonctions (usages) sont énumérées avec leur probabilité de succès dans les types de muskegs donnés.

_ *** _

There is now a growing awareness of the problem of what peat can be used for. To what extent, therefore, can we use the present cover formulae to help us assess organic terrain for peat utilization? This is answered in the following table of Functions and Development Factors.

The question of classification always arises, and the material is classified on the basis of a particular need. This may be accomplished by the Radforth, von Post, or some other system. This is not important; the important thing is that the classification systems be inter-related. In the USSR, for instance, the exploitation of peat for electrical energy is very important. In Scotland, they are interested in peat for the production of Scotch Whiskey, elsewhere the major interest is in the procurement of horticultural peat.

With reference to the list of functions in the table, in the numbering system number 1 represents the best type of muskeg for a particular function. The letter "P" represents a condition that has never yet been utilized, but its use is predicted. For example, articulated wheeled vehicles have not been tested in HE, but it is predicted that they will perform best in that type of muskeg.

This table integrates a use for peat with the muskeg cover type. To fully exploit this integration, we have to utilize peat wherever it occurs on this table.

| FUNCTION: | DEVELOPMENT FACTOR (Identified by Cover Formulae) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AEI | ADE | ABE | AFI | BEI | DFI | IE | EI | EH | HE | FI |
| Off Road Access | | | | | | | | | | | |
| -Articulated Wh. Vehicle | 2 | 3 | 4 | 5 | 7 | 8 | $P_{10}$ | 9 | $P_6$ | $P_1$ | 11 |
| -Articulated Tr. Vehicle | 9 | 10 | 2 | 11 | 1 | 8 | $P_4$ | 3 | 5 | 6 | 7 |
| -Roller Track Vehicle | - | 10 | 7 | 9 | 6 | 8 | $P_2$ | 3 | 4 | 5 | 1 |
| -Non-Arctic Tr. Vehicle | 9 | 10 | 5 | 11 | 4 | 8 | $P_7$ | 2 | 1 | 3 | 6 |
| -Non-Arctic Wh. Vehicle | - | - | 4 | - | 1 | - | - | 2 | $P_3$ | $P_5$ | - |
| -Ground Effect Vehicle | - | - | - | - | - | - | $P_1$ | 3 | $P_4$ | $P_5$ | 2 |
| -Helicopter | - | - | - | - | - | - | 3 | 2 | $P_1$ | $P_4$ | - |
| Road Access | | | | | | | | | | | |
| -Public Road Hwy. | 2 | 1 | 3 | - | 5 | 6 | $P_8$ | 7 | 4 | 7 | $P_9$ |
| -Industrial Road | 2 | 1 | 5 | $P_{11}$ | 6 | 7 | $P_9$ | 8 | 3 | 4 | $P_{10}$ |
| -All purpose Secondary | 3 | 4 | 7 | 11 | 6 | 9 | $P_8$ | 5 | 1 | 2 | 10 |
| Mining Method | | | | | | | | | | | |
| -by Milling & Excavation | 5 | - | - | - | 3 | - | $P_1$ | 2 | 4 | - | 7 |
| -by Pipelining | $P_7$ | - | $P_5$ | $P_{10}$ | $P_3$ | - | $P_1$ | 2 | $P_6$ | $P_8$ | $P_9$ |
| Structural Foundations | | | | | | | | | | | |
| -Buildings | 1 | 2 | 3 | $P_9$ | 6 | - | $P_8$ | 7 | 5 | 4 | - |
| -Miscellaneous (Tank-farms, Oil rigs) | 6 | 7 | 8 | 9 | 5 | - | $P_{10}$ | 3 | 1 | 2 | 4 |
| Forest Products | | | | | | | | | | | |
| -Timber | 2 | 1 | 3 | 4 | 5 | $P_{10}$ | $P_7$ | 6 | $P_8$ | - | $P_9$ |
| -Pulp | 2 | 1 | 3 | 5 | 4 | $P_{11}$ | $P_7$ | $P_6$ | $P_8$ | $P_{10}$ | $P_9$ |
| Agricultural Products | | | | | | | | | | | |
| -Vegetable growing | - | - | - | - | 4 | - | $P_5$ | 1 | 2 | - | 3 |
| -Berry crops | $P_6$ | - | $P_8$ | - | 5 | - | 1 | 2 | 3 | 4 | $P_7$ |
| -Cattle raising | - | - | - | - | $P_5$ | - | 4 | 3 | 1 | $P_6$ | 2 |
| -Sheep raising | - | - | - | $P_7$ | 5 | - | $P_6$ | 2 | 3 | $P_4$ | 1 |
| Muskeg Product | | | | | | | | | | | |
| -Pelletizing | $P_7$ | - | $P_6$ | - | $P_4$ | - | $P_5$ | 3 | $P_2$ | $P_1$ | - |
| -Hort. Peat | $P_7$ | - | $P_5$ | - | 4 | - | $P_1$ | 2 | 3 | $P_7$ | - |
| -Plant holders | $P_6$ | - | $P_6$ | - | $P_4$ | - | $P_2$ | 1 | $P_3$ | $P_5$ | - |
| -Paper | $P_7$ | - | $P_5$ | - | $P_4$ | - | $P_1$ | 2 | $P_3$ | $P_6$ | - |
| -Fibre Board | $P_4$ | $P_{10}$ | $P_3$ | $P_5$ | $P_1$ | $P_{11}$ | $P_8$ | 2 | $P_6$ | $P_7$ | $P_9$ |
| -Drugs | | | | | | | | | | | |

## IV.4. GENERAL DISCUSSION

Dr. Haas raised the question of peat sampling and he and Mr. Hodek described a special sampler ("Cryogenic Valve") which has been developed at Michigan Technological University. This sampler utilizes the principle of freezing the material in place after the sample tube has been placed around it.

Essentially, the sampling device is composed of two parts. The inner part is a 12-foot length of nominally 4-inch diameter aluminum tubing of 3/32-inch wall thickness. The bottom of this tube is cut at an angle of 45°. The outer part is a nominally 6-inch diameter casing of plastic (polyvinyl-chloride) pipe. Attached to the bottom portion of this outer pipe is a steel penetrating head. Between this head and the inner tube is an O-ring.

After first removing the surface mat, the inner tube is rapidly pushed into the peat to the desired depth. The outer casing is then positioned over the sample tube and pushed down until the penetrating head is near the upper end of the angled cutting edge. About 8 pounds of dry ice is dropped down between the two tubes and left for approximately 45 minutes. A frozen plug is thereby obtained at the bottom and the sample can be easily extracted. Dr. Haas reported that they can get about 85% recovery.

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## IV.5. CLOSING REMARKS

Dr. Radforth thanked the Chairmen of the various Sessions and also expressed his appreciation for the efforts of the various authors who had presented papers.

Mr. Brawner, on behalf of the Associate Committee on Soil and Snow Mechanics, and of the Muskeg Subcommittee, expressed appreciation for the hospitality of Laurentian University in making available such fine facilities for the Conference.

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APPENDIX "A"

LIST OF DELEGATES TO THE ELEVENTH MUSKEG RESEARCH CONFERENCE, LAURENTIAN UNIVERSITY, SUDBURY, 6 AND 7 MAY, 1965

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