AERIAL INTERPRETATION OF MUSKEG

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A CRITICAL ANALYSIS OF FORM FEATURES IN THE CANADIAN MUSKEG COMPLEX

by

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SCOPE AND CONTENTS: The ontogeny of a specific high altitude (30,000') airform pattern was investigated. The possibilities of using this pattern, and certain related phenomena which appear with it, for sub-surface ice prediction was demonstrated. For the purpose of laying out the general background of the controls of paludification, as they affect indirectly the pattern development, a rather detailed account of the geomorphology, geology and climate of the study areas was given. The summaries of these accounts demonstrate their effect on pattern evolution. These background data as a foundation for a more specific account of the developmental processes of the airform pattern were given as based on abiotic and biotic interplay in the development.

Finally in order to demonstrate universal application of aerial interpretation of muskeg a brief comparison of

the analogous conditions of paludification and pattern in Finnish and Canadian muskeg was given.

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INTRODUCTION

There is a very large number of botanical, geological and physical studies on muskeg and peat based on field investigation made directly at ground level. In many instances there is enough knowledge of muskeg and peat acquired through this approach to render further direct field study unnecessary. Examples of studies based on the ground observations and their application to interpretation of certain muskeg conditions are those of Radforth 1962, and Kennedy 1963.

In small countries with limited areas of muskeg ground observations will usually satisfy the need of investigation but in larger countries, as in Canada, a more practical and faster method is required. This was recognized by Radforth in Canada when he developed the first system for airphoto interpretation of muskeg (Radforth 1955a and 1958). The development of the northern parts of Canada, where the largest areas of muskeg are situated, moreover has made airphoto interpretation increasingly important. In some cases, it is the only practical and reasonable way of studying the problems. In the present study the use of aerial photographs as the main method of investigation has been prompted by the inaccessibility of large northern muskeg areas by land and by a need as well to develop the method itself. It is notable that aerial photographic interpretation has been used quite widely in the earth sciences, engineering geology and plant geography but that it still is a relatively fresh way of studying muskeg. There still is a need to expose, in wide perspective, relationship governing muskeg organization if it exists.

The Use of Aerial Photographs in Botanical Studies

Before writing especially on the aerial photographic studies of organic terrain, a short review of the application of aerial interpretation to botany will be given because muskeg studies are very often botanical in their nature. There is a great number of aerial works on agriculture and especially on forestry from the time period between the two World Wars, but more or less purely botanical application became strong only after World War II. Quite a few of the earlier works were applied to mapping vegetation (Benninghof 1950). Often they had a marked military slant because aerial photographs were, in many instances, the only means of getting information about the areas held by the enemy. Especially important was the use of aerial interpretation of the ground condition by using the vegetation as an indicator (Colwell 1948). For example, in one of his works of this nature, Colwell (1948) gives a key of the vegetational features for aerial interpretation of tropical areas for military purposes. It is interesting to note that he uses letters from A to M to denote different cover types as Radforth uses A to I in his cover classification system for the organic terrain (Radforth 1952) but the values for the letter symbols are not comparable. Of the other studies on aerial classification of vegetation should be mentioned that by Wieslander and Wilson (1942). In this paper, as in others, the vegetation is of great importance in the analysis of the soils; it is used as an indicator, for instance by Tomlinson and Brown (1962) and Stone (1948). Another aerial study is that by Schantz and Turner (1958) in Africa. Their emphasis is on changes of the vegetation resulting from natural and cultural forces as reflected by comparative aerial photography of identical areas taken at a thirty year interval.

Different kinds of film have been analyzed as to their adaptability to studies of vegetation. O. W. Schulte (1951) analyzed infrared, panchromatic and colour films for the study of plant distribution. His main conclusion was that while in some conditions and in certain regions some films give better results than others the conditions may be different in some other location. Thus, results should not be generalized hastily. He maintains that the best results may be obtained by using these three films in concert.

The fact that vegetation can be used as an indicator of geomorphic feature and soil type has been utilized in aerial interpretation in Russia. For example, Zagrebina (1965) interpreted from aerial photographs the relationship between vegetation and the rock lithology in Yakutia (USSR) and Leonteva (1965) deciphered soils from aerial photos by using the vegetation as an indicator.

Also, it is helpful to refer to the utilization of the vegetation and plant species in aerial interpretation of hydrological conditions in the landscape for instance by Popova (1965) in Russia.

The new concept, so-called remote sensing, has opened new vistas for the biological use of different techniques. One such device is "side-looking airborne radar" (SLAR) which is used by the military for vegetation analysis, but the results and even the photos have been classified and are out of the reach of civilian biologists. The release of certain data a few years ago has enabled botanists and other scientists to start using this method. There are already many publications of the use of SLAR for botanical and biological use in general (Moore and Simonett 1967), Morain and Simonett 1966, Morain 1967). Some of the more sophisticated methods like the use of infrared photography are under development. Heat emission thermographically recorded and its possible use in biology has been tried by Colwell (1967). So-called multispectral sensing and its use in different fields also shows promise. Multispectral sensing utilizes the infrared, visible and ultraviolet regions of the spectrum in concert (Holter 1967).

Use of Aerial Photographic Interpretation in Organic Terrain Studies

It is interesting to note that regardless of the extensive use of aerial interpretation in more or less purely botanical studies, its systematic utilization in organic terrain research is quite recent and somewhat sporadic. This situation is surprising when one realizes how common and extensive a phenomenon the organic terrain condition is especially in the northern hemisphere. Some estimates advise (Radforth 1962b) that in Canada there are approximately 500,000 square miles of organic terrain (about 130 million hectares). According to Kivinen (1948), there are 130 million hectares of muskeg in Russia; in Finland 10 million hectares, and then in decreased order follow Sweden (5.3 million hectares), Poland (3.9 million hectares), Great Britain and Ireland (2.5 million hectares), and Germany (before World War II, 2.1 million hectares). These figures, as well as a very extensive literature on organic terrain, form a good indicator of the magnitude of the phenomenon which may require interpretation. In organic terrain studies generally, the older references reveal no systematic application of aerial photographic interpretation. On the other hand, occasional aerial photos used in the initial studies are available and sometimes apply to analysis of muskeg. Thus, for instance, Sjörs illustrated his extensive, mainly ecological study of Swedish muskeg with aerial photos introducing an analytical approach (Sjörs 1948). Belcher, as early as 1945, utilized aerial views of organic terrain to explain the ground conditions for engineering purposes. Very commonly there are references to the utilization of aerial photos in muskeg studies as a means and approach for obtaining data of the conditions but without showing the actual photos used in the work (Aartolahti 1965). In some recent literature there are attempts to interpret from aerial photos whether a muskeg, or a part of it, is minerotrophic or ombrotrophic (Ruuhijärvi 1960). The Russians have carried out work on aerial photographic interpretation of 'bog massifs' as their term is translated (Galkina 1964, Lebedeva 1964). The chronic problem with the Russian literature seems to be its general unavailability and when available the aerial photographs have been omitted from the text, and only diagrams of the result are given as in the earlier mentioned works by Zagrebina (1965), Leonteva (1965), and Popova (1965) to mention only a few examples.

It is quite understandable that there are no specific systems of aerial photographic interpretation for muskeg in smaller countries, as in Finland and Sweden. The extent of the organic terrain is not as vast as in Canada where, for instance, it imposes a really sizeable obstacle to access.

If one considers the abundance of this kind of work done in other fields, one begins to wonder why there is such a dearth of work on muskeg. This may be because organic terrain has been assumed to be unorganized constitutionally and thus uninterpretable from the air. Recurrence of certain conditions and patterns which are the basic requirements for an interpretive system has not been sufficiently stressed. In fact, organic terrain, often apparently unorganized to a casual observer, suggests organization following more careful scrutiny.

The basis for systematic aerial photographic interpretation of organic terrain in this country was laid in 1952 when the Radforth classification for the cover types of muskeg from observation at ground level was published (Radforth 1952). Appendix A offers a short description of this system.

The need for the system had arisen from the fast-growing interest in the development of the Northland and from the engineering problems encountered in the vast northern muskeg areas. For an observer lacking botanical background this system of vegetal structure reference offers a sound means for a relatively easy assessment of different conditions in muskeg as for example in the go-no-go condition determination by a driver of an off-road vehicle. The system is applicable to any muskeg in both hemispheres with perhaps minor adjustments to meet some regional conditions. Figures 121 and 122 suggest how this system through analogy might be adaptable both to Finnish and Canadian muskeg, an idea which will be developed in a later section of this thesis. This system of study at ground level illustrates how recurring environmental conditions form the basis for a possible aerial interpretation system for muskeg.

The actual aerial interpretation was started with the publication of a system for altitudes less than 1000 feet (Radforth 1955b) in the form of a handbook. It deals mostly with object indicators since it is fairly difficult to discern any patterns from low altitude. Handbook 2 (Radforth 1958) on the other hand depicts an airform pattern system for the altitudes from 1000 to 5000 feet (300-1500 m). There are six main patterns: Planoid, Apiculoid, Vermiculoid, Cumuloid, Polygoid (polygonoid) and Intrusoid. In addition to these, the Vermiculoid pattern is divided into three secondary configurations: Vermiculoid I, II, and III. Appendix B offers further information about this system.

Before Handbook 2 was published, airform patterns for high altitude (30,000 feet, 9000 m) had been described (Radforth 1956a and b). There are five main patterns in this system: Dermatoid, Stipploid, Terrazoid, Reticuloid and Marbloid. Since the present author utilizes mainly these high altitude patterns, their short description seems reasonable in this context.

Briefly, they are described as follows:

Dermatoid: chiefly textureless and plain, a simple cover lacking ornamentation (skinlike in the literal sense).

Stipploid: constituted of closely applied dots.

Terrazoid: a patchwork mixture of two major muskeg types.

Reticuloid: network (with a varying mesh size).

Marbloid: an image of a polished marble surface.

Appendix C offers further information about this system and about its relationship to the other systems and cover classes and shows photographs of the actual patterns.

This system has given an initiation to an organized interpretation of muskeg from aerial photographs and it has been used by some other authors already in their work (Mollard 1960, Korpijaakko and Radforth 1965, Korpijaakko 1966).

Use of Aerial Photographic Interpretation in Permafrost Studies

A large portion of the northern muskeg lies in the permafrost areas, either within the limits of the continuous or discontinuous permafrost zone. This situation brings into consideration the ice factor in organic terrain and its effect on different muskeg studies. Since the present study endeavours to solve some problems which are a combination of the ice factor and the organic terrain environment, it seems reasonable to mention some examples of the ways in which some researchers have attempted to interpret permafrost from the air.

The literature on permafrost studies is very extensive and a large portion of it is Russian. Reference to it when pertinent will be made as the ensuing context suggests and no general review will be attempted.

The attempts to recognize permafrost features in airphoto interpretation are fairly numerous but only moderate efforts have been made to construct a key to systems of recognizable indicators as there are, for example, in photo identification of glacial landforms (Powers 1951), and vegetation (Colwell 1948). Belcher (1945) in his study on the engineering significance of soil patterns claims that vegetation alone may indicate the existence of permafrost. He suggests that in permanently frozen ground plants with deep roots, for example large trees, do not survive as well as small shrubs, which thus may indicate possible occurrence of frozen ground. He also refers to the polygons as indicators of frozen ground. Sager (1951) lists in his more detailed study some features seen from the air which help in recognition of frozen conditions. Such features are for example polygons, pingos, 'drunken forests', cave-in lakes, and 'swampy' (quotation marks by the present author) muskeg conditions. He also deals with the ideas of how these features can be utilized in soil studies, trafficability investigations, etc., by using them together with the knowledge they offer about the frost and ice conditions. Black (1952) maintains in his aerial study on permafrost that the polygons are one of the main indicators of the existence of permafrost. He also discusses their use in aerial interpretation of permanently frozen ground in general. Many authors follow these lines more or less and mention approximately the same features (polygons, 'drunken forests', beaded streams, certain vegetational features, drainage patterns, etc.) as indicators of permafrost or sub-surface ice (Frost 1952, Krynine and Jude 1957, Lueder 1959, Ray 1960, von Bandat 1962). These investigations do not link permafrost with muskeg. Interest in the use of aerial interpretation of ice conditions in muskeg started with Mollard 1960.

The Problems and Objectives of the Present Study

The above analysis indicates that although aerial photographic interpretation is an accepted and widely used research method and with other aerial reconnaissance methods perhaps highly developed, the possibilities of using it to gain better understanding of organic terrain have not yet been fully realized. Also from the standpoint of national economics the need for the increased knowledge is unquestioned.

The application of the existing system for airphoto interpretation of organic terrain exposes new problems. One critical problem relates to sub-surface ice. There is a need to know whether the ice, if predictable, is seasonal or the effect of permafrost, and if the latter, whether it results from a continuous or discontinuous condition.

The initial problem of this work was to reveal whether it is possible to predict the nature and distribution of sub-surface ice in muskeg from the air on the basis of certain observed phenomena and features as listed below. To solve this problem a comprehensive treatment of both general and detailed features of paludification(formation of muskeg) became necessary because, without accounting for them and using them as a foundation for the evidence, it would have been difficult to explain clearly the genesis of some features of muskeg and their relation to sub-surface ice.

If one flies along a transect from the south to the north across the southern limits of discontinuous and continuous permafrost zones he may observe that certain patterns and features of organic terrain have an optimum distribution and frequency of occurrence on areas of various types of permafrost. Thus it appears that the Marbloid high altitude airform pattern, H cover class (H-factor, lichens), some smaller scale patterns such as polygons, traces of original soil circles, steps and stripes in organic terrain, thaw lakes, and beaded and rectangular streams are closely related to the sub-surface ice conditions existing in muskeg. The initial working hypothesis was that these features might be used in the aerial photographic interpretation of sub-surface ice conditions in muskeg.

The search for evidence for the initial hypothesis revealed that pattern development was involved. Also to account for this development an extensive treatment of several aspects of paludification was necessary and the following approach was adopted.

First, to give a wide basic background for pattern evolution a rather detailed account of the primary controls of paludification, geology, geomorphology and climate, was given. In the attached summaries is expressed the present author's concept of their effect on paludification.

The second section explains the features and phenomena listed above which are apparently connected closely with sub-surface in muskeg.

The third section traces the various stages in pattern evolution and their distribution.

The fourth main section deals with the details of abiotic and biotic features involved in the development of Marbloid and also in the development of some other airform patterns.

The last section deals directly with the formation of various 'form objects' contributing to the airform pattern. This section combines the knowledge of the effect of the general controls and interaction of abiotic and biotic factors working in the pattern development acquired in the previous sections.

By presenting this broad account starting with the general controls of paludification followed by the summaries with the author's interpretation of their effect on paludification, physical properties, and mode of formation of peat, it is hoped to reveal the mechanics of pattern development and the close ties with sub-surface ice conditions. Furthermore, this work is an attempt to furnish evidence as a basis for using the listed phenomena and features in aerial prediction of sub-surface ice conditions on muskeg. It also is hoped to help reveal possible utilitarian application. Indirectly, disclosure might help in scientific procedures related to hydrology and reclamation of muskeg for forestry and agriculture.

As an exercise in application of evidence there is a short section dealing with the investigation of possible analogous conditions of muskeg in two geographically widely separated countries, Canada and Finland. The need for this type of study is increasing with the possibility of photographing large areas of the earth from satellites. The analogy study draws into focus the confusion of terminology in the field of muskeg studies. This problem has been hopefully met by the derivation of a glossary in which expressions and concepts in use in different countries have been explained or where necessary compared.

METHODS

When possible the main aspects of method were in accordance with the steps and sequence given below:

1. A preliminary airphoto study was made in the laboratory to select the areas for detailed study (ground checks and low altitude flights).
2. Ground checks were made at predetermined locations. This means that conclusions reached by comparative airphoto study were checked on the actual locations by verification on the ground of the presence of geomorphic and vegetal conditions identified in the photographs.
3. Additional low altitude flights were made to resynthesize new evidence from step 2.
4. Final laboratory analysis and interpretation of the data obtained through the above steps were made in terms of large scale comparison.

In the preliminary study, high altitude (30,000 ft.) airphotos were utilized as a principal tool. In every possible case they were used to predetermine the desired areas for further ground and low altitude studies. However, in some cases, as in the flights over central and northern Manitoba, this step was not used because of inconsistencies in field arrangements. On these occasions the ground checks and low altitude flights were executed first.

A strong factor affecting the selection of the locations for ground checks was their accessibility, because in most of the muskeg areas of the north, there are no roads or railways. Also opportunities of procuring appropriate air travel were slight.

Areas selected as representatives of distinctive airphoto configurations were visited on the ground. Features responsible for the configurations were noted and the depth to the permafrost, if present, were determined. The record was supplemented with ground photos both in black and white and in colour.

On each occasion, where possible, low altitude flights were performed with additional photography (black and white and colour) with conventional 35 mm cameras (f 50 mm). Also, landings for ground checks in the places far from the roads and railways were executed when required.

The last step entailed evolution study by comparison of the geomorphic and other data obtained from ground studies. The ground photos were used as illustration aids in the analysis and identification of the high altitude photographic configurations. Important tools in this study were stereoscopes. For small scale work a pocket stereoscope with magnification power of two (2 x) manufactured by Abrams Instrument Corporation was used. For detailed inspection a mirror stereoscope with magnification powers of two (2 x) and four and half (4.5 x) was utilized. The manufacturer is unknown but the piece of equipment used is identical to a simple mirror stereoscope manufacturered by, for example, Harrison Ryker, Inc.

DESCRIPTION OF STUDY AREAS

Location For Comparative Investigation

The study areas are scattered within wide limits the approximate coordinates of which are 60° N latitude and 45° W longitude and 50° 30' N latitude and 105° W longitude. These limits include a wide range of geological and climatic differences. The actual locations and designations of the ground study areas and of the low altitude flights are as follows (Figure 1):

Area 1. Cambridge Bay, Victoria Island, N.W.T.

This is the northernmost study area. It is situated at 69° 8' N latitude and 104° 10' W longitude on the southern coast of Victoria Island. Cambridge Bay was a centre of embarkation for two low altitude flights.

Flight 1 - This flight was performed at an altitude of about 1000-2000 feet (300-600m) approximately 50 miles (80 km) south of Cambridge Bay over the mainland on the coast of Kent Peninsula. No ground checks were possible except in the vicinity of Cambridge Bay. Photographs both in colour and black and white were taken.

Flight 2 - This flight consisted of a two-day trip to a point about 400 miles (650 km) east of Cambridge Bay.

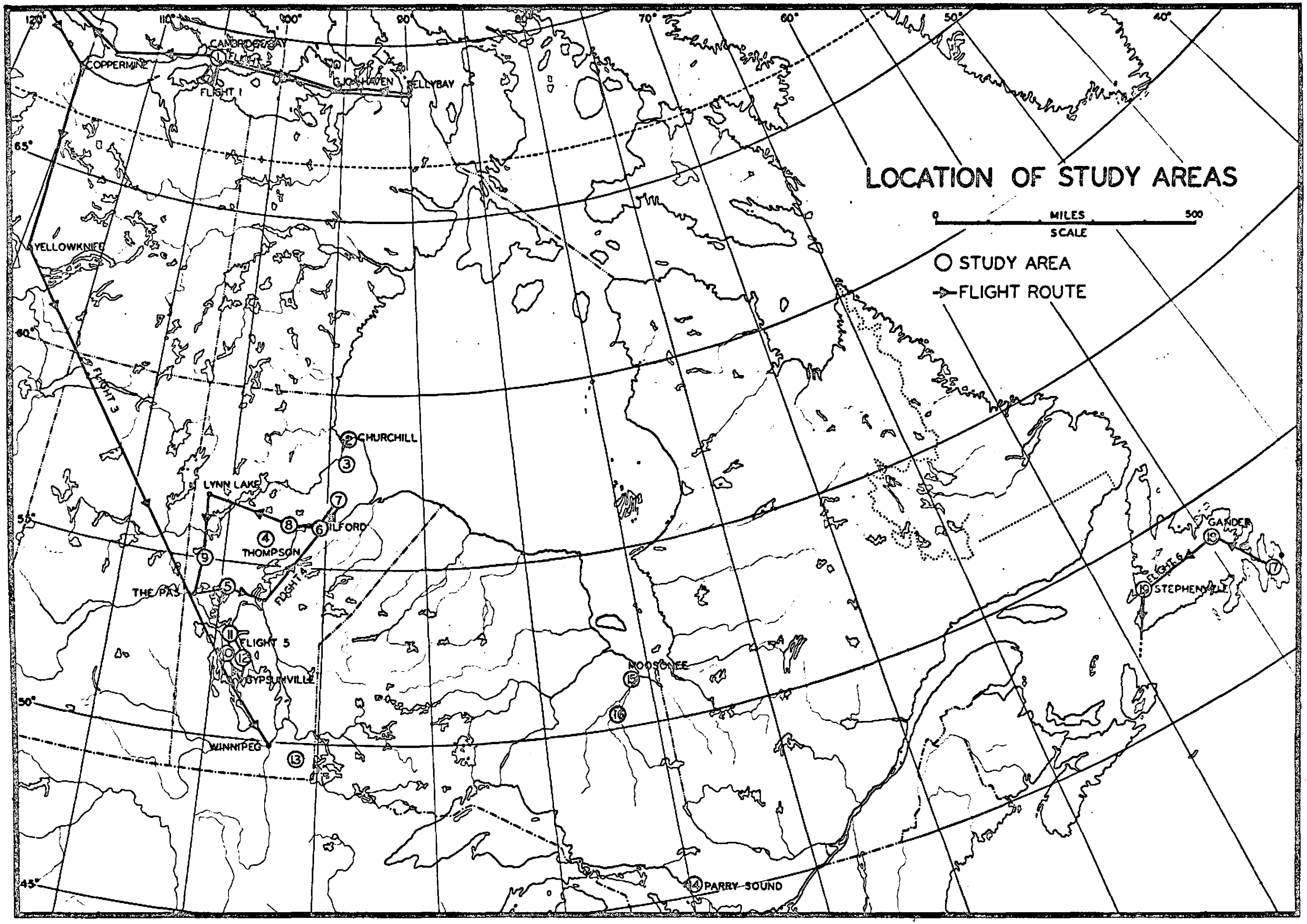


Fig. 1. Location of study areas and flight routes.

It was executed over the southeastern corner of Victoria Island, over Royal Geographical Society Islands to Gjoa Haven on King William Island where there was a short stopover (68° 50' N latitude, 94° 40' W longitude). From there the flight continued eastward across the stem of Boothia Peninsula to Pelly Bay on Melville Peninsula (68° 30' N latitude, 89° 50' W longitude) which was the point of return to Cambridge Bay. Ground checks were limited to Pelly Bay. Extensive photography was done from the altitudes of 1000-2000 feet (300-600 m).

Flight 3 - This flight was made following the route Cambridge Bay-Cape Parry-Coppermine-Yellowknife-The Pas-Winnipeg. Photography was possible only between Coppermine and The Pas due to the weather and light conditions. The flying altitude was 10,000 feet (3000 m).

Area 2. Churchill, Manitoba

Churchill is in northern Manitoba on Hudson Bay at 58° 45' N latitude and 94° 10' W longitude. Only ground studies were made in this locality.

Area 3. Chesnaye, Manitoba

Chesnaye, where ground studies were also made, is a siding on the Hudson Bay railway about 50 miles (80 km) south of Churchill at 58° 10' N latitude and 94° 10' W longitude. Also here only ground studies were executed.

Area 4. Thompson, Manitoba

Thompson is situated at 56° 45' N latitude and 97° 50' W longitude. Some ground studies on different examples of confined muskeg (Radforth 1963) were done here.

Flight 4 - This involved a two-day trip in northern Manitoba along the route The Pas-Norway House-Ilford-Charlebois-Ilford-Lynn Lake-The Pas. The altitude was about 1000 feet (300 m) and a large number of photos was taken. Ground studies were conducted in five locations as follows (areas 5-9 incl.):

Area 5. A small unnamed lake about 20 miles (30 km) south of Wekusko (a small station by the Hudson Bay railway).

This area is situated at 54° 15' N latitude and 99° 40' W longitude. The muskeg studied here is overgrowing the lake.

Area 6. Ilford

Ilford is a station by the Hudson Bay railway about 210 miles (340 km) south of Churchill along the tracks at 56° 51' N latitude and 95° 35' W longitude.

Area 7. The vicinity of a small lake about 10.5 miles (17 km) west of Charlebois (a small station about 125 miles (200 km) south of Churchill.

This area is situated at 56° 40' N latitude and 94° W longitude.

Area 8. Assean Lake 56° 10' N latitude, 96° 35' W longitude) about 28 miles (45 km) west of Ilford.

Area 9. A muskeg by a small lake about 30 miles (50 km) south of Lynn Lake at 54° 52' N latitude and 101° 10' W longitude.

Flight 5 - was executed in Manitoba also. It was effected by a helicopter in central Manitoba between Lake Winnipeg and Lake Winnipegosis. The flight altitude varied from 100 to 400 feet (30 - 120 km). Three ground checks were performed as follows:

Area 10. About a mile north of Chitek Lake at 52° 30' N latitude and 99° 10' W longitude.

Area 11. About 8 miles (13 km) north of Katimik Lake at 52° 55' N latitude and 99° 10' W longitude.

Area 12. About 3 miles (5 km) east of Devil's Lake at 52° 25' N latitude and 98° 50' W longitude.

Area 13. A two-day study was extended to southeastern Manitoba where Precambrian changes over to Palaeozoic and where there is a transition between confined and unconfined muskeg.

Area 14. In Ontario the initial ground and low altitude studies were carried out in Parry Sound at 45° 25' N latitude and 80° W longitude.

Area 15. Situated at Moosonee at the estuary of Moose River on James Bay at 51° 15' N latitude and 80° 40° W longitude. Ground investigation was done here to accompany airphoto study on high altitude photos in the laboratory.

Area 16. This is about a 15 mile (25 km) long stretch from Ranoke (110 km = 70 miles south of Moosonee, at 50° 25' N latitude and 81° 40° W longitude) to Otter Rapids (135 km = 85 miles south of Moosonee, at 50° 10' N latitude and 81° 40' W longitude). In this area ground studies were performed throughout.

Flight 6 - The last remaining areas are in Newfoundland where a few aerial photos were taken from a commercial aircraft between St. John's and Gander, Gander and Stephenville, and between Stephenville and Port aux Basques.

Area 17. The ground check locations in the vicinity of St. John's (approximately 47° 35' N latitude and 52° 40' W longitude).

Area 18. The ground check points near Gander (49° N latitude and 54° 35' W longitude).

Area 19. The ground check points close to Stephenville (48° 30' N latitude and 58° 25' W longitude).

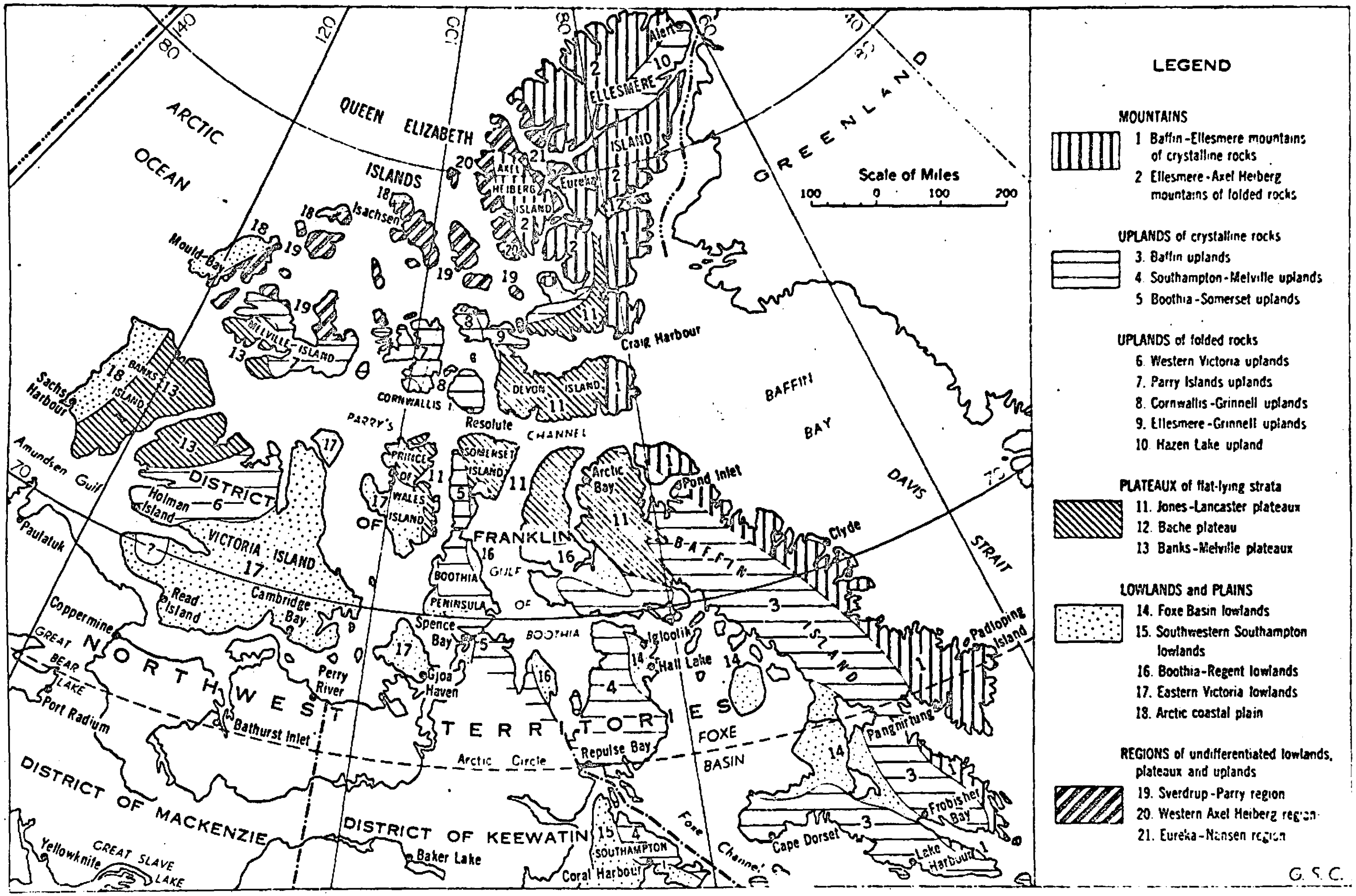


Fig. 2. Provisional physiographic divisions of the Arctic Archipelago (From <u>Geology and Economic Minerals of Canada</u>. Dept. of Mines and Technical Surveys, 1963).

Geological and Physiographical Aspects

Because geology and physiography are of prime importance in controlling paludification and because the understanding of the basic background of paludification is a basic requirement for clearer understanding of pattern evolution, a rather detailed description of the geological and physiographical features of the study areas is given with a summary of their effect on paludification as interpreted by the present author.

Most of the study areas lie within the limits of four main physiographic regions of Canada, and include the Canadian Shield, Arctic Archipelago, Hudson Bay Lowland and Interior Lowlands. (Department of Mines 1963, Putnam et al 1963). Thus both Precambrian and Palaeozoic formations are involved in this investigation.

Area 1 and Flight 2 from Cambridge Bay to the western fringe of Boothia Peninsula lie within Arctic Lowlands Plains and specifically in the Eastern Victoria Lowland (Figure 2). This area is low in relief and the elevations rarely reach over 300 feet (90 m) above sea level. There is one exception; Mount Pelly, over 600 feet, near Cambridge Bay (Dunbar and Greenaway 1956). This region is underlain by flat-lying Palaeozoic strata. Geologically this region is known as Victoria Strait Basin (Figure 2) (Dept. of Mines 1963). Bedrock outcrops occur to some extent but

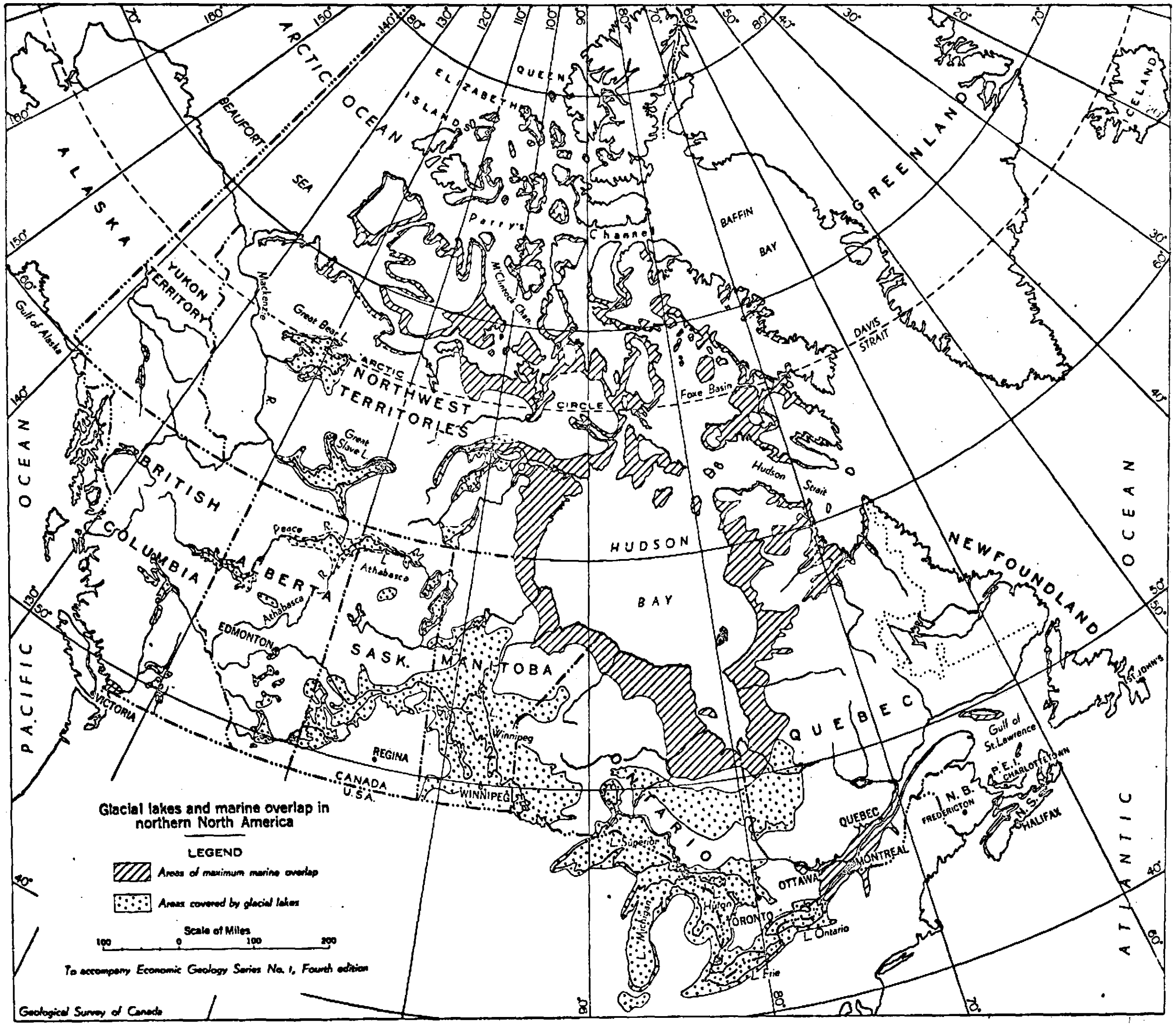


Fig. 3. Glacial lakes and marine overlap in northern North America (From *Geology and Economic Minerals of Canada*. Dept. of Mines and Technical Surveys, 1963).

mostly the ground is covered by glacial drift and also by shallow organic terrain. The glacial deposits are commonly drumlins, eskers and fluted moraines. It is assumed that these are evidence of Laurentian glaciation and that Victoria Island may have had its own ice cap at a later stage of deglaciation (Dept. of Mines 1963). In many places these glacial deposits show signs of having been reworked by the sea and old beachlines are a common and conspicuous feature. The map showing the marine overlap in northern North America (Figure 3) refers to this possibility (Dept. of Mines 1963).

The drainage of these regions, quite irregular, youthful and poorly integrated, has not had opportunity to develop during the short time elapsed since the last glaciation and also shows the influence of permafrost on the drainage. The relative smoothness of the relief may contribute to the poor integration of the drainage system. The area is dotted with thousands of small lakes of which many are possibly thaw lakes typifying permafrost country.

The eastern portion of Flight 2 from the western fringe of Boothia Peninsula to Pelly Bay crosses a physiographic region designated as Uplands of Crystalline Rocks and specifically known as the Boothia-Somerset Uplands (Figure 2) (Dept. of Mines 1963). Geologically, this area coincides with the Boothia Arch (Figure 4). It is composed of Precambrian rocks, mainly of granites and gneisses. The relief

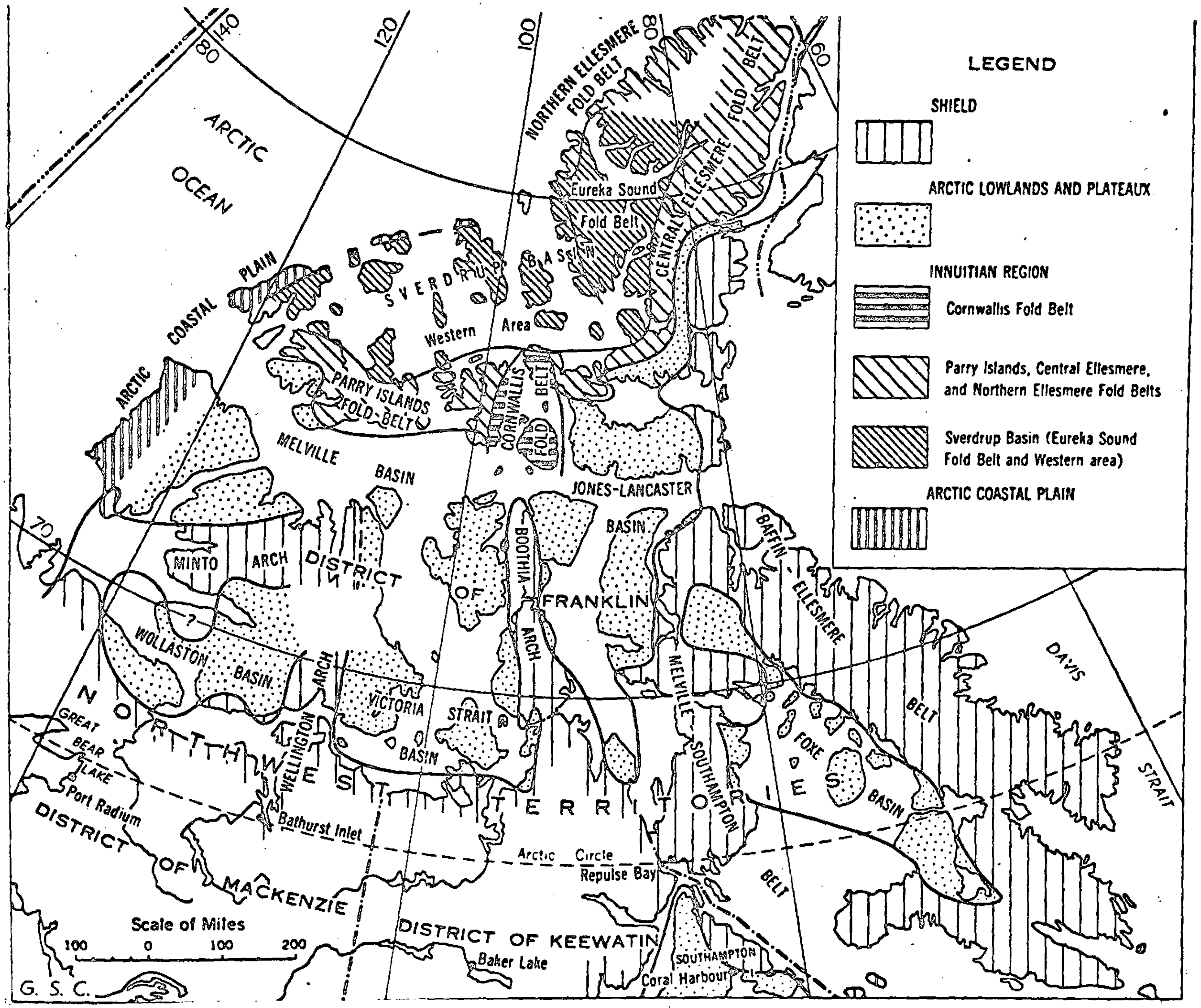


Fig. 4. Geological regions and subdivisions of the Arctic Archipelago (From Geology and Economic Minerals of Canada. Dept. of Mines and Technical Surveys, 1963).

is quite bold in contrast to the Eastern Victoria Lowlands. The elevations reach up to 1000-2000 feet (300-600 m) above sea level and bedrock outcrops are numerous. There is some glacial drift with easterly orientation especially on Boothia Isthmus where the flight crosses Boothia Area (Dunbar and Greenaway 1956, Dept. of Mines 1957). Some shallow organic terrain can be seen in depressions and also on the slopes almost anywhere in this area (Figure 7).

Flight 1 over Kent Peninsula is on Precambrian Shield. Nevertheless, this area has relatively smooth relief and the elevations do not exceed 600 feet (180 m) (Dunbar and Greenaway 1956). Geologically, it is a part of the so-called Wellington Arch which extends to the central parts of Victoria Island (Figure 4). The rocks are mostly Proterozoic volcanic and sedimentary rocks (Dept. of Mines 1963). Here also incipient organic terrain is quite common and is located often on the slight gradients (Figure 66).

Flight 3 between Coppermine (N.W.T.) and Flin Flon (Manitoba) also crosses the Precambrian Canadian shield with its intrusives blended with sedimentary and volcanic rocks. The relief near Coppermine and south of it seems to be relatively smooth with rounded hills. This smoothness prevails almost to the Yellowknife area and also shows clear evidence of glaciation. Eskers especially are easily discernible from the air. Their orientation points towards the Keewatin ice divide in the easterly direction. The rather smooth relief near Coppermine offers possibilities for unconfined development of organic terrain which is incipient. Towards the south near Yellowknife and between it and Flin Flon the relief is still quite low, about 2000 feet above sea level, but its detail is rugged partly due to the gouging effect of the continental ice during glaciation. Rock outcrops are numerous and the organic terrain is confined to pockets in the terrain.

Just south of Flin Flon flight 3 passes over a physiographic area called the Interior Plains, and more specifically here the First Prairie Plain or the Manitoba Lowland (Putnam et al 1963) (Figure 5). Geologically, this area is composed of Palaeozoic rocks and includes Ordovician, Silurian and Devonian limestones with gypsum in the Silurian beds (Putnam et al 1963). This area is very flat and low-lying and does not exceed 1000 feet (300 m) above sea level in height. There are numerous large lakes, for example, Lake Winnipeg, Lake Winnipegosis and Cedar Lake which are remnants of the ancient Lake Agassiz once estimated to have covered an area of 110,000 square miles (275,000 sq. km) (Putnam et al 1963, Dept. of Mines 1957). Near Winnipeg this area is covered with thick layers of fertile clays but to the north, between Lake Winnipeg and Lake Winnipegosis and Cedar Lake, the soil is thin and mostly organic with tendencies to extend over unconfined areas. Drumlins and old beachlines of Lake Agassiz are conspicuous and often affect the

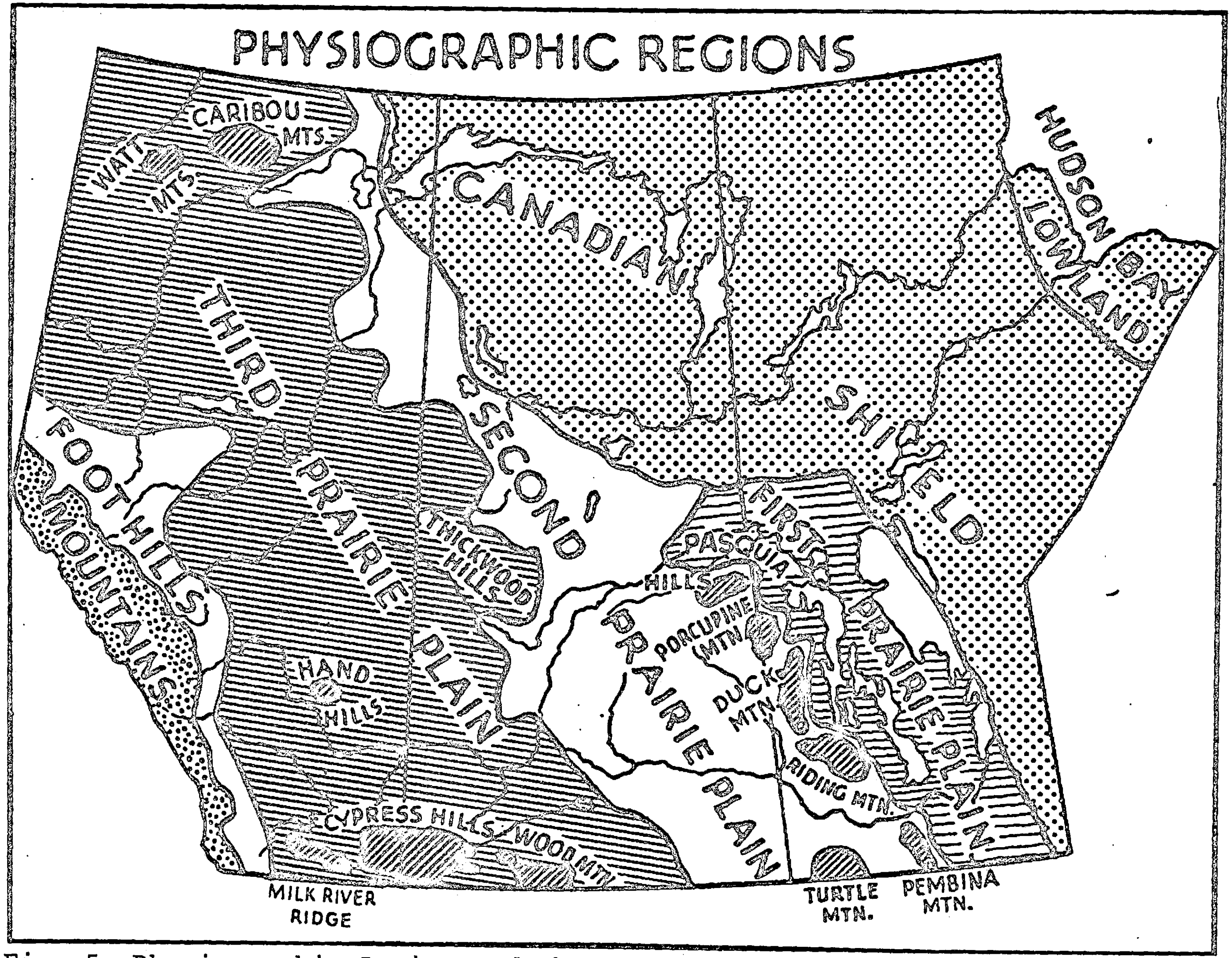


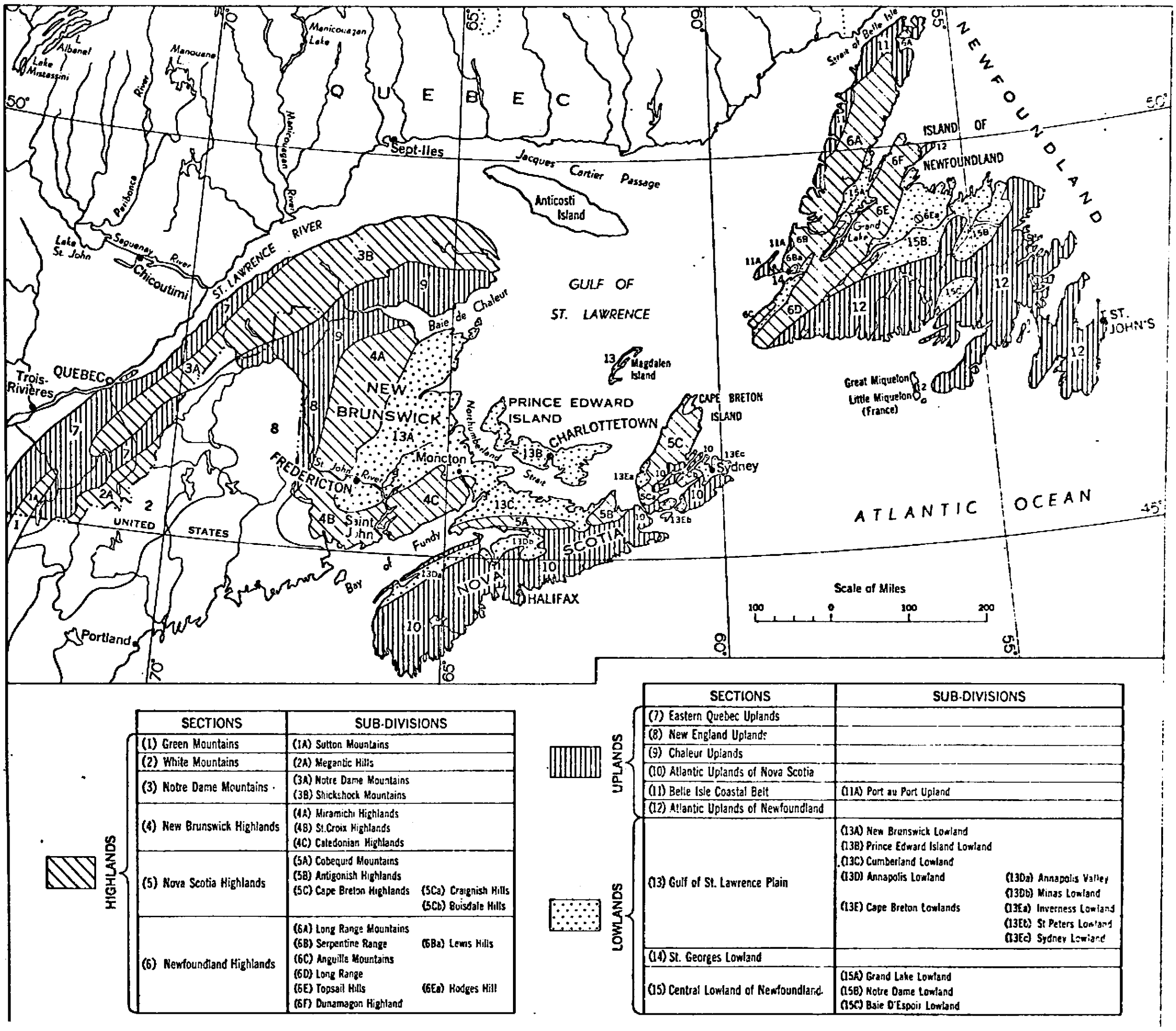
Fig. 5. Physiographic Regions of the Prairie Provinces (After Putnam et al, 1963).

occurrence and distribution of muskeg (Figure 16). Flight 5, a short portion of Flight 4 between The Pas and Norway House and the Areas 5, 10, 11 and 12 also lie within the limits of this physiographic and geological region (Figure 5).

Flight 4 and Areas 4, 6, 8 and 9 from Norway House to Ilford, Lynn Lake and back to The Pas chiefly cover Precambrian rocks. The relief is quite low, and the elevation is mostly under 1000 feet (300 m) above sea level as the measurements along the Hudson Bay railway show (Ehrlich et al 1959). The country here is dotted by thousands of lakes as a result of the last glaciation. Rock outcrops are numerous and the drainage features indicate 'youthful' conditions since there are only a few well-developed river systems. Muskeg is mostly confined in depressions. It appears in an unconfined condition only near Ilford where it extends continuously over large areas. The Canadian Shield near Ilford is quite smooth and low and between Gillam and Charlebois, it is transformed almost imperceptibly into the Hudson Bay Lowland with its Palaeozoic rocks. Part of Flight 4 and Areas 2, 3 and 7 are situated in this last mentioned region. This area, characterized by flatness and poor drainage, is overlain by extensive tracts of organic terrain and contains a great number of small lakes. The area has been covered by the sea during the maximum marine overlap (Figure 3) (Dept. of Mines 1957).

Area 13 (southeastern Manitoba) and Area 16 (northern Ontario) are comparable with each other since they both are in the transition zone between the Canadian Shield and Palaeozoic Lowlands. In the case of Area 13, the transition is between the Canadian Shield and the Manitoba Lowland, whereas Area 16 traverses the Canadian Shield and the Hudson Bay Lowland with its Palaeozoic rocks and quite smooth flat topography. Area 13 is more rugged with numerous rock outcrops and lakes whereas in Area 16, there is heavier overburden of glacial origin. The rock outcrops here are less numerous and the topography is more gently rolling. Lacustrine deposits cover large areas and muskeg is more extensive in this Precambrian region than it is in that of Area 13. The Hudson Bay Lowland here is very flat as it is in the north. Here it is treed though it is only about 30 miles (50 km) south of Moosonee. Lakes are less numerous here than in the treeless permafrost area farther north. The main conformity between Area 13 and these northern Ontario areas (15 and 16) is the gradual transformation of organic terrain from a confined into an unconfined condition associated with the change of Precambrian Canadian Shield into Palaeozoic Lowland areas (Figure 17).

Area 14 is also situated in the Canadian Shield and with its rugged rocky topography shows all the physiographic characteristics that have been mentioned earlier for other areas which also lie in the Canadian Shield, cf. Area 4, etc.



	SECTIONS	SUB-DIVISIONS
▨ HIGHLANDS	(1) Green Mountains	(1A) Sutton Mountains
	(2) White Mountains	(2A) Megantic Hills
	(3) Notre Dame Mountains	(3A) Notre Dame Mountains (3B) Shickshock Mountains
	(4) New Brunswick Highlands	(4A) Miramichi Highlands (4B) St.Croix Highlands (4C) Caledonian Highlands
	(5) Nova Scotia Highlands	(5A) Cobequid Mountains (5B) Antigonish Highlands (5C) Cape Breton Highlands (5Ca) Craignish Hills (5Cb) Boisdale Hills
	(6) Newfoundland Highlands	(6A) Long Range Mountains (6B) Serpentine Range (6Ba) Lewis Hills (6C) Anguille Mountains (6D) Long Range (6E) Topsail Hills (6Ea) Hodges Hill (6F) Dunamagon Highland

	SECTIONS	SUB-DIVISIONS
▥ UPLANDS	(7) Eastern Quebec Uplands	
	(8) New England Uplands	
	(9) Chaleur Uplands	
	(10) Atlantic Uplands of Nova Scotia	
	(11) Belle Isle Coastal Belt	(11A) Port au Port Upland
	(12) Atlantic Uplands of Newfoundland	
░ LOWLANDS	(13) Gulf of St. Lawrence Plain	(13A) New Brunswick Lowland (13B) Prince Edward Island Lowland (13C) Cumberland Lowland (13D) Annapolis Lowland (13Da) Annapolis Valley (13Db) Minas Lowland (13E) Cape Breton Lowlands (13Ea) Inverness Lowland (13Eb) St Peters Lowland (13Ec) Sydney Lowland
	(14) St. Georges Lowland	
	(15) Central Lowland of Newfoundland	(15A) Grand Lake Lowland (15B) Notre Dame Lowland (15C) Baie D'Espoir Lowland

Fig. 6. Physiographic divisions of the Appalachian Region of Canada (From Geology and Economic Minerals of Canada. Dept. of Mines and Technical Surveys, 1963).

Areas 17, 18 and 19 and Flight 6 in Newfoundland lie in the Appalachian Physiographic Region (Figure 6). Area 17 lies in the so-called Atlantic Uplands of Newfoundland (Dept. of Mines 1963). This area is commonly between 100 and 600 feet (30-180m) above sea level. It displays quite a gently rolling relief except where river flow has been strong enough to erode it. The rocks in this area are mostly Precambrian sedimentary rocks with a few Palaeozoic outliers. Muskeg occurs commonly on slopes (Figure 7), except in the most rugged areas where it is confined to the depressions provided by the topography.

Area 18 is in the Central Lowlands of Newfoundland and specifically in the Notre Dame Lowland (Dept. of Mines 1963). This area is gently rolling, largely covered with heavy overburden, and generally sharply separated from the surrounding regions of intrusive rocks. It is mainly underlain by Palaeozoic (especially Ordivician) sedimentary rocks (Putnam et al. 1963, Dept. of Mines 1963). The relief is generally under 500 feet (150 m) above sea level.

Area 19 is situated by the border of two physiographic sub-regions, namely, the Central Newfoundland Lowlands and the Newfoundland Highlands (Lewis Hills - Long Range) (Dept. of Mines 1963). The characteristics of the lowlands were discussed above. The highlands are, as a rule, quite rugged (Figure 8) and the relief varies from 600-700 feet (180-210 m) up to an occasional peak of 2,000

Fig. 7. Large virtually unconfined ombrogenic muskeg in Colinet, Nfld. Cover in the foreground is HE (lichen is in this oblique view hidden by shrubs) and FI in the background.

Fig. 8. Unconfined ombrogenic muskeg near Stephenville, Nfld. Note how paludification takes place on rather steep slopes. Main cover is EI.

feet (600 m). Area 19 is in the region where the hills are still quite gently rolling although rather high. The gentle amplitude may occur because this area is underlain largely by undivided Palaeozoic sedimentary rocks and partly by Ordovician and Cambrian sedimentary rocks. Organic terrain here displays a strange tendency to form quite unconfined mats over rather steep slopes.

The unconsolidated deposits in Newfoundland testify that the island has been under the influence of glaciation. According to Putnam (1963), there seem to have been at least two or even more periods of glaciation. It seems that the island was completely covered with glacier ice in Wisconsin time and that Labrador-derived ice invaded the island at the maximum of the Wisconsin glaciation. Later, during the deglaciation, Newfoundland developed ice caps of its own and from these the ice spread in all directions cutting deep valleys and depositing till in a complex pattern (Dept. of Mines 1963).

The Effect of Underlying Mineral Soil and Topography on Paludification

The effect of geology on paludification is mainly indirect through the influence of the underlying soil type and topography. The following is a short summary of the influence of these two factors on paludification as interpreted by the present author. In addition to shed more light on the edaphic causes and controls of paludification in general it is hoped that this section will provide background information in accounting for distribution of confined muskeg as contrasted with that of unconfined. Thus it is hoped also to explain indirectly the large scale control by topography of the distribution of Marbloid airform pattern. It becomes evident that most of the high altitude airform patterns, to appear as such on aerial photographs, require unconfined muskeg conditions due to the scale factor.

The latest glaciation covered all the study areas as Figure 9 reveals. There were two major ice-divides, one northwest of Hudson Bay, the Keewatin ice-divide, and another one east of Hudson Bay, the Labrador ice-divide.

In the study areas glaciation distributed soils which are impervious to the water because large ice sheets deposited till and the large glacial lakes acted as basins for sedimentation of the impervious clays. This condition has favoured paludification for which excess water is needed. The condition is still progressing wherever the environment favours it.

Quite often the soil is impervious in Areas 1 to 9 because of permafrost, but only areas 1 and 2 are in the zone of continuous permafrost. The other areas are in the discontinuous permafrost zone where the properties of the underlying soil are the most significant factors encouraging

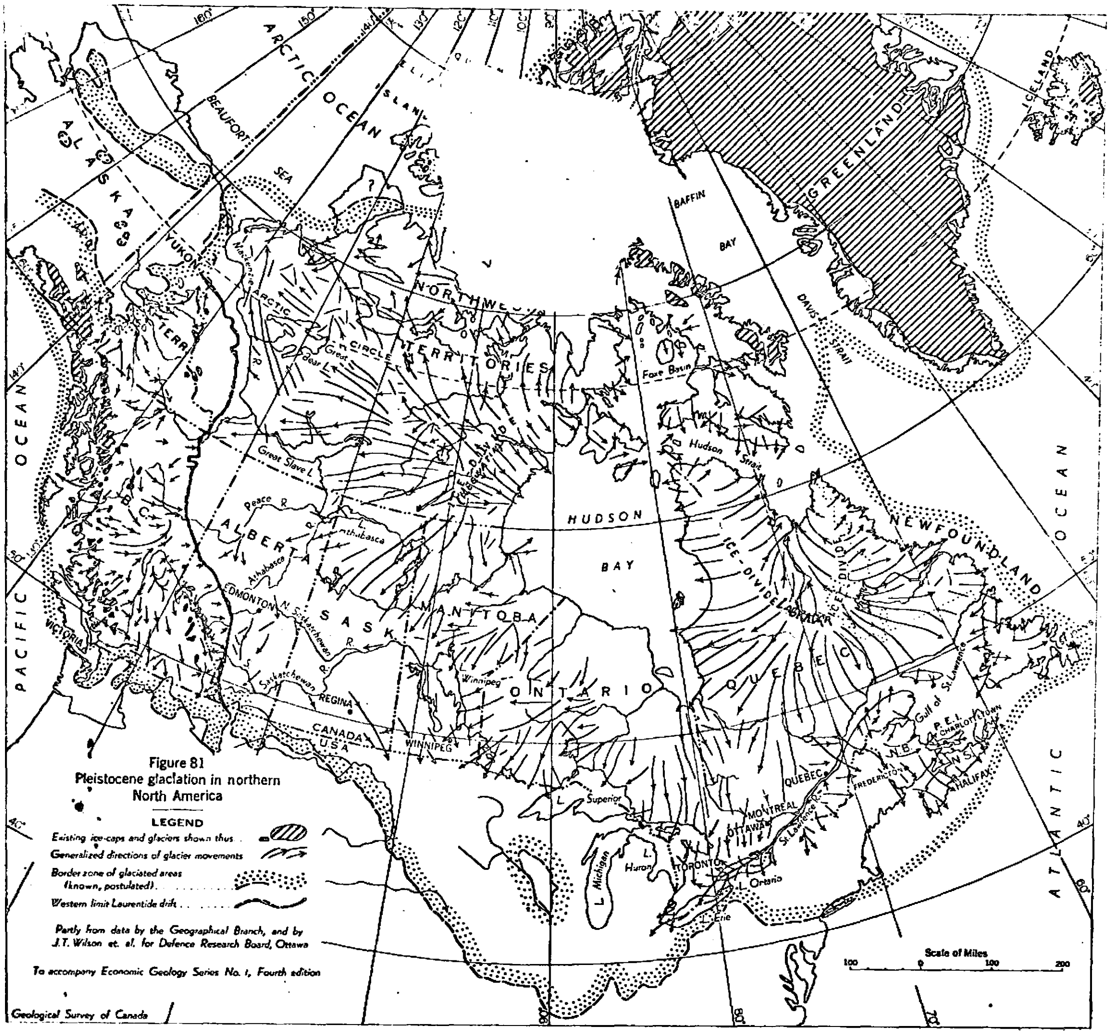


Figure 81
Pleistocene glaciation in northern North America

Partly from data by the Geographical Branch, and by J.T. Wilson et. al. for Defence Research Board, Ottawa

To accompany Economic Geology Series No. 1, Fourth edition

Geological Survey of Canada

Fig. 9. Pleistocene glaciation in northern north
America (From Geology and Economic Minerals of Canada.
Dept. of Mines and Technical Sutveys, 1963).

paludification. In Areas 2, 3, 15 and 16, glaciation in addition to permafrost, has supported the marked paludification. This condition represents activity which commenced as a widespread phenomenon following deglaciation and after the land area had been depressed several hundred feet by the weight of the ice. When these areas were covered by the sea, the blanket of sediments that ensued retained surface water enabling muskeg to form later (paludification).

Areas 6 and 7 do not seem to have been inundated (cf. Figure 3, depicting the maximum extent of glacial lakes and marine overlap). These areas however bear large amounts of till which also serves as a good foundation for paludification. The same applies to Areas 17 to 19 although climatic factors are there more influential in determining paludification.

Areas 4 and 5 and 9 to 13 have been inundated also and the resulting sediments play a partial role in forming impervious soils. This is especially true for Areas 5 and 10 to 12 which are in the Manitoba Lowland area (Figure 5) where Lake Agassiz has deposited large areas of rich clays and where the topography is flat and provides ideal conditions for paludification.

Area 13 is also partly in this region but partly it is affected very strongly by the Precambrian Shield.

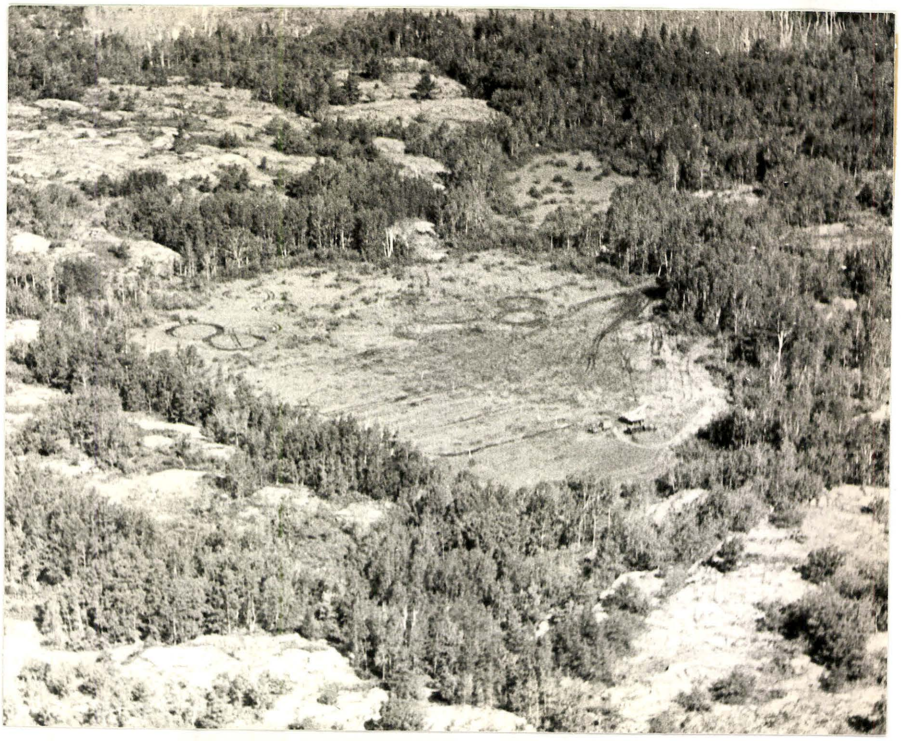
Probably Area 14 was inundated several times but the imperviousness of glacial drift and sediments does not play as large a role in paludification of this area as does the ruggedness of the rocky topography.

In all study areas, Area 1 excepted because of its limiting climate, muskeg has developed persistently and extensively. Often the effects of climate and underlying mineral terrain are overidden by the topographic factor. The division of muskeg into two groups, confined and unconfined (Radforth 1963), indirectly recognizes topographic effect though this circumstance has not been explained. Actually to a certain extent the major effect of topography on paludification is that it determines the size and depth of the muskeg area.

A confined muskeg with its size limited by certain factors such as topography is referred to in some countries by the term peat bog. Areas 4, 8, 9 and 14 in the typical Precambrian Shield country with its relatively rugged topography and few expanses show this condition favourably. Muskeg is characteristically confined to the depressions, because the climate is not humid enough to encourage overgrowth. Thus, these areas comprise mostly small muskegs which sometimes appear in contiguous linear formations when they are interconnected by narrow strips of muskeg in narrow depressions which often are paludified drainage channels. Figure 10 is an example of typical confined muskeg in Area 14 just north of Parry Sound, Ontario. This muskeg, or peat bog as it could be called, is entirely surrounded

Fig. 10. Low altitude (1000') oblique view of confined muskeg in the Precambrian Shield near Parry Sound, Ontario. Cover is mainly FI and EFI.

Fig. 11. Small lake partly filled by muskeg near Parry Sound, Ontario.



by rocks and has some lacustrine sediments under the peat suggesting that it has been a small lake subsequently filled by paludification. Figure 11 shows another example of a peat bog and indicates how a small lake is gradually being invaded by peat-forming vegetation. This is also in Area 14.

Despite low humidity and rugged topography paludification other than that arising in lakes may occur, and indeed may be common. Detailed studies in Finland have shown that in the western coastal areas lake paludification accounts for only about 5-10% of the total muskeg area (Backman 1919). Recent studies now indicate that in central Finland too the significance of lake paludification is not as great as it was once thought (M.L. Korpijaakko 1966).

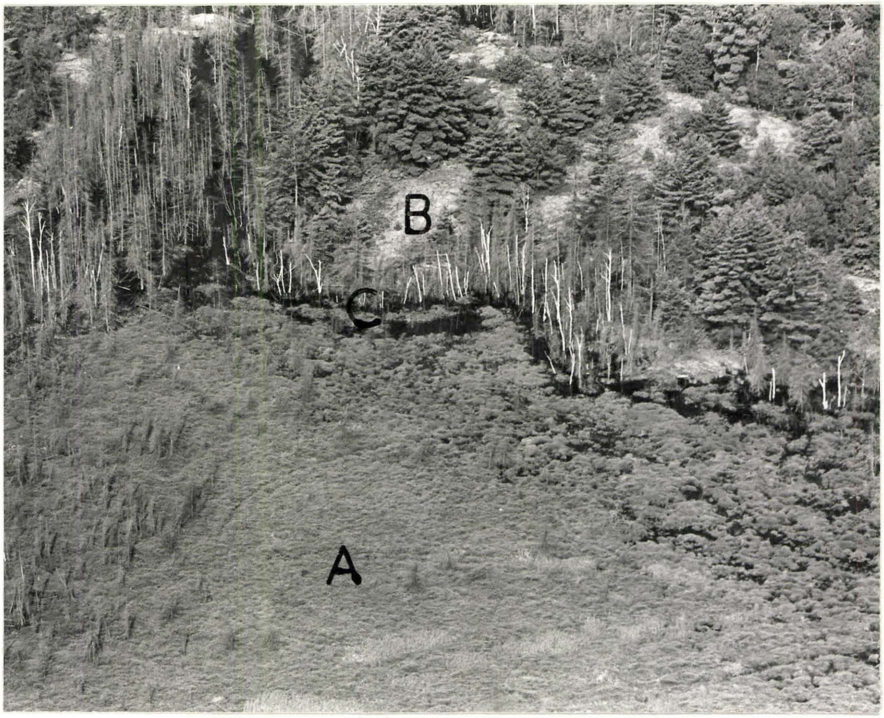
The small peat bogs shown in Figure 10 frequently develop into larger ones or into a network of bogs by encroaching on the surrounding terrain. Once the peat deposits have developed to such depth that they rise higher than the surrounding mineral terrain water spills over the edges of their shallow basins. Very often confined bogs are surrounded by a wet zone where the peat is still very shallow or almost absent but where there is often even free water being slowly pushed into the neighbouring mineral terrain. Frequently, in this zone there are dead and dying trees indicating that paludification is encroaching on the surrounding mineral terrain. This is an example of what is called a "lagg" and Figure 12 shows a low altitude photo of a typical lagg in Area 14. Note, in this photo, the dying trees and the abundance of water in the lagg. The lagg indicates also that the centre of the muskeg in question is higher than its edges are.

Areas 2, 3, 5, 6, 7, 10 to 12 and 15 are in a region of a less rugged topography than those discussed above. There is tendency towards the unconfined condition in the muskeg of these areas. Thus although Areas 6 and 7 are in the Precambrian Shield region, the muskeg is not confined (the common condition in this landscape) mainly because of the smoothness of these parts of the Precambrian Shield.

Areas 2, 3 and 15 are on the flat Palaeozoic Hudson Bay Lowland region which, topographically, is most favourable for the development of unconfined muskeg. Also with climatic and edaphic factors being favourable, paludification dominates. Paludification here is further enhanced by the fact that these areas are still under the influence of the crustal uplift which has been taking place since the ice masses disappeared. The uplift makes the drainage difficult in this area by slowing it down. Water has found its way into the sea through new areas which are constantly emerging from the sea and where drainage has not had time to develop as well as it has in areas further inland. Also, the uplift is on a differential basis here so that the rate of lift is higher near the sea than inland where it

Fig. 12. Low altitude (500') oblique view of lagg in a confined muskeg in Parry Sound, Ontario. Note the dying trees (C) in the wet lagg just at demarcation between mineral terrain (B) and muskeg (A). Activity of beaver has helped raise water level in this muskeg.

Fig. 13. Wet unconfined muskeg near Moosonee, Ontario. High transient water regime helps the growth of *Typha* (cover class C) locally. General cover is BFI, where B is formed by *Larix laricina*.


B
C
A

gradually diminishes to zero. This, of course, tends to render these areas even more water-saturated and thus more susceptible to paludification. Figures 38, 41 and 44 among others show representative conditions in the muskeg in Hudson Bay Lowland areas in Study Area 3.

Figures 13 and 14 are examples of unconfined very wet muskeg in area 15. Figure 14 shows an area which reveals quite a few characteristics of a "raised bog" (cf. Glossary) in a limited area within unconfined muskeg, a condition not uncommon in the Moosonee area in northern Ontario.

Areas 5 and 10 to 12 are on the Palaeozoic Manitoba Lowlands region (Figure 5), the area once covered by the glacial Lake Agassiz. Unconfined paludification, the common condition, is to be expected despite the climate which is insufficiently cool and humid to contribute to the development of the extensive muskeg areas found. In this case topographic and edaphic factors combine to supply the highly favourable conditions for muskeg formation. Figure 15 shows a low altitude aerial view over part of Area 11.

Figure 16 is a stereopair from Area 11 also showing the effect of glacial topography on the distribution of muskeg. In this photo, there is a curved beachline of Lake Agassiz. Areas above the upper part of the beachline and below the lower part of it are covered by extensive unconfined muskegs which lie in the basin of Lake Agassiz. The upper beachline has dammed water in small ponds above

Fig. 14. Unconfined muskeg in Area 16 near Coral Rapids, Ontario. Main cover here is BEI, where B is formed by *Picea mariana*. This location is representative of one of the dark areas of Figure 17.

Fig. 15. Low altitude (300') oblique view of unconfined muskeg in Area 11, central Manitoba. Light yellowish colour is rendered by FI cover. Dark magenta areas have EI cover while treed areas display AEI cover.

it and between a group of drumlins perpendicular to it. The drumlins indicate that the movement of the ice in this location has been almost exactly from the north. It is interesting to note that between the drumlins and above the beachline there are small confined bogs with pattern oriented at right angles to the gradient.

Here is a good example of how the topography may determine the size of muskeg areas. Paludification between the drumlins probably commenced by the filling in of ponds, a process still in progress as the open character of remaining ponds suggests. The condition was generated because the underlying till was impervious and facilitated the maintenance of the ponds between the drumlins. In the unconfined muskeg of the flatter topography, the underlying mineral soil is clay deposited on the bottom of former Lake Agassiz.

Areas 13 and 16 are probably the most interesting in regard to the effect of topography on paludification. They are both only partly on the rugged Precambrian terrain. Area 13 is also partly in the flat Manitoba Lowland and Area 16 on the flat Hudson Bay Lowland area. Figure 17 is a mosaic compiled from high altitude aerial photographs of Area 16 to show the effect of topography on paludification and especially how it affects the distribution of confined and unconfined muskeg. To the left on the mosaic is the Precambrian Shield with its relatively rugged topography.

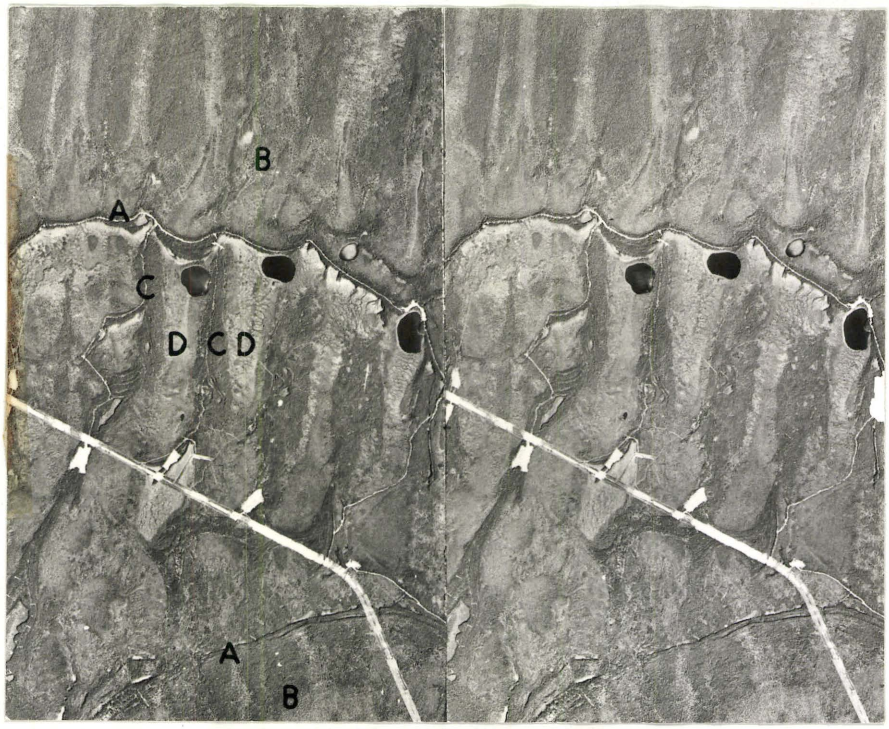


Fig. 16. High altitude (30,000') vertical stereopair of confined and unconfined muskeg in central Manitoba between Lake Winnipeg and Lake Winnipegosis just north of Lake Tikimaki.

A = ancient beachlines of Lake Agassiz.
B = areas of unconfined muskeg.
C = drumlins.
D = confined muskeg with reticulate pattern. This pattern implies existence of eccentric raised bog.

There the muskeg areas are confined and in some areas quite small as the outlines show. But nearer the centre of the area shown in the figure, the examples of muskeg become progressively more numerous and eventually form a network in which muskeg area increases as the demarcation between the Precambrian and Palaeozoic is approached. This line is approximately in the middle of the mosaic as marked. To the right of it lies the Palaeozoic Hudson Bay Lowland. Here the topography is remarkably flat and is reflected immediately by the sudden expansiveness of unconfined muskeg.

In this example one finds again the areas of muskeg with characteristics of raised bogs encountered in the ground-level view shown in Figure 14.

Areas 17 to 19 provide peculiar characteristics in relation to the factors affecting paludification. In these areas even rugged topography has not limited paludification. Muskeg has formed in large unconfined areas. It occurs on steep hillsides and even covers small steep hillocks as Figures 7 and 8 testify. Here the major mode of paludification is encouraged by the relatively high humidity of the cool moist climate. Paludification in these circumstances is neither confined to flat areas nor to impervious soils but climbs hills and extends over well-drained soils.

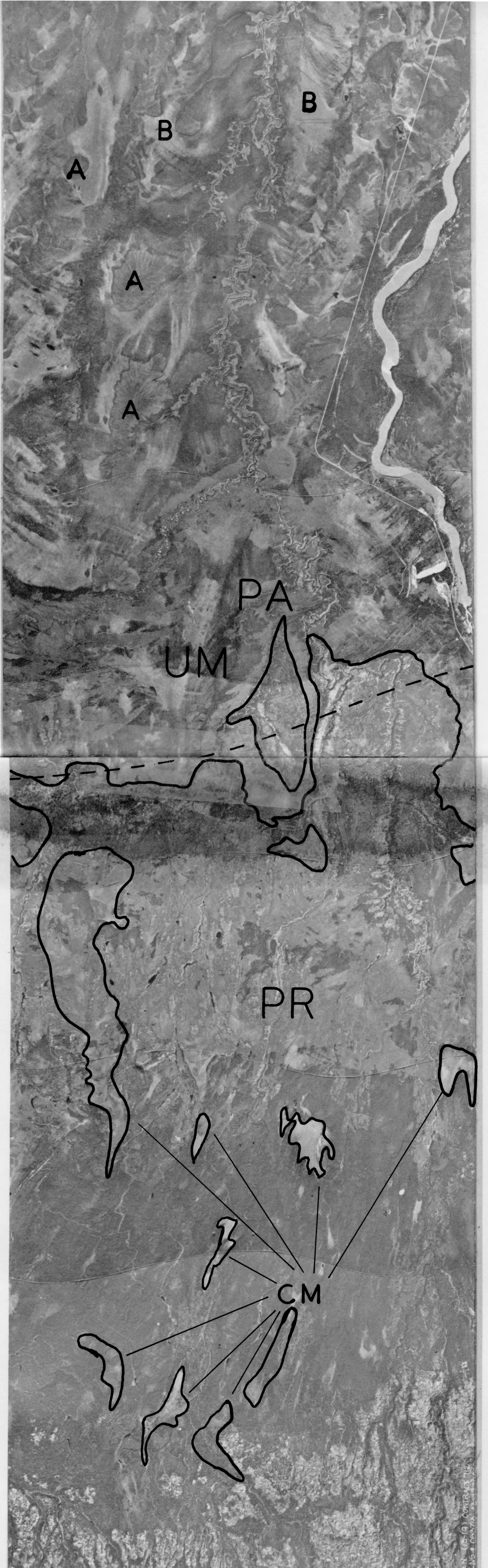
Fig. 17. High altitude (30,000') mosaic from Study Areas 15 - 16 in Otter Rapids - Coral Rapids region, northern Ontario. This figure shows gradual change from confined muskeg of the Precambrian areas to unconfined muskeg of Palaeozoic Hudson Bay Lowland. Broken line is the approximate demarcation between the Precambrian Shield on the left and the Palaeozoic Hudson Bay Lowland on the right. Outlined areas (CM) denote confined muskeg. Unconfined muskeg is marked with letters (UM).

A = remnants of old Marbloid peat plateaus with BEI cover where B is formed by *Picea mariana*.

B = areas with higher water regime with BFI cover. B in this case is formed by *Larix laricina*.

PA = Palaeozoic formations.

PR = Precambrian formations.


B
B
A
A
A
PA
UM
PR
CM
N (13-19) CONTRACT 712

Climate

Climate together with geological and physiographical factors forms the second major control of paludification. Quite often it has been falsely maintained that climate alone would be the only factor controlling paludification. To establish a sound background for the present study a general account of various climatic aspects which affect muskeg formation have been given. Their importance in this connection grows because the climate also controls the distribution of permafrost and thus a major phase of sub-surface ice in muskeg. It is also hoped that this section with its summary will rectify the erroneous concept of the overall importance of climate alone or some individual climatic aspects alone being the prime controllers of paludification and will establish that there is an interaction of edaphic, climatic, and biotic environment contributing to paludification.

1. General Climatic Regions of the Study Areas

To give a comprehensive account of the general climatic conditions of the study areas where these have bearing on the problem under study, Köppen's climatic classification system has been used because it gives substantial amounts of quantitative data and is also in common use in several atlases, for example the Atlas of Canada (Dept. of Mines and Techn. Surveys, Atlas of Canada, 1957). Also the

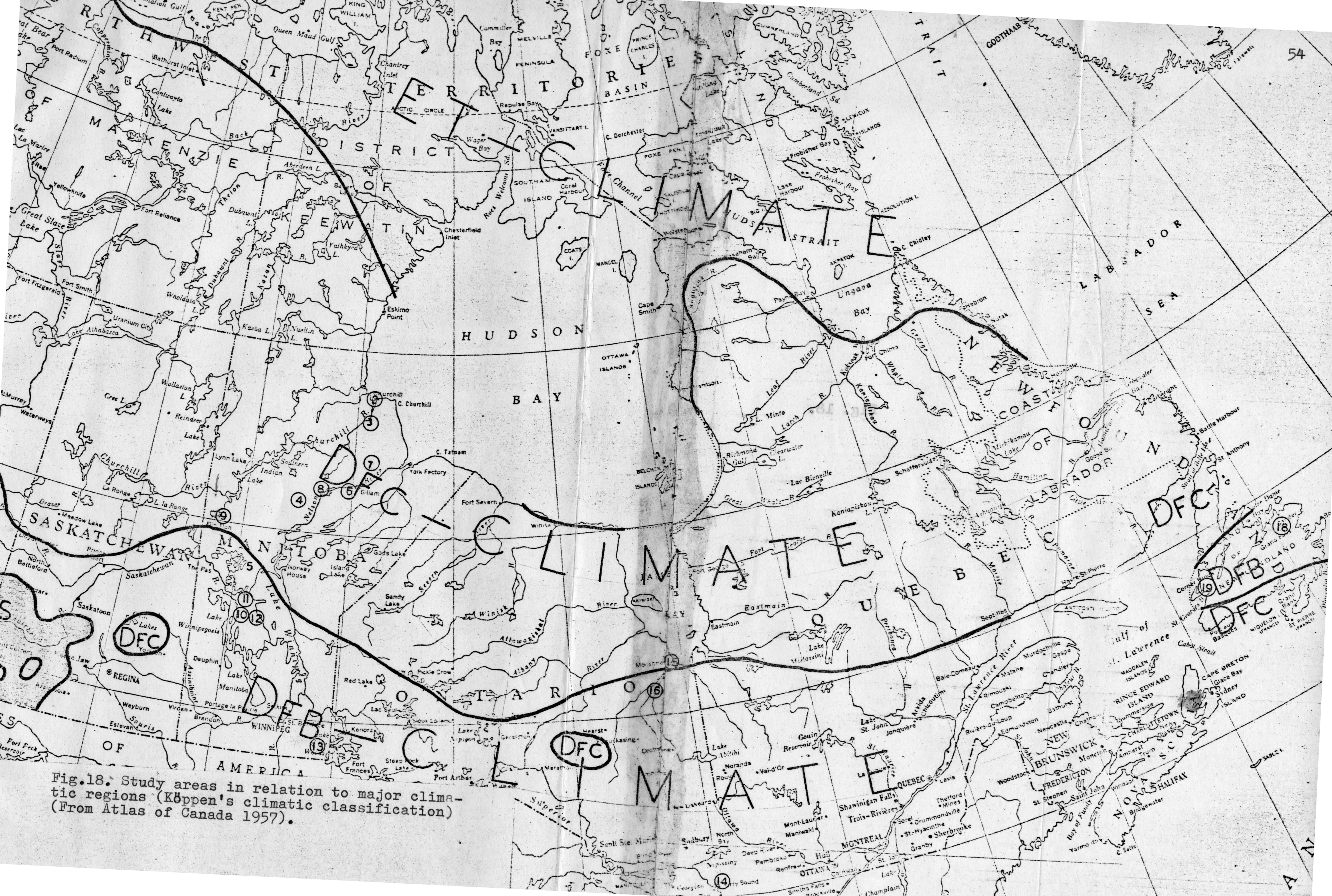


Fig.18. Study areas in relation to major climatic regions (Köppen's climatic classification) (From Atlas of Canada 1957).

Thornthwaite system has been used particularly for moisture index.

Figure 18 displays the major climatic regions within which the study areas lie. Area 1 and Flights 1 and 2 as well as part of Flight 3 are situated in the polar climate region, specifically in the tundra climate region. This region is denoted by the letters ET. E refers to the polar climates in general; cool climates with the average annual temperature below 50° F (10° C). T specifies further that the average temperature of the warmest month is between 32° and 50° F (0° - 10° C).

The rest of the study areas lie under the influence of cold forest climates (symbol D). These are climates with severe winters. The average temperature of the coldest month stays below 32° F (0° C) and the average temperature of the warmest month is above 50° F (10° C).

Areas 2 to 4, 6 to 9, 15 and 17, and Flight 3 between Coppermine (N.W.T.) and Flin Flon (Man.) and most of Flight 4 are characterized according to the influence of climatic group denoted by Dfc. D-climate is characterized by general humidity without any dry season so that the driest month in the summer receives 30 mm (1.2 in.) of rain. The wettest winter month is less than 3 times wetter than the driest winter month. All this is denoted by the letter f. Letter c specifies that the average temperature of from one to three months is 50° F (10° C) or above and that during the warmest

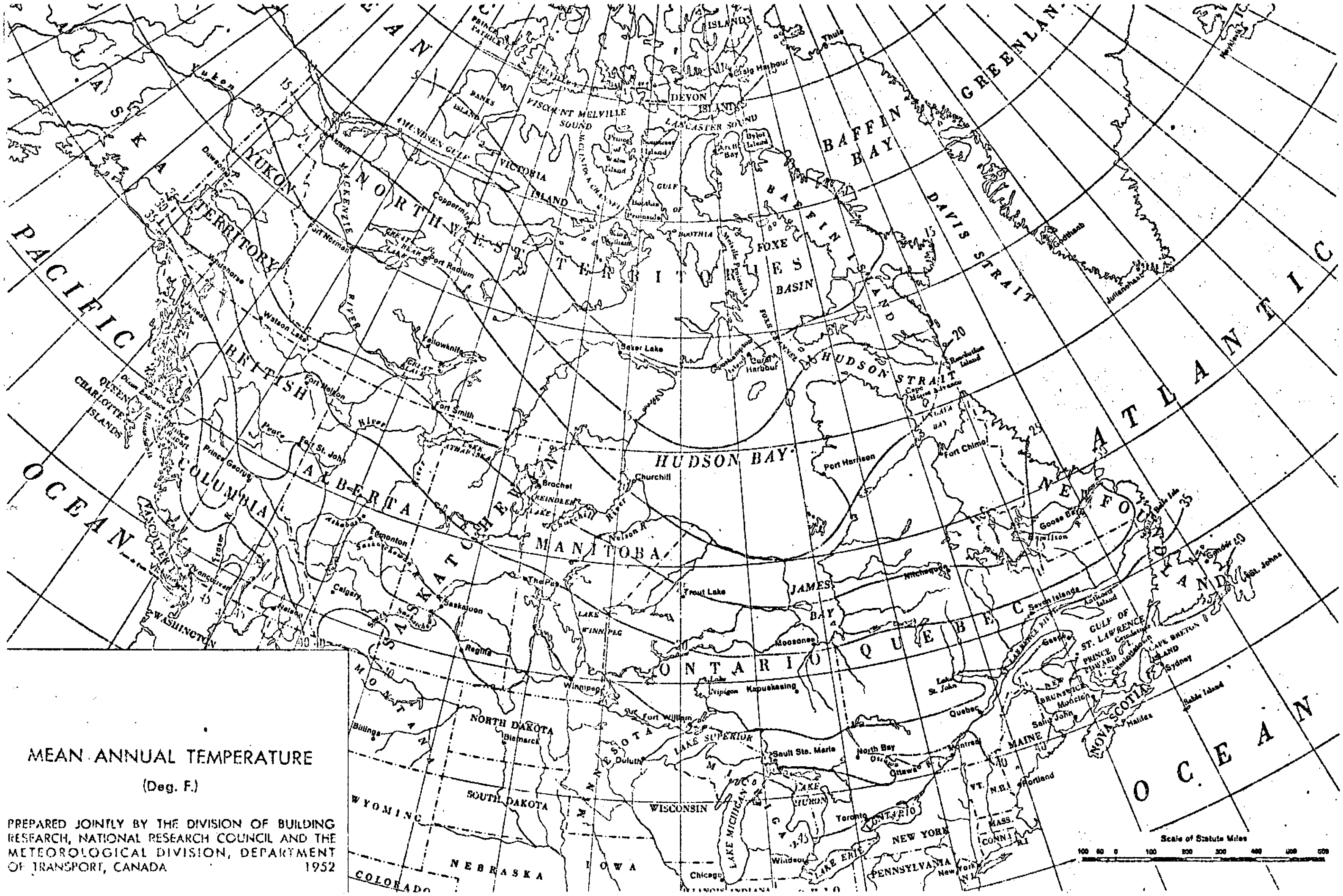


Fig. 19. Mean annual temperature in Canada (From Thomas 1953, Climatological Atlas of Canada, NRC, No 3151).

month the average temperature stays below 71.6° F (22° C).

Areas 5, 10 to 12, 14 and 16 to 19 as well as Flights 5 and 6 belong to the subgroup Dfb. The letter b specifies that the average temperature of each of the warmest month is 50° F (10° C) or higher, and that the temperature of the warmest month is below 71.6° F (22° C) (Trewartha 1954; Critchfield 1966).

2. Temperature Effects

Often the significance of temperature has been unduly emphasized as the main factor in the process of paludification and in the distribution of organic terrain. The wide distribution of muskeg over large areas, not only in the temperate areas, but also in the high arctic as in Ellesmere Island near the ice cap (Radforth 1965), and in the subtropical areas, not only at high elevation, but also in low lying locations as in Florida (Radforth 1965) indicates that the temperature cannot be the only factor affecting paludification. Temperature is important, but only when it acts in concert with some other climatic factors, such as humidity, etc.

Figure 19 displays the mean annual temperatures of Canada (Thomas 1953). This illustration reveals that the average temperatures of the study areas are within wide limits. The highest, about 40° F (4.5° C), is encountered in Areas 14, 17 and 19, and the lowest value, about 5° F (-15° C),

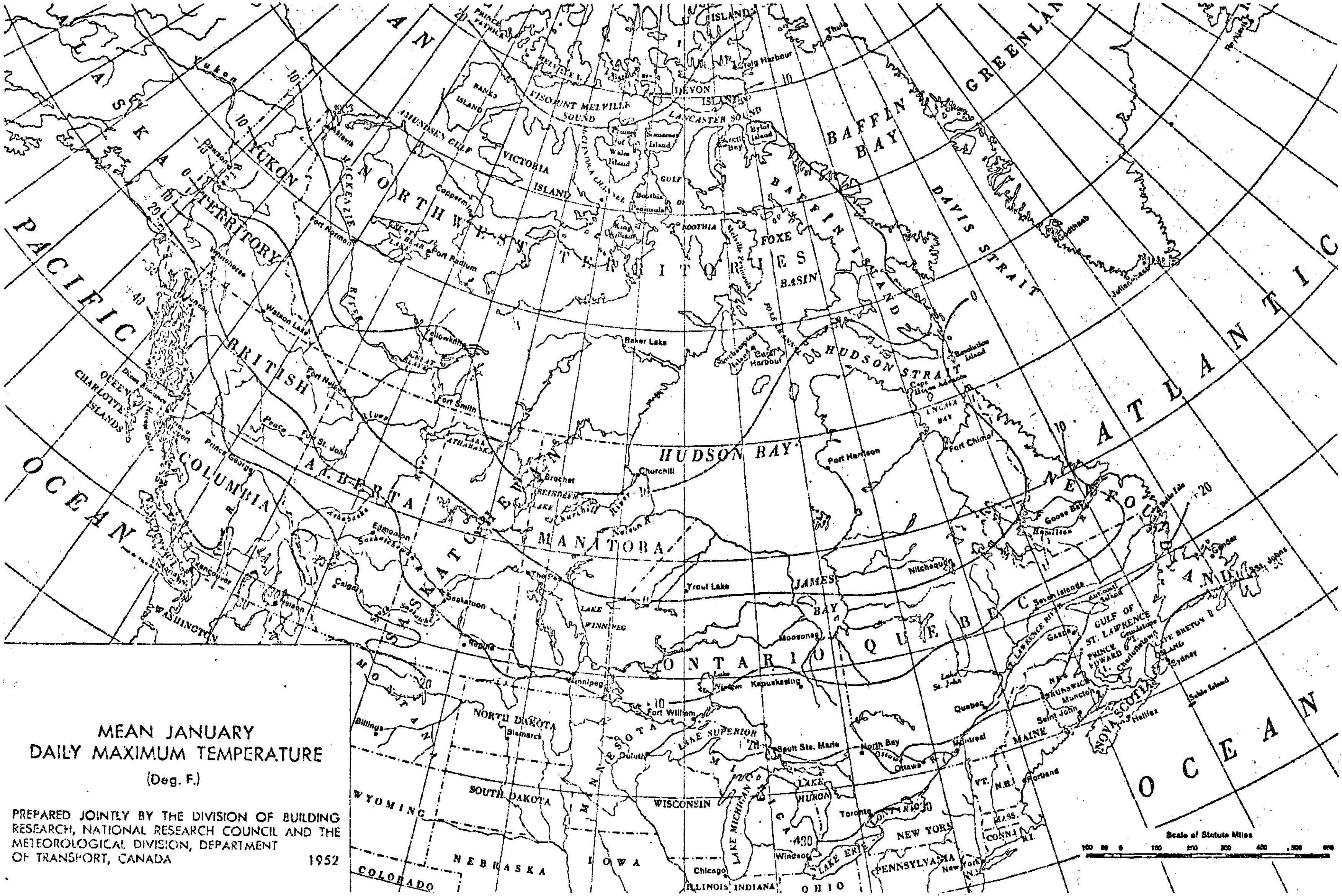


Fig. 20. Mean January daily maximum temperature (From Thomas 1953, Climatological Atlas of Canada, NRC, No 3151

in Area 1.

Figure 19 shows the characteristic curvature of the isotherms towards the south in the Hudson Bay-Great Lakes area, and towards the north, east and west of them. This is attributable to the moderating effect of the oceans and of the large water bodies of Hudson Bay and the Great Lakes. Also the position of the Rockies as a modifier of the westerly air mass circulation pattern is believed to have its effect upon this curvature.

The large water bodies with their high heat capacities exert a stronger moderating influence on extreme temperatures by repressing their peaks. This is shown by the maps of the January and July mean daily maximum temperatures (Figures 20 and 21). In the winter the isotherms curve to the north in the coastal areas and to south in the central areas, while in the summer they tend to stay far south in the coastal areas. In the winter, the northwesterly cold air masses keep the Hudson Bay areas cool, regardless of the heat capacity of the water mass. In the summer, the same happens because of the cooling effect of the cold water masses.

For the vegetation, and thus for the paludification as a function of the growth of certain plants, the most important temperature features are those governing the summer half of the year when vegetative growth is possible. Figure 22 illustrates the time during which the mean temperatures stay above 32° F (0° C).

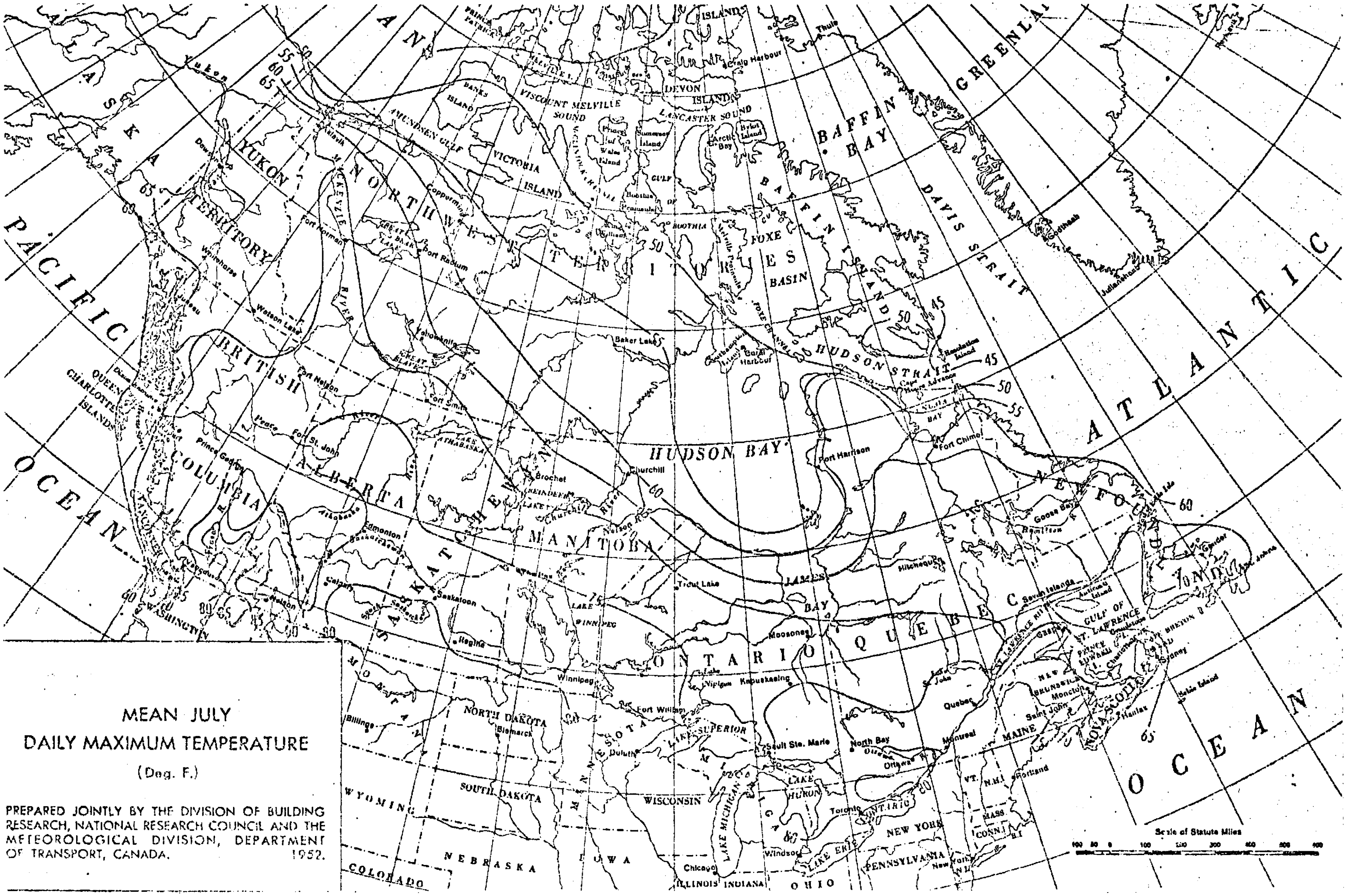


Fig. 21. Mean July daily maximum temperature (From Thomas 1953, Climatological Atlas of Canada, NRC, No 3151

Area 1 and Flights 1 and 2 have a frost-free period of about 40 to 60 days. One should note the vicinity of Great Slave Lake where the frost-free period is longer than in the immediate surroundings (80 days versus 60 days). This is presumably because of the moderating effect of the high heat capacity of this large lake.

Areas 2, 6, 7 and 15 are between 60 and 80 day limits. Areas 4, 5, 9 to 12, 14 and 16 are between 80 and 100 day limits and the rest of the study areas have a frost-free period of over 100 days. The frost-free period is longest in Areas 14, 17 and 19 (120 - 140 days) (Atlas of Canada).

The length of the frost-free period has a strong effect upon the length of the growing season, as Figures 22 and 23 indicate. The growing season is that part of the year when the mean daily temperature is about 42° F (5.5° C) (Atlas of Canada). Sometimes the growing season is defined as the span of time between the mean dates of the last spring frost and the first autumn frost (Critchfield 1966).

As Figure 23 shows, in Area 1 and for Flights 1 and 2, the growing season is of about the same duration as the frost-free period, or approximately 40 to 60 days.

Areas 2, 3, 6 and 7 are between the limits of 90 and 120 days. Areas 4, 5, 8 to 19 have a growing season over 120 days and the maximum, 140 days, is encountered in Area 14.

The short frost-free periods and growing seasons in the north probably are compensated to some extent by longer

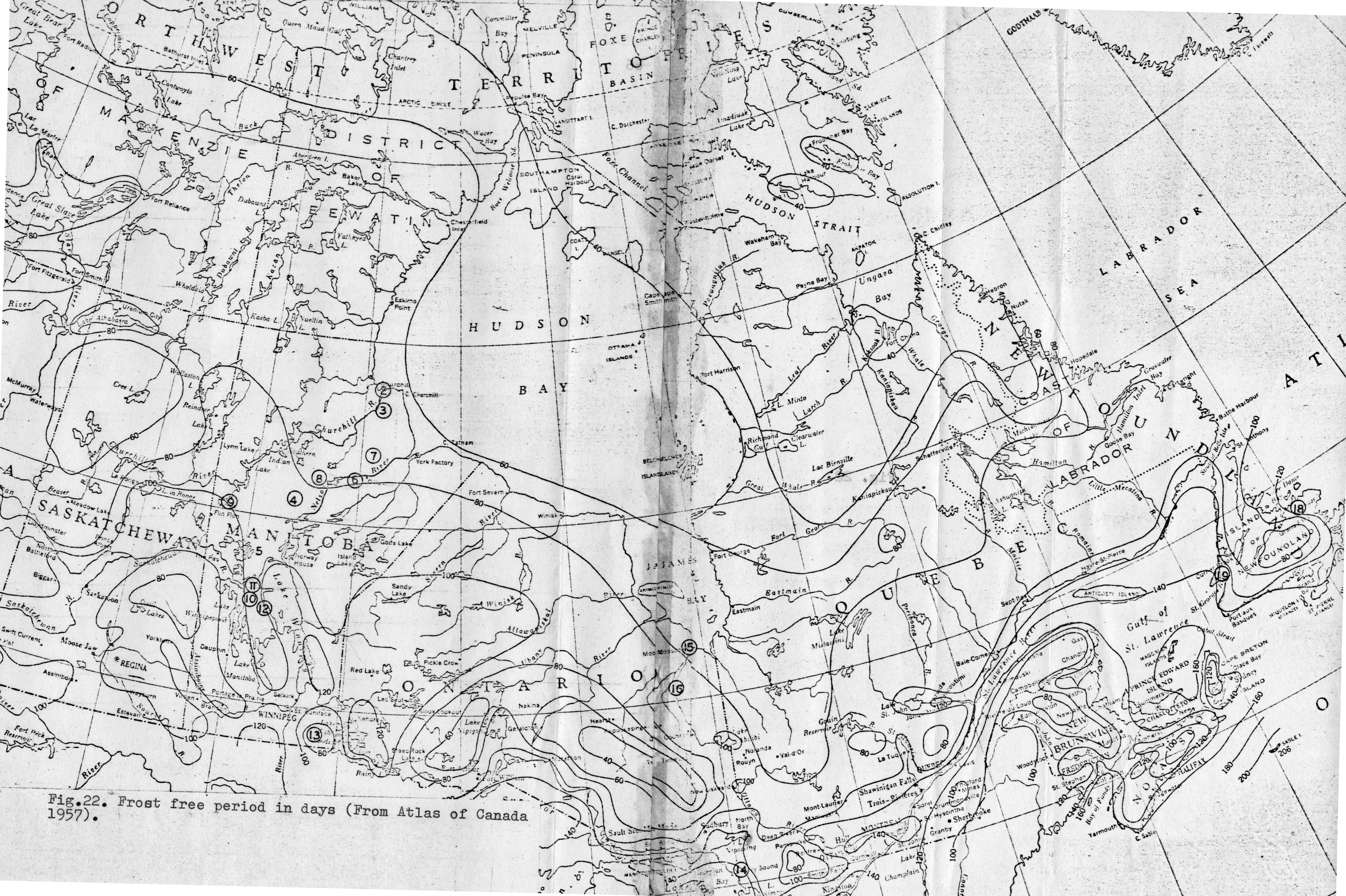


Fig.22. Frost free period in days (From Atlas of Canada 1957).

days.

A more quantitative image of the temperature conditions may be obtained from the data depicting the mean number of degree days during the growing season. Figure 24 is representative of the mean annual number of degree days above 42° F (5.5° C) (Atlas of Canada).

For any one day when the mean temperature is over 42° F, there are as many degree days as there are Fahrenheit degrees in the difference between the mean temperature of that day and 42° F. The mean annual number of degree days thus is the mean of annual totals of the degree days for the year record.

This concept indicates a summation of energy rather than a number of days during which an effective growth could be possible. In the absence of data for the growing season only, the data for the entire year is given in Figure 24. This illustration reveals that only Area 1 and those pertinent for Flights 1 and 2 in the high arctic have less than 1000 degree days a year. The others have values over 1000 and up to 3000-5000 degree days maximum for Area 14.

3. Moisture Effects

Moisture conditions affecting paludification are closely tied to the temperature conditions. It is reasonable in this connection to describe generally certain features of moisture and the significance of these features as they

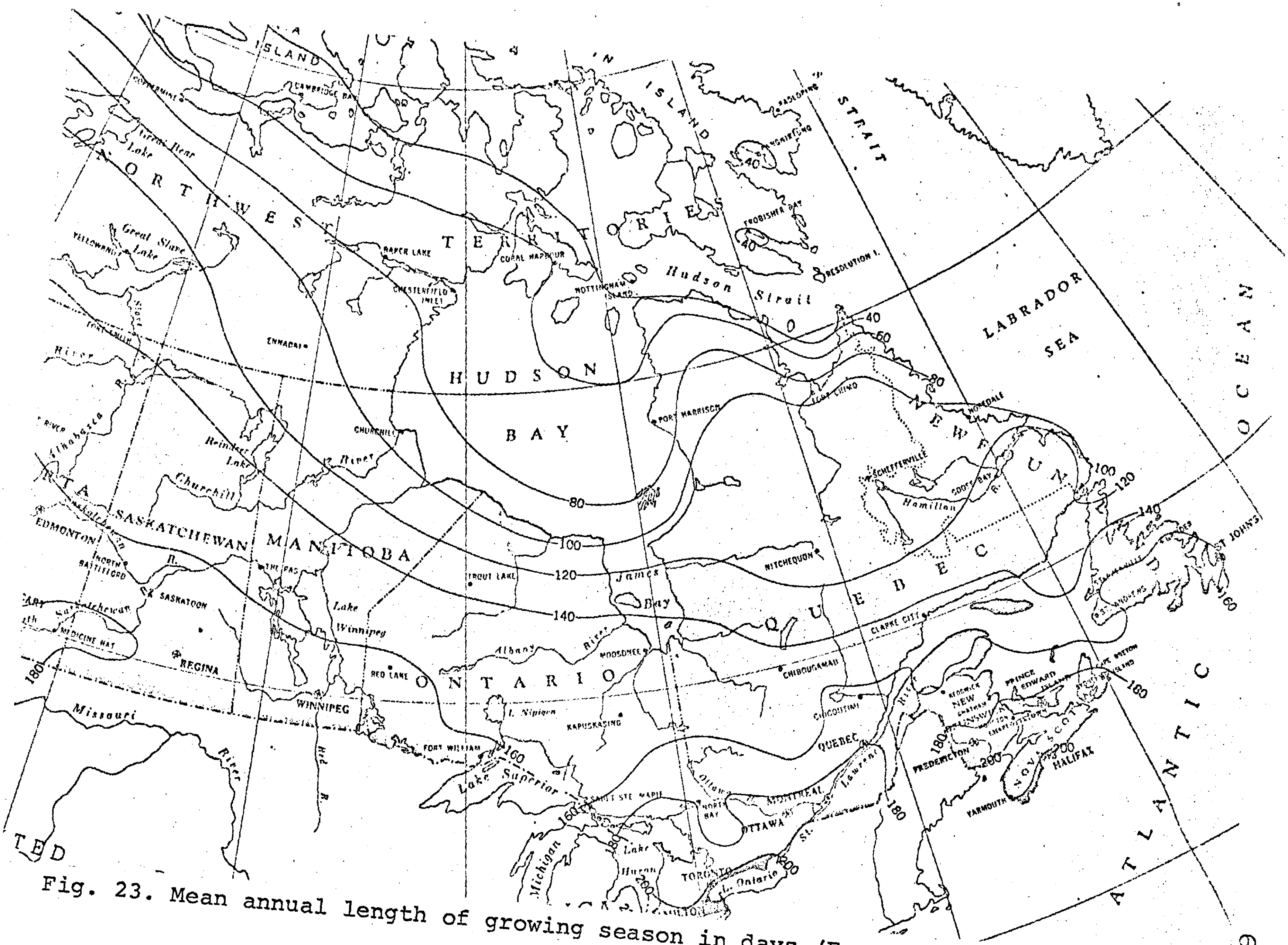


Fig. 23. Mean annual length of growing season in days (From Atlas of Canada 1957)

affect this study.

Figure 25 (Thomas 1953) shows that the highest annual total precipitation is encountered in the eastern coastal Study Areas 17 to 19 where it reaches up to 35-50 inches a year (890-1270 mm). The high precipitation here is because from the southwest or west, cyclones bring abundant moisture which then is given up as precipitation when the winds meet the higher ground. The summer and springtime are drier here than the fall because the long-lasting sea ice keeps the sea cool and maintains a low level of humidity.

The precipitation is still quite high in Area 14 where it is about 35 inches (890 mm) a year. This is presumably partly caused by the westerly winds which have picked up moisture on their journey over the Great Lakes and then released it as a result of an adiabatic cooling caused by the orographic lifting on the shore lines.

Next to be considered are Areas 13, 15 and 16 where the precipitation reaches up to 20 inches (508 mm) a year. The rest of the areas in central and northern Manitoba are within the range of 15 to 20 inches (308-508 mm). The lowest values are found in area 1 (under 10 inches (254 mm) per year). These last mentioned areas are situated in the internal continental region where, for various reasons, the precipitation is quite low.

Perhaps more important for the muskeg vegetation than the annual precipitation is the rainfall of the summer season

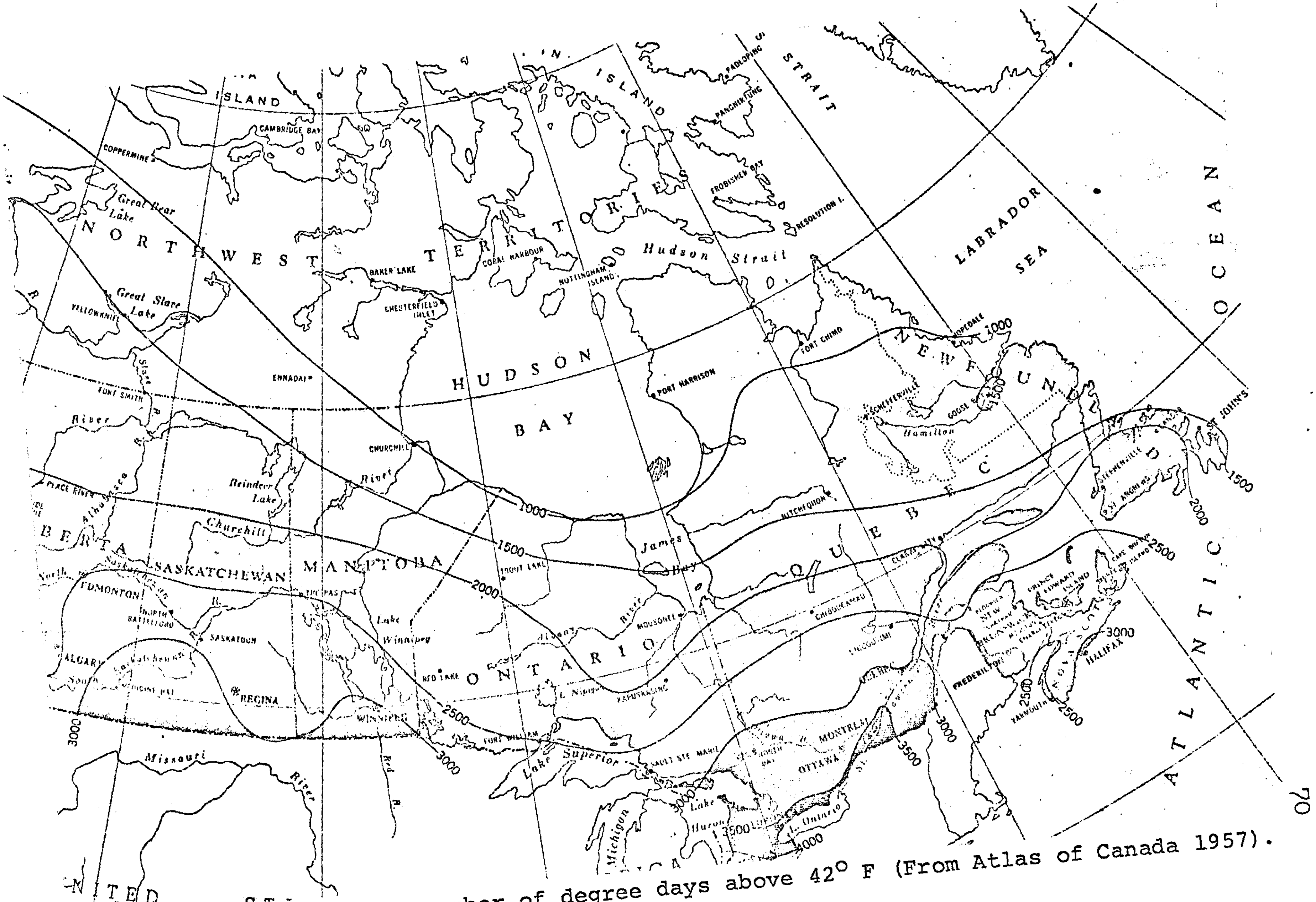


Fig. 24. Mean annual number of degree days above 42° F (From Atlas of Canada 1957).

(July-August) (Figure 26). In the study areas this period is the time of the heaviest rainfall. The maximum is reached in Areas 17 to 19 where it is about 10 inches (254 mm). The other areas receive 7.5 to 10 inches (190-254 mm) except Areas 2 and 3 where the rainfall of summer is 5 to 7.5 inches (127-190 mm), and Area 1 which receives only 2.5 inches during the summer (64 mm).

The rainfall or precipitation data themselves do not give any direct indications of the amount of water available for vegetative growth. A better image of good or unfavourable moisture conditions with respect to the vegetation may be obtained from the data on evapotranspiration and different entities which can be computed from this kind of information, as Thornthwaite (1948) has shown in his attempts to establish some biologically significant climatological concepts.

Potential evapotranspiration varies between rather wide limits from one group of study areas to another. Potential evapotranspiration is that theoretical amount of moisture that would be evaporated from the soil and transpired by the plants if it were available. It is influenced by various climatic factors such as temperature, humidity, wind, and net radiation at ground level (Critchfield 1966).

It varies considerably in different study areas, the maximum being attained in Areas 14, 17 to 19 (500 mm and over). Some stations in the vicinity of areas 5 and 10 to

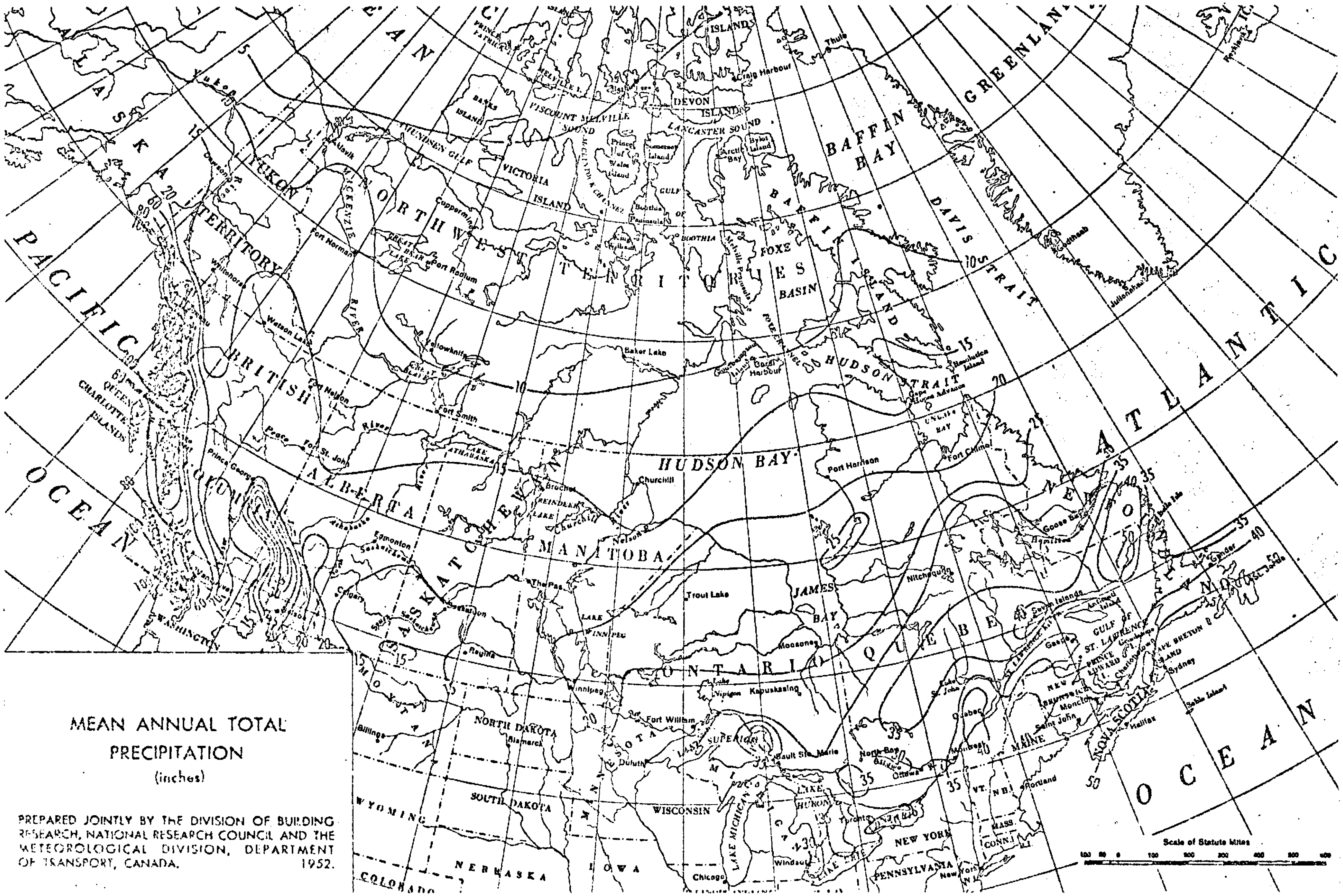


Fig. 25. Mean annual total precipitation (From Thomas 1953, Climatological Atlas of Canada, NRC, No. 3151).

13 report values in excess of 500 mm a year. Areas 4 and 6 to 9 are within the limits of 400-430 mm per year. Areas 2 and 3 have the values of about 300-330 mm per year. The lowest value, 239 mm per year, occurs in Area 1. These low values in the north are attributable to the dependence of potential evapotranspiration on temperature and evaporation which are low there. Also the season for potential evapotranspiration in the north is short since the frost-free period there is quite short. Some authors have used the potential evapotranspiration values as a growth index similar to the sum of degree days (Thornthwaite 1948).

The writer judges that especially in regard to paludification, a biologically significant moisture factor is the so-called "moisture index" which was formulated by Thornthwaite (Thornthwaite 1948). In the early literature (Thornthwaite 1948) it has been calculated according to the formula $I_m = \frac{100\ s - 60d}{n}$, where I_m = moisture index, s = water surplus (the excess precipitation which occurs **after** the soil moisture storage equals the water holding capacity of soil (100 mm)), d = water deficiency (the difference between the potential evapotranspiration (PE) and actual evapotranspiration (AE), and n = the potential evapotranspiration or water need. However, since 1955 (Thornthwaite, C.W. and T.R. Mather 1955), a revised equation has been used as follows:

$I_m = 100\ (\frac{P}{PE} - 1)$. (P = precipitation, PE = potential

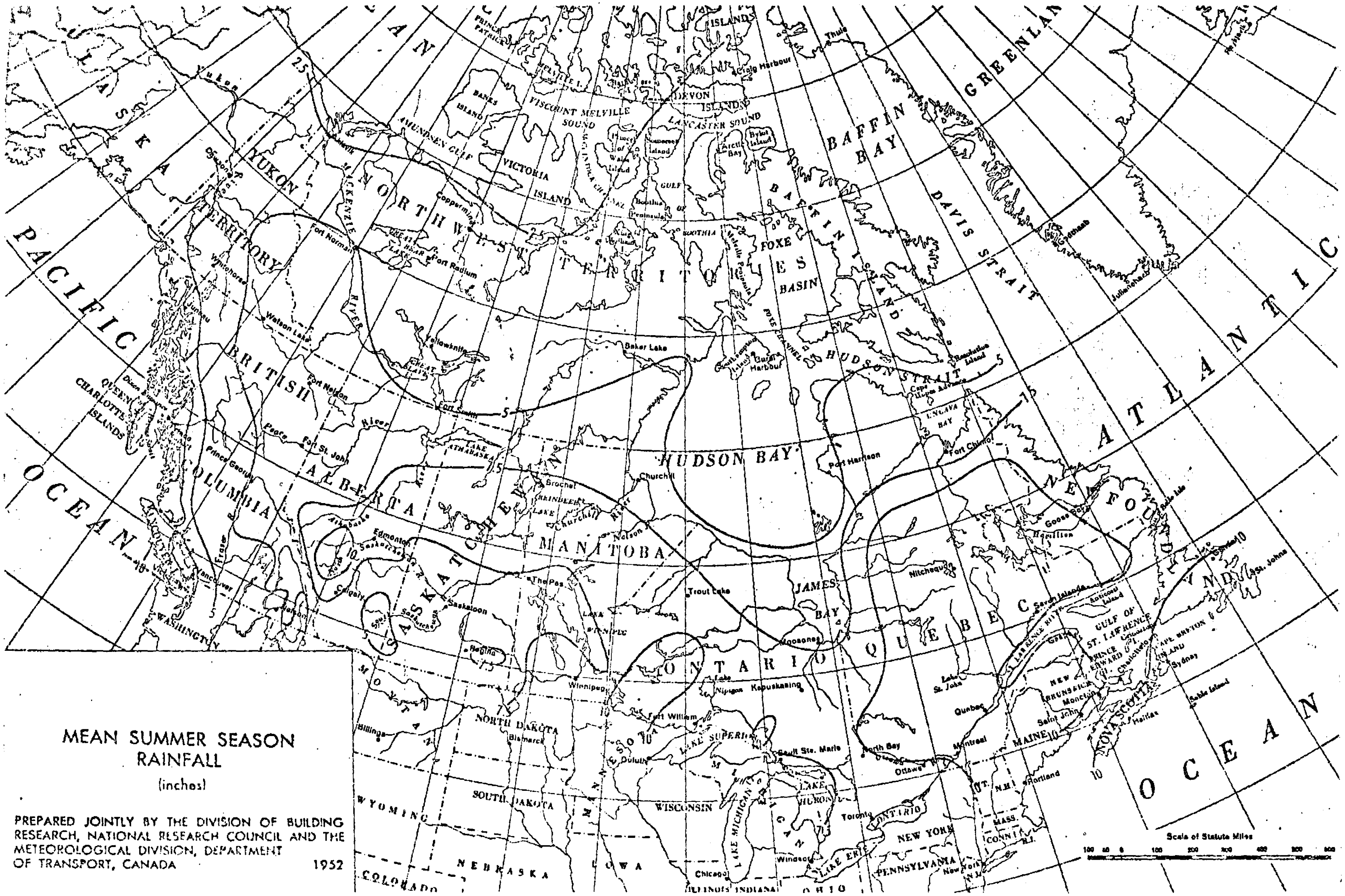


Fig. 26. Mean summer season rainfall (From Thomas 1953, Climatological Atlas of Canada, NRC, No. 3151).

evapotranspiration). The data in Figures 29 and 30 have been calculated by using this revised equation. Also, the waterholding capacity of soils has been changed from 100 mm to 300 mm.

The moisture index gives a fairly good image of the biologically significant moisture conditions affecting paludification, and has been used in Finland in some studies on organic terrain (Ruuhijärvi 1960). The values below zero indicate dry climates and those above zero indicate humid climates.

Figure 27 depicts the moisture indices in relation to the study areas. The values were calculated by utilizing the data extracted from a publication by Mather (1964). This figure is possibly not entirely accurate as an indicator for strong paludification. There may be inaccuracies due to various reasons. First, the density of observation stations in the north is too low to allow for an accurate representation of the distribution of moisture index. Secondly, the presence of permafrost complicates the situation in the north in several ways by changing the characteristics of water surplus (run-off), by its imperviousness to water and also by changing the factors governing the soil water storage capacity. This has been assumed to be 300 mm. In addition to permafrost change in the soil type affects it. For an accurate local determination, the type of soil should be taken into consideration and the soil water storage capacity

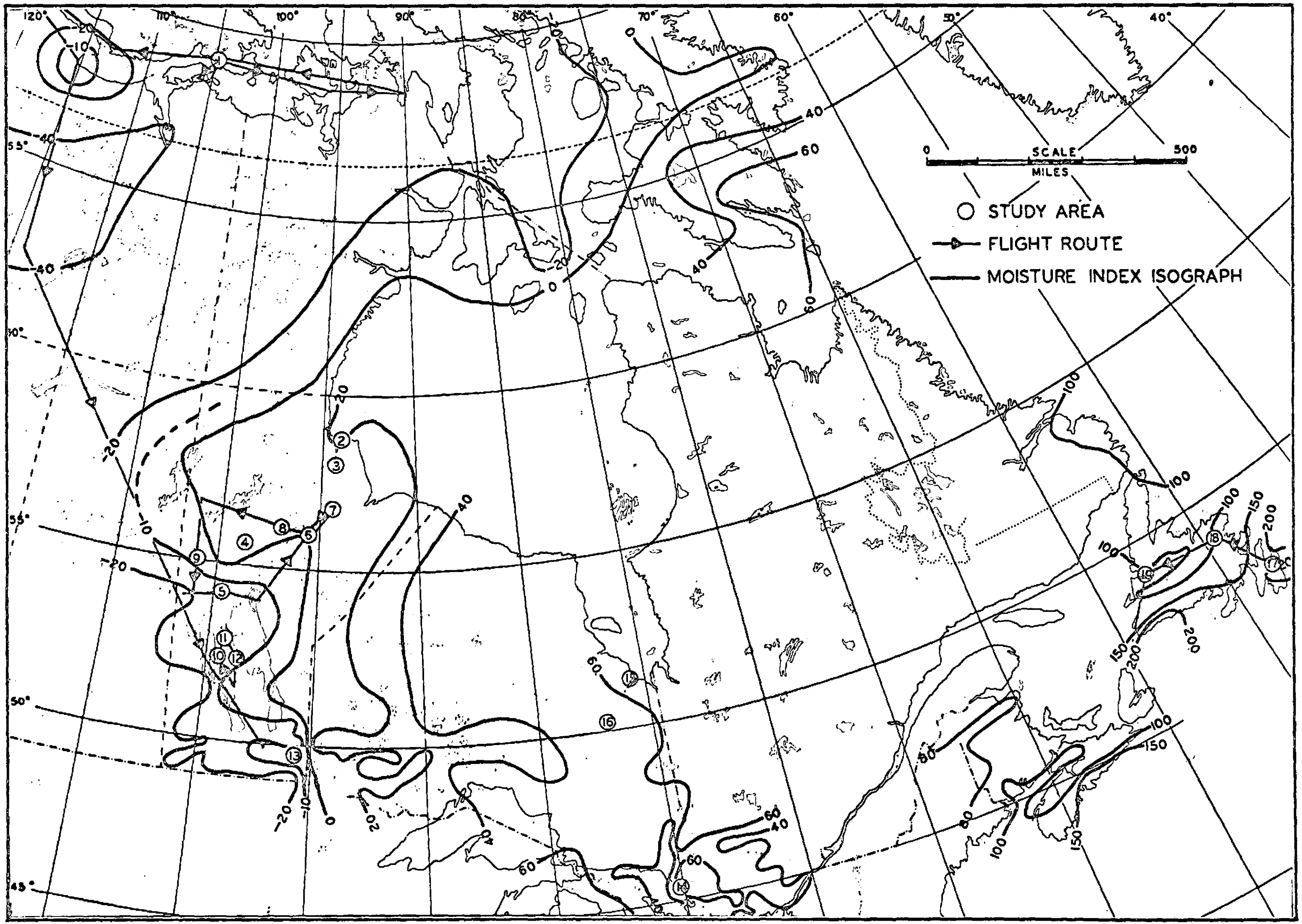


Fig. 27. The relationship of study areas and moisture indices. Data for calculations extracted from Mather 1964.

recalculated by using the appropriate water holding capacities. In the present study Figure 27 is approximate and adequate for the purposes if one keeps in mind the sources of error.

The highest values for moisture index are obtained in Areas 17 to 19. These areas are also the least continental among the study areas. The values here are of the regime of 100 to 200 and even greater.

Moisture index decreases steadily towards the western and northern study areas. Areas 14 to 16 are just above the limit of 60. Here again one can notice the effect of the large water bodies and the westerly circulation pattern in the rather large value 60 or over on the eastern shore of Lake Huron as contrasted to that on its western shore (40).

In northern Manitoba Area 2 has a value of about 20. The zero line follows the border of Ontario and Manitoba for a short distance and, at higher latitudes, turns towards the northwest probably because of the influence of Hudson Bay. The study areas 3, 4, and 6 to 8 are between the limits 0 to 20. The remaining areas 1, 5 and 9 have values below zero.

The moisture index map of Finland (Figure 117) and a map showing the distribution of muskeg in Finland (Figure 118) reveal that the frequency of muskeg is not always high in areas of high moisture index due to complicating factors to be explained later in this work. They indicate, however, possibilities of using climatic factors in concert to study causes of paludification. Since there are no exact data delineating the distribution of muskeg in Canada very accurate comparison between this country and Finland in terms of moisture index is not possible at present. However, a preliminary analysis can be obtained from the knowledge about general distribution of muskeg in Canada. In the study areas those characterized by higher moisture index values also have a high frequency of muskeg. Also, it should be noted that the so-called raised bog, which is defined as a bog that obtains all its moisture from the atmosphere, is most common in Areas 17 to 19, where the moisture indices are highest. In the other areas, the topography and certain other factors already mentioned earlier may obscure more direct manifestation of correlation between this index and the distribution of organic terrain.

Figures 29 and 30 display graphically the average water balances of some of the study areas and their surroundings. The data are extracted and adapted from a work by Mather (1964). These graphs also indicate that there is more water available for paludification in the east than in the west and in the north. They also indicate that very often the summer, when precipitation is at its highest , is the driest time as far as the availability of water for paludification is concerned. This can be explained simply by observing the values of potential evapotranspiration. It is at its highest during the summer when the higher temperatures and vigorous vegetative growth enhance it. This causes deficiency of water. The situation is alleviated temporarily and locally by heavy thunder showers in the course of the summer. The high values of water deficiency in the north probably are not so serious as it would appear from these graphs. There, especially in the organic terrain, the situation is alleviated by the lower potential evapotranspiration because of lower temperatures and also due to the lesser amounts of plant material. Also the accumulation of snow during the winter helps in building up a water surplus which is released in the spring as run-off. In the muskeg areas of the north, the run-off, however, is hindered by the flatness of the topography and by the imperviousness of permafrost which prevents percolation downwards. This makes quite a large amount of water available for paludification and this water, furthermore, is retained by the extremely high water holding capacities of peat. This analysis accounts for some of the factors promoting paludification and forecasts, through hypothesis, that Radforth's airform patterns (cf. p. 12) may have different genesis and development.

Of several other climatic factors which could be described here, only the concept of continentality will be briefly discussed. This concept has been connected to organic terrain studies elsewhere (Ruuhijärvi 1960). It has been stated in the literature that at least in certain regions raised bogs (for the explanation of this term see

Glossary) are most common in the regions with maritime climates, while, on the other hand, aapamoors (Glossary) prevail in the more continental climates (Ruuhijärvi 1960, Aartolahti 1965, Auer 1952). Since this has possible bearing on the patterns in the organic terrain, it seems reasonable to deal briefly with continentality as applying to Canada.

Figure 28 is representative of continentality in Canada as computed according to Johansson's formula by McKay and Cook (McKay and Cook 1963):

$$K = \frac{1.6A}{\sin \phi} - 14$$

K = continentality per cent, A = the mean annual range of temperature, ϕ = the geographical latitude.

For the study areas, the lowest continentality occurs in Areas 17 to 19 (values 30 to 35%). The highest values (up to 65%) are encountered in Areas 4, 8 and 9. The other areas in Manitoba are between the limits of 60 and 65% except Area 2 which is below 60.

Area 1 in N.W.T. and Area 14 in Ontario are below 50%. Areas 15 and 16 have values between 55 and 60%.

This map clearly depicts the effect of the distribution of land and water as well as the effect of the westerly circulation pattern. These two factors are the main causes of the existence of the centres of high continentality, one west of Hudson Bay and the other east of it. The vicinity

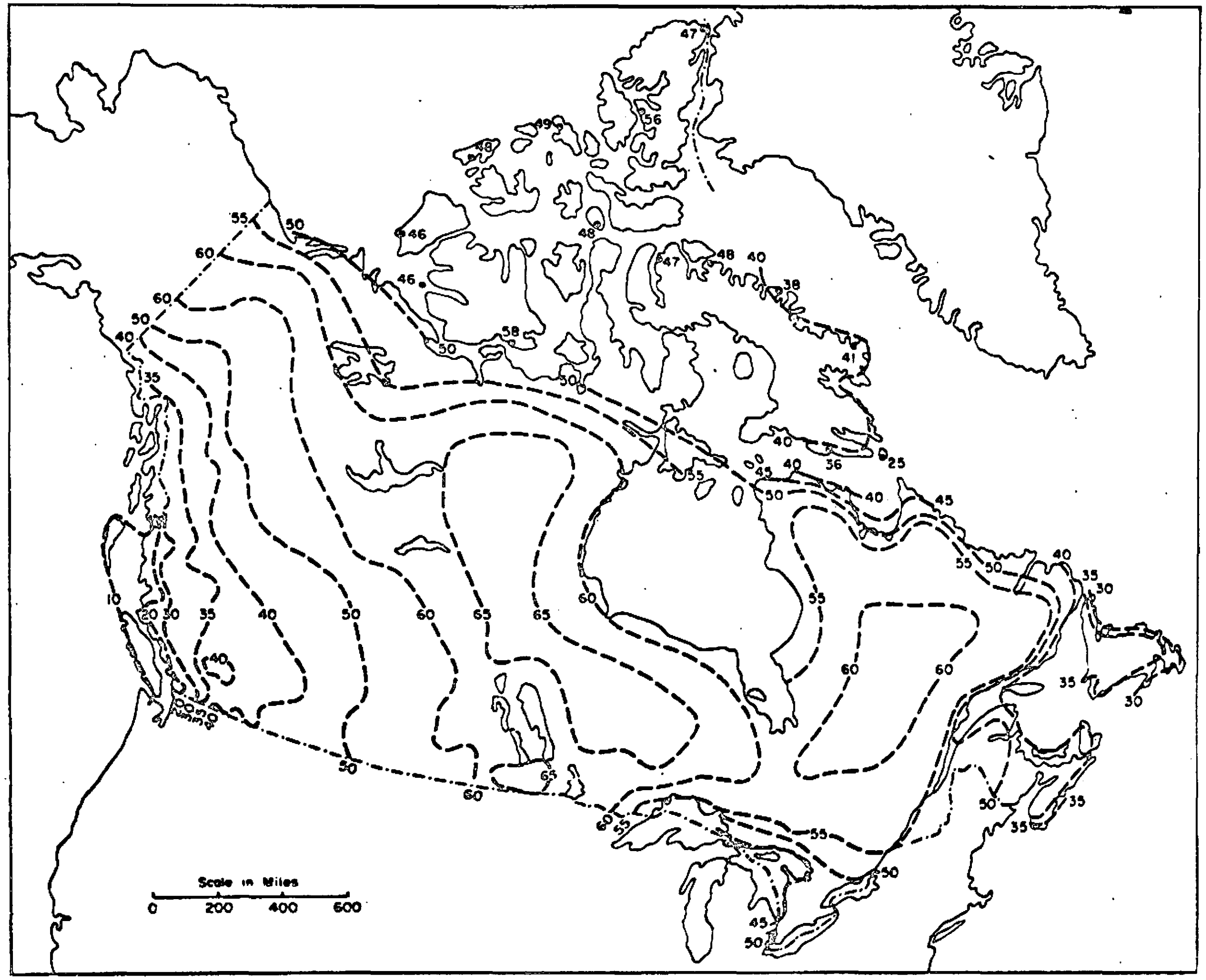


Fig. 28. Preliminary map of continentality for Canada (After MacKay, D.K. and Cook, Frank A., 1963).

of Hudson Bay and a corridor south of James Bay to the Great Lakes are less continental than their surroundings. Also; the eastern coast (Areas 17 to 19) have low continentality values due to the oceanic influence.

4. Summary of the Effect of the Climate on Paludification

The following summary attempts to express the author's understanding of the ways in which paludification is affected by various climatic factors, both individually and collectively.

In this context certain climatic data such as water balance and moisture index have been used. This section hopefully not only reveals the general influence of climate on paludification and on possible pattern genesis of muskeg but also illuminates the possibilities of utilizing climatic factors in other muskeg studies. These factors would be even more useful in this respect if the systems were developed and adjusted for the special muskeg conditions. It is apparent that there are still quite a few inaccuracies in the existing climatic systems as far as their use in muskeg studies is concerned.

The relatively cool eastern areas with the high precipitation are the most humid and thus favourable for paludification. The accompanying high atmospheric moisture there is also regarded as influential in formation of airform pattern as will be later demonstrated. On the other hand, the effect of low precipitation in the northern areas is compensated for by lower potential evapotranspiration due to lower temperatures and also probably because of paucity of vegetation. Finally, the spring water surplus, which is retained because of flat topography, helps alleviate the apparent water deficiency, thus making conditions more favourable to paludification. The effect of the short growing season may be offset by the long days in the north making up some of the loss of radiation energy.

As it is now evident climate is not the only factor, not even always the major one affecting and regulating paludification, but it associates with topography and soil conditions to create environmental circumstances that are favourable for paludification. Also temperature and rainfall are not the only or the most important climatic features operating in paludification as sometimes has been claimed (Kivinen 1948). They are only two of the major factors which, in certain circumstances, may produce conditions which are extremely favourable for paludification if other factors are not limiting. Expressed briefly, the general climatic condition conducive to possible paludification is a relatively cool and humid climate. The word 'relatively' is noteworthy since muskeg appears in areas which lie in a wide range of temperatures and rainfall but which, as a result of the combinations of these factors, are relatively cool and humid regardless of the actual amounts of rainfall or the actual temperatures. This derived observation will be expanded.

In general, when the soil and topographic conditions are suitable, muskeg occurs if the climate is favourable to the vegetation that forms peat. In most cases, paludification is initiated by various moisture-loving mosses of which Sphagna are the most common. Other mosses, however, may have started paludification previously by initiating ground cover which may not be especially moisture-loving, for example, Polytrichum and Pleurozium, but which may retain water and help the invasion by Sphagnum. Afterwards, sedges and/or various small shrubs may appear in muskeg. In many cases these vascular plants may themselves initiate paludification.

The main composite climatic requisite, cool and humid climate, is attained by combined effect of temperature and precipitation. Thus if the cool temperature values at Cambridge Bay, N.W.T. (mean annual temperature 5° F (2° C)) were to increase to the level of warmer values of Areas 17 to 19 in Newfoundland (mean annual temperature about 40° F (5.5° C)), the precipitation would have to increase in proportion to keep humidity high enough for paludification. This is because the potential evapotranspiration increases strongly with the temperature increase. The reasoning is supported in fact through comparative study. The mean annual total precipitation in Cambridge Bay is only about 150 mm

(5 inches) and the annual potential evapotranspiration only 239 mm while the mean annual total precipitation in Areas 17 to 19 is about 1000-2000 mm (40" to 50") and the annual potential evapotranspiration over 500 mm. Thus, Areas 17 to 19 are quite humid but Area 1, though lower, is still humid enough for paludification. However, effect of low potential evapotranspiration is not the sole stimulus because permafrost and the water surplus from winter also help to saturate the ground and thus enhance paludification.

Examination of Figure 27 showing the moisture indices of study areas suggests that several of the study areas are subject to dry climates if the moisture index below zero signifies dry and above zero humid relationship. This can be utilized in further study. However, this map contains quite a few sources of error (cf. page 75) inherent in the system of calculating the moisture index values. Regardless of the possible errors, the map shows that the intensity of paludification increases from areas with low index to the areas with high index. This index can be used therefore to account for distribution of muskeg as to the extent that it depends on climatic factors.

Indirectly the moisture index also reveals that the effect of climate on paludification may be displaced by other factors. For instance, although Areas 5 and 10 to 13 have negative moisture index values, muskeg in these areas is unconfined presumably because of soil and topographic factors. These areas also have a relatively high potential evapotranspiration (500 mm/year or even over) as compared with certain other localities. Evidently this is not limiting to paludification if soil and/or topographic factors are favourable. According to new data, all the study areas would belong to sub-humid, humid, or per-humid climatic areas (Carter and Mather 1966). Thus areas which, according to Figure 27, have moisture index values from -33.3 to 0 would belong to a so-called dry sub-humid climate. Areas with values from 0 to 20 belong to moist sub-humid climate; areas with values from 20 to 100 belong to humid, and areas with values over 100 to per-humid climates.

Further inspection of the water balance values (Figures 29 and 30) will give a better understanding of the overall influence of climate on paludification in the study areas. One should realize also that in the calculations for these graphs and the results they portray, there are certain inherent sources of error partly because of the lack of climatic and geomorphic data for large areas of Canada. Also these systems have not yet been fully developed to give a desirable degree of accuracy. A hasty look at these graphs would indicate that the conditions for paludification in most of the study areas are not favourable except in areas 17 to 19 where there is a large water surplus even in the growing seasons as contrasted to the "apparent" water deficiency for the other areas.

The most humid part of Area 17, the Colinet area, is to the south (Figure 30). Here there is a continuous water surplus even through the summer season while in Areas 18 and 19 and 17 north there is a slight water deficiency as the graphs show.

This deficiency is not as severe as it is in some parts of Manitoba (Figure 29), as it is alleviated by the water which is accumulated as snow and ice during the winter. This accumulation represents a considerable surplus which is released during the spring and early summer when, according to the graphs, there is supposed to be water deficiency. The large winter surplus and high precipitation in the fall and in late spring and quite high precipitation in the summer render the climate here humid enough to favour paludification dependent on atmospheric water (ombrogenic) (Aartolahti 1965). Because there is little nutriment in the rainwater the muskeg that arises is oligotrophic (cf. Glossary). This water is not entirely devoid of nutrients but, according to Viro (1955) in the rainwater deposits in all Finland, there are, on the average, the following amounts of various materials as expressed in $kg/km^2/year$: organic material 2740, inorganic material 3170, SiO_2 291, Al_2O_3 and Fe_2O_3 31, Ca 199, Mg 131, K 245, Na 183, P 8.6, SO_4 416, CL 576 and N 587. Actually, the rainwater deposits a low but significant amount of

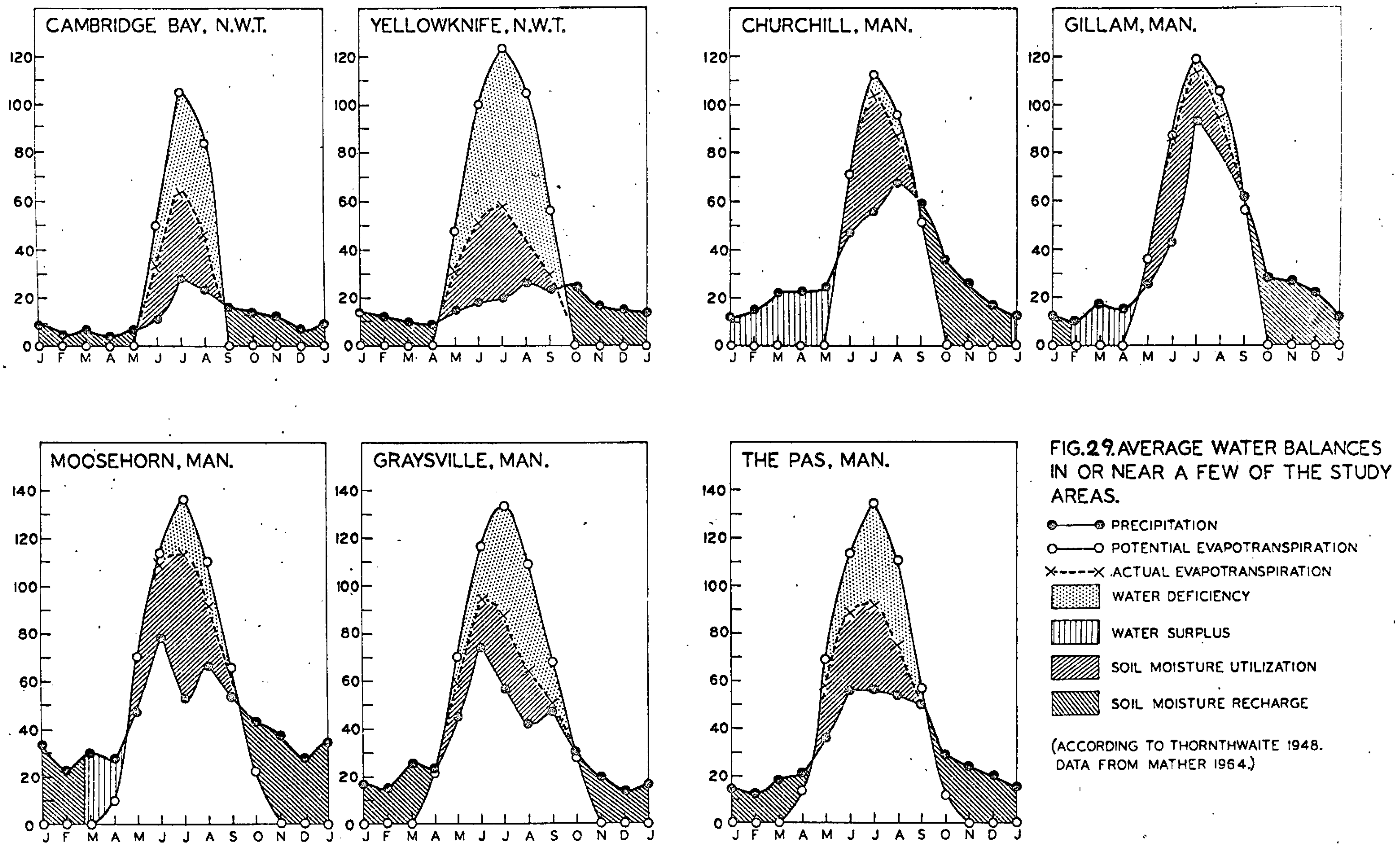


FIG.29. AVERAGE WATER BALANCES IN OR NEAR A FEW OF THE STUDY AREAS.

(ACCORDING TO THORNTHWAITE 1948. DATA FROM MATHER 1964.)

Fig. 29.

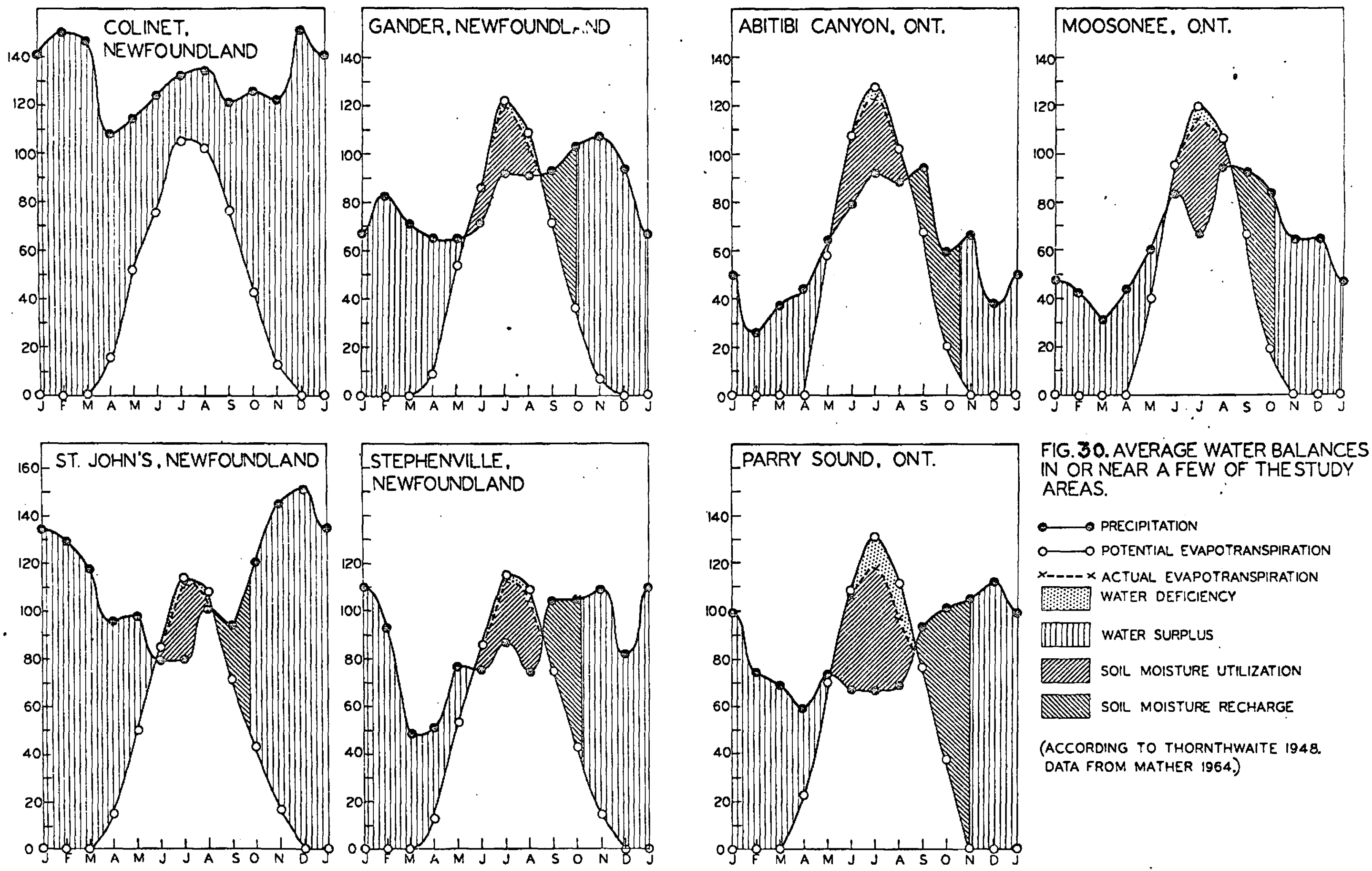


FIG. 30. AVERAGE WATER BALANCES IN OR NEAR A FEW OF THE STUDY AREAS.

Fig. 30.

nutriment and, according to Witting (1948), the amount becomes larger as one approaches the sea. One might assume that considerably larger amounts could be found in the maritime areas of Canada which are near the open ocean. The Baltic Sea in Finland is only slightly brackish.

It is thus quite easy to explain the marked paludification in Areas 17 to 19 as being due to the climatic influence. The climate there is obviously very cool and humid. For the other study areas, the climate is not so obviously cool or humid (cf. Figures 27, 29 and 30). Calculations of these data (loc. cit.) are not appropriate for specialized muskeg environment and need to be adjusted for it to be directly valid. Some of the inherent sources of error needing adjustment have been mentioned on page 75 .

The highest water deficiency among the study areas is encountered along the flight route from Coppermine through Yellowknife (N.W.T.) to Winnipeg (Figure 29). This is due to low precipitation and relatively high evapotranspiration. This high water deficiency is reflected in appropriate trends in paludification. There is no evidence of unconfined paludification and no ombrogenic paludification in this area. Muskeg here is totally confined in rather limited depressions offered by the rugged Precambrian topography. In this connection the curve in Figure 29 explains the relationship between paludification and climate.

Area 14 is basically identical in topography to the areas near Yellowknife. However, for Area 14, the climate shows definitely high humidity. The soil moisture utilization as well as water deficiency is low. The precipitation shows a distinct winter maximum implying a condition paralleling that in the maritime climatic region on the eastern coast (see Figure 30). The winter precipitation maximum symbolizes a maritime climate. In Area 14 the high humidity may be attributed to the predominantly westerly winds which blow over the Great Lakes and load the air with moisture picked up over the Lakes. Nevertheless, muskeg is still confined in Area 14 due to ruggedness of the Precambrian terrain, thus showing how geomorphic effect is limiting despite the highly favouring climatic stimulus.

There are two sets of study areas with unconfined muskeg which in other aspects do not resemble each other very much. The first one is the group consisting of Areas 5 and 10 to 13. They are represented by the Moosehorn, Graysville and The Pas graphs in Figure 29. In these areas there is a relatively high water deficiency and high soil moisture utilization during the growing season, due to a high evapotranspiration and fairly low precipitation. Despite this, these areas are covered by unconfined muskeg. This shows that the water balance data, without appropriate interpretation, are not necessarily applicable in muskeg studies. These areas have very favourable soil conditions for paludification. The high water deficiency implied by the graphs in Figure 29 is also only apparent as far as muskeg is concerned. There is an ample amount of water which drains slowly from the flat areas and which keeps the ground saturated longer than the first glance at the graphs would indicate. This situation maintains paludification. Once muskeg is established, its development ensues rather steadily because peat, having very good water-holding capacities, holds the water surplus from the spring thaw longer than other types of soil. The covering vegetation thus will not suffer from any water deficiency although the vegetation in the surrounding mineral terrain may do so. Because peat also is a very good insulator, seasonal frost is preserved in it quite late into the summer. The slow thawing of the frost in peat facilitates slow release of water in the summer to compensate for water deficiency caused by higher potential evapotranspiration, and lower precipitation which prevail in the summer time.

Areas 2, 3 and 7 form another group with unconfined muskeg and a climate apparently too dry to warrant unconfined paludification according to the graphs in Figure 29 (Churchill and Gillam). The graphs show that the water deficiency is quite low here due to low potential evapotranspiration. Soil moisture utilization is relatively high because precipitation is low. Some botanists and geographers have suggested that the precipitation alone in some parts of the western North American Arctic is not sufficient to support any vegetation (Johnson 1963). However, it is believed that errors in sampling are large enough to underestimate precipitation by one half (Black 1954). Thus, the values in Figure 24 would be too low if this claim were assumed to apply also in this part of the Arctic. Also it has been demonstrated that evapotranspiration is less than precipitation in many parts of the Arctic (Mather and Thornthwaite 1956; Clebsch 1957).

Areas 3 and 7 are also situated in the discontinuous permafrost zone but Area 2 is in continuous permafrost. Permafrost of course contributes to the maintenance of high soil moisture by confining most of the melt and rain water to the thin upper region of the peat which thaws only about 12 to 20 inches (30 to 50 cm) during the summer (for example in Area 3). Flat topography implies shallow gradient and thus slow run-off. In Areas 3 and 7 as well as in Areas 5 and 10 to 13, the thaw of seasonal frost is another source of water for summer growth. Permafrost itself cannot provide water for the vegetal growth except when it is degrading as it is in some localities near Area 7. In this case, as well as in the case of the thaw of seasonal frost in peat, it becomes evident that the amount of 300 mm as the soil moisture-holding capacity used for the calculation of the water balances for the mineral soils does not apply for muskeg. The primary characteristic of the peat which puts this figure in question is the high water holding capacity of peat. Normally peat contains water to the extent of 80 to 95% of wet weight. There may be short term seasonal or local variations of these figures but the above mentioned amount could be regarded as providing a general guideline. For frozen peat the water (ice) content is much higher than for non-frozen peat. Investigations in Sweden have revealed that the permanently frozen peat of palsa formations may contain water (ice) from 1890 to 3950% of dry weight (Forsgren 1966). In the frozen mineral soil at the same sites the water content was only 26.9 to 43.9%. This shows that frozen peat is potentially rich in water if it has a chance to thaw.

Water balances in Areas 15 and 16 are represented by the graphs from Moosonee and Abitibi Canyon respectively (Figure 30). These areas exhibit mostly unconfined muskeg. One can see that, if compared with other areas, their moisture conditions are intermediate in category. These areas do not present any difficult interpretation problems but the graphs would show the water balance situation in about the right proportions once qualitative adjustments had been made in the same way as for the previous examples.

The above summary illustrates the effect of climate on paludification and how the existing climatic data need adjustment and careful interpretation if one wishes to appreciate the degree to which climate controls paludification in the study areas. It also shows that climate alone cannot control paludification but that its influence is combined with that of other factors.

Study Areas in Relation to the Major Vegetation Regions

Because the general types of vegetation, for example, forest, are significant in the composition of muskeg, and also contribute to the airform patterns, a brief portrayal of major vegetation regions of the study areas is justified. Also a few allusions will be made to the effect of vegetation on the airform patterns.

Figure 31 (Rowe 1959) depicts the natural (forest) vegetation regions and their relation to the study areas. As it reveals, only Areas 1 and 14 are outside the Boreal (Coniferous) Forest Region. Area 1 is situated in tundra, where organic terrain in most cases is still in its early stages of development.

Area 14 as well as part of Area 13 are in the Great Lakes-St. Lawrence Forest Region (Rowe 1959). This region is transitional between the Boreal coniferous forests and the deciduous forests of eastern North America (Putnam 1963). It is dominated by white pine (Pinus strobus), red pine (Pinus resinosa), hemlock (Tsuga canadensis) and by a great number of deciduous trees among which are elms, oaks,

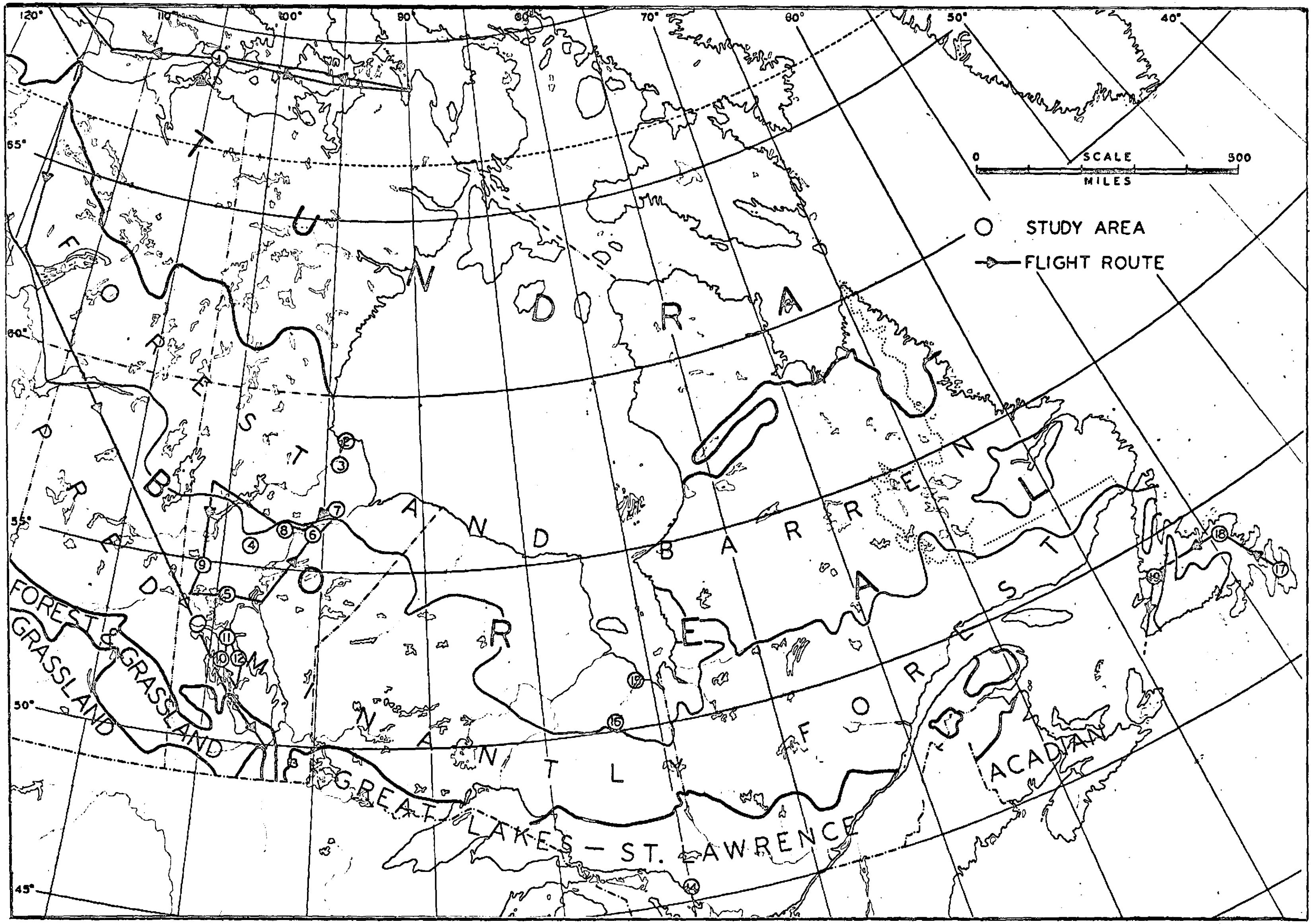


Fig. 31. Relation of study areas to the forest regions of Canada (Rowe 1959).

maples and birches (Rowe 1959). Because of a rugged Precambrian topography, muskeg in these study areas is mostly confined. Stipploid airform pattern is widespread with Dermatoid commonly associated with it.

The remaining study areas are in the Boreal (Coniferous) Forest Region. Areas 2, 3, 7, 15 and 16 are in a northern zone of the Boreal Forest Region, defined as a region of forest and barrens (Rowe 1959). These areas are situated in a sub-group called the Hudson Bay Lowlands Section. It is characterized by an open appearance which defines a subarctic landscape. Areas 2 and 3 especially are very open and the trees are confined to the well-drained river banks and the rest of the terrain is dominated by unconfined muskeg with Marbloid airform pattern prevalent. Black spruce (Picea mariana) is the most common species in these areas.

Area 7 is more densely treed. In muskeg black spruce dominates but bordering the well-drained water courses, poplar (Populus balsamea), trembling aspen (Populus tremuloides) and white spruce (Picea glauca) are common. The airform pattern is still basically Marbloid but a Stipploid condition is superimposed by the trees.

Areas 15 and 16 are not so open as Areas 2, 3 and 7. These two areas have a rather dense cover of black spruce in the drier sites and tamarack in the wetter more minerotrophic (cf. Glossary   ) sites. White spruce, trembling aspen and white birch (Betula papyrifera) are common along the water courses.

The remaining Areas 4 to 6, 8 to 12 and 17 to 19 are in that zone of the Boreal Forest Region which is predominantly forested. These areas are divided into three sections: Areas 4 and 6 are in the Northern Coniferous Section, where black spruce is dominant and is sometimes associated with jack pine (Pinus banksiana) following destruction by fire of the primary vegetation. In these two areas, the organic terrain is confined and characterized by Stipploid and Dermatoid patterns in the more southern Area 4 and by Stipploid to Marbloid in the more northern Area 6.

Area 8, which is the Nelson River Section, is between Areas 4 and 6 as to its characteristics. Muskeg is often on the slopes and shows trees growing in rings around old frost polygons.

Areas 5 and 10 to 12 are in the flat and poorly drained Manitoba Lowland Section. Large areas are covered by muskeg with black spruce and tamarack with associated large areas of FI cover (cf. Glossary and Appendix A). In these study areas, in addition to Stipploid, Dermatoid is rather common with Vermiculoid low-altitude configurations.

Areas 17 to 19 in Newfoundland are divided among three sections. Area 17 is in the Avalon Section with balsam fir (Abies balsamea) as a dominant tree species.

Black spruce grows here in the poorly drained areas of organic terrain. Large areas of muskeg are without tree cover regardless of the fact that the thermal efficiency (PE) is adequate for a closed forest ('moss barren'; Hare 1952). This is presumably because of the cool humid climate with a high water surplus which especially favours ombrogenic paludification. Figure 30 illustrates this point well (vide the graph of the water balance for Colinet). The ensuing strong paludification does not favour afforestation.

Area 18 is in the Grand Falls Section. In this area black spruce is common in unhumified peat according to Rowe (1959). Here the forests are denser than in Area 17 and the muskeg is more confined.

Area 19 is in the Corner Brook Section. It is also characterized by balsam fir, black spruce, white spruce and a few deciduous tree species, for example, white birch and trembling aspen. The geomorphology of the study area is rather rugged with high rolling hills which carry large raised bogs or muskeg on the slopes giving the image of raised bogs in the air photos. Apparently, they compare favourably with so-called eccentric raised bogs of Finland (Ruuhijärvi 1960). Large areas are treeless. Here too a cool and humid climate apparently favours ombrogenic paludification.

Distribution of Permafrost in Relation to the Study Areas

There are many definitions for permafrost. The main criteria of identification nowadays have been adopted from the Russian practice since Russians presumably have worked more on permafrost problems than anybody else.

Permafrost, or perennially frozen ground, is defined on the basis of temperature and refers to the ground (soil, rock) the temperature of which stays below 32°F (0°C) for a number of years (Brown 1967a). The shortest possible duration of permafrost starts one winter when the ground freezes and remains frozen through the following summer into next winter and thereafter thaws during the spring (Brown 1967a). Some authors claim that the ground is permanently frozen if it remains so for two years (Muller 1947).

The age of permafrost varies greatly. Sometimes it may be thousands of years old, but it may be also very recent (or even temporary).

The thickness of permafrost varies between wide limits of depth. It may be only a few inches thick, but is usually from a few feet up to hundreds of feet thick. The highest values have been recorded in Russia. There permafrost attains thicknesses of about 500 meters (1,650 feet) in Taymyr Peninsula (Brown 1960).

As Figure 32 shows, the permafrost region has been divided into two zones: the continuous permafrost and the

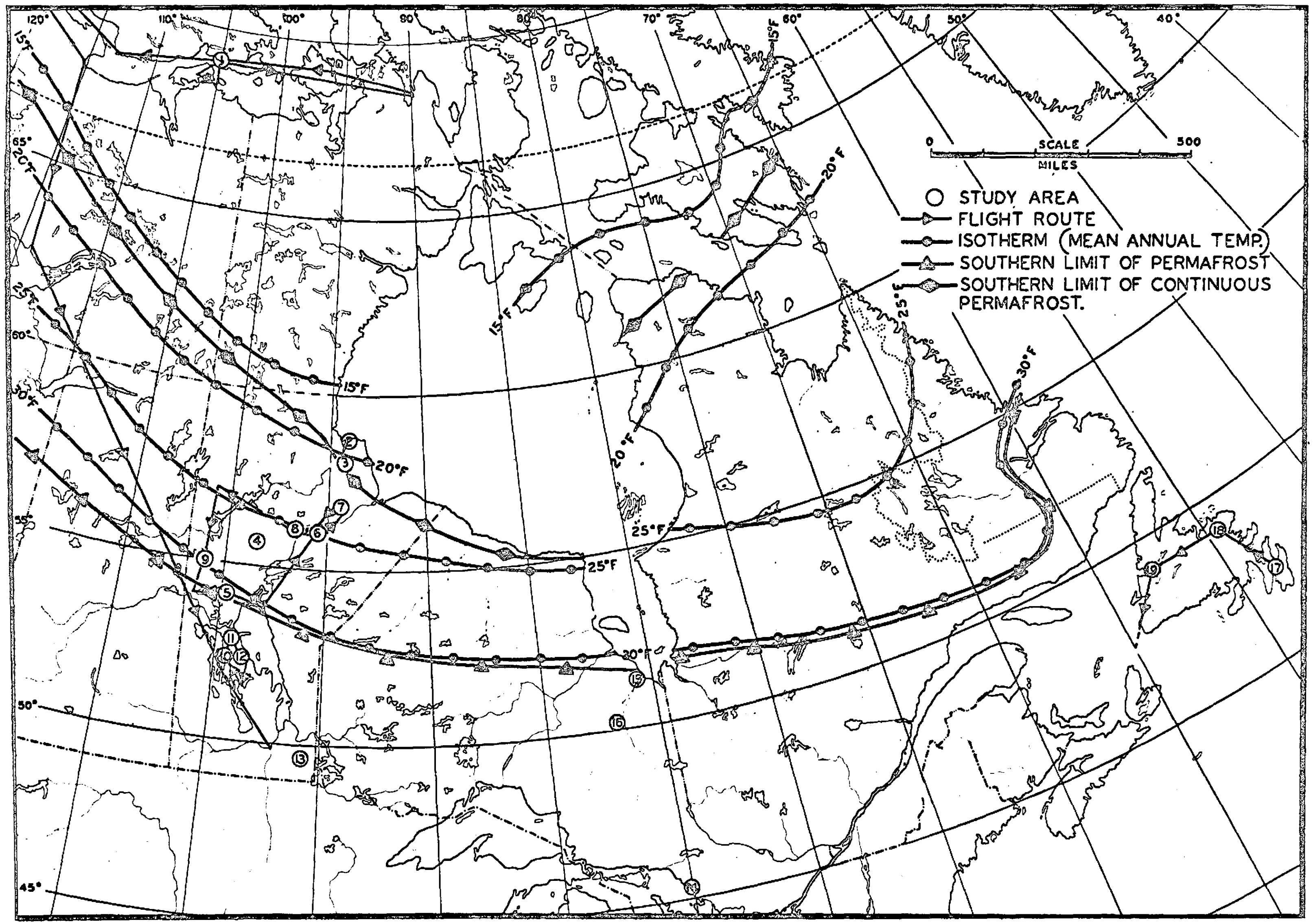


Fig. 32. Permafrost in Canada (After R.J. Brown 1967).

discontinuous permafrost. The division between these two zones is arbitrarily set by the Russian researchers to follow the isotherm of -5°C (23°F) mean annual ground temperature as measured from below the level of seasonal variations (zero amplitude). This practice has also been adopted in North America (Brown 1967a).

As Figure 32 reveals, the southern limit of the discontinuous permafrost zone follows quite closely the isotherm of 30°F (-1°C) (mean annual air temperature). Thus Areas 10 to 19 are south of the southern limit of permafrost. Area 5 is approximately on this limit. Areas 4 and 6 to 9 are in the discontinuous permafrost zone. Areas 1 and 2 are in the continuous permafrost zone and Area 3 is near its southern limit.

Flights 1 and 2 and a large part of Flight 3 are over the continuous permafrost zone. Some of Flight 3 and most of Flight 5 are over the discontinuous permafrost zone. Flights 4 and 6 are south of the permafrost region.

Radforth (1954) refers to sub-surface topography of ice caused by permafrost in organic terrain. Often permafrost is encountered mainly in the organic terrain within the discontinuous permafrost zone. This has been stated several times in the literature (Johnston, Brown and Pickersgill 1963; Brown 1967a).

Even south of the permafrost region, the organic terrain, depending on the yearly variations in climate and/

or weather, can harbour ice through the summer. Thus, the author has encountered ice in the peat in southern Finland at the end of summer far south of the permafrost region. This kind of ice is sometimes called climafrost (Radforth, 1954) but it also suits the definition of permafrost as used in North America and in Russia.

These phenomena will be evaluated in detail later as they are encountered in relation to this study.

General Distribution of Muskeg and Its Relation to the Study Areas

Muskeg (organic terrain) is a widely spread phenomenon on the earth. The largest areas of muskeg are encountered in the cold temperate climatic zones of the northern hemisphere for the simple reason that the land area of the corresponding climatic zone of the southern hemisphere is quite small compared with that in the north. Though muskeg is also common on the corresponding land masses of the southern hemisphere as Figure 33 (Bülov 1925) shows it is not as extensive as in the north. In the southern hemisphere the largest areas are encountered in Tierra del Fuego, Falkland Islands, New Zealand and Tasmania as well as in Patagonia (Kats 1966) which is already within a warmer climatic zone. Muskeg is also met within the tropical areas but mostly at higher elevation where the climate is often cool and humid. There are, however,

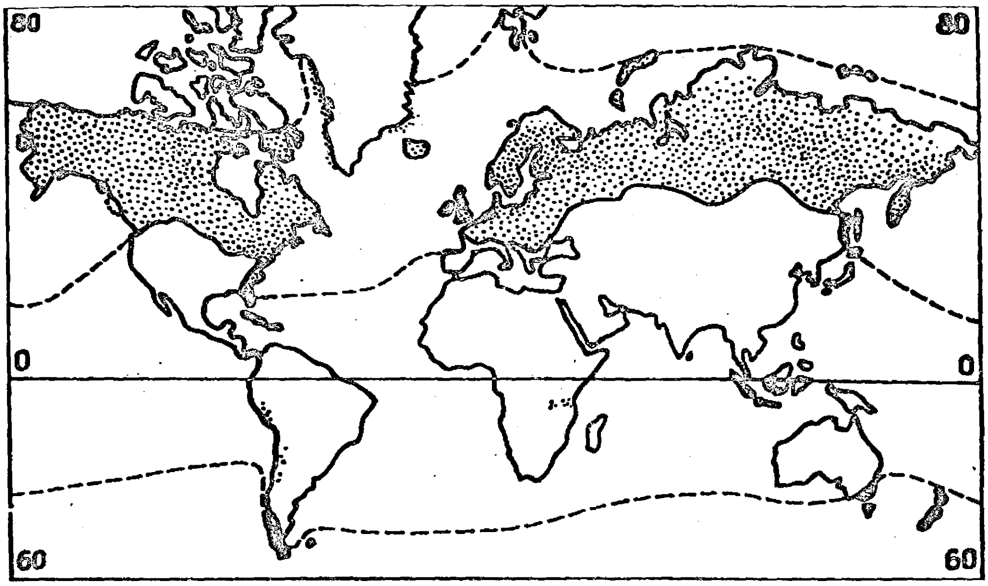


Fig. 33. World distribution of muskeg (after Bülov' 1925).

reports of its existence also in lower areas in the tropical climatic areas such as in Uruguay and Guyana and in Florida (Radforth 1966, verbal communication).

The high arctic has some muskeg even near the toes of the permanent ice caps (Radforth 1965).

In Canada muskeg is spread all over the country from the southernmost tip of Ontario to the northern tip of Ellesmere Island (Radforth 1965), from the easternmost coast of Newfoundland to the islands of the Pacific Ocean in British Columbia. Only the frequency of occurrence varies from region to region. It has been estimated that muskeg covers about 12%, that is about 500,000 square miles (1.295 million sq. km., 129 million hectares) of the whole of Canada (Radforth 1962b). According to some sources, Russia has the largest areas of muskeg which are estimated to be about 130 million hectares (Kivinen 1948). Both these estimates should be regarded as tentative, approximate and conservative.

Figure 34 depicts the areas of organic terrain where engineering problems occur, the limits of the most common cover types as classified according to the Radforth classification system (Radforth 1952) and the frequency of occurrence of muskeg in Canada (Radforth, 1955a). This map is the only one depicting the distribution of muskeg in Canada and contains some inaccuracies. However, it gives a relatively accurate picture of the distribution of muskeg in

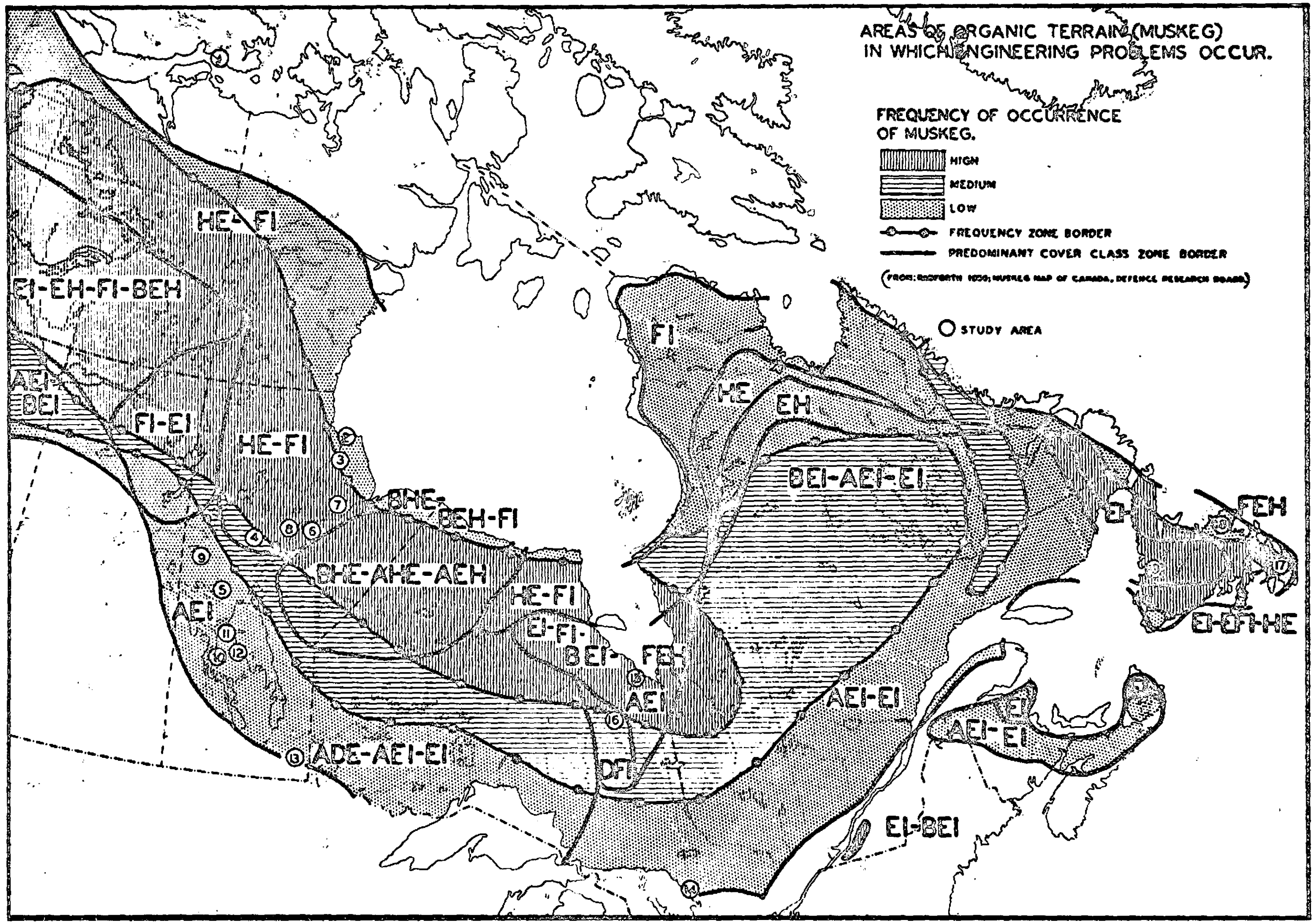


Fig. 34. Relationship of study areas to distribution of muskeg in Canada. Information of the distribution of muskeg from Muskeg Map of Canada, Radforth 1960, Defence Research Board, Ottawa.

Canada and of the relation of study areas to it.

According to this map, Areas 3, 6 to 8 and 15 to 19 are in the zone of high frequency of occurrence of muskeg. This zone covers most of Newfoundland, the area of an intense ombrogenic paludification, most of the Hudson Bay Lowland area and, in addition to it, a large area extending northwest into the Northwest Territories up to Great Bear Lake. Area 2 in Churchill should be included in this zone since it is still in the area of unconfined muskeg of the Hudson Bay Lowland, although according to Figure 34 it would be in the zone of low frequency of occurrence of muskeg. Areas 5 and 10 to 13 could be placed in the zone of high frequency of occurrence since they too have an unconfined muskeg cover. In the map they also would fall into the low frequency zone. According to the map only Area 4 would be in the medium frequency zone, but perhaps this zone could now be extended to include Area 14.

Area 9 would be the only one after this in the low frequency zone, and Area 1 in the zone of no frequency of occurrence at all. The author's experience as well as information cited already in the literature (Radforth 1965) shows that there is muskeg in the Arctic. Thus actually almost all the white areas of Figure 34 probably could be marked off as the zone of very low frequency of occurrence of muskeg when additional inventory has been made. Also there are some areas with no muskeg on the prairies and in certain rugged mountainous areas as well as in the Arctic, at least where there are ice caps.

Figure 34 thus reveals that the study areas are distributed among a large variety of muskeg conditions and distributional frequency zones and therefore represent a good enough sample to warrant generalization concerning the sub-surface ice conditions to be made later.

The reasons for the distributional trends of muskeg in Canada and in the study areas have been explained in the chapters on climate, geology, and physiographic features of the study areas.

DESCRIPTION AND DISTRIBUTION OF ORGANIC TERRAIN FEATURES WITH SIGNIFICANCE FOR AERIAL INTERPRETATION OF SUB-SURFACE ICE CONDITIONS AND RELEVANCE TO DEVELOPMENT OF CERTAIN AIRFORM PATTERNS

Airform Patterns

There are five major high altitude (30,000 feet, 9000 meters) airform patterns, Dermatoid, Marbloid, Reticuloid, Stipploid and Terrazoid described in Appendix C as Radforth introduced them originally (Radforth 1956a and 1956b). In addition to these there is a total of seven low altitude (1000-5000 feet, 300-1500 meters) airform patterns, Cumuloid, Intrusoid, Planoid, Polygoid, Vermiculoid I, II and III summarized in Appendix B according to Radforth's original descriptions (Radforth 1958).

Each of these airform patterns has highest frequency in certain environmental conditions, but most of them occur to some extent almost anywhere where muskeg occurs. Very rarely are there large areas covered by one pattern only. Usually several patterns are represented in most locations although one of them may clearly predominate. Thus, for instance, Marbloid pattern often occurs with a lower percentage of Dermatoid or Reticuloid and quite often it is interwoven with Terrazoid pattern. Planoid may alternate with small areas of Polygoid, etc.

However, only the occurrence of the Marbloid pattern can be readily related to the occurrence of permafrost or some other sub-surface ice condition. As will be seen later, the development of this pattern is closely influenced by permafrost and severe sub-surface ice conditions in general. One can obtain a good concept of the distribution and morphological variation of the Marbloid pattern by performing a long traverse by air over the organic terrain starting, say, in Gypsumville in central Manitoba far south of the southern limit of permafrost and proceeding over the permafrost country far to the north and terminating in the Arctic, on, say, Victoria Island or Ellesmere Island. This kind of traverse suggests how the occurrence of the Marbloid pattern is linked with that of permafrost, as will be shown later.

Morphology of Typical Marbloid Pattern

In its typical form Marbloid pattern is encountered near the northern parts of the discontinuous permafrost in northern Manitoba. Here it distinctly resembles the surface of a polished marble slab with its convolutions, lobate pattern, and light tone. The light tone is due to the high albedo of lichens, or H-factor, to use the engineering term for the lichen cover, in Radforth's classification system (Radforth 1952). Lichen is very characteristic of the Marbloid pattern and usually grows in abundance on it.

Figure 35 illustrates this typical Marbloid as seen from an altitude of about 9000 meters (30,000 feet) and as photographed with a 152 mm (6") lens with the resulting scale of 1:60,000 (one inch equals approximately a mile). The area shown in this figure is situated about 45 miles (70 km) SSW of Churchill (Man.) and about 13 miles (20 km) west of Churchill River, at the demarcation between the Hudson Bay Lowland Palaeozoic and the Canadian Shield Precambrian. The Precambrian here is quite flat and featureless and does not exhibit the ruggedness of small features which normally characterize it if one observes it farther west or south.

As one can see from Figure 35, the Marbloid pattern is composed of a variety of plateaus. Their lobate edges are constituted of various sizes of peat mounds some of which suggest the palsa formation of northern Scandinavia. This complex is dissected by a very irregular, deranged drainage system (Thornbury 1966, Lueder 1959).

The flatter parts of plateaus especially, are dotted with numerous small ponds. The sizes of these ponds vary from a few meters in diameter up to several hundreds of meters and sometimes over two kilometers. Usually the ponds and lakes are fairly shallow. The high density of this occurrence often imparts a reticulate character to

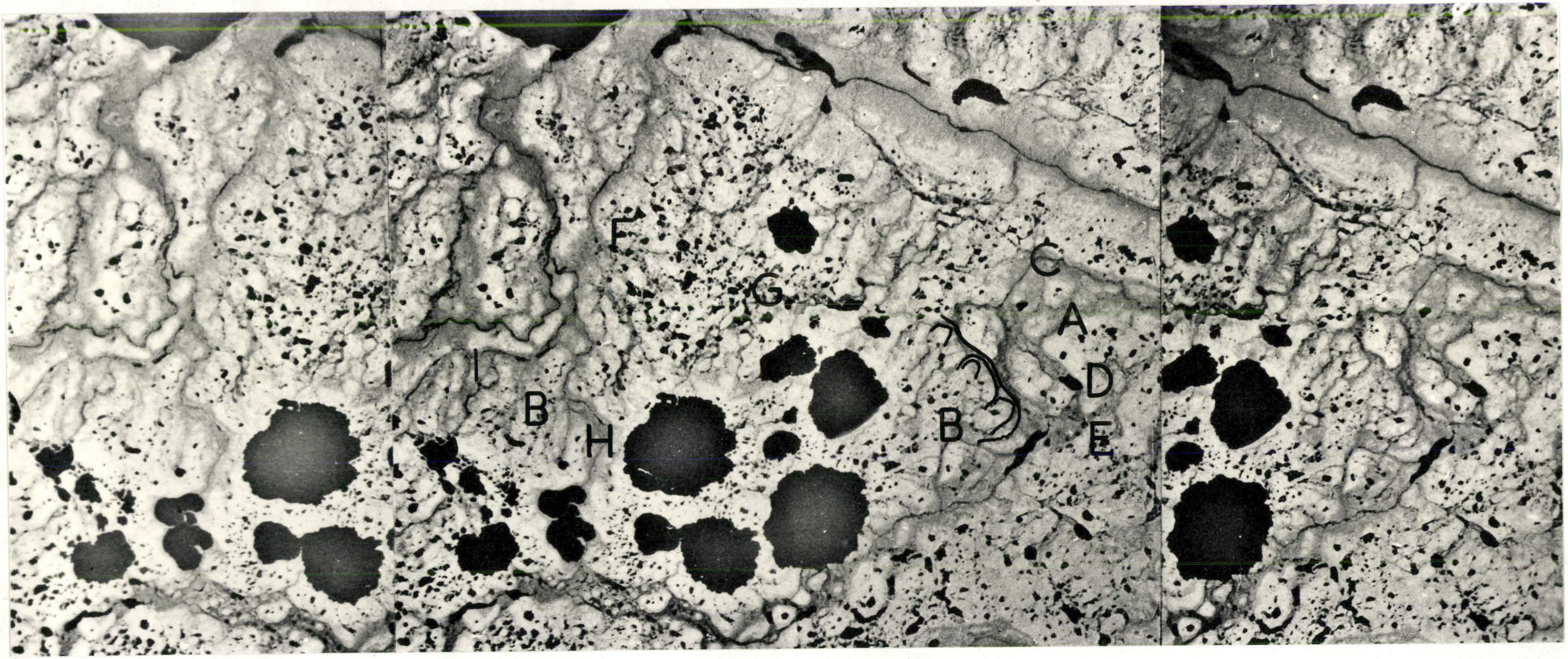


Fig. 35. High altitude (30,000') vertical stereopair of typical Marbloid condition in Area 3, northern Manitoba.
A = small detached peat plateau.
B = large complex typical Marbloid peat plateau.
C = peat plateau lobe size order 1.
D = peat plateau lobe size order 2.
E = peat plateau lobe size order 3.
F = large drainage channel.
G = shallow FI drainage channel.
H = ice wedge polygons oriented along the slope to form narrow drainage channels. Light tone is rendered by H-factor (lichens).
I = horsetail drainage.

the Marbloid pattern and often this feature becomes an integrated system of Reticuloid and Marbloid areas. This Reticuloid is not, however, the typical Reticuloid as described by Radforth (Radforth, 1956a) which is mainly composed of a well-organized arrangement of peat ridges, but is more irregular.

Near the edges the plateaus are drier due to better drainage through the small numerous eroded gullies which are found here and lead into drainage channels of a higher order. The drainage channels are very often responsible for the shape of the edges of peat plateaus and also for the convoluted or lobate condition. In some areas the lobate pattern of the edges of peat plateaus is caused by a small drainage channel traversing them. There may be erosional gullies or results of differential growth due to varying moisture regimes. The edges of peat plateaus may be very steep as in Figure 36 where the peat plateau descends, quite abruptly, about two meters onto a medium sized drainage channel lying directly on mineral terrain. The cover at the well-drained edge is composed of stunted *Picea mariana* (black spruce) or large ericaceous shrubs, usually, *Ledum groenlandicum*, and lichen and mosses. By using the engineering cover classification system, it is designated as BEH cover (Radforth 1952). This medium size channel in Figure 37 is one of those contributing to the lobate pattern of Marbloid. As Figure 37 reveals, there

Fig. 36. Medium sized drainage channel in typical Marbloid area in Chesnaye, northern Manitoba. Cover in the foreground is FI. Note steep edge of peat plateau in the background with BEH cover.

Fig. 37. The same drainage channel as that in Figure 36 from a different angle. FI cover dominates in the foreground while DFI cover is in the area in the background.

is a comparatively wide area of sedge-covered shallow muskeg on the bottom of the drainage channel. Commonly willows occur in the same channel. The former represent FI cover and the latter DFI cover. Figure 38 shows a narrow and quite wet shallow depression which is a common feature on the Marbloid peat plateaus and which serves as one of the tertiary drainage channels which drain the plateau along these surfaces either into the ponds or into the larger drainage channels as the one shown in Figures 36 and 37. These two sizes of drainage channels are recognized on the peat plateaus from aerial photographs because of the dark tone they render. They drain into some larger channels which are already large streams. These rivers have mineral terrain embankments usually with Picea glauca (white spruce) and sometimes poplar (Populus sp.). These larger rivers are naturally not as densely spaced as the small ones, being often only 30-60 meters (100-280 feet) apart while the smallest ones are usually only 10-20 meters apart. The large rivers occur about one every two kilometers.

The peat plateaus form the main conspicuous feature of Marbloid. This is primarily due to the light colour of the majority of peat plateaus. If one were to describe the cover here in the engineering terms, it would be designated as HE or sometimes EH (small shrubs and lichen in the botanical sense). The high albedo of the dense lichen cover is

Fig. 38. Shallow wet FI drainage channel in typical Marbloid in Chesnaye, northern Manitoba. Cf. item G in Figure 35.

Fig. 39. Typical HE cover in Marbloid area in Chesnaye, northern Manitoba. Dominant lichens belong to genus Cladonia, and the dominant shrub is Ledum groenlandicum. This area is patterned with ice wedge polygons.

responsible for the light tone of this pattern in aerial photographs. The most common lichen species are Cladonia spp. and among them Cl.alpestris. The shrubs are mostly ericaceous but dwarf birch (Betula glandulosa) is not uncommon. Figures 39 and 40 illustrate this kind of cover. Instead of HE and EH small areas of sedges with Sphagnum spp. appear in the low-lying and wetter places (Figure 38). The polygons with depressed centers have a sedge-moss (FI) cover in their centers while the high peripheral ridges, with ice wedges inside, bear HE-type coverage (Figure 41). Also, in the fissures with higher water regimes between the ice wedge polygons of the flat plateaus I or FI cover predominates (Figure 42). This cover or the associated clear water in the fissures (resulting dark tone) contrasts well against the light tone of the centers of polygons thus enabling the observer to detect the polygons. Though these may be only 10 meters wide, they may be seen on aerial photographs taken at an altitude of 9,000 meters (30,000 feet).

Figure 43 illustrates the effect of wind erosion on points of highest elevation of the polygons. During the winter these high areas have no snow cover and are thus left exposed to the high winds. Ice, snow and winds combine to break the surfaces and start erosion. The polygons as a feature of Marbloid pattern will be analyzed in detail later.

Fig. 40. Typical Marbloid area showing dominant HE cover, wind erosion (brown areas in the background) and channel type polygons in Chesnaye, northern Manitoba.

Fig. 41. Depressed centre polygons in Marbloid area in Chesnaye, northern Manitoba. Note FI cover in the wet centres of the polygons and EI or EIH on the higher ridges under which the ice wedges are located.

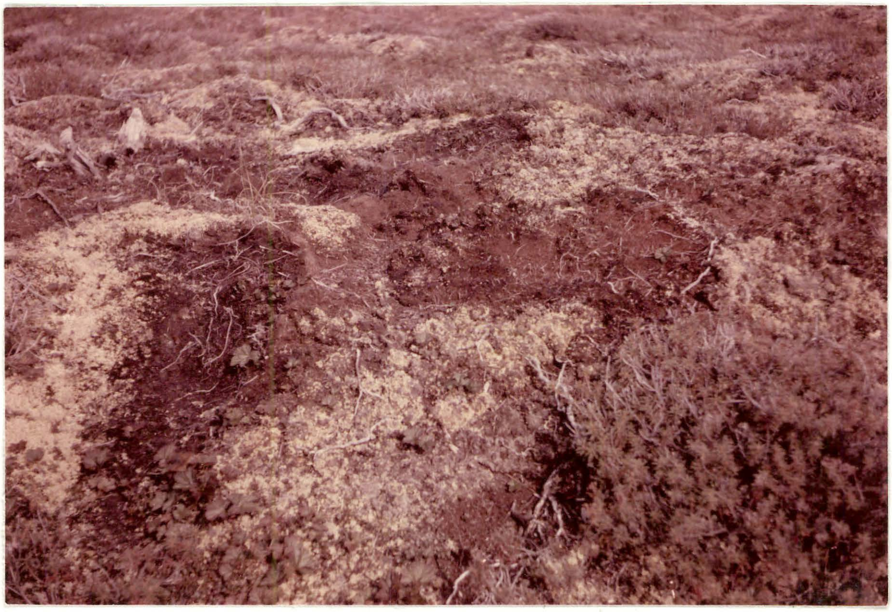
Large areas of the Marbloid pattern are composed of roundish or oval shapes which do not strictly deserve the designation "peat plateau" since actual "plateau area" is singularly small. These features are an integral part of the lobate pattern of edges of peat plateaus. They are, in many cases, small and separate but tend to grow gradually together joining to form clusters some of which are quite regular. The clusters are attached to the edges of peat plateaus and if the uniting feature (from the plateau proper) is wide enough they form a lobate fringe. The smallest domes, only about 30 meters (100 feet) in diameter each with a frozen peat core, resemble the Scandinavian mounds which are called palsas. In Scandinavia palsa formations can attain widths of over 200 meters (600 feet) and heights up to 7-8 meters (29 feet). Some of the formations of this type in Manitoba, in the areas shown in Figure 84, are about this size before they join to constitute a peat plateau with its lobes and other characteristics. The cover on these formations may be EH or HE while between them it is usually either FI or DFI.

An inherent feature in the Marbloid pattern is high frequency of ponds and small lakes, and it seems reasonable to account for their main characteristics here.

Figure 44 shows a typical gently sloping pond edge in northern Manitoba. In this case, the pond appears to be being slowly overgrown by vegetation which is mostly sedges

Fig. 42. Trench between adjacent channel type polygons in Chesnaye, northern Manitoba. Note free water in the trench with loose FI cover as contrasted to EH cover on the centres of polygons.

Fig. 43. Wind erosion on a high-lying peat mound. Brown area is exposed peat and is a common sight in the Arctic where high mounds often remain above sheltering snow cover during the winter. Typical Marbloid area in Chesnaye, northern Manitoba.



and Sphagnum spp. (FI cover). The physical action of the ice on the shoreline has not been very marked in this case probably due to the shallowness of the pond.

Figure 45 shows a typical abrupt pond margin from the same northern Manitoba area as Figure 44. Here the water is deeper and the ice acts more strongly on the margins of the pond. Growth of vegetation over the water is impeded and the ice has thrust the peat up forming an embankment which may attain heights up to a few feet above the surface of surrounding muskeg. This kind of margin forms a notable hindrance to overland mobility of off-road vehicles in these (Marbloid) areas.

Many of these ponds and small lakes are so-called "thaw lakes" which abound in the permafrost areas. They result where the peaty insulation on the permafrost breaks down and allows for local alleviation of the permafrost conditions. The ice in the underlying frozen soil thus thaws causing slumping of the surface and formation of ponds and lakes.

The features described here are part of a typical Marbloid airform pattern. They contribute to the development of this easily distinguished pattern and many of them persist relatively far south. There is a wide variety of Marbloid conditions starting in the north and ending near the southern limit of permafrost where strong vegetal growth obliterates Marbloid pattern as will be seen in a

Fig. 44. Sloping pond edge in typical Marbloid near Chesnaye, northern Manitoba.

Fig. 45. Abrupt pond edge in Marbloid area (Area 3), northern Manitoba. Note BEI cover by the pond.

later section of this work.

H-Factor

The peculiarly light tone of the Marbloid pattern has been referred to several times and is caused by the predominating growth of lichen. In large areas the dominant species is Cladonia alpestris.

In the Radforth cover classification system for the engineer the lichens constitute a class designated by the letter H (Radforth 1952). It is described in this system as non-woody, 0-4 inches high, leathery to crispy by texture and showing mostly as a continuous mat. For brevity, the structural condition will be referred to as H or the H-factor.

Figures 46 and 47 show that the H cover may be continuous and indicate how its high albedo is capable of rendering a light tone to the Marbloid airform pattern.

Lichens grow almost everywhere in the world and are especially common on drier mineral soils forming as a main component large heaths in some areas. They occur also on muskeg to a lesser extent almost everywhere where the conditions on the muskeg favour their growth. However, in most cases, the favourable conditions are limited to areas representing local microconditions which, in most cases, do not extend over areas wide enough to be discernible from the air, especially from high altitudes. This situation

Fig. 46. Continuous mat of lichens (H-factor) with <u>Cladonia alpestris</u> as dominating species in Area 2. This figure reveals well how lichens with their high albedo can impart such a light tone to typical Marbloid pattern as seen in Figure 78.

Fig. 47. An example of lichenaceous growth in typical Marbloid area near Churchill, northern Manitoba (cf. colours in Figure 46).

arises in the areas south of the southern limit of permafrost. The image changes when one flies north over muskeg at the southern limit of permafrost. Near this limit the H-factor becomes quite prominent even in flat open muskeg as Figure 99 shows. This area is just north of the presently designated southern limit of permafrost near the northern tip of Lake Winnipeg and west of Norway House.

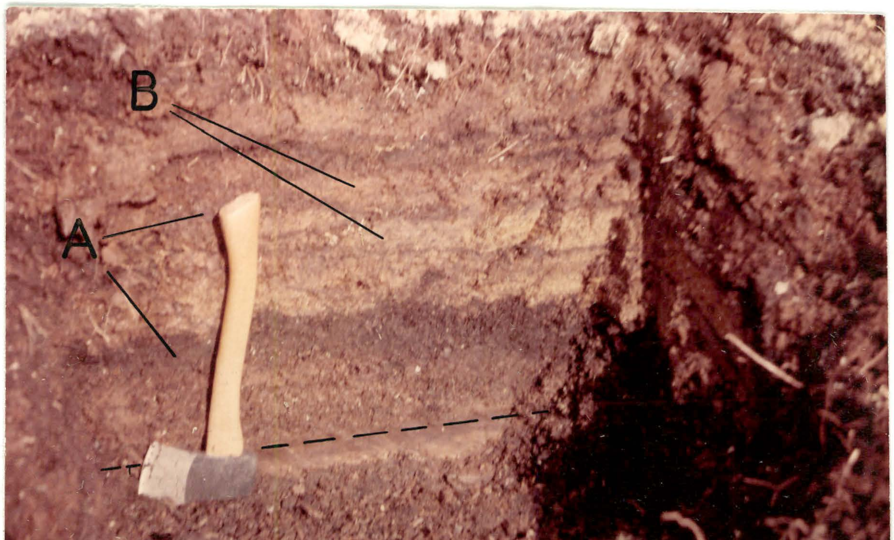
If one continues to fly over muskeg further north, the H-factor becomes gradually more evident first in the treed areas where the cover frequently is either AEH or BEH. In the botanical terms, this means trees over fifteen feet in height with shrubs less than two feet in height and lichens, and trees less than fifteen feet high with the same understory respectively. In large areas of northern Manitoba, lichens predominate as Figures 40, 46, 47, 48 and 99 show. It may form large, nearly continuous mats being almost the only member of the understory as Figures 46-47 reveal, but in most cases it occurs with small shrubs as Figures 40 and 48 illustrate.

In the Arctic the lichens are quite common on mineral soils but they appear also on newly forming muskeg mostly on the mounds and ridges as Figure 70 reveals.

In Newfoundland, south of permafrost lichens may be found quite often on muskeg. The growth here is, however, intermittent and is confined to the drier places on muskeg.

Fig. 48. Typical HE cover of Marbloid between Areas 2 and 3 in northern Manitoba.

Fig. 49. Typical peat deposit in Marbloid area near Chesnaye, northern Manitoba. Broken line shows the location of permafrost table, which in this case was about 20 inches from the surface. Dark peat layers (A) are composed of well humified Sphagnum - shrub peat. Light (B) peat layers are composed of mainly poorly humified Sphagnum peat. Predominant cover in this location is HE.


B
A

Thus, they grow on the ridges and on the mounds. These formations are quite common in Newfoundland because large areas of muskeg in Newfoundland are raised and ombrotrophic with high ridges which offer dry growing conditions to lichens. Here as well as in other muskegs outside the permafrost region the H-factor does not play a strong enough role to render it visible from high altitudes except occasionally in small and localized areas.

Polygonal Patterns on Muskeg

The polygons as a feature of patterned mineral terrain are a widely distributed and extensively studied phenomenon encountered in regions of cold climates both in the northern and southern latitudes as well as at high elevations in various mountainous parts of the world.

It is generally accepted that, in most cases, the polygons are a direct result of cold climate and factors connected with it. However, there are polygons (an unrelated phenomenon) in the regions of warmer climates, too. Almost everyone is familiar with polygonal pattern arising in a clay field or on the bottom of a small pond temporarily dried up during the driest summers. Larger polygons than these occur in deserts. They may have been formed by the activity of crystallization and resolution of salts which play a similar role to that of regelation in frozen ground (Troll 1944). Polygons are fairly common near the southern limit of permafrost where the permafrost table has been lowered, the frozen portions of polygons have been replaced by silty material and the polygonal pattern thus has been retained. These so-called 'relic' polygons can be distinguished from others by various factors including vegetation (Sager 1951).

For more details on the polygons of mineral terrain, the reader is referred to Washburn's work (Washburn 1956).

The ice wedge polygons, the type of polygons which are quite common in the muskeg, are defined by Washburn as non-sorted polygons characterized by bordering ice wedges. "Non-sorted polygons are patterned ground the mesh of which is polygonal and has a non-sorted appearance due to the absence of the border of stones such as that characterizing sorted polygons" (loc. cit.).

There is a common disagreement as to whether all non-sorted polygons could be regarded as indicators of permafrost, because they are found also in the areas without permafrost. It is agreed that permafrost is always present with ice wedge polygons (loc. cit.).

Many writers have used polygons in aerial photographic interpretation as permafrost indicators (Sager 1951, Black 1952, Lueder 1959, Thoren 1959).

Ice wedge polygons are quite common in northern muskeg as has been mentioned in connection with the description of the Marbloid airform pattern.

There are suspicions as to the causes of the genesis of polygons in peat. Troll, for instance, maintains that in peat the polygons have nothing to do with frost, but that they are formed by wind erosion, gullying, anthills, animal paths, growth habits of plants, etc. (Troll 1944). This may apply to some polygons in the muskegs far south from the permafrost region, but it is not true for permafrost areas, although some of these factors may well be influential secondarily.

The polygons which are discernible from the air from an altitude of 9000 meters (30,000 feet) are large, the diameter varying generally between 10 and 40 meters (30-130 feet), the largest ones being over 60 meters (200 feet) in diameter. The shape varies too. The most common forms are from tetragonal to hexagonal. The tetragonal polygons predominate in the areas for which Figure 35 is typical. This area is very flat and the occurrence of tetragonal polygons appears to be in contradiction to what several authors (Sager 1954, Schenk 1955) maintain, namely that tetragonal polygons are usually located on slopes while hexagonal ones indicate level ground.

In muskeg, as in mineral terrain, there are usually two kinds of ice wedge polygons, those with depressed centers surrounded by higher ridges in which the ice wedge is located, and others with higher domed centres which consist of a frozen peat core. In this case, the ice wedge is at the base of the fissures between the adjacent polygons. Both types are extant in the Marbloid in Chesnaye in northern Manitoba. There is of course a set of transitional forms separating these two main forms.

Figure 41 illustrates a polygon with a depressed centre. This type is often regarded as an indicator of very poor drainage (Sager 1951). It is typically low-lying and has a wet centre which is covered by sedges and mosses; in other words, it has an FI cover. The ridges with better drainage are able to create favourable growing conditions for the lichens and therefore frequently have a cover of lichens and small shrubs, HE or EH.

The strong lateral growth of ice wedges may raise the centres of the polygons with depressed centres gradually resulting in a polygon with raised centre or "channel type polygon" as they are commonly called. Figure 40 shows a channel type polygon in northern Manitoba in Chesnaye. The centre of the polygon is considerably higher than the edges. This quite well drained centre is covered by the typical Marbloid cover, EH or HE, lichens and small shrubs. Frost thaws in the centres to a depth of about 12 to 20 inches during the summer (Figure 49). The fissures between the adjacent polygons are approximately 50 to 150 cm wide and vary from 20 to 60 cm in depth (Figure 42). Often water is present in the fissure and sometimes flows slowly down a gentle gradient collecting in the small FI drainage channels described in connection with Marbloid. These trenches abundantly grow various species of Sphagnum such as S. cuspidatum which favours wet habitats, and also sedges. This cover type (dark lines from the air) is quite strongly contrasted against the light cover type of the centres of polygons.

In general, the polygons in muskeg are widely distributed from the southern limit of permafrost up to the Arctic where they either transgress into the peat or are formed in the peat directly. This aspect of polygons will be discussed in detail later in connection with the development of Marbloid airform pattern. The reader is also referred to Figures 90 and 96 which show the appearance, or should it be stated the disappearance, of polygons in the peat together with the disappearance of the Marbloid airform pattern.

Miscellaneous Features Related to the Occurrence of Sub-surface Ice

There are several miscellaneous features of terrain which are visible on the aerial photographs and which are connected with the occurrence of permafrost or some other distinctive sub-surface ice condition. Many of these features originate and predominate in the mineral terrain, but are quite unique to organic terrain. Certain of these features that are diagnostic will now be described and rationalized in terms of aerial interpretation.

1. Sorted Circles

These are patterns which are found in mineral terrain but often transgress into organic terrain.

Most of the circles that the present author encountered in the areas of initial paludification in the Arctic in the Victoria Island and Pelly Bay region were sorted circles. They are defined as "patterned ground the mesh of which is dominantly circular and has a sorted appearance commonly due to a border of stones surrounding finer material" (Washburn 1956). Figure 50 illustrates typical sorted circles in Cambridge Bay, Victoria Island, N.W.T. The fine grain material concentrated in the centre of the circles has a high albedo and appears very light especially on low altitude aerial photographs as Figure 78 reveals. The circles appear to be concentrated on the tops of small hillocks where gradient is almost lacking. Usually the centres contain fine material but circles occur in which the centres are composed of coarse material (Figure 51). The coarse material in the border ranges from pebbles to quite large stones (diameter 20 cm) - (Figure 52). According to some authors, the size of bordering stones increases as the depth and breadth of the circles increase in general (Iwan 1936).

The vegetation sometimes enhances this pattern (Figures 50 and 51). Here the vegetation is concentrated in

Fig. 50. Sorted circles with coarse material bordering silty fines in the centres of circles. Note initial growth of peat in the low-lying depressions surrounding centres of circles. Cambridge Bay, Victoria Island, N.W.T. Cf. Figure 51.

Fig. 51. Sorted circles with coarse material in the centres and fine material along the edges. Note initial growth of peat in the depressions around the centres of circles. Cambridge Bay, Victoria Island, N.W.T.

the fissures. In some cases the vegetation grows on the centre if the aggregate is too coarse, (Figure 52). In most cases paludification commences in the fissures where there is more water available to the plants that constitute muskeg cover.

2. Sorted Steps

The sorted steps are concentrated mostly downslope from the sorted circles in the Cambridge Bay-Pelly Bay area as far as the paludified places are concerned. They seem to have been formed by a slight solifluction or soil creep from the sorted circles. Washburn (1956) has defined "sorted steps as patterned ground with steplike form and a sorted appearance due to a downslope border of stones embanking an area of finer material upslope". The sorted steps are formed by intermediary phases from the sorted circles as the gradient gets steeper. Figure 80 from Victoria Island shows sorted circles on the top of a hillock (till) and gradually longer sorted steps appear progressively downslope. Figures 68 and 53 show poorly sorted steps in which the sorting has been obscured by initial shallow deposit of peat on them. Figure 54 is a diagrammatic illustration of sorted steps according to Sharp (1942). In the sorted steps, similar to the sorted circles, the centre is composed of fines, usually silt, and the border of coarse material or stones up to 30 cm (1 foot) in diameter.

Fig. 52. Sorted circles with extremely coarse material surrounding lower-lying centres. In this case paludification has started in the centres which, as low-lying locations, offer favourable conditions for paludification while the coarse material surrounding the centres is too coarse for initial paludification. Cf. Figures 50 and 51.

Fig. 53. Poorly sorted steps in Victoria Island, N.W.T. Shallow initial muskeg covers most of the coarse material in the depressions among the steps.

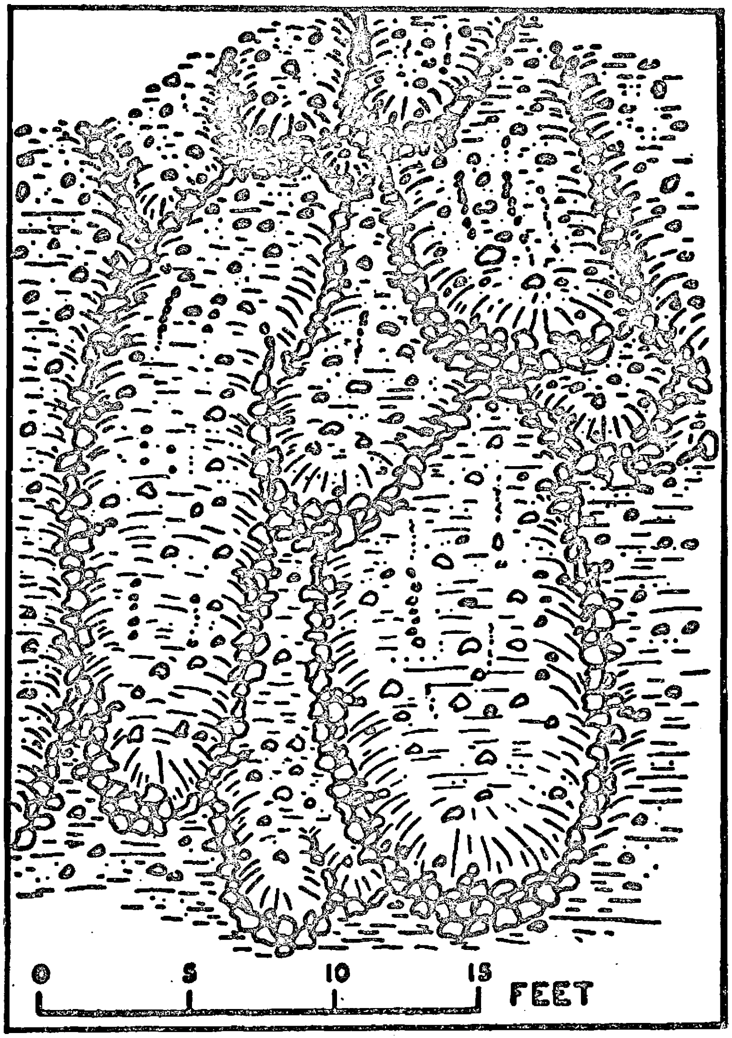


Fig. 54. Diagram of sorted steps (after Sharp 1942). Present author maintains that paludification starts in the trenches between adjacent steps if the material there is not too coarse and well drained and if they are sufficiently low in relation to the centres.

The length of steps varies greatly and the width is generally from 40 to 100 cm.

3. Sorted and Non-sorted Stripes

Stripes, whether they be sorted or non-sorted, appear as long soil strips along slopes with a depression between them. The stripes are fairly common in Boothia Peninsula on the slopes created by the rugged Precambrian terrain. Figures 55, 56 and 57 show a typical view over a slope in Boothia Peninsula covered by a thin layer of peat which gives the reddish brown colour to the colour photo.

All the patterns (circles, steps and stripes) become part of the Marbloid airform pattern as they transgress into peat in the initiation of paludification and are strongly expressed especially later as the Marbloid intensifiers.

There are various hypotheses and theories about their genesis in the mineral terrain. Thus, for instance, the sorted nets (circles) could be formed by water under hydrostatic pressure which might dome the surface resulting in the nets. This is so-called artesian hypothesis and it requiries the existence of a slope (Ule 1911).

Steps and stripes on the other hand may have been formed by solifluction on the slopes (Nordenskjöld 1909).

The rillwork hypothesis might account for the formation of stripes. Several workers have claimed that rillwork on the slopes creates parallel channels in which stones

Fig. 55. Initial muskeg on the slopes of the Precambrian Shield in Boothia Peninsula, N.W.T. Shallow peat derives its striped appearance from the mineral terrain which it covers. Note the bare Precambrian rock outcrops (A). Cf. Figure 56.

Fig. 56. For annotation cf. Figure 55. The reddish brown colour of the organic terrain is due to autumn colours of muskeg vegetation.


A

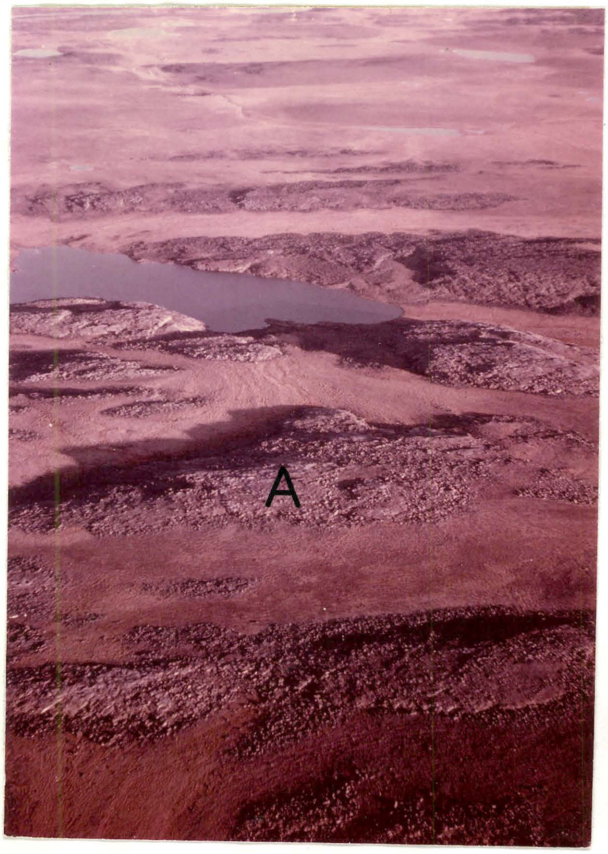

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Fig. 57. Initial paludification on a slope patterned with soil stripes in Boothia Peninsula, N.W.T. Cf. Figures 55 and 56.

become concentrated and that this process explains the sorted stripes (Ule 1911, Cairnes 1912, Salomon 1929).

Most persons who work on the patterned ground phenomenon seem to be of the opinion that there are several factors co-operating in the genesis of patterned ground. For more details the reader is again referred to Washburn (1956). Aspects of the formation of patterned ground in muskeg will be dealt with later at greater length.

Drainage Features Present in the Marbloid and Related to Sub-surface Ice Conditions

There are many drainage features which largely owe their presence to permafrost or some other marked sub-surface ice condition and which become an integral part of the Marbloid airform pattern. The most distinctive ones are explained as follows.

1. Thaw Lakes

The term "thaw lakes" has already been introduced (page 77). There is a special type of thaw lake which appears occasionally in muskeg known as the 'relic' thaw lake where drainage has left a regular circular formation often conspicuous from the air. It appears in muskeg as Figure 82 reveals. It is supposed that the thaw lakes are the result of thawing of permafrost under a water body or that they follow deterioration of the insulative peat which in turn results in the slumping of the ground which occupies a larger volume when it is frozen than when unfrozen. Drainage of the lake may be complete and the escaped water may collect in some other location at a lower level and finally find its way into a larger river leaving behind at least one circular depression which sometimes overlap (Figure 82). These depressions may be partially filled with exposed peat as is the case in Figure 82.

2. Rectangular streams

Rectangular streams display right-angled bends. The bends are considered to reflect control exerted by a joint or fault system although too much weight should not be put upon the influence of these factors (Thornbury 1966).

In permanently frozen organic terrain with a polygonal pattern, the rectangular pattern indicates the existence of polygons which may not be otherwise clearly visible on high altitude air photos. On these photographs, for example, representing an altitude of 9000 meters (30,000 feet), the polygons are not always readily discernible without using stereoglasses or some other aid, but the rectangular pattern of the streams is more easily observed and thus indirectly reveals the existence of polygons and also suggests the occurrence of permafrost. Figure 58 shows a rectangular stream in northern Manitoba in a Marbloid area. The small streams in this case develop the quite

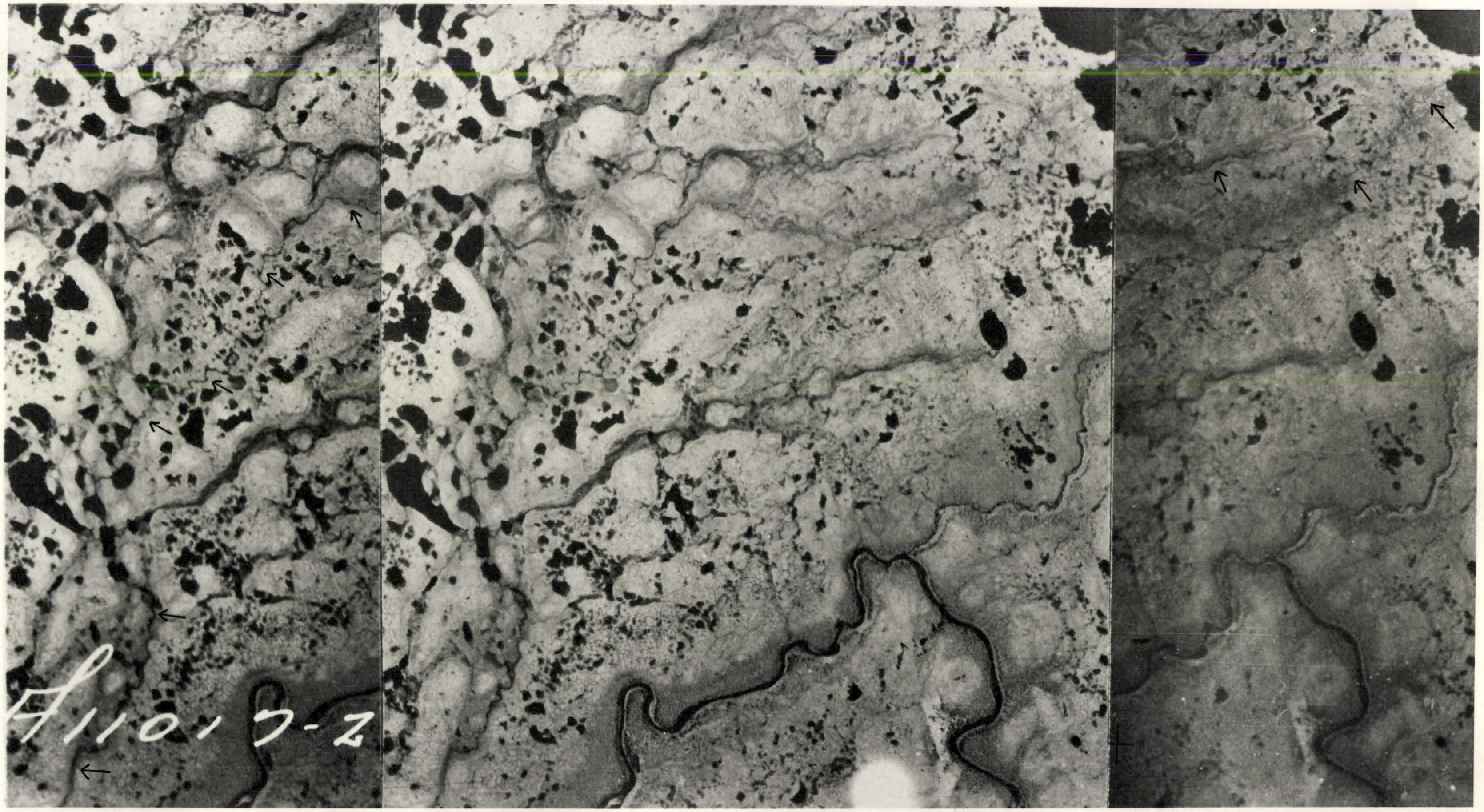


Fig.58. High altitude (30,000') vertical stereotriplet of rectangular stream in a Marbloid system in northern Manitoba. Location of the stream is shown by arrows.

regular angular pattern by initially following the fissures between polygons. This identifies early initiation of small streams and with continued erosion a rectangular stream results. Later, when the stream grows in depth and width, contains more water, and is older, the rectangular pattern disappears.

3. Beaded Stream

Another form of stream which is considered to be an indicator of permafrost is a beaded stream. It is often formed in the valley bottoms with a slight gradient and resembles a string of pearls, hence the name. These streams are a result of erosional action on polygons. When the ice on the perimeter of a polygon melts, the same happens to the ice in the centre of the same polygon with the resulting slumping down of the centre and formation of a depression which will be filled with water and is seen on an aerial photograph as a single "pearl" of a beaded stream. These streams also appear in the organic terrain as Figure 59 shows near Churchill in northern Manitoba.

4. Asymmetrical Valleys

Asymmetrical valleys are quite common in various parts of the world and in different climatic regions. In permafrost areas the asymmetry of east-west valleys is not uncommon and is regarded as one sign of the occurrence of sub-surface ice. This phenomenon was first evaluated by

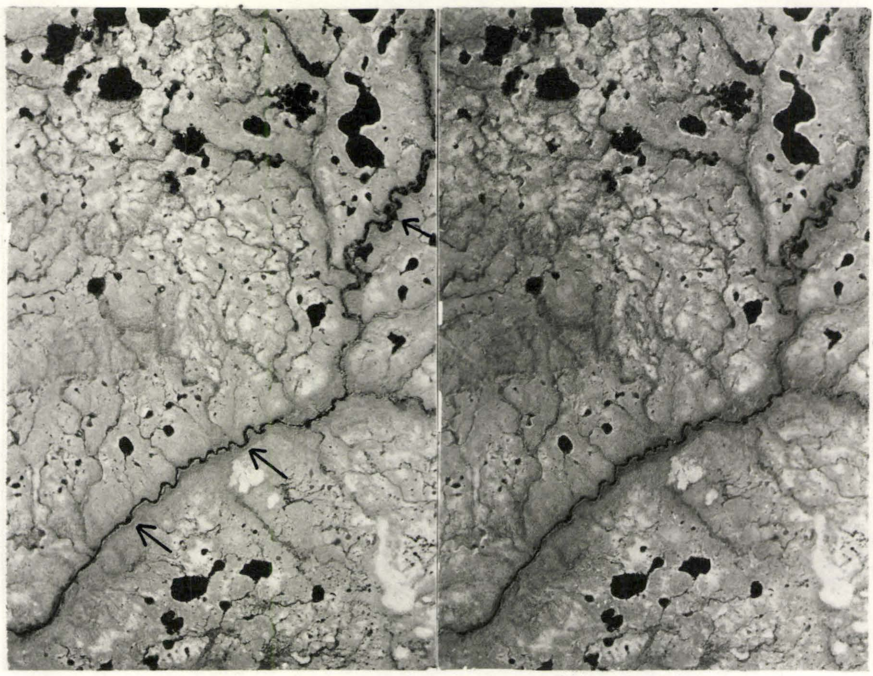


Fig.59. High altitude (30,000') vertical stereopair of beaded stream (arrows) in a Marbloid system, northern Manitoba.

Schoslakowitsch in 1927 in Siberia. Briefly, the asymmetry results largely from the effects of difference in exposure upon the rates of weathering, mass wasting and erosion. A south-facing slope (in the northern hemisphere) will receive more sunshine, have a higher evaporation loss, experience more frequent thawing and freezing and retain snow for a shorter period than will a north-facing slope. As a result of higher temperatures and lower soil moistures on the south-facing slope, there will be less vegetation (muskeg). Hence, weathering, sheetwash and mass wasting will go on more rapidly and this slope of valley side will be less steep than the north-facing one (Thornbury 1966). This reasoning obtains for mineral terrain.

However, the asymmetrical valleys also appear in the organic terrain as Figure 102 shows (K). Here the most important factor contributing to the gentleness of the south-facing slope is again its greater exposure to the sun. This results ultimately in the thawing of the ice. This action, on the other hand, is indirectly initiated by the fragmenting and drying of the insulating peat overburden which then has greater vulnerability to the erosional action of strong winds, the effect of which is enhanced by the shorter duration of the snow cover on this south-facing slope. Thus, the slope slumps down when the ice melts in it and the erosion wastes it faster than on the north-facing slope.

5. Oriented Polygons

Very often the polygons in muskeg have linear orientation when they are on slopes. Figure 60 shows how they may occur in long rows. Thus small parallel drainage channels are formed between several rows of oriented polygons serving as primary drainage channels for peat plateaus in Marbloid areas.

6. Horsetail Drainage

Sometimes the pattern of drainage in permafrost areas is referred to as horsetail drainage. This name is derived from the arrangement of the secondary or tertiary drainage channels more or less parallel to each other in groups which join the next largest drainage channel creating a pattern which resembles a partially open horsetail. Figure 35 ($\overset{I}{H}$) shows a good example of this kind of drainage pattern near Churchill in northern Manitoba.

It is hoped that this short description and explanation of various factors as they pertain to muskeg and relate to sub-surface ice conditions as well as to the airform patterns will offer background for discussion on a hypothesis suggesting a characteristic genesis and development of aerial patterns.

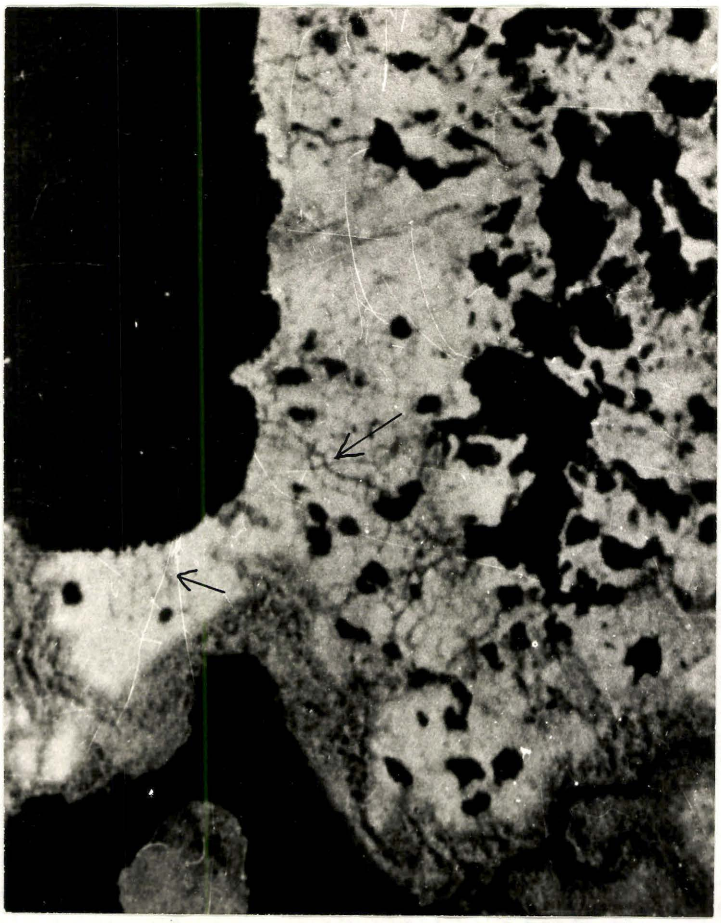


Fig. 60. Ice wedge polygons oriented along the slope to form drainage channels in typical Marbloid near Chesnaye, northern Manitoba. Enlarged from high altitude (30,000') airphoto.

DEVELOPMENT OF THE MARBLOID AIRFORM PATTERN AND DESCRIPTION OF VARIOUS STAGES IN THIS DEVELOPMENT

The strongest argument which justifies the use of the Marbloid airform pattern as an indicator of sub-surface ice conditions is the proposed progression of Marbloid from an initial stage far in the north through various developmental stages into its senescent form near the southern limit of permafrost. Associated with this development is the manner in which it is closely tied to frost phenomena in peat. The existence of this proposed development became evident only after further examination of the phenomena some of which were listed in the introduction and described in detail in the previous section. The pattern development has turned out to be of prime importance in the study of the relationship between airform pattern and sub-surface ice. It also is responsible for the widening of the initial scope of this work to cover many general aspects of paludification which help understand pattern evolution and thus indirectly also the relationship between muskeg pattern and sub-surface ice. This section will deal mainly with the identification and description of the proposed development as the present author has discovered and sees it with various interphases in the developmental trend proposed as encompassing and accounting for the variations in Marbloid pattern. The section following thereafter will deal more with the physical and biological implications and factors affecting this trend.

Assuming that the hypothesis is valid the evidence for the development of Marbloid can be marshalled as follows. The initial stages of the pattern are encountered far in the north where the first traces of paludification can be found. Some of the characteristics of Marbloid appear as far north as the northern parts of Ellesmere Island and in a more characteristic way on other arctic islands, for example, as on Victoria Island where Study Area 1 is located. In these areas Marbloid when it appears in the initial organic terrain is very strongly influenced by the underlying patterned mineral terrain, which is projected into the organic terrain. For instance, Figure 77 shows an initial Marbloid pattern as seen from an altitude of about 2000 feet (600 m) on Victoria Island (N.W.T.).

From this early stage, the development gradually passes through several intermediate stages into the typical Marbloid pattern, of which Figure 35 is a good example as seen from an altitude of about 30,000 feet (9,140 m). This typical Marbloid is most common in the northern part of the zone of discontinuous permafrost as in Areas 2 and 3. South of this region the warmer climate affects the distribution of permafrost and the vegetation on muskeg becomes more luxurious and almost obscures the Marbloid pattern as seen in Figures 90 and 95.

Near the southern limit of permafrost (southern limit of discontinuous permafrost zone), the Marbloid pattern has almost entirely disappeared and only a few of its characteristic features are recognizable from the air photos. Here permanent sub-surface ice is scattered (cf. Figure 99).

Features of Initial Marbloid Arising With Paludification

It is reasoned that the muskeg in Area 1 and along Flight Line 2 is essentially confined because this area has not been free from the ice of the last glaciation long enough for unconfined paludification to occur. Also the climate is still too cold to encourage the strong vegetal growth essential for rapid unconfined paludification. Humidity and geomorphic features here would favour unconfined paludification.

While in most cases the peat deposits here are only a few inches deep, in some areas they attain thicknesses in excess of two feet, especially in large mounds and peat plateaus or small initial palsa formations.

Usually peat starts forming here in locations where free water is available or on saturated ground. These sites are usually either lower than the surrounding areas or they are on gentle slopes where water trickles on the surface and slowly flows down the slopes.

Very commonly paludification here is initiated on the shores of the numerous lakes and ponds which dot the arctic landscape. These lakes are usually shallow so that wave or ice action is not strong enough to hinder the paludification which in the form of slowly growing mats of muskeg vegetation is encroaching on these shallow water bodies. Most of the lake beds have been carved by the ice during the glaciation or are thaw lakes (cf. ref. on page 78, and also Figure 82). There is a tendency for the thaw lakes to move when the temperature differentials between opposite shores cause temporary recession of permafrost on one shore. This causes the ground to settle enabling the water in the lake to fill the resulting depression. The settlement may even open a new drainage channel and the whole lake may slowly empty (Figure 82). This emptying or moving of a thaw lake often causes the opposite shore to emerge from the water. If this happens slowly enough, the ample amount of water and well saturated ground starts to paludify and helps the formation of muskeg on and over the lakes. Figure 82 shows a good example of this phenomenon in the typical Marbloid condition. Here the emptied thaw lakes have been entirely covered by organic terrain. Figures 61 and 62 are examples of how muskeg is beginning to invade shallow ponds in the Cambridge Bay area on Victoria Island, N.W.T. (Area 1).

Figure 61 shows active paludification in a pond by semi-aquatic plants (mostly sedges) which are growing in the shallow water and may be covered, during spring floods, by water for short periods of time. This can occur in the centre of the pond where the shallow peat deposits hardly reach above the surface of the water even during the interval when there is no flooding. This type of paludification is sometimes called telmatic paludification, which means that the peat is formed in locations which are sometimes covered by water and sometimes stay relatively dry (Kivinen 1948; Lukkala and Kotilainen 1951). Peat formed this way characteristically contains many remains of sedges in addition to Sphagnum and to some extent, at least in North America, remnants of shrubs (E-class). The latter, however, are not so common in telmatic conditions in northern Europe.

Figure 61 is an example of progressive paludification on Victoria Island showing that the effect of the pond ice on peat along the shore is almost negligible. This is evidenced by the sloping edges of the initial peat mat or peat plateau in both the background and in the foreground, as well as by the vegetation invading the shallow water in the centre of the pond. The early formation of mounds in the foreground is also apparent.

Figure 62 shows a more advanced state of paludification than that in the previous figure. Here the physical effect of the ice on the edges of the peat layers beside the pond is evident. The ice has thrust or broken the edges of the peat plateaus into steep slopes as contrasted

Fig. 61. Initial muskeg being formed by filling up of a pond in Cambridge Bay, Victoria Island, N.W.T. Note the sloping pond edge and loose FI vegetation in the water.

Fig. 62. Initial muskeg in Cambridge Bay, Victoria Island, N.W.T. Dominating cover is FI. In the foreground there is a silty mound of mineral terrain, which is either the centre of an uncovered soil circle or a frost boil which has pierced the shallow peat layer.

with the condition in Figure 61. Peat deposits here are also thicker, reaching up to 1 to 1.5 feet in thickness. The advance of the peat into the pond is slower than in the location shown in Figure 61. It does take place, however, as the muskeg vegetation growing in the water in the background shows. The longitudinal furrows in the peat plateau on the left and also the silty frost boil in the foreground piercing the peat layer are indications of frost activity in the peat and in the underlying mineral terrain.

The confined peat areas shown in Figures 61 and 62 are initial stages of future larger peat deposits and also signify the presence of early Marbloid pattern.

Paludification in the Arctic is initiated directly on mineral terrain if it is saturated. These conditions almost always exist mainly because the permanently frozen ground keeps the water largely on the surface. Paludification taking place on the ground which is above the surfaces of water bodies is called "terrestic" (Lukkala and Kotilainen 1951). It also is called primary paludification when it takes place on the mineral terrain which paludifies directly after emerging from the water as happens on the western coast of Finland, in the Canadian Arctic, and along Hudson Bay. In these areas the land is still emerging from the sea as the crust of the earth assumes its equilibrium following the recession of the heavy masses of continental ice.

The paludification of mineral terrain takes place

Fig. 63. Initial paludification on a gentle slope in Cambridge Bay, Victoria Island, N.W.T.

Fig. 64. Shallow depression under paludification in Cambridge Bay, Victoria Island, N.W.T. Note how paludification proceeds along the shallow depression on the slope in the background.

mostly on gentle slopes and flat areas which are readily saturated in the spring when the snow thaws, and later in the summer by precipitation, and finally by the water slowly released from the thawing of the active layer of permafrost. In Area 1 the frost may recede about 12 to 15 inches into the peat.

Figures 63 and 64 are examples of shallow depressions which have paludified due to trickles of water running slowly through them. Figure 64 also reveals how paludification may fill small depressions higher on the slope (on the right in the figure) and then spill the excess water over the edge to enhance paludification down the gradient (on the left in Figure; cf. also Figure 65). When the peat deposits become deeper, the muskeg will spread over the mineral terrain around it and if conditions are favourable an unconfined muskeg may be formed. Figure 64 shows how the initial muskeg on Victoria Island may cover fairly large areas and how it is encroaching relentlessly on new areas like the narrow channel-like depression on the gentle slope in the centre of the background. This channel, when the development of Marbloid pattern has reached its maturity (cf. Figure 35), probably will represent a shallow FI (sedge-Sphagnum spp.) drainage channel (cf. Figure 38).

Figure 66 shows clearly from low altitude (2000 feet) the advance of paludification along the slopes in the manner described. Here one can also discern Microreticuloid pattern

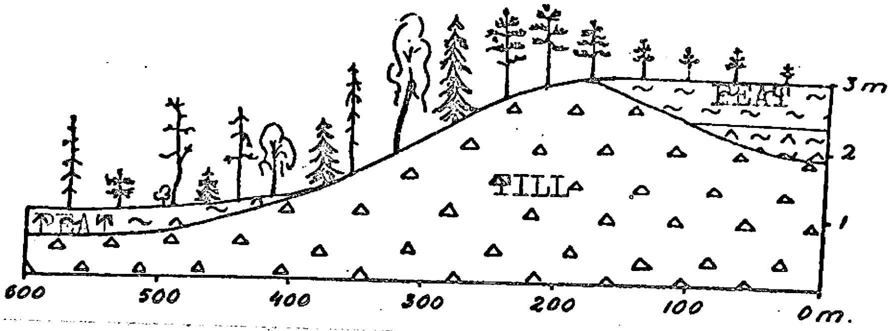


Fig. 65. When muskeg on the right on top of the hill becomes deep enough it begins to spill excess water over the ridge in the centre. The slope and lower ground on the left will begin to paludify as has happened on the left already. Impervious till helps keep the ground saturated and enhances paludification. This process is observable in Study Area 1 (cf. Figure 63). (Diagram after Kivinen 1948).

which is common in permafrost areas, especially in the initial permafrost areas. Outside the permafrost zone it is fairly common, especially on raised bogs where it is in the form of concentric ridges called "kermis", which appear in areas of ombrogenic paludification.

The third main location for the initiation of muskeg in arctic areas is the depressions among sorted circles, steps and soil stripes, ice wedge polygons, and sometimes in the centre of sorted circles when the coarse material around them is too coarse for vegetation and also higher than the centres (Figure 52).

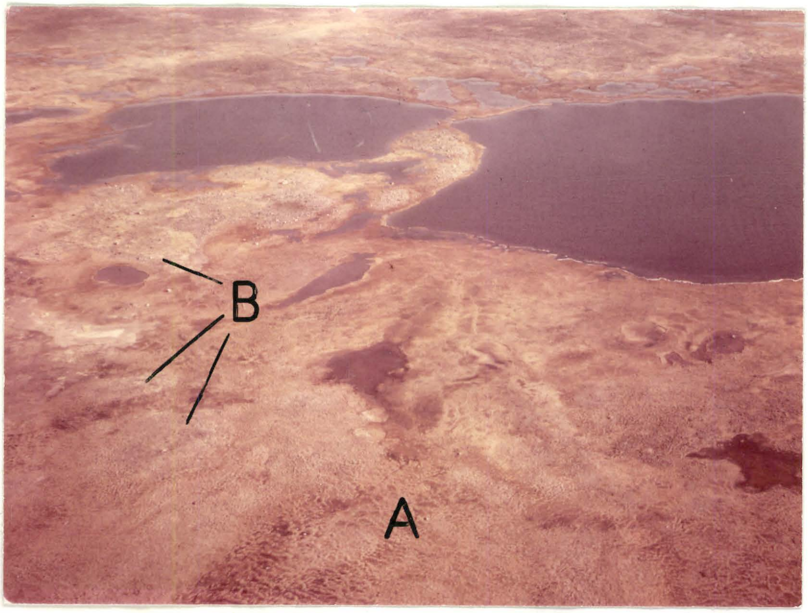
These kinds of depressions contain a significant amount of water which often runs slowly, carrying nutriment. They favour muskeg formation more than the surrounding high microtopographic locations. Figure 50 shows initiation of muskeg in the fissures among sorted circles on Victoria Island, N.W.T. In this case the fissures have been filled with a thin layer of peat and it is only a question of time until the peat deposits will spread over the centres of the circles and form a continuous mat of organic terrain. The marked frost activity in the silty fines of the centres of the circles in many cases may hinder paludification for longer periods and may even break the already existing peat mat as in the foreground of Figure 62. Here a silty frost boil indicates the possible existence of a circle covered by peat.

Fig. 66. Low altitude (1500') oblique view of initial muskeg on gently sloping hillside in Kent Peninsula, N.W.T. Note Microreticuloid pattern (A) and initial peat plateaus (B) with lichens (H-factor).

Fig. 67. Low altitude (2000') oblique view of initial Marbloid pattern in Victoria Island, N.W.T.

A - depressed centre polygons covered almost totally with peat.

B - channel type polygons partially covered with peat.


B
A

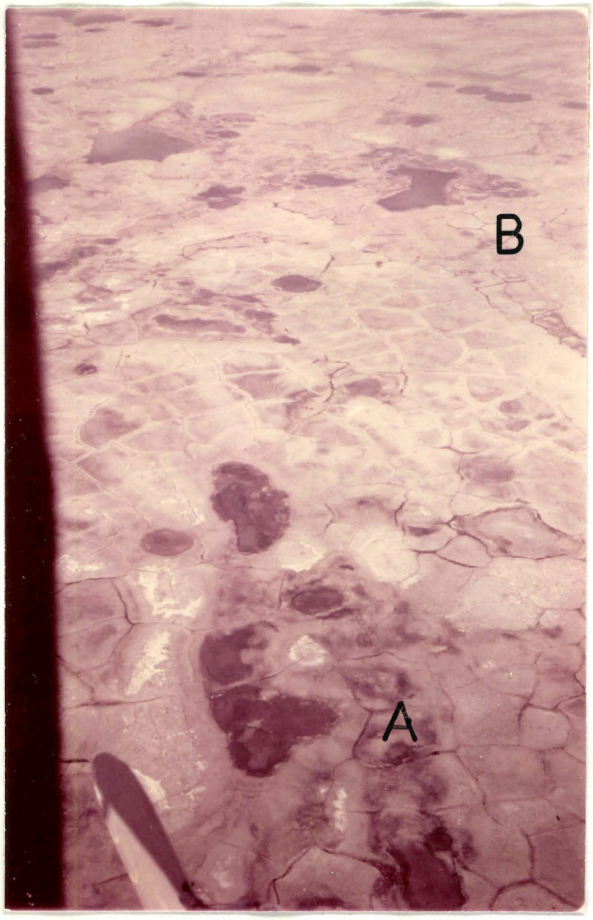

B
A

Figure 52 is an example of a reversed situation as compared with that in Figure 50. In this case the peat has started forming at the centre of a sorted circle. The coarse soil near the edge of the circle will not support any muskeg vegetation. Also it is higher than the centre and thus more susceptible to adverse climatic conditions.

The fissures between the raised centres of ice wedge polygons (Washburn 1956) also offer good locations for initial paludification in the arctic regions. Figure 67 shows both types of polygons undergoing initial paludification on Victoria Island as seen from an altitude of about 2000 feet. In the foreground the centres of some depressed centre polygons have been covered by a shallow deposit of peat which appears flecked due to the hummocky growth of peat. This feature is common in areas with sub-surface ice as will be seen later. In the background of this figure, there are also a few channel type polygons under the influence of paludification, but here only the fissures between polygons contain peat; the centres are still quite bare. Figure 68 shows the spreading of organic terrain from between sorted steps in the foreground in the flatter and featureless slope into a less confined muskeg area. In the former location the mineral sub-layer formations are projected into the organic material while in the latter area frost and ice activity will form and indeed already has formed mounds. These mounds resemble the mounds and "elongated

Fig. 68. Initial paludification on sorted steps in the form of hummocks and tussocks. Note how paludification is concentrated in depressions. Cambridge Bay, Victoria Island, N.W.T.

Fig. 69. Poorly drained initial muskeg in Cambridge Bay, Victoria Island, N.W.T. Note how muskeg in this case is formed mainly by hummocks.

mounds" (ridges) formed by the transgression of the contours of patterned mineral layers into the peat.

General Features Caused by Transgression of Mineral Soil Patterns Into Peat Deposits

The previous pages have given explanations and descriptions related to the main microlocalities where muskeg is initiated in the arctic study areas. The following pages will describe some of the features, for example, mounds, and tussocks*, and their relation to the underlying mineral soil patterns such as sorted circles, steps, stripes, and polygons and the general features of their transgression into peat.

The forms in which the peat grows in the arctic study areas are strongly affected by the growth habit of plants such as tussock growth, and by the pattern of the underlying mineral soil. Not only does the pattern create suitable microlocation for peat to begin its formation, but also the pattern of the mineral terrain transgresses into the overlying peat.

Figure 69 is a good example of a hummocky growth assemblages associated with peat deposition in the Arctic.

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*Radforth (1955b) in differentiating between mounds and hummocks avoids the expression tussock by incorporating it under hummock on the basis that it signifies the same form relationships as tussock. The writer uses tussock in a genetic sense and retains it.

This form is common but is commonest in certain conditions in arctic muskeg. This hummocky development is attained mainly through the action of ice. A small patch of Sphagnum may have initially insulated the ground and through regelation started development of an earth mound with an ever thickening deposit of peat on it. An example of this hummocky type of peat area is shown in Figure 69 and is referred to in Finland as 'pounikko'. It occurs very commonly in northern Finland in regions having very sporadic permafrost or at least frost which occasionally survives through one or two summers (Ruuhijärvi, 1960). According to Ruuhijärvi, formation of hummocks having a permanently frozen mineral soil core can be explained only by regelation, that is, through the action of repeated thawing and freezing.

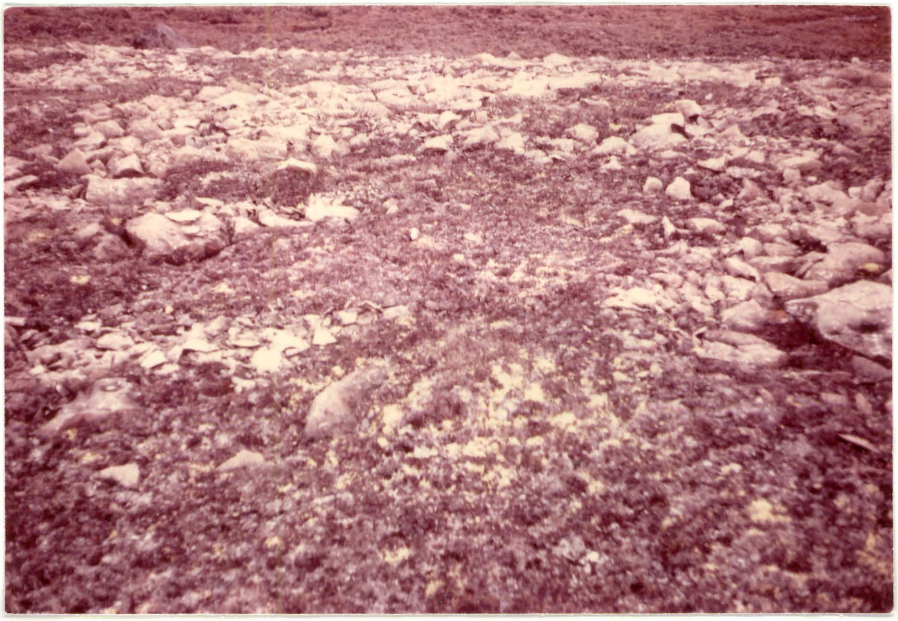
These hummocks ('pounu') formations appear most commonly on slight slopes where the surface water trickles slowly down, or on flat featureless expanses which are saturated as in Figure 69 (slope) and 70 (background flat area).

In the background of Figure 70 appears, in an advanced state of development, a peat plateau originating from separate pounu formations which have become contiguous.

In the foreground is the sequel to the condition shown in Figure 68. Here one can see that also in the shallow areas between sorted steps there are hummocks which, by increasing in size, become contiguous and first fill the fissures with mounded peat, then spread over the centres, and

Fig. .70. Initial peat plateaus being formed by coalescence of peat mounds at Cambridge Bay, Victoria Island, N.W.T. Note marked H-factor on initial peat plateaus (yellow to white in colour).

Fig. 71. Initial transgression of sorted steps into peat and appearance of H-factor (lichens) on peat as revealed by yellow colour in the foreground. Cambridge Bay, Victoria Island, N.W.T.



finally cover them with mounded peat as in the foreground of Figure 70. Here outlines of steps are still visible through the peat where some hummocks and tussocks have lost their identity and produce mounds which no longer conform to the contours in the underlying mineral terrain, the sorted steps. This photo also shows how these two formations join each other gradually to form a peat plateau with characteristic features varying from the background hummocky appearance into the mounded condition of the foreground. It also shows how these microtopographic features may symbolize by implication the topography of the underlying mineral terrain.

The pounikko formation is more common on areas with slightly better drainage than on areas with fairly uniform FI type muskeg which is often formed by overgrowth of ponds.

Reference was made to Figures 50, 51 and 52, among others, when the possible locations and modes of initiation of paludification in Area 1 were explained. All these figures show too the initiation of the development of peat in the areas with patterned mineral soil. Figure 79 shows how sorted steps in the far north may be invaded by peat and how these features transgress into the peat. Figure 71 shows in addition that sometimes this transgression may start in the centres of the circles and gradually cover them, resulting in the incorporation of this feature into the overlying peat. Further evidence of this is given in Figure 62 where there is a silty frost boil in the foreground indicating the presence of a covered sorted circle in the underlying mineral terrain. Either this circle was so elevated that it still has not been covered fully like others in the vicinity, or the frost activity in the silty centre has been so strong that it has disrupted the existing shallow deposit of peat.

Frequently, the circles, steps and stripes, after contributing to peat microtopography, maintain their identity until the late stages of development of Marbloid arise.

Figure 72 reveals how peat covers steps and how the original sorted pattern form deteriorates due to the covering peat mat in the course of change to muskeg.

The polygons or at least certain elements of polygonal formations offer favourable sites for the initiation of muskeg. The polygons also extend into overgrowing peat deposits. This transgression starts very early. Figure 73, taken on Ellesmere Island at its northern end near the permanent ice cap, shows polygons of mineral terrain and their gradual transgression into the peat. The polygons of the slope in the background, as well as those in the near foreground, are still devoid of peat. In the centre they have been invaded by a thin but not always continuous layer of peat, which shows "pounikko" type growth, initiated by small frozen earth mounds like those in the background on the slope. One can see how some of the polygons of the bare

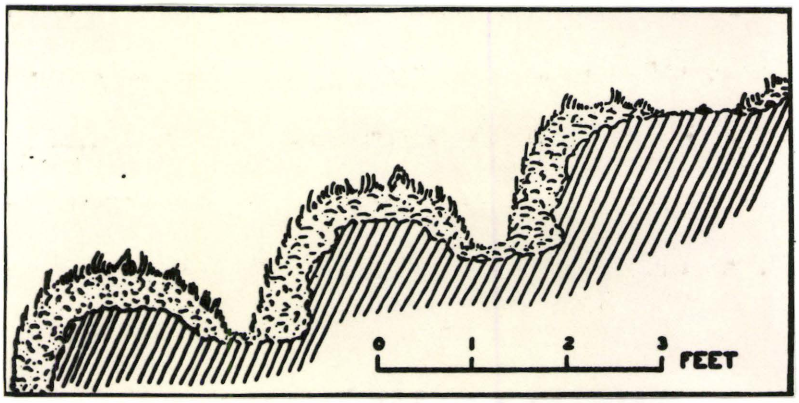
Fig. 72. Diagram of earth mounds (on the left) and nonsorted step (on the right) after Sharp 1942. These earth hummocks represent the hummocks of initial muskeg in Figure 69 where most of the peat is on top of the hummock. The step is representative of the conditions in Figure 68. Peat has not covered it totally yet. This shows how an originally sorted step of mineral terrain becomes non-sorted when it acquires a peat cover which camouflages the sorted appearance of the underlying mineral terrain.

Fig. 73. Polygons being transgressed into initial muskeg in Ellesmere Island, N.W.T.

A = bare mineral terrain with polygons.

B = polygon partially covered with peat.

C = polygons covered with a thin virtually continuous peat deposit.


0
1
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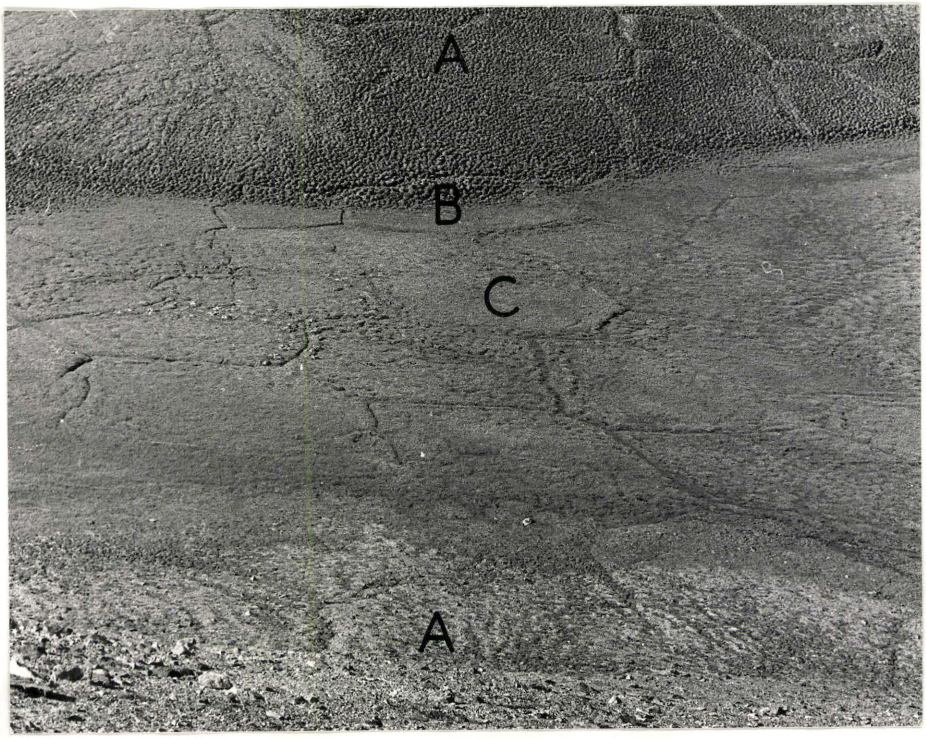

A
B
C
A

mineral terrain continue without interruption into the peat-covered area and are clearly apparent in the peat.

Figure 77 shows a low altitude view over a polygonal area on Victoria Island. It reveals how the shallow deposits of peat covering the almost fully depressed centres of the polygons in the foreground have been transgressed by these configurations. In the centre of the photo some polygons with raised centres are only partially covered by peat.

Polygons also may arise in the peat itself when the depth of deposits is great enough. Figure 74 and 109 show a polygon formed in the peat in a location where the depth of peat is about six to twelve inches and three to four feet respectively. The depth of the deposit is sufficient to encourage drying. A peat plateau is in the process of being formed. The typical cover of small shrubs and lichen (HE) is predominating here.

Figure 75 shows a relatively deep peat deposit in which a set of polygons has formed. This area is, however, more confined than that in Figure 74. The peat is about one to two feet thick. It is apparent that the raw peat is exposed in the fissure between two polygons implying possible contraction in the frozen peat resulting in splitting of the peat deposit. The typical HE cover of Marbloid is obvious especially on the polygons of Figure 75.

Earlier in the account, it was indicated that peat,

Fig. 74. Large ice wedge polygons being formed in the peat of initial muskeg, Cambridge Bay, Victoria Island, N.W.T.

Fig. 75. Polygon under development in a relatively deep initial peat deposit in Cambridge Bay, Victoria Island, N.W.T.

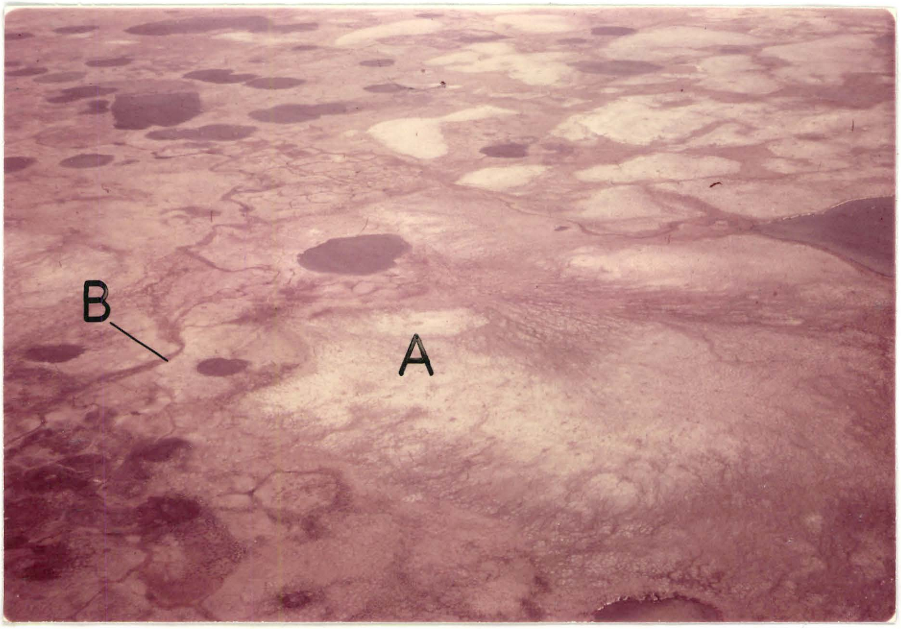
in its initial stage, often exhibits a hummocky appearance. It is evident also that mounds are formed where there is no clear mineral soil pattern as a foundation or where there are no tussocks or hummock ("pounu") features. In these terms small mounds appear as shown in Figure 76. This figure indicates initial paludification of a shallow pond by muskeg vegetation. The mounds are due to differential growth of various components of the muskeg vegetation. Certain sedges, which thrive well in a moist environment, grow in an uneven formation and form clusters of vegetation. The clusters, at higher elevation than the surrounding background, support vegetation which consists of species requiring slightly drier conditions for growth. They accumulate and a small mound begins its development. This mound usually persists and develops quickly. Sphagnum fuscum and other species, which favour relatively dry conditions, are very common in these mounds. The hollows between the mounds are often invaded by Sphagnum cuspidatum which favours wet conditions. However, the mounds acquire other plants like shrubs, grow larger, join each other, and soon may form ridges (Fig. 112) or large extensive areas with mounds and intervening spaces with shallow wet hollows (Fig. 64). These later form major components of the Marbloid peat plateaus.

Fig. 76. Initial muskeg in Cambridge Bay, Victoria Island, N.W.T., showing initial peat ridges, hummocks, tussocks and peat mounds.

Fig. 77. Low altitude (2000') oblique view of initial Marbloid in Victoria Island, N.W.T.

A - initial peat plateau.

B - future drainage channel of Marbloid comparable with those of typical Marbloid, cf. Figure 35 (F).


B
A

The Main Cover Classes of the Early Marbloid Condition

As Figures 61 to 64 reveal, the most common cover in large areas is FI, basically sedges and mosses. In the FI cover there are patches of EFI. The "pounikko" areas display FI and sometimes EFI cover in small hollows. The E component consists of small arctic shrubs. However, E class does not have the same significance in the formation of peaty overburden as in areas of typical Marbloid where E is quite strong and becomes prominent as a constituent of the peat. Frequently the initial cover of certain sorted circles is composed of the classes E and H which form very low vegetation as Figure 71 shows. E is often composed of small arctic creeping willows and short ericaceous shrubs or other shrub-like plants (Cassiope, Dryas, etc.).

The cover on the mounds and on young peat plateaus is very often almost the same as on the typical Marbloid, dominantly EH or HE. Figures 74, and 75 show this cover on polygons formed in peat on Victoria Island. It is apparent also on smaller mounds as Figure 70 reveals. Here H appears as yellow-coloured patches on the highest mounds. However, the H-factor (lichen) is not yet so marked as to impart the typical light tone which is a characteristic feature of the areas of typical Marbloid.

Contrast Between Typical and Initial Marbloid Features

1. The General Marbloid Appearance of Organic Terrain in the Arctic Area

The questions which arise now are how does the initial muskeg forming Marbloid arise and how does it compare with typical Marbloid described earlier.

The initial organic terrain in Area 1 has many features which on the ground are identical to those of muskeg which displays a typical Marbloid pattern. These features, when seen from the air, convey the appearance of the first stages of the Marbloid condition. Low altitude views especially bear many resemblances to Marbloid, but careful inspection is necessary to reveal the same resemblance from a high altitude view.

Figures 67, 77, 78, 80 and 81 are examples of low altitude views over initial muskeg in Area 1 and along Flight Line 2 giving indications of the developmental trend towards Marbloid. These photos were taken at an altitude of about 2000 feet (600 m). Figure 85 is a high altitude stereo pair of the general area revealing a few features which imply the existence of a trend toward a Marbloid condition.

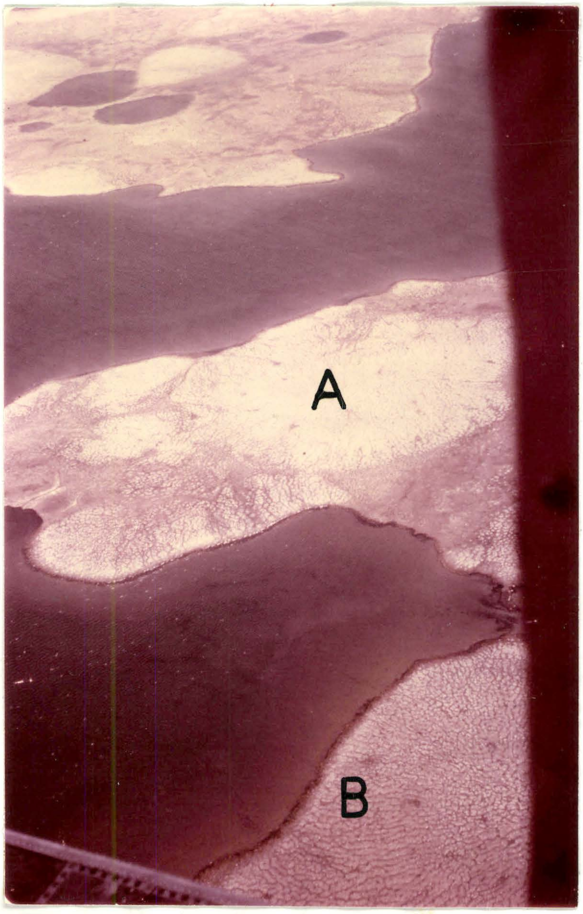
Figure 67 gives an overall view of quite a typical marble-like condition on Flight Line 2. Most of the ground here has an intermittent overburden of shallow peat. The light tone in the higher areas is derived from the fines in the centres of sorted circles, sorted steps and other related patterns, rather than by the H-factor of the typical Marbloid. Figure 77 gives another general view of polygons many of which have been invaded by a shallow deposit of muskeg.

How do these views and their details, as seen from the air and on the ground, compare with the features of the typical Marbloid as seen in Figure 35.

In the general view of Figure 77, elevated, light toned areas on the right side of the figure represent the future peat plateaus comparable to those in Figure 35, (cf. letter (A)). They are also identical to the plateaus of Figure 103 (A). The light tone of Figure 77 in the high areas, in most cases, results from the high albedo of the silty fines located in the centres of the sorted circles and steps which abound on these elevated areas, rather than from the H-factor in the typical or near typical Marbloid of Figures 35 and 103 respectively. A close inspection of the hillocks of Figure 77 shows that the peat is invading them along the fissures between circles and steps as seen, for instance, in Figures 50, 51 and 68. The lower lying areas among the hillocks are saturated and more extensively peat covered. These areas show more polygons and fewer other patterns, especially in Figure 67, and will be eventually incorporated into the large peat plateaus of Figure 35(B) when the peat deposits are more extensive. Figure 103

Fig. 78. Low altitude (2000') view of areas with initial muskeg (magenta in colour) near Cambridge Bay, Victoria Island, N.W.T. Note high albedo of the fines (A) in the centres of sorted circles which have concentrated to the tops of hillocks and of sorted steps (B) on the slopes. Initial muskeg has invaded depressions between these patterns and shows in this figure as magenta in colour.

Fig. 79. Marbloid peat plateau at a relatively deep thaw lake where wave action hinders paludification in the water. Northern Manitoba.


A
B

is an intermediate stage in this direction so that the large peat plateaus (B) have not yet joined as completely as in Figure 35, but show large reticuloid (C) or Microreticuloid (D) spaces between them. Sometimes these Microreticuloid patterns appear (without stereoglasses) as Dermatoid areas (Figure 103).

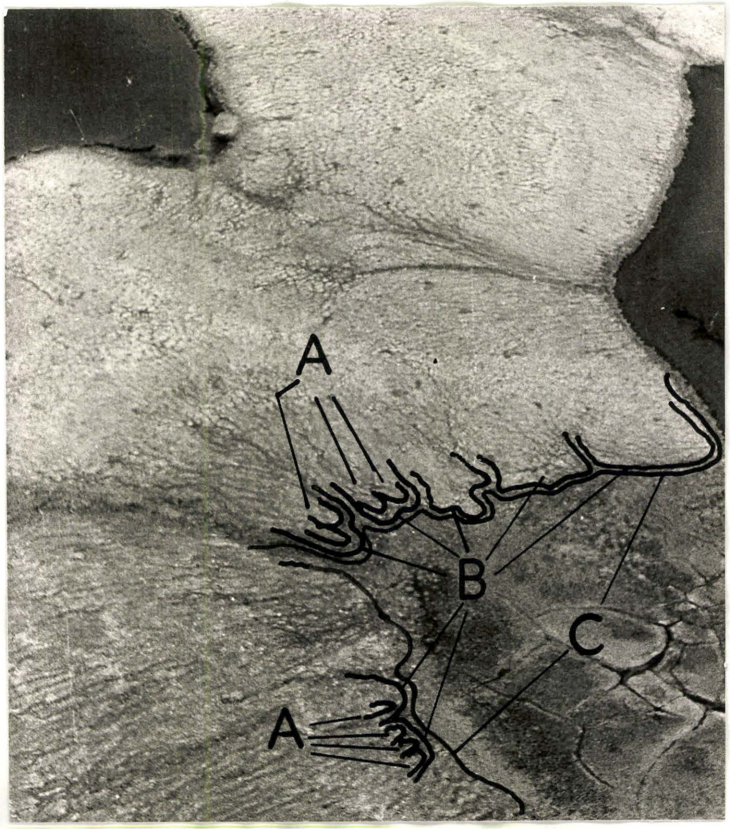
The smaller features also form features comparable to those in the typical Marbloid condition. Thus, for instance, Figure 78 showing a typical patterned hillock from low altitude shows the invasion of peat on flatter areas in wide belts and on slopes in narrower ones. The purplish coloured areas (purple because of inadequate colour control in the print processing) are covered by an almost continuous peat layer which sends branches up the slope. This photo shows a developing peat plateau by a relatively deep lake, which probably will remain open when the muskeg is well-developed and the peat plateau will appear as a steeply sloped shore of this lake. This condition is well revealed by a high steep peat plateau rising from a lake in the areas of typical Marbloid such as that shown in Figure 79. It shows a peat plateau which has developed on a site similar to that shown in Figure 78. The peat plateau in Figure 79 did not have an opportunity to spread over the water, the depth of which has facilitated strong wave and ice action on the edge of the peat plateau thereby keeping it steep.

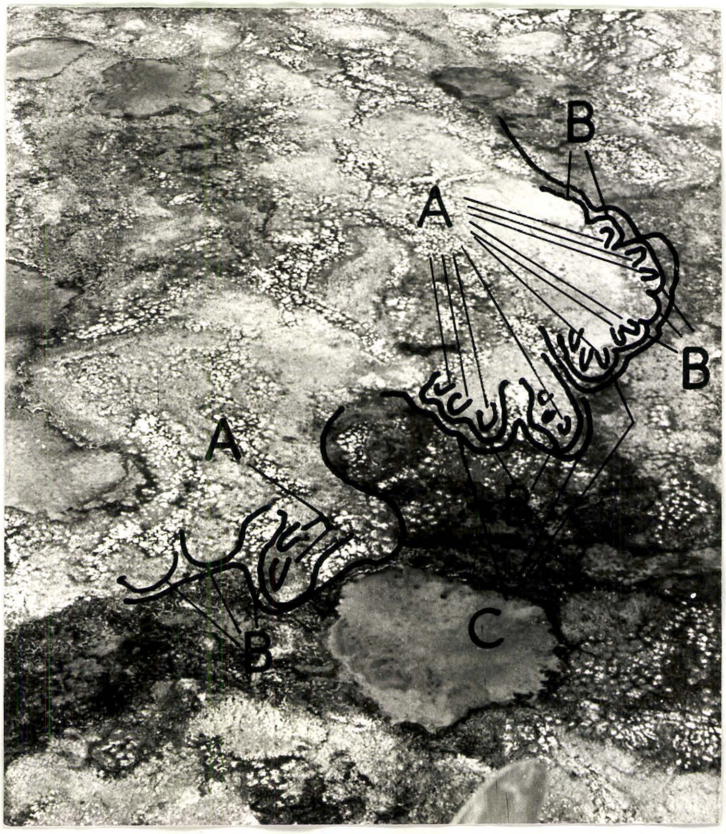
Fig. 80. Low altitude (2000') oblique view of initial Marbloid on Victoria Island, N.W.T. showing the concentration of sorted circles on top of the hill and sorted steps on the slopes. Initial muskeg still occurs mainly in the trenches between circles and steps. Only the area with polygons in the lower right corner of the figure has virtually continuous peat cover.

A - future peat plateau lobe size order 1.
B - future peat plateau lobe size order 2.
C - future peat plateau lobe size order 3.

Fig. 81. Low altitude (2000') oblique view of initial muskeg on King William Island, N.W.T. Initial Marbloid features recognizable as follows:

A - Marbloid peat plateau lobe size order 1.
B - Marbloid peat plateau lobe size order 2.
C - Marbloid peat plateau lobe size order 3.


A
B
C
A


B
A
B
A
B
C

Figures 80 and 81, on the other hand, show the spreading of peat on shallow ponds as well as over mineral terrain. These figures compare favourably with Figure 35 and 103 in this respect. Thus, the areas in Figures 80 and 81 marked with (A) are early representatives of the large lobes of peat plateaus of the typical Marbloid condition in Figure 35 (letter C) and letter(E)in Figure 103. The next order of lobe size of the lobes (B) in the initial peat plateaus represents the young degree of size in the typical Marbloid (D) in Figure 35 and(F)in Figure 103. The third order of the initial Marbloid plateau, (C) is comparable with (E) in the typical Marbloid of Figure 35 and(G)in Figure 103. These figures suggest that the mineral terrain pattern often has a strong influence on the later morphology of the Marbloid pattern. This will become especially clear in connection with the comparison of these stages of Marbloid development with the senescent stages of Marbloid.

2. Drainage Channels

Drainage channels that give a characteristic impression in typical Marbloid are the narrow channels formed by the widening of the fissures in the polygons under the influence of gently running water. These channels are oriented often along the slope as seen in Figures 35 and 60 and as marked with the letter (H) and arrows respectively. These channels are derived from the original polygons projected into the peat during the initiation of paludification as found now in the north (Figure 73). Their further development is sometimes responsible for the formation of rectangular streams (Figure 58).

Some of the larger channels have been derived probably from the larger ones of the type seen in the centre of Figure 77. This would correspond to the channel seen in Figure 37 in the typical Marbloid or one marked with the letter (F) in Figure 35.

Shallow FI drainage channels are either widened channels arising between polygons or derived from shallow paludified depressions of the type seen in the centre of the background of Figure 63. This would correspond to the channel seen in Figure 38 from Chesnaye area in northern Manitoba or to the channel (G) in Figure 35.

In any case the direct derivation of the drainage channels from channels in the initial muskeg is not usually discernible because of the great changes in the development of the drainage features in general and because of so many variables affecting their development. One can assume, however, as a result of the above comparison that certain types of drainage configuration in the initial muskeg lead to recognized features in the typical Marbloid not only directly but by succession through several steps.

3. Thaw Lakes and Ponds

The numerous thaw lakes form a feature which is very typical in both the initial and typical Marbloid condition. The major difference between the appearance of the lakes in the two cases is that the edges of peat plateaus in the initial muskeg areas are mostly sloping because the peat deposits are not very thick. In the typical Marbloid, the sloping pond and lake margins are also common and quite often imply paludification of the lakes by overgrowth (Figure 44). Steep pond margins are more frequent here than further north (Figure 45). The same condition prevails farther north as shown in Figure 79. The thaw lakes tend to migrate because of the differential temperatures in their immediate vicinity and/or due to tilting action of the emergence of the land from the sea. This migration is not very apparent in the initial muskeg areas where the peat deposits are intermittent and thin. If a thaw lake does empty suddenly because of tilt there will not be marked telltale depressions revealing its previous position because of incomplete peat deposits. In typical Marbloid on the other hand, emptying is often revealed by regular depressions in well developed, relatively thick peat deposits. Thus, Figure 82 reveals a set of thaw lakes in Marbloid country which have drained at various times (A) or which are still being emptied by new drainage channels (B) or which have emptied only partially (C) or which are threatened with this

Fig. 82. High altitude (30,000') vertical stereopair near Area 2 showing thaw lakes in different stages of development.

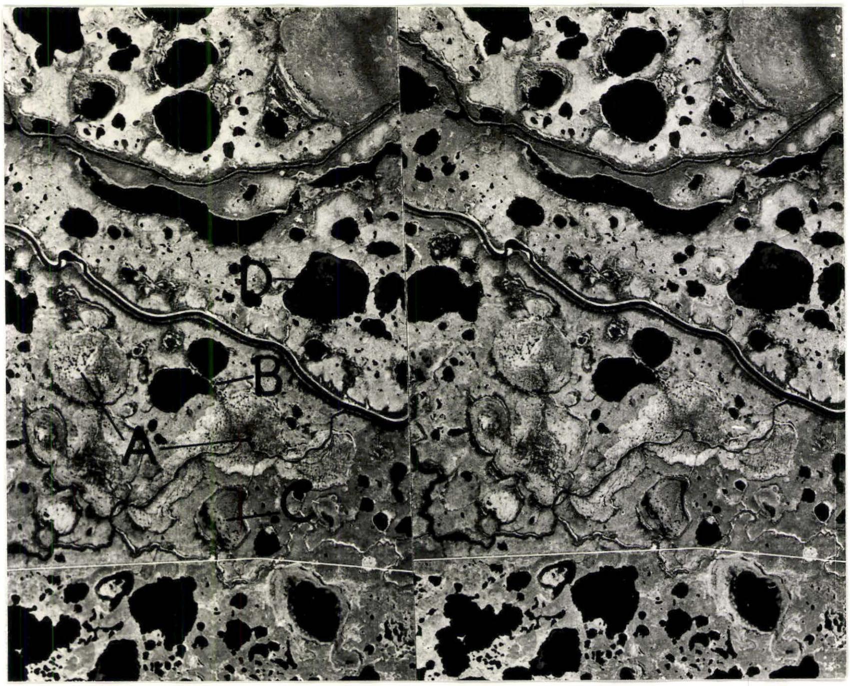
A - empty thaw lakes of various ages.

B - thaw lake being drained.

C - partially emptied thaw lake.

D - thaw lake which will empty if permafrost undergoes further regression.

Fig. 83. Markedly eroded trench between ice wedge polygons serving as a drainage channel in young Marbloid area, Ennadai, N.W.T.


D
B
A
C

fate if the permafrost retreats locally (D). The empty thaw lakes which have had some time to paludify have usually developed DFI cover mainly due to the high water regime in them caused by their low position in the landscape.

4. Comparison of Cover Formulae in Relation to Initial and Typical Marbloid

The major difference between the cover classes of initial Marbloid and typical Marbloid is the smaller variety of cover in the former as compared with the latter. The major cover formula in the initial muskeg area is FI, even on fairly well developed peat plateaus. This formula plays only a secondary role in the cover of the typical Marbloid. It appears there mainly along drainage channels (Figures 36 and 37). Occasionally it may cover fairly large areas in the locations where polygons with depressed centres appear (Figure 41).

In the initial muskeg areas, EFI and FEI formulae are fairly common. These appear on typical Marbloid only to a limited extent along the edges of peat plateaus. The cover formed by lichens and small shrubs as a main constituent, EH or HE, appears on the best developed initial peat plateaus as in the location shown by Figures 70, 74 and 75. In typical Marbloid this cover is the predominant one. It is the most visibly striking and gives the light tone which contributes so noticeably to its marbled appearance.

Cover formulae which are quite common in the typical Marbloid but which do not occur in the initial muskeg Area 1, for example, are those with trees, AEI and, more often, BEI and BEH. They are missing from the initial muskeg areas for the reason that the climate is too severe for tree growth. Cover with larger bushes, for example willows, (D class), appears only farther south where typical Marbloid becomes common. This formula appears earlier than those with trees (Figures 79 and 83).

Thus the difference in the cover between the initial muskeg and the typical Marbloid reflects the amelioration of the climate and other environmental conditions along with the more vigorous paludification and faster development of Marbloid.

5. Comparison of Transgressed Mineral Soil Patterns in Initial and Typical Marbloid

The typical features like non-sorted circles, steps and stripes and polygons observed from the ground in the initial muskeg areas are not always easily recognized in the high altitude photos. Polygons can be seen under close inspection of a stereopair with stereoglasses. In Figure 85 polygons are in evidence although their detection in this case is difficult due to the bad photographic conditions at the time of photography. On the other hand, in Figure 35, from a typical Marbloid area, they are easily observed in great numbers. From lower altitudes the smaller features are fairly easy to detect and they show clear-cut evidence of the developmental trend of Marbloid.

In the typical Marbloid the polygons on the peat plateau seem to be oriented along the slope quite often as seen in Figure 35. This orientation is not often observable in the initial Marbloid. The orientation may lead through enhanced erosion to the formation of small drainage channels in the Marbloid. Figure 83 shows a very clearly developed polygonal drainage channel with FI and EFI cover in it. This kind of channel in older Marbloid further south may develop into a beaded stream. Figure 59 is a high altitude view of this kind of development.

Also the polygonal fissures, when oriented, may not be in a direct line but form sudden bends and this can result in an angular stream like the one shown in Figure 58.

6. Comparison of a High Altitude View of Initial Marbloid With that of Typical Marbloid

Figure 85 is a stereopair of the initial Marbloid as it is seen from an altitude of about 30,000 feet (9140 m) on Victoria Island. It does not have the obvious light tone as the typical Marbloid condition does due to the fact that the muskeg has not developed to that degree yet and the typical Marbloid cover EH or HE is still quite limited in amount as is indeed the entire peat area. This figure compares well with Figure 84, which is also a high altitude stereopair. It is from a point just north of the southern limit of the zone of continuous permafrost in northern Manitoba in an area where typical Marbloid is just beginning to appear very prominently. In this figure the small round formations marked with the letter (A) represent palsa-formation. They are large peat mounds with frozen peat or, in some cases, frozen mineral soil cores. These formations have been first described as occurring in northern Finland where they are quite a common sight in the areas with discontinuous permafrost. There they may attain heights of over 7 meters and widths of over 200 meters (Ruuhijärvi 1960). In the case of Figure 84, these formations are truly palsas since they demonstrate peat cover. Only field study would reveal whether they have peat or mineral soil cores and quite probably there are both types in this location. In this area the smallest ones which are distinctly recognizable from high altitudes are only about 10 meters in diameter. The largest ones still recognizable as separate individual palsas are up to 300 meters (1,000 feet) wide. The small palsas here appear to be undergoing formation and increasing in size. When several of them coalesce they form groups which gradually widen towards the lower edge of the figure and form lobes of typical Marbloid plateaus and finally entire plateaus (B, C and D). The amplitude of height was not measurable with a pocket stereomicrometer because

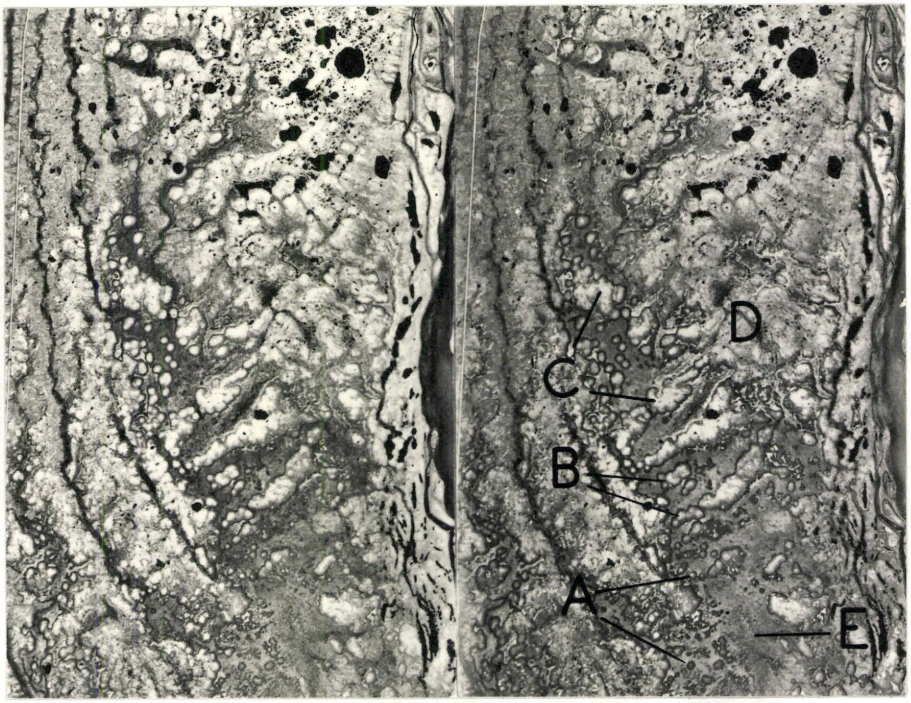


Fig. 84. High altitude (30,000') vertical stereopair showing formation of Marbloid peat plateaus by coalescing palsas in Area 2, northern Manitoba.

A - unattached palsas.
B - a group of contiguous palsas.
C - initial confined peat plateau formed by coalesced palsas.
D - mature Marbloid peat plateau formed by coalesced palsas.
E - Microreticuloid pattern localized in FI areas.

its accuracy is less than the attainable accuracy of 2 per mille (2 $^{o}/oo$) of the photographic altitude (for an accurate height measurement use of a stereoplotter was not obtainable and even then the results could deviate ±2 meters or about 25 per cent from the probable maximum height of a palsa). These formations have HE as major cover. The spaces between them are identified with FI, EFI, and DFI cover and show locally small areas of microreticuloid pattern (E).

The pattern in Figure 85 corresponds well in main features with that shown in Figure 84. The extensive light areas are still mainly devoid of a continuous peat layer. The light tone there is still imparted by the fine mineral material located in the centres of sorted circles and steps, etc. Some of the light toned areas here are hills too high to become paludified except if the climate should be favourable enough for ombrogenic paludification as in Areas 17 to 19. The low dark-toned area is already paludified as are the smaller light-toned areas within it. There is a number of small palsa-like formations here (A) comparable with those in Figure 84 (A). They have a peat cover but the cover formulae are mostly FI or EFI on the low ones as they were on the smallest ones in Figure 84. Here, only the larger palsa formations have enough H cover to render a light tone (B). There is also some amalgamation of a few palsas here to imply the possible initiation of a Marbloid peat plateau

(C). Although ground checks were not carried out in this location, from the short time available for paludification as well as from the prevalence of a severe climate one can deduce with reasonable certainty that these palsas have a frozen mineral soil core.

Comparison of the Features of Initial and Typical Marbloid With Those of Senescent Marbloid

The features of more advanced, older Marbloid, south of Areas 2 and 3, have not been mentioned yet. This section will deal in more detail with the features of senescent Marbloid and with the description of how typical Marbloid loses its characteristics south of Areas 2 and 3 where Marbloid airform pattern occurs in its most typical form. During a southward traverse from Areas 2 and 3, the Marbloid airform pattern gradually loses its identity until it disappears entirely at the southern limit of permafrost just at the northern tip of Lake Winnipeg. Traces of its former existence outside the permafrost zone are to be found, for example, in the Moosonee area.

The main general reasons for the disappearance of the Marbloid airform pattern in the south are the warmer climate which is favourable to vegetal growth and the longer time for development since the emergence of the land from the continental ice sheet and from the sea after the latest glaciation. These factors have ensured that under improving conditions, paludification has become stronger and has, along with the recession of permafrost, slowly covered the features in muskeg which were formerly connected with severe ice conditions.

The first features to disappear are polygons. This does not mean that they have ceased to exist, but that they are obscurbed mostly by intensified growth of the surface vegetation and are not so easily observable directly from the air. Mainly, the denser growth of shrubs (E-class) and the appearance of small trees in abundance even on the peat plateaus conceal the outlines of polygons from direct observation. Thus, in Figure 86, which is a high altitude stereopair from northern Manitoba about 140 miles (225 km) south of Churchill, the polygons are not visible from this altitude. The peat plateaus of the typical Marbloid (Figure 35) here are being heavily invaded by tree growth, (<u>Picea mariana</u>) and display Stipploid appearances (A). The polygonal outlines are still seen in some areas as implied indirectly by the more or less circular growth of trees along the fissures of polygons under recessive development as marked by (B) (Figure 86). The lobate configuration of typical Marbloid is lost here to quite a marked degree due to the thawing of permafrost which promotes slumping of peat plateaus. This is seen in numerous locations in Figure 86 (C).

The drainage is better developed here than in typical Marbloid. The channels are more numerous and small channels

Fig. 85. High altitude (30,000') vertical stereopair showing initial Marbloid on Victoria Island, N.W.T.

A - small palsa.

B - larger palsa with lichenaceous cover (H class).

C - initial peat plateau formed by coalesced palsas.

Fig. 86. High altitude (30,000') vertical stereopair showing old Marbloid in northern Manitoba.

A - peat plateaus have been invaded by trees and have acquired Stipploid pattern.

B - trees growing in circles implying existence of disappearing polygons.

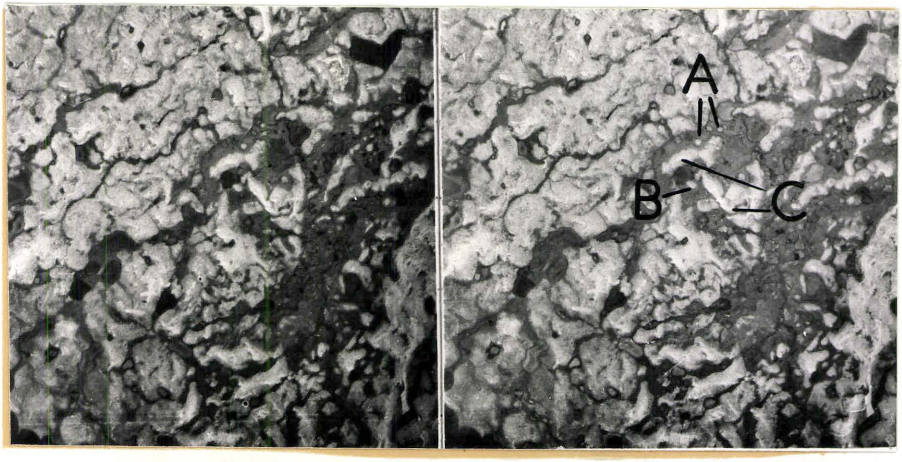
C - slumped and irregularly shaped edges of peat plateaus implying regressive development of permafrost.

D - medium size drainage channel in development towards its maturity.

E - slight meandering is evident in drainage channels as testified by paludified old channels with FI cover (channel visible as a dark line).

F - thaw lakes filled up by muskeg vegetation.

G - paludification of thaw lakes still under progress.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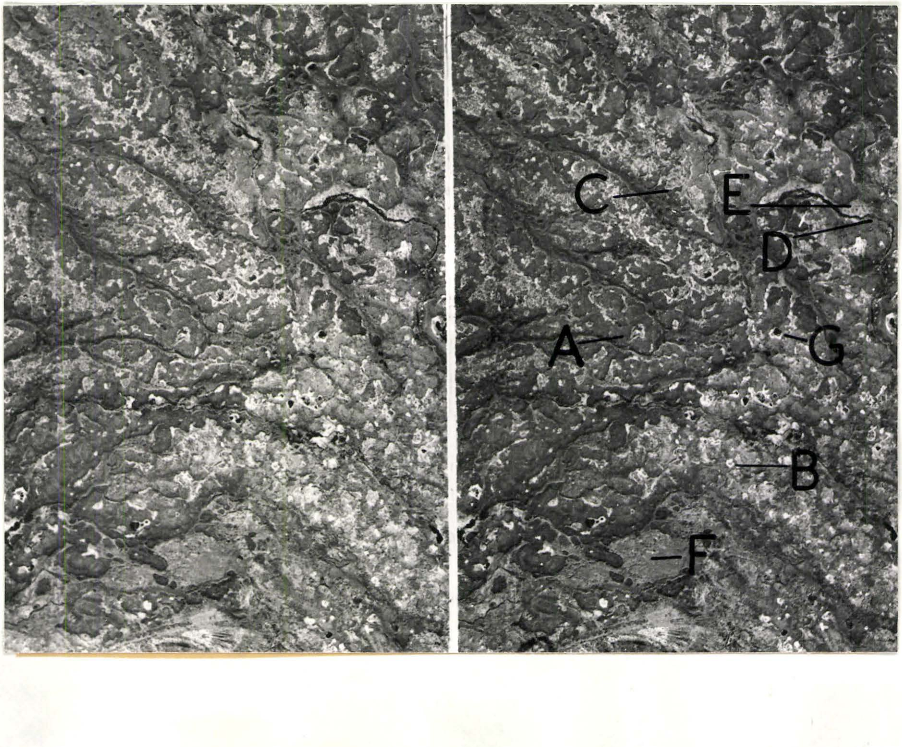
C
E
D
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of the type seen in Figures 37 and 38 have here developed into larger ones and have caused some erosion of the adjacent peat plateaus (Figure 86 (D)). Often these channels have quite wide flat areas beside them with DFI and FI cover predominating. These flat areas also commonly have a Microreticuloid pattern (Figure 86 (E)).

The number of thaw lakes is smaller here than in the earlier stages of Marbloid development. The lakes have either drained as happened in the typical Marbloid (cf. Figure 82) or even more often they have been filled with muskeg vegetation which has overgrown them and shows now as large FI areas (Figure 86 (F)). Some of the lakes show evidence of overgrowing to be still in progress (Figure 86 (G)). The filling up of the lakes and ponds also contributes to the increasing amount of FI and EFI cover here as compared with the typical Marbloid north of this area.

The peat plateaus still have generally EH or HE cover, but B and A also appear here, in some locations quite markedly.

Figure 87 shows from a low altitude (about 1,000 feet, 300 m) a condition identical to that in Figure 86 about 20 miles (30 km) south of the location of the area shown in Figure 89. In the foreground there is a peat plateau with trees of the class B and an understory of HE. This kind of peat plateau is permanently frozen while the open areas behind

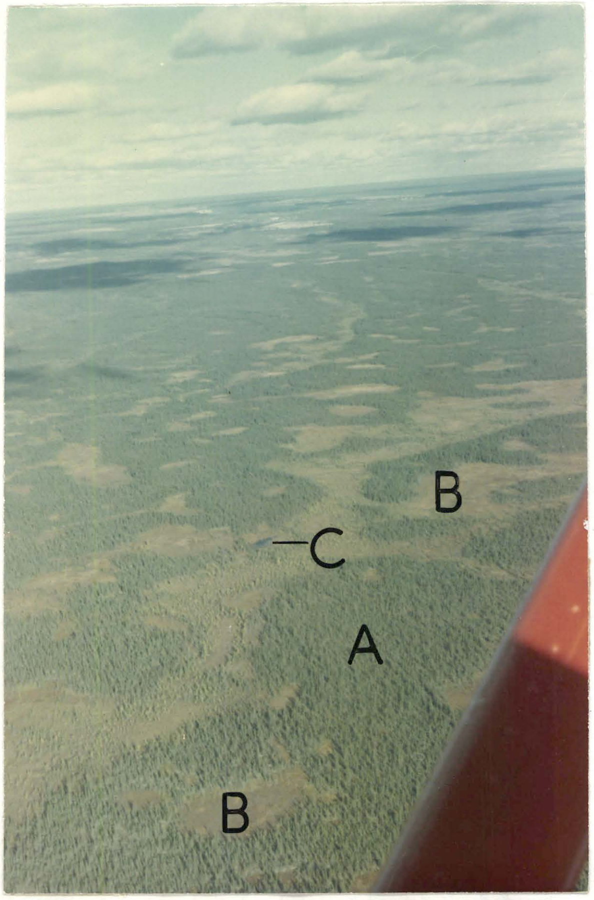


Fig. 87. Low altitude (2000') oblique view of old treed Marbloid area which corresponds to that in Figure 86.

A - treed Marbloid peat plateau.
B - areas with FI to EHI cover representing either filled in thaw lakes or areas where permafrost has receded from the peat plateaus and which have repaludified with resulting cover mentioned.
C - thaw lake being filled up with muskeg vegetation.

it with FI cover along its edges do not contain any ice, at least in the peat. H, in this case, appears dull gray in colour as seen in the centre of the first small open area in the foreground in Figure 87. Usually there is ice under this cover whenever there is H in it. The only lake which has not been overgrown by peat is to be seen in the centre of the foreground as a blue spot.

In Figure 86 the drainage channels do not show a beaded appearance or any angularity, features which are interpreted as signs of severe permafrost conditions. The lack of these features thus implies ameliorating conditions in this respect. These features accompanied by the weakening influence of permafrost have been obscured by intensified stream erosion and have been replaced by other features of more mature rivers with wider valleys accommodating meanders (Figure 86 (E)).

Further south, Marbloid becomes even less typical by losing more and more of its characteristic features although some features persist as reflected indirectly by the pattern. Thus, Figure 88, a high altitude stereopair of a Marbloid still older than that in the previous figures, and located near Willbeach about 170 miles (275 km) SSW of Churchill, Manitoba, reveals several Marbloid features although they are more subdued.

The EFI and FI areas between fading peat plateaus occupy much more space and regularly show Microreticuloid

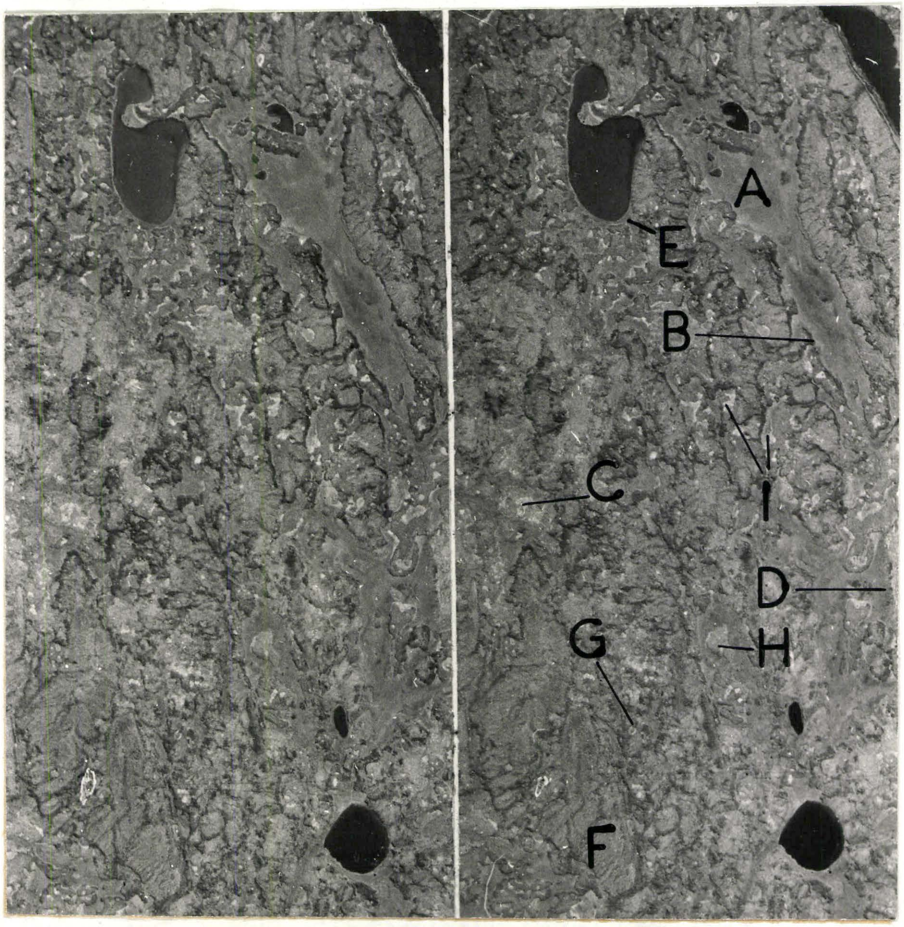


Fig. 88. High altitude (30,000') vertical stereopair of senescent Marbloid near Willbeach, northern Manitoba.

A - wide FI to EFI areas typifying this stage.
B - irregular edges of peat plateaus.
C - pure FI areas.
D - Microreticuloid faintly visible on FI-EFI areas.
E - concentric peat ridges adorning the shore of a thaw lake.
F - parallel growth of trees along the gentle slopes implying that the underlying mineral terrain patterns have transgressed into peat (soil circles, steps and stripes).
G - trees growing in circles implying existence of polygons in peat.
H - palsa formation.
I - FI areas being formed along the edges of receding peat plateaus.
This area is a representative of an area with both Marbloid and Terrazoid features.

pattern which is typical both of the northern initial muskeg as well as of certain southern muskeg but is relatively uncommon in the typical Marbloid condition (Figure 88 (A)). The peat plateaus are disappearing quite rapidly due mainly to the changes in the environment caused by gradual thawing out of permafrost even in the peat where it generally lasts longest. The plateaus assume even more angular forms than in the areas shown in Figure 86 (Figure 88 (B)). However, the H-factor is still quite strong on the peat plateaus where the major cover is BEH or BHE. The light gray tone is rendered by the high albedo of the H-factor and is now much more subdued than the bright light tone of typical Marbloid (cf. Figure 35). The pure FI areas show as very light, almost white, limited areas (C) and are often located in the middle of broken down peat plateaus implying either filled-up pond conditions or filled-up thaw depressions. Some of the larger FI areas bordering the edges of receding peat plateaus signify newly started muskeg vegetation growing in the shallow depressions. These are along the edges of peat plateaus where thawing of ice in peat has formed them. They are favourable for the growth of FI vegetation due to their high water regime (I).

Some of the largest open areas display FI cover alternating with EFI or even BFI cover on parallel ridges as in (D) in Figure 88. The concentrically arched peat ridges along the large lake in the upper half of Figure 88 (E) imply that some of this Microreticuloid pattern may have been formed as ice thrust peat ridges along the lakes or ponds.

Some large peat plateaus support the growth of small trees of class B in rows which are more or less parallel to the gradient of the gentle slopes. This type of growth implies the existence of mineral soil features such as sorted circles, steps and stripes, which have transgressed into the peat as the initial development of Marbloid in the north implied (cf. Figures 50, 51, 53, 57, 78, and 81) (Figure 88 (F)).

Also the former existence of ice wedge polygons in the peat is still visible in the circular growth rows of small trees seen even at high altitude (Figure 88 (G)). The trees in this case grow better along the trenches between the polygons where the ice has receded deeper than in the centre of the polygons where the insulating effect of peat preserves ice closer to the surface thus hindering the growth of the tree roots.

There is a number of palsas (H) near the eroding edges of the peat plateaus. The palsas also show erosional characteristics although there is a slight disagreement among investigators as to whether they are growing or actually under erosion.

The area shown in Figure 88, is actually a "hybrid" between typical Marbloid and typical Terrazoid conditions, being treed Marbloid-treed Terrazoid. The co-existence of Terrazoid and the Macroreticuloid with Marbloid justifies a short detailed glance into their features in the next section to aid in the final analyses of certain factors involved in the development of the Marbloid pattern and its relation to sub-surface ice.

Figure 89 is another high altitude stereopair of a stage in the development of Marbloid condition slightly more advanced than that shown in Figure 88. In this figure the relief appears too rugged and high to contain any organic terrain but one should keep in mind that the stereoeffect exaggerates the height by a factor of about 3 and thus even small elevations may seem very high and gentle slopes very steep. The area shown in Figure 89 is located in northern Manitoba just near the southern limit of the Hudson Bay unconfined muskeg which here is interrupted by rugged Precambrian topography and reassumes unconfined features only near the northern end of Lake Winnipeg.

The mineral terrain features such as sorted circles and steps which have transgressed into peat are very prominent here and give a striped appearance to large areas of this senescent Marbloid (Figure 89 (A)). The H-factor is still fairly strong here and still renders a light tone to most of the muskeg. In the flatter areas the peat plateaus have attained to a great degree the form of treed Terrazoid which seems to become more common when one approaches the

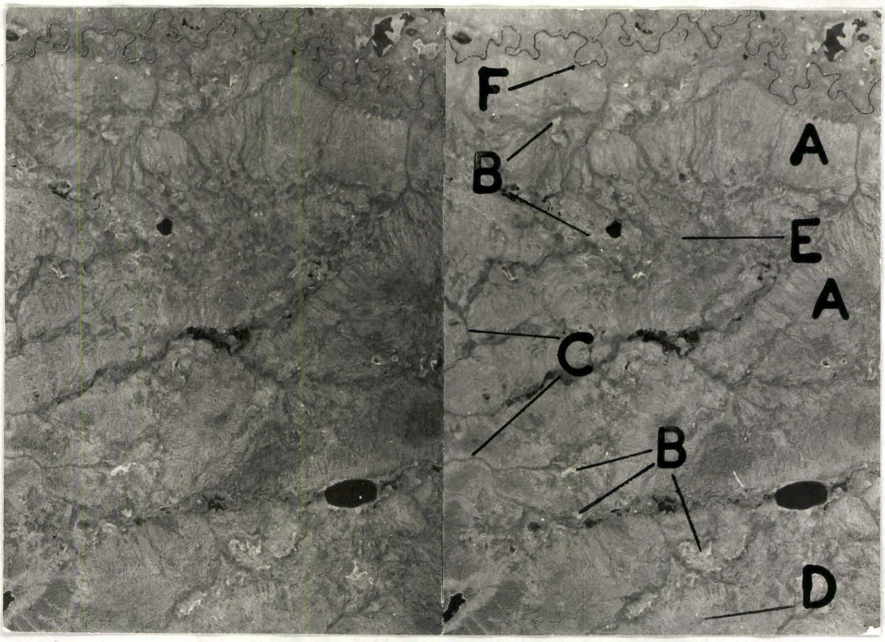


Fig. 89. High altitude (30,000') vertical stereopair illustrating relatively old Marbloid condition near area 7 in northern Manitoba.

A - areas of muskeg where mineral terrain patterns such as sorted circles and steps have transgressed into peat.
B - thaw lakes and ponds filled with peat and displaying predominantly FI cover.
C - initial dendritic drainage pattern.
D - rock outcrop.
E - circular growth pattern of trees implying frost polygons.
F - meandering river.

southern limit of permafrost, confusing features in the old Marbloid.

Almost all the thaw lakes have been overgrown or emptied and have all but lost their identity (B). The stream valleys are deeper than earlier and the one in the upper part of the figure shows wide meanders (F) implying its old age as compared with the streams in the younger Marbloid condition. The cover in the valley varies being BEH, AEH, AEI and BEI with narrow zones of DFI and FI along the water. The drainage pattern is in general better arranged here than in the young Marbloid showing initial dendritic pattern (C), as compared with the deranged drainage (Thornbury 1966) pattern of the typical Marbloid area (Figure 35).

The small features such as polygons are still in indirect evidence. Although it is quite difficult to observe them from high altitudes, from low altitudes these features can still be identified. Figure 90 is a representative example of conditions identical to those shown in Figure 89, seen from a low altitude (2,000 feet, about 600 m) in northern Manitoba. In this area the outlines of polygons projected into the peat or formed in it, can be observed indirectly. The polygonal outlines are delineated quite accurately by the rows of trees growing most vigorously along the fissures between adjacent polygons. These trenches form a more favourable location for the trees to grow than the

Fig. 90. Low altitude (2000') oblique view of muskeg in its senescent Marbloid state showing outlines of disappearing polygons as outlined in the lower duplicate. Note how thaw lakes have been filled and display FI cover. Northern Manitoba.


F1

centres of the polygons since the ice is receding in the ground and the trenches have a greater depth of unfrozen peat than the centres. There the dry peat with H-cover forms a good insulator against the heat of the sun thus preserving the ice. This preservation results in a higher permafrost table which does not favour strong tree growth because the roots cannot thrive in the severe ice conditions. Only small B-class trees grow in the centre. The outlines of polygons have been marked with a stippled line on the duplicate copy of Figure 90 to show where the outlines of polygons lie. The small FI and EFI areas in Figure 90 represent the remnants of thaw lakes and ponds which have paludified. This area is comparable with those shown in Figures 67, 73, 74 and 80 of initial Marbloid and with those shown in Figures 35 and 40 of typical Marbloid in Area 3.

Figure 91 demonstrates the appearance of one of the striped slopes seen in Figures 88 (F) and 89 (A) from a low altitude of about 2,000 feet (600 m). This figure is a good example of a late stage in the development of Marbloid which in the far north was initiated on patterned mineral terrain where these configurations transgressed into peat. The condition here is identical to those shown in Figures 50, 51, 56, 57, 68, and 78.

The light coloured area in Figure 91 shaped like an inverted triangle is a confined peat plateau developed on a slope with existing patterned mineral terrain. The plateau

Fig. 91. Low altitude (1500') oblique view of senescent Marbloid peat plateau showing the patterns of original mineral terrain which have transgressed into the peat. Near Area 8, northern Manitoba.

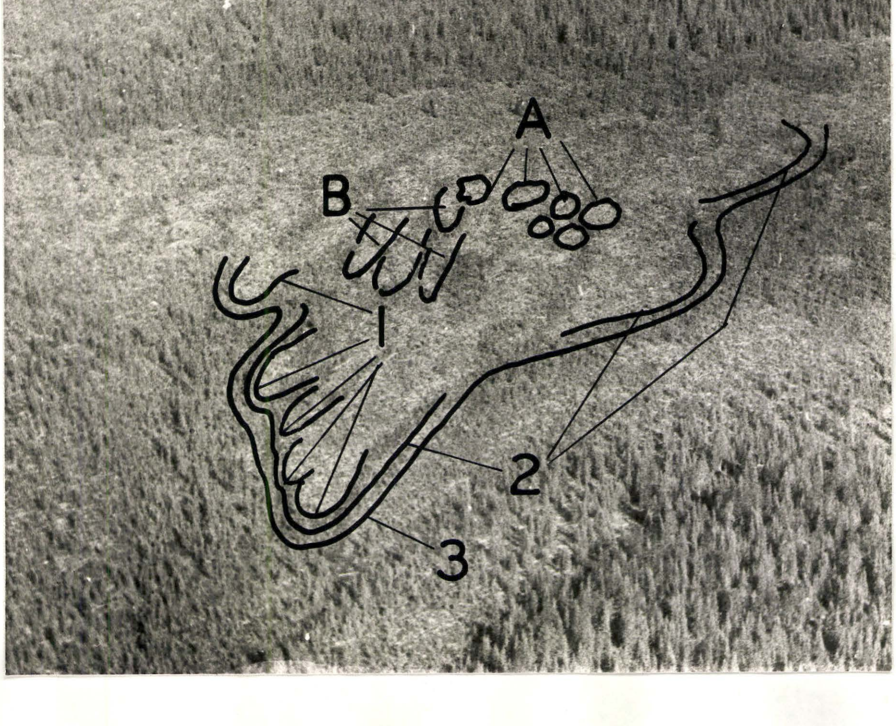
1 - peat plateau lobe, size order 1.

2 - peat plateau lobe, size order 2.

3 - peat plateau lobe size order 3.

A - traces of transgressed soil circles in form of peat mounds.

B - traces of transferred soil steps in the form of elongated peat mounds forming part of the peat plateau lobe system.


A
B
1
2
3

has a flecked appearance on its upper parts in the background (A). These flecks become elongated when one proceeds downslope towards the centre of the foreground. The "flecks" in the background represent circles which have transgressed into the peat-like condition which is in its initial stage in Figure 51. Towards the lower end of the plateau the circles are stretched and represent stripes or steps as in Figures 57 and 68 which have transgressed into the peat. The outlines here are accentuated by the small trees growing in lines along the trenches between the circles and steps, because as in the case of polygons, the trenches offer deeper soil for the tree roots than the domed centres of these formations where the ice is preserved. The light tone here is rendered by the H-factor which with E forms the main cover on the centres of the circles and steps, rather than silty fines as in initial Marbloid. The above-mentioned features have been outlined and annotated on the duplicate of Figure 91 to show them more clearly.

As compared with the typical and initial Marbloid in terms of components of peat plateaus, the following is apparent. In Figure 91, areas 1, 2 and 3 would correspond to areas (A), (B) and (C) in Figure 80 and (C), (D) and (E) in Figure 35 respectively thus denoting the three main size categories for lobes of a peat plateau.

Figure 92 shows a general low altitude view over an area identical to that seen in Figure 89, from high altitude.

This figure reveals clearly how the stereo effect exaggerates the dimension of height and how the relief is really quite smooth and not rugged as suggested by the stereopair, Figure 89. Figure 92 shows prominent DFI cover along the stream in the centre, a feature which is becoming more evident here in the south than in the north mainly because of the more favourable climate. This area also reveals the extensive destruction of the tree cover by fire, a fact which is demonstrated by fallen tree trunks which appear as short light-coloured lines on the ground. The cover on the peat plateaus is HE or EH with some B where the fire has not destroyed it all. Between the plateaus there is also some AEH cover. It, as well as B class, grows in parallel lines, the implications of which were dealt with in the previous pages. It should be mentioned here that there are numerous outcrops of mineral terrain in these areas, especially in the locality where Figure 89 was taken. These areas are marked with the letter (D) in Figure 89.

The condition seen in Figure 93 is in areas in northern Manitoba near Ilford where the muskeg is still rather unconfined, although it shows some signs of the confining effects of the Precambrian topography. Figure 93 is also from about the same areas as Figure 90, and from a low altitude shows the recurrence of conditions identical to those in Figure 90. This area, however, is almost level and there are signs of only circles and possibly of polygons which

Fig. 92. Low altitude (2000') oblique view of an area identical to that in Figure 89, northern Manitoba.

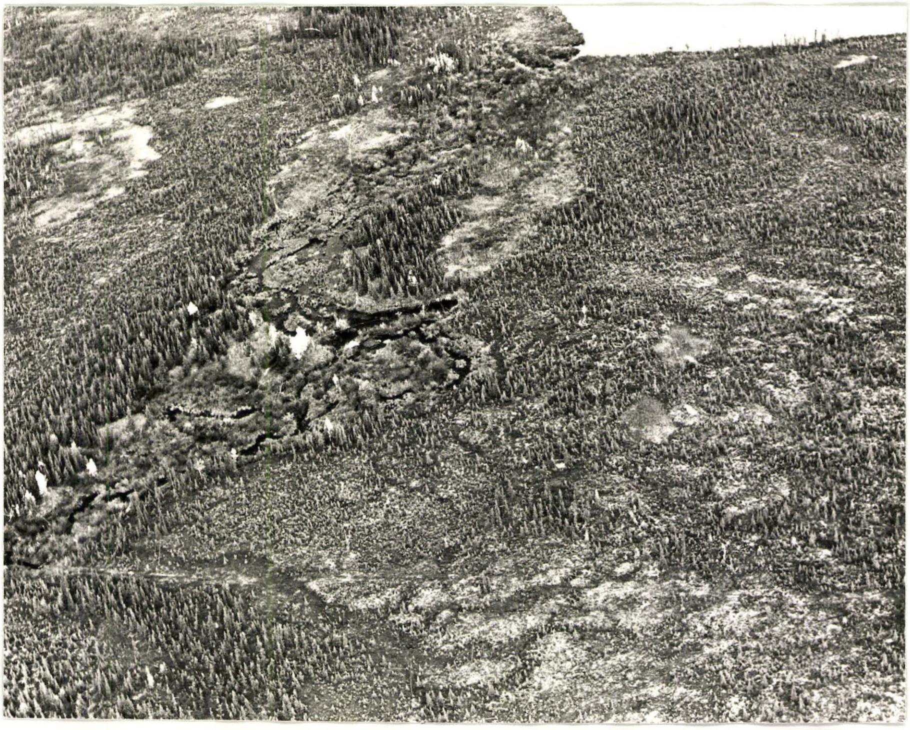
Fig. 93. Low altitude (2000') oblique view of senescent Marbloid near Ilford, northern Manitoba. Note outlines of polygons in peat plateaus and a filled up pond in the lower right side of figure.

have transgressed into the overlying peat deposits. The FI area on the right in the foreground represents a thaw lake overgrown by peat. It does not appear to be the result of thawing of the adjacent peat plateau since there is no slumping or eroded peat surface visible. This type of peat plateau is similar to the flat area with polygons seen in Figure 80, of an initial muskeg in Area 1 along Flight Line 2. The light tone is rendered by the H-factor in EH cover. Here too the lichens (H) are concentrated on the higher centres of the circles and/or polygons covered with peat. The narrow trenches among the polygons and the circles have FI cover with some small trees of B-class.

As a rule the Marbloid features are not sufficiently characteristic of the muskegs of Precambrian areas to be visible clearly from the air. They still exist there but in restricted form and can be seen from a low altitude only. Figure 94 is an example of this kind of condition. This area is located about 8 miles (13 km) west of Lynn Lake in northern Manitoba near the border of Saskatchewan and Manitoba. There is a small muskeg with typical remnants of a Marbloid peat plateau in its confined form visible from a low altitude (2,000 feet). This plateau is bisected by a DFI drainage channel which is typical of small drainage channels of southern muskeg. In the left background treed Terrazoid interferes and the Marbloid features are totally lost. The existence of the Marbloid features with strong, although local,

Fig. 94. Low altitude (2000') oblique view of senescent Marbloid peat plateau in a confined muskeg about 8 miles west of Lynn Lake, northern Manitoba. Note the strong DFI cover along the drainage channel and treed Terrazoid in the background.

Fig. 95. Low altitude (2000') oblique view of senescent Marbloid near Ilford, northern Manitoba. Light tone in the treed area is imparted by lichens (H-factor).



H-factor implies severe local sub-surface ice condition in this muskeg, which could be expected since this area is still within the zone of discontinuous permafrost.

South of Ilford, the Marbloid pattern gradually loses its characteristic features, partly because of the confined conditions of the Precambrian which do not favour large peat plateaus and thus hinder the regular development of Marbloid airform pattern. Only near the southern limit of permafrost at the northern end of Lake Winnipeg does the flat topography facilitating unconfined muskeg make possible the appearance of the last traces of Marbloid characteristics before their final disappearance from view in areas south of the southern limit of discontinuous permafrost.

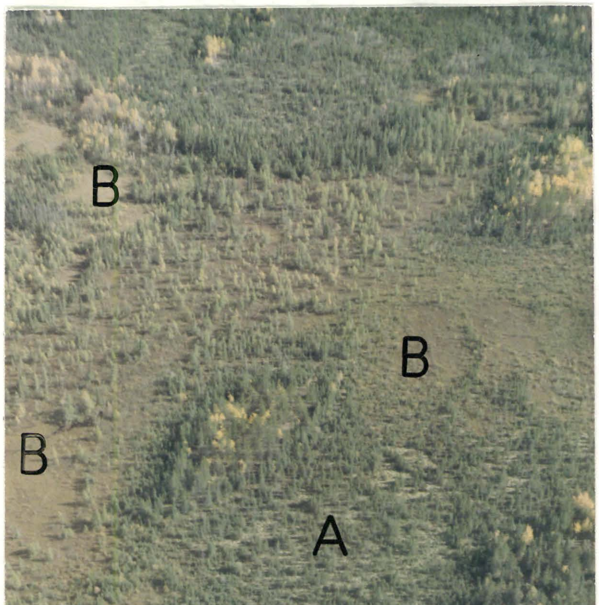
Figures 95 and 96 are 50 miles south of Ilford in northern Manitoba and near the rugged part of Precambrian but still display a smooth relief which is conducive to an unconfined muskeg condition. These areas display Marbloid which begins to be very heavily treed and definitely loses its characteristics even when viewed from low altitude. In Figure 95, the FI areas of earlier muskeg have become treed to a great extent as the AFI and AEI in the foreground show. The polygon covered peat plateaus are about to lose their polygonal pattern and are acquiring strong tree growth. They display BEH and even AEH cover in both of these figures and especially so in Figure 96. The strong growth of trees obscures the effect of the H-factor and, seen from a higher

Fig. 96. Low altitude (2000') oblique view of unconfined senescent Marbloid south of Ilford, northern Manitoba. Note heavy tree growth and how the trees are arranged into circles and rows implying existence of patterned mineral terrain under muskeg.

Fig. 97. Low altitude (1500') oblique view of senescent Marbloid between Norway House and Ilford in Manitoba.

A - remnants of Marbloid peat plateau. Dominating cover on them is BHE (light tone).

B - areas which were formerly thaw lakes and ponds but have been paludified later. Dominating cover is EFI - FI.


B
B
B
A

altitude, these areas have no really appreciable light tone. In fact, the areas lightest in tone are now formed by FI cover although its intensity is not of the same level as that rendered by H-cover.

Further south, the Marbloid plateaus, although still recognizable from the air, are very limited in area while FI and EFI cover are increasing in area along with treed muskeg. Figure 97, 20 miles south of the area shown in Figures 95 and 96, shows an old unconfined Marbloid peat plateau as seen from an altitude of about 1500 feet (450 m). This plateau is in the centre of the foreground of the figure and is covered with BEH, that is with short trees (mainly Picea mariana), ericaceous shrubs, and lichens. In the background there is another even more heavily treed peat plateau. On the left in the centre of the photo there is a small area of wet FI possibly denoting a paludified pond. Behind the first peat plateau the cover is largely EFI and EI (brownish in colour) which is being invaded with trees. In this area, ice is encountered only in the peat plateaus as far as the organic terrain is concerned.

Between this area and the large unconfined muskeg at the northern end of Lake Winnipeg muskeg is restricted to the depressions in the rugged Precambrian topography and, mostly because of small size, does not show any clearcut high altitude airform patterns. Near Lake Winnipeg there is again some evidence of remnants of an old senescent Marbloid.

However, here even they are obscured by other patterns like Stipploid and Dermatoid and especially by treed Terrazoid. The number of peat plateaus with H in them is very limited and generally H is hidden under heavy tree cover.

Figure 98 is an example of this sort of condition at Lake Winnipeg, northwest from Norway House as seen from an altitude of about 1,500 feet (450 m). The Marbloid peat plateaus have all but disappeared since the ice in them has thawed. They, or whatever is left of them (Figure 98 (A)), are surrounded by FI and EFI cover which later will also support trees (Figure 98 (B) and (C)), and often show microreticuloid pattern. The wide FI-BEI channel in the background (D) could be construed as a widened shallow FI channel of the typical Marbloid condition seen in Figure 35 (G). Some of the Marbloid plateaus support H cover but are obscured by BE and AE. This condition is just a more advanced stage in the development of typical Marbloid through the treed Terrazoid-Marbloid condition of Figure 88, to this condition where treed Terrazoid is dominant over Marbloid and which farther south will become mainly an area of intermittent Dermatoid and Stipploid patterns mixed with occasional Reticuloid and common Microreticuloid areas.

The last marked occurrences of H-factor near the southern limit of discontinuous permafrost are seen in large Dermatoid areas at the northern end of Lake Winnipeg. This does not mean that there would not be any H on muskeg

Fig. 98. Low altitude (1500') oblique view of treed Terrazoid - Marbloid area just north of the southern limit of discontinuous permafrost near Norway House, Manitoba.

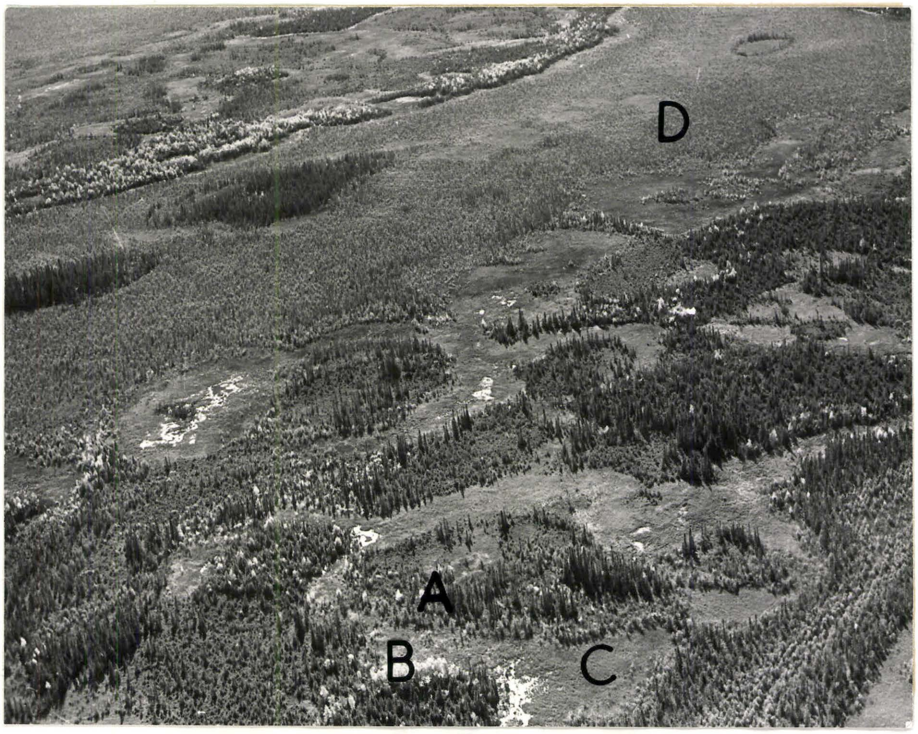
A - senescent treed Marbloid peat plateau.

B - FI cover in depressions caused by slumping of peat plateaus after permafrost in them had thawed.

C - EFI cover in older areas of regressive permafrost development.

D - FI - BEI channel with Microreticuloid pattern.

Fig. 99. First signs of very marked H-factor on muskeg on a traverse from north to south near southern limit of discontinuous permafrost near Norway House, Manitoba. Low altitude (2000') oblique view. H-factor shows as whitish flecks on the ridges.


D
A
B
C

further south, but it means that the intensity of H here is such that it is easily detected from quite a high altitude. Figure 99 shows this condition from an altitude of about 2,000 feet (600 m). The dominant cover in the wet depressions is FI showing as greenish yellow in colour and EFI on slightly drier locations with some brown added. The remnants of the peat plateaus appear as bluish green with white at the edges. The blue is due to atmospheric haze; the green is rendered by small trees growing on the plateaus, and the intermittent light tone is accounted for by EH and HE cover. This area is just about at the southern limit of discontinuous permafrost as it is set by Brown (Brown 1967). From here southwards, the H-factor rarely appears on open muskeg and is mainly confined to drier and mostly treed areas where it is not readily observed from the air. Ground studies reveal that the frequency of occurrence of lichens (H-factor) on muskeg is fairly high in certain conditions as will be seen later but it shows, at the same time, that its intensity is so low that it does not have any significance in the formation of airform patterns or even as a component of the factors rendering tone to them.

The only possible remnants of a Marbloid condition in the study areas outside the permafrost zones, and recognizable from a high altitude, encountered in this study are those seen in Figure 17 from Area 16, in the general area of Abitibi Canyon-Coral Rapids. The possible peat plateaus show as clearly delineated dark areas (Figure 17 (A)) and generally have a cover of AEI or BEI where the trees specifically are Picea mariana (black spruce) while in the surrounding light areas, where the cover also is treed (AFI or BFI to AEI and BEI), the trees are mainly larch (tamarack, Larix laricina). The dark peat plateaus are raised above their immediate surroundings and the water regime is them is lower than in the surroundings. There is a fair amount of lichen (H-factor) on these plateaus, but not enough to show on aerial photos or to be influential in a primary sense in cover formulae. The author is, however, inclined to regard these plateaus as initial raised bogs since the climatic data of this area imply rather cool-humid conditions (cf. Figure 27 and 30) which could favour the ombrogenous mode of paludification. Still the raised areas may have been established on remnants of old Marbloid peat plateaus which, as higher locations, would be more favourable than their surroundings to ombrotrophic plants. No ice was found in these plateaus in August 1966 which is to be expected since this area is outside the permafrost zone.

RETICULOID AND TERRAZOID AIRFORM PATTERNS: THEIR GENERAL FEATURES AND DISTRIBUTION IN RELATION TO THE MARBLOID PATTERN

Although Marbloid pattern is the most striking and predominant one in the areas of permafrost, and especially in the zone of discontinuous permafrost and the one which can be best used in the prediction of sub-surface ice conditions, it is not the only one. It is accompanied by all other airform patterns of which, however, only two, namely Terrazoid and Reticuloid patterns occur in higher frequency in permafrost areas than elsewhere and seem to have certain relation to the sub-surface ice conditions as well as to the Marbloid condition. These patterns can also be used to a certain extent in the prediction of sub-surface ice conditions from the air and, in some cases, they even allow refinements in the prediction of occurrence of sub-surface ice in muskeg. This justifies a concise description of their relevant features in addition to that in the Appendix C.

Reticuloid Pattern: 1) Its Characteristic Features and Distribution in Relation to Marbloid Pattern

The Reticuloid pattern can be divided into two categories, that is, into Microreticuloid and Macroreticuloid.

Macroreticuloid appears to be most common in the northern parts of the discontinuous permafrost zone, especially in areas with flat topography. Macroreticuloid, or Reticuloid as this word was and has been used for the easily discernible high altitude pattern named by Radforth (1956a and b), is a pattern which shows reticulations in which the elements are formed by large peat ridges and the mesh is formed by more or less open spaces between the elements. The size of mesh varies within wide limits from about 20 feet (6 m) up to 250 feet (75 m) in width, while the elements are generally narrower extending from 20 feet up to 100 feet in width. In some areas Reticuloid is quite coarse and the mesh may average 600 feet and the reticula about 100 feet. Figure 103, in addition to that one in Appendix C, shows well developed Reticuloid in Marbloid area.

Small scale Reticuloid could be called Microreticuloid as already suggested. This pattern is not generally readily observed from high altitude airphotos, but to investigate it, one should use magnifying stereoglasses in connection with stereopairs. The reticula are between one foot and 30 feet in width and the mesh varies from about 5 feet to 100 feet but is rarely so wide. This pattern almost always corresponds to the low altitude airform pattern called Vermiculoid II (Radforth, 1958), of which a short description and a photo are given in Appendix B. The Reticuloid pattern is divided into Micro- and Macroreticuloid to help in understanding its genesis and in interpretation of the effect of sub-surface ice on the development of muskeg and muskeg patterns.

2. Characteristic Cover of the Reticuloid Pattern

The cover of Microreticuloid pattern in the areas of initial muskeg is predominantly FI to EFI. FI cover is especially plentiful in the spaces among the elements (ridges) whenever there is some vegetation, although the mesh here very often contains open water. Often the cover consists of only sparse F in the most watery areas. The ridges commonly display FI and often also EFI cover in these low, mostly Microreticuloid reticula. On the larger ridges E becomes more common as a part of the cover. In the best developed ridges H-factor also becomes prominent. Especially in the Macroreticuloid areas the role of H is significant due to the fact that the ridges here are higher and drier than in Microreticuloid.

In the areas where tree growth is possible, the elements acquire trees and the cover, especially on Macroreticuloid, is commonly BEI and BEH or BHE and can even be characterized by A in the form of larger trees. Also Microreticuloid regularly displays trees. Figure 100 shows a low altitude view of treed Macroreticuloid in Ilford in northern Manitoba. The ridges are covered with low trees, lichens and small ericaceous shrubs, that is with BHE cover,

Fig. 100. Low altitude (100') oblique view of treed Macroreticuloid pattern in a Marbloid area near Ilford, northern Manitoba. Cover on the ridges is BHE and between them EFI to FI.

Fig. 101. Low altitude (1500') oblique view of unconfined muskeg with Microreticuloid pattern near the southern limit of discontinuous permafrost east of The Pas in Manitoba.

in which the trees (B-class) are Picea mariana. The spaces between the ridges carry a cover constituted of small shrubs, sedges and mostly Sphagnum mosses, that is EFI cover, with only FI just by the ridges probably because this represents a more moist microlocation than the centres of the mesh.

Figure 101 is an example of a large Microreticuloid area in the southern part of northern Manitoba from an altitude of about 1500 feet (450 m). This shows how the ridges carry a BEI cover while the mesh carries an FI and EFI cover, the latter being dominant. However, the Microreticuloid cover here, and especially south of the permafrost region, does not always display trees but is composed of FI, F and I cover classes. Thus, quite commonly the mesh may be open water or carry only a loose vegetation of sedges alone, F, or mosses alone, I, while the ridges carry FI cover and show as lighter areas in the aerial photographs against the dark background provided by the wet mesh.

A common and striking special form of Reticuloid outside the permafrost region is that formed by raised bogs, or, in other words, by ombrogenic muskeg, in areas where the climate is humid enough for ombrogenic paludification. In its most typical and striking form a raised bog has a reticuloid pattern in which the ridges form concentric rings around the highest place of the bog which often is near the centre. These ridges, often called by their Finnish name, "kermi", are arranged perpendicular to the water flow. This type is called concentric raised bog (Ruuhijärvi 1960). Bogs in which the ridges do not form a full circle are called eccentric raised bogs (Ruuhijärvi 1960). Even here the ridges are concentric and perpendicular to the gradient. Figure 102 is a low altitude example of a concentric raised bog in southern Finland clearly showing the arrangement of the ridges. Figure 127 is an example of a raised bog pattern in eastern Canada.

3. Distribution of Reticuloid in Relation to Marbloid Airform Pattern

The Microreticuloid pattern appears to be fairly common almost anywhere in muskeg both within and outside the permafrost zone. However, its frequency is higher in the permafrost zone than elsewhere and especially so in the areas of initial muskeg although there its detection from high altitude may be difficult. However, it is readily observed from a low altitude as Figure 66 shows near Area 1 and on the ground as Figure 112 shows in Area 1. Its genesis and appearance here are closely tied to the ice conditions as will be demonstrated later.

The Macroreticuloid pattern, with the pattern of raised bogs as an exception, is generally common only in the areas of permafrost and especially in the zone of discontinuous permafrost. Quite commonly it is an integral part of the Marbloid condition and may even become predominant

Fig. 102. Low altitude (1000') view of concentric raised (ombrogenic) bog in southern Finland. Note the typical concentric arrangements of peat ridges, called kermi, and flarkes (rimpis). This type of Macroreticuloid pattern is also typical of maritime ombrogenic muskeg in Canada. The highest place in the bog is in its centre, so that the ridges are perpendicular to the gradient and thus to the flow of water.

in areas with very flat, smooth topography. Figure 103 is a good example of a mixture of Reticuloid patterns and Marbloid as seen from high altitude in Area 3. In this area there are large typical Marbloid peat plateaus (B) with typical Macroreticuloid pattern intermixed with it (C). There is also some Microreticuloid (D) in the flatter areas between peat plateaus. Some of the peat plateaus themselves also exhibit irregular Reticuloid pattern as a result of numerous small thaw lakes on them (B). Strong influence exerted by Reticuloid on the Marbloid condition appears to be limited to the northern half of the zone of discontinuous permafrost, and even there to areas with the smoothest relief.

Towards the southern part of the discontinuous permafrost zone Macroreticuloid pattern disappears from the landscape due to the strong paludification of watery mesh in this pattern resulting in larger areas of FI and EFI which, in turn, are characterized by larger areas of Microreticuloid pattern, as seen in Figures 86, 88 and 89. In other words, the Microreticuloid pattern appears to be more common in areas with initial and senescent Marbloid while Macroreticuloid makes its strongest appearance in the areas of typical Marbloid.

The physical and biotic factors involved in the genesis of this pattern will be dealt with in the next chapter together with those involved in the development of

Fig. 103. High altitude (30,000') vertical stereopair of Marbloid airform pattern with strong Reticuloid pattern invading it in northern Manitoba.

A - medium sized rather undeveloped peat plateau.

B - well developed peat plateau riddled with reticulate pattern formed by thaw lakes.

C - typical Macroreticuloid pattern.

D - Microreticuloid pattern in a low-lying FI area.

E - peat plateau lobe size order 1.

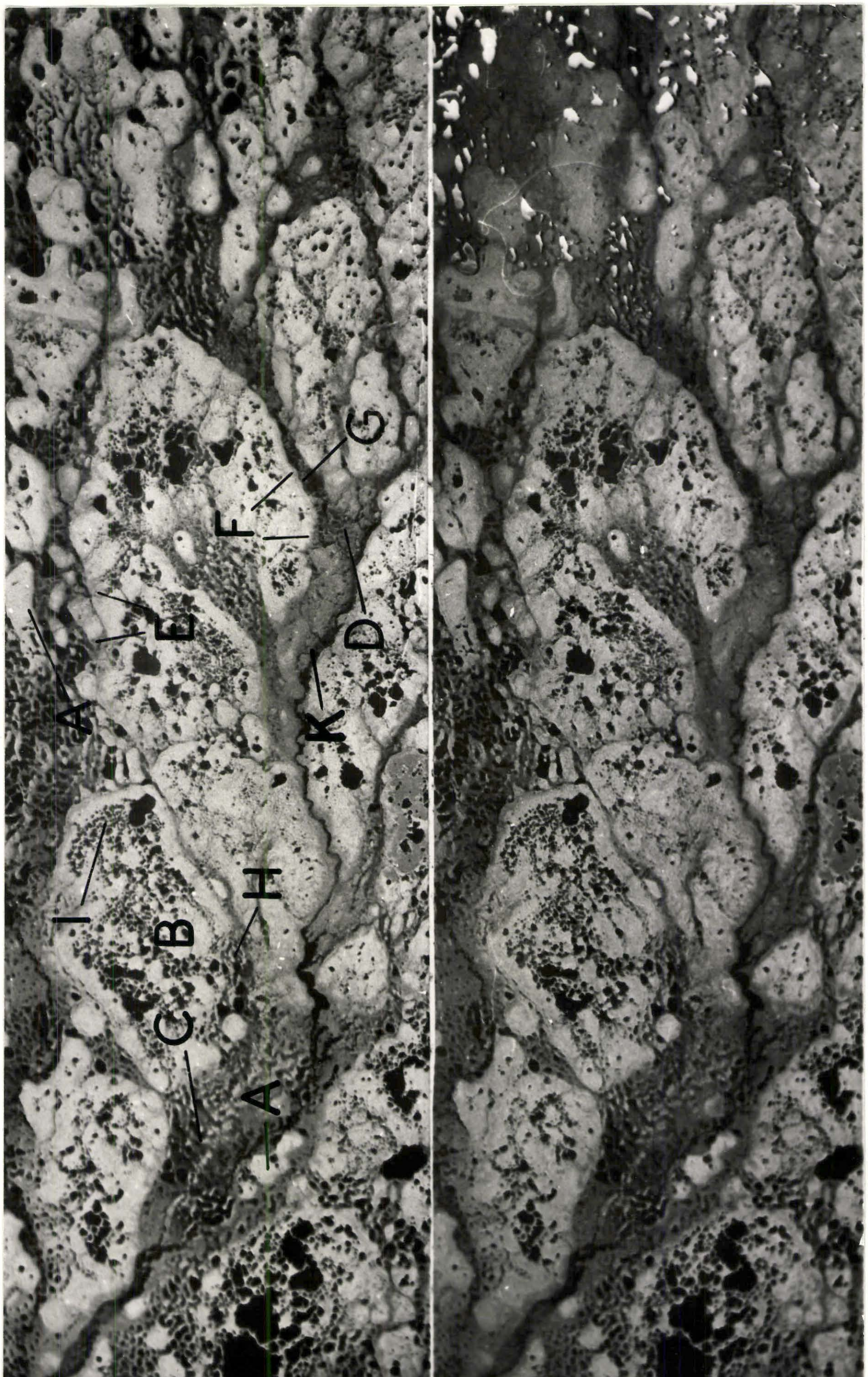
F - peat plateau lobe size order 2.

G - peat plateau lobe size order 3.

H - Reticuloid pattern created by solifluction.

I - parallel rows of lakes resembling thaw lakes but created by solifluction.

K - Asymmetrical valley.


A
E
F
G
I
B
H
C
A
K
D

Marbloid pattern and Terrazoid pattern.

Terrazoid Pattern Features as a Part of the Marbloid Condition

The second pattern also common as an integral part of the Marbloid condition is the Terrazoid airform pattern. It is also a high altitude airform pattern and gives an image of a table top sprinkled with salt and pepper because of the irregular white and dark patches which give it a mottled appearance. In Appendix C there is a figure and a short description of its main characteristics but a more exact description will be given here.

Typical Terrazoid is composed of the above-mentioned dark and light patches. These are related to the dark and light areas of a low altitude (1,000-5,000 feet) airform pattern called Intrusoid (Radforth 1958). In its most typical form, Terrazoid is devoid of trees, contains numerous ponds and lakes and is most frequent quite far north in areas where the typical Marbloid conditions make their first appearance. The dark areas of typical Terrazoid are mostly covered with FI or F and occasionally I alone. These areas are flat and lie lower than the light areas which represent shallow peat plateaus with HE or EH cover, rendering them light in tone. These shallow plateaus can be construed as initial stages of typical Marbloid peat plateaus, stages which are more advanced than those in the areas of initial muskeg as in Area 1. Terrazoid pattern appears to be in many cases a marginal pattern in the development of Marbloid pattern. It is common in areas where the typical Marbloid is gaining area, but when typical Marbloid is fully developed Terrazoid pattern all but disappears to make its reappearance further south where the senescence of typical Marbloid is advanced. In both areas of its main frequency of occurrence the Terrazoid pattern has the same mottled appearance although the identical looking pattern components are not necessarily homologous but rather are analogous in their development. Thus, for instance, in Figure 86, which shows a good example of a pattern which has components from both Marbloid and Terrazoid, the Terrazoid appearance is represented by large dark EFI and FI areas as seen in locations (E and F) and by very light tone areas as seen in locations (E) and (B). Although the former correspond partly to the dark areas of typical Terrazoid through their ontogeny, in most cases they have different development so that they have not always been low-lying FI or EFI areas but often have been formed from thawed peat plateaus or from enlarged drainage channels. The light areas here have this light tone not due to HE or EH cover but to dense wet FI cover, being thus totally non-homologous to the initial Terrazoid where they represent shallow peat plateaus as contrasted to this case. Here they represent thawed edges of permanently frozen peat plateaus in which the slumping of peat has created extremely wet depressions where FI cover thrives. This difference in appearance and the difference it implies in the development of these variations of Terrazoid, imply the possible potential of this pattern, if used in association with Marbloid and Reticuloid, in refinement of the prediction of the qualities of sub-surface ice conditions in peat.

The initiation of typical Terrazoid begins approximately in the same area as that of typical Marbloid and may signify the presence of severe ice conditions. In the areas of typical Marbloid, Terrazoid is absent, but at the onset of the regressive phase in the development of Marbloid the other type of Terrazoid appears implying the onset of regressive development of permafrost. Further south near the southern limit of permafrost where Marbloid pattern disappears, Terrazoid does the same. Even here in the south, the light EH areas of the far north are still represented by equivalent low wet FI areas adjacent to ancient Marbloid peat plateaus (Figure 98). In the same figure, one can see that some of the dark areas have acquired BEI or even AEI cover.

ABIOTIC AND BIOTIC FACTORS INVOLVED IN THE DEVELOPMENT OF THE MARBLOID AIRFORM PATTERN

This section thus deals with certain abiotic and biotic factors contributing directly or indirectly to the formation of airform pattern. Most of the measurements concerning the physical properties of peat have been derived from the existing literature. They are of such nature that the author did not feel it to be necessary to duplicate them by carrying them out especially for this work. The measurements in the literature originally were not performed for this type of work and any conclusions and deductions here based on the existing figures reflect analysis of the figures by the present author. The author's contribution in the form of conclusion in this section is an integral part of the section and can be identified through the references to the effect of various factors on paludification or pattern formation.

Permafrost

The major sub-surface ice phenomenon concerned in this study in relation to the high altitude airform patterns is permafrost. In a former section the distribution in relation to the study areas was described briefly. Here a few more factors affecting the occurrence of permafrost in general will be dealt with before describing in detail how its presence affects the growth and development of muskeg features leading to Marbloid and other airform pattern.

As Figure 32 reveals, the southern limit of continuous permafrost follows closely the -5° C (20-25° F) isotherm of mean annual air temperature and the southern limit of discontinuous permafrost follows quite closely the 30° F (-1° C) isotherm of mean annual air temperature. The broad scale of occurrence of permafrost is thus determined by the climate, the effect of which of course, is locally acted upon by factors such as exposure of the slope, snow cover, elevation, soil type, vegetation, drainage conditions, and existence of large water bodies.

The southern limit of discontinuous permafrost following the isotherm of 23° F mean annual ground temperature follows quite near the isotherm of 30° F mean annual air temperature and shows that on the average the difference between the ground and air temperature is about 6° F. This figure can be used to predict the approximate ground temperature in the permafrost region if the air temperature is known (Brown 1968b).

Between the isotherms of 30° F and 25° F mean annual air temperature permafrost is highly discontinuous, if not sporadic, and very often limited to peat lands due to certain special properties of peat. Also, the high air temperature here does not allow any large increases in temperature before permafrost starts regressing even in peat. At the isotherm of 25° F mean annual air temperature, and north of it, the difference of 6° F between the ground and air temperatures which allows a small margin for negative (below freezing) temperatures in almost any kind of soil and permafrost is considerably more widely spread here than farther south. At about the isotherm of 17° F mean annual air temperature permafrost becomes continuous and ubiquitous (Brown 1967a). Only east of Churchill does continuous permafrost in the Hudson Bay Lowlands reach south of this isotherm, probably because of the large unconfined muskeg areas there.

The seasonal variations in temperature affect mostly only a thin layer of the surface called the active layer of permafrost. The thickness of the active layer varies according to the climatic conditions as well as to the local features that affect distribution of permafrost. In the Arctic the thickness of the active layer is in most cases from one to three feet (loc. cit.). In these arctic areas the thickness of permafrost itself varies from more than 1,000 feet (300 m) in the north to about 200 feet (60 m) at the southern limit of the continuous permafrost zone (loc. cit.).

In the discontinuous permafrost zone the thickness in its northern parts down to about the isotherm of 25° F mean annual air temperature varies from about 50 feet (15 m) to 200 feet (60 m). Southward from here it thins out sometimes to a few inches only. The depth from the surface to the permafrost table varies between 2 and over 10 feet (.6 m to 3 m) and, in general, the active layer reaches the permafrost table only where it lies within 5 feet (1.5 m) from the surface (loc. cit.). In the discontinuous permafrost zone, there are areas of permafrost at great depths where the thaw does not reach. These areas were presumably formed during the eras of very cold climates (loc. cit.). In muskeg the figures given do not always apply, because of specific characteristics of peat as will be explained later.

The general terrain conditions affect greatly the local occurrence of permafrost. Thus, the relief is of great importance since it affects thermal insulation. The southern slopes generally get more solar radiation than the northern ones where permafrost thus appears more prominently. This is clearly seen in many areas of senescent Marbloid where the regressive development of permafrost has set in so that the peat plateaus show signs of permafrost thawing more often in their southward facing slopes than on their northward facing ones.

Although the elevation above sea level has a strong effect on the distribution of permafrost since the temperature falls with increased elevation, this factor is not significant in the present study.

The general drainage conditions affect locally the distribution of permafrost. Thus, for instance, large water bodies do not have permafrost under them due to their large heat capacities and moderating effects. The existence of this type of unfrozen area depends on the depth, temperature and surface area of the water body as well as on the thickness of ice, snow cover on the water body during winter and on the composition of bottom sediments (Brown 1968b). In general, very large areas with unfavourable drainage conditions also tend to have unfrozen gaps in the permafrost presumably due to the moderating effect of water masses on the ground temperatures. On the other hand, in some cases, very well drained areas may not have permafrost depending on the soil type.

A very important factor in the local distribution of permafrost is snow cover. The general thickness of snow cover, the time when the first snow comes in relation to the onset of below freezing temperatures, and the time of the thaw of the snow in the spring affect the permafrost conditions strongly. More details on the effect of snow in connection with other physical and biotic factors as they affect the formation of certain pattern constituents will be given later.

Vegetation also has a strong local influence on the distribution of permafrost, but this also will be dealt with later and only that of muskeg vegetation will be discussed because other aspects are beyond the scope of this work.

The above-mentioned factors should provide a basis for considering the effects of ice in peat. Meanwhile a short discussion of the principal theory of formation of ice lenses in soils is offered.

Formation of Ice Lenses in Soil

It is known that ice commonly appears as large lenses varying from a few millimeters to as much as a meter thick in peat and also in other soils. This phenomenon is very common in peat and has been studied to a certain extent although generally the hard work in obtaining any good samples or profiles of massively frozen peat has hindered these studies. Some recent studies in Scandinavia (Forsgren 1966) and Finland (Salmi 1968) refer to more extensive studies in this field and particularly to the fact that in some palsa formations the major part of the thickness is made of ice lenses and that the peat appears as thin layers in them, (Salmi 1968).

There are various hypothesis about the formation of ice lenses in soils but the exact physical details still remain a mystery. The general features of the process, however, are as follows. When the temperature is lowered slowly the ice lenses are formed. If the freezing takes place rapidly, there will be no lenses. In slow freezing, the water starts to freeze in the spaces in the soil and the last spaces to freeze are small pores. It is notable that in the small capillaries of the soil the water may be considerably overcooled since the freezing point of water under pressure is lowered and in the capillaries there are high pressures due to the cohesion of the water molecules in confined spaces and in small droplets. Thus, the frost area may contain unfrozen water which is important since when the water in the larger spaces has frozen more water is attracted to the freezing area by suction at the crystallization surface. This water is obtained from the capillaries where it is still unfrozen. Thus, an ice lense is formed and its thickness and extensiveness depends on the availability of water. If there is an ample amount of water available, as generally is the case in peat, the ice lense may grow quite large or several ice lenses may be formed until the surrounding soil is exhausted of water. As a result the profile of a frozen soil now shows layers of the parent soil alternating with quite clean, clear ice. The soil between the layers sometimes appears quite dry but its temperatures are well below freezing. Even sampled peat thus frozen appears dry for a few seconds before the ice starts melting. This kind of growth of ice lenses causes lift on the surface. The conditions of the locality determine whether this lift will be temporary or permanent.

Between the layers of frozen soil there may remain unfrozen water. According to Brenner (1931), in rich clay, water may remain unfrozen even at -22° C, because of the fine pores with high pore pressure in this soil. In coarse sand the freezing begins at about -0.15 to 0° C because of large pores with low pressure. There are no figures like this for peat.

The Effect of Vegetation on the Distribution and Occurrence of Sub-Surface Ice

An important factor locally affecting the distribution of sub-surface ice, either permanent or temporary, is vegetation. A few major points will be briefly discussed here as an introduction to the effect of muskeg vegetation, and peat on the ice and *vice versa*.

In general, the literature, in most cases, seems to agree that the vegetation favours permafrost whenever the climatic, terrain and other local conditions are suitable for permanent sub-surface ice (Benninghof 1952, Tyrtikov 1956, Brown 1963). It should be kept in mind that the effect of the vegetation, whether it be either beneficial or detrimental to sub-surface ice, is a complex matter affected and modified by factors such as evaporation, transpiration, temperature, snow cover and terrain conditions, locally and to some extent also regionally. Thus, the effect of the same vegetational features in one area may be quite different and, in some cases, even reversed from that in another. Also large seasonal variations of the climatic factors modify strongly the effect of vegetation, as well as that of muskeg, on the sub-surface ice.

Vegetation affects sub-surface ice predominantly by interfering in various ways with the heat balance of the soil. In the north where due to cold climate the bacterial activity in the soil is slow the litter from the vegetation does not humify as fast as it does in the warm climates. As a result of this, a considerable layer of litter accumulates on the surface. Especially in the coniferous forest this litter blankets the ground as one can see even in southern Canada in dense growths, say, of white pine. This litter with large air spaces forms a good insulating layer against heat exchange between the atmosphere and the soil. It tends to retain moisture in large amounts often containing 100 to 150 per cent of water of its dry weight (Tyrtikov 1956). Thus, in its dry state, it acts as an insulator and in its wet state as a heat conductor or coolant due to evaporation from its surface. Hence if the soil is frozen under it and if the litter is dry the soil tends to remain frozen. Now, if the dryness and the wetness vary in a certain sequence together with the air temperatures so that dryness prevails when the air is warm and wetness prevails when the air is cold, the soil tends to stay cold and the persistence of sub-surface ice is secured due to coolness of the surface caused by the different physical characteristics of the litter. Actually peat acts to a great extent in a similar way. This sequence takes place in the areas of permafrost quite often (Tyrtikov 1956).

The transpiration of water through vegetation also affects the moisture exchange between the soil and atmosphere and thus the heat balance. When the plants transpire they absorb moisture from the soil reducing its water content and reducing at the same time its heat capacity which means that the soil temperature will rise faster with the same heat input. But, at the same time, evaporation from the soil's surface decreases the temperature at the surface and together with the transpiration increases the dryness of the soil surface and increases its insulating capacities by reducing its heat conductivity. All this contributes to slower warming up of the soil and, if it is cold already, to the preservation of coldness and existing sub-surface ice in it.

The snow cover and forest together create conditions which affect strongly the local distribution of sub-surface ice. This is based on the fact that trees shelter the ground from the insolation and also from heavy winds and affect the accumulation of snow on the ground. The shadowing effect against insolation will tend to keep the ground cool under a forest cover.

The interaction of snow and trees is more complex. Very often the first snows come and settle on the tree crowns and do not reach the ground as fast as in open spaces. This leaves the ground in the forest exposed to the cold air for a longer period than in the surrounding open areas and thus enhances the freezing of the soil to greater depth and helps preserve permafrost table higher under the forest cover. Later, during the winter, the snow falls off the tree crowns and also the snow drifting in the wind on the open spaces tends to accumulate around obstacles of which a treed area is a notable one. Thus, when the winter continues, the snow cover in the forest tends to grow thicker than in the surroundings. In the spring, the tree crowns again offer shelter against the heat from the sun and so the thaw progresses faster in the open spaces than in the treed areas. To this is added the effect of lingering snow since it, as a good insulator, adds to the sheltering effect of the tree crowns and keeps the underlying soil cooler much longer than the soil in the surrounding open spaces where the snow disappears earlier. These circumstances together with other factors further contribute to favourable conditions for preserving the sub-surface ice in the areas covered with vegetation. Based on this in the north, black spruce on poorly drained grounds thus may be used as an indicator of severe sub-surface ice conditions and this associates with Marbloid condition especially in areas of senescent Marbloid.

These examples are only a few of how the vegetation and permafrost or sub-surface ice condition interact in terms of energy relations. The reader is referred to Tikhomirov (1952) and Tyrtikov (1956, 1959) for further details about the effect of vegetation on the sub-surface ice.

Major Reasons For Accumulation of Peat Deposits

Muskeg vegetation and especially peat underlying it forms a special vegetal environment in a biological sense. Muskeg is also a geological formation if one considers only the peat deposits, which in that case may be regarded as a group of soils.

Two features of the climate, low temperature and high humidity, are two of the fundamental causes of peat formation, a degenerated mass of fossilized plant remains. Since the decaying of dead plant remains is a result of bacterial and fungal activity and,in a rarer case,of the activity of certain algae, the ambient temperature affects it strongly. Thus, for instance, in the warmer climates there is not very much undecayed, unhumified litter due to temperature conditions which favour bacterial and fungal activity. In the tropics dead plant material is very rapidly turned into soil and does not have a chance to accumulate to a significant degree. In the north, on the other hand, the climate is cooler, the activity of micro-organisms is greatly reduced and the litter in the forests and plant material in the bogs does not humify readily but accumulates. The temperature alone could not, however, ensure very large accumulations of unhumified plant material, because in thicker deposits the heat resulting from the bacterial activity would be retained better and actually could raise the temperatures quite high. The increase in temperature would stimulate degradation.

Relatively low temperature slows down the activity of micro-organisms which normally cause decay of plant material, and peat will form. This is further helped by wet environment which plays a very significant role. The general high water regime ensures that the environment approaches anaerobic conditions. This means that whatever humification there is in the developing peat deposits, is a result mainly of activity of anaeroboic bacteria. Thus most, but not all, of the aerobic activity is eliminated in these conditions, especially so in the deeper layers. Therefore, most humification takes place near the surface, because even in a dry muskeg, the water regime becomes higher with increasing depth, slowing down the aerobic activity.

A third, rather special feature of muskeg environment is its high acidity. This depends on various associated features, for example, the composition of the underlying bedrock. The peat is more acid above an acid rock formation than above a basic one (Salmi 1958). Thus, the reaction of underlying rocks seems to affect directly that of the peat. However, it has been noticed that the acidity of peat which is composed mainly of Sphagnum is generally higher than that of other peats. Thus, for instance, Salmi (1949) gives the following pH values for different peat types of a bog in southwestern Finland in the following table.

Table 1

pH Values of Various Peat Types in
Pinomäensuo, Southwestern Finland (after Salmi 1949)

Sphagnum peat	pH	3.20 - 4.11,	average 3.77
Eriophorum-Sphagnum peat	pH	3.59 - 4.35,	average 3.90
Carex-Sphagnum peat	pH	4.02 - 5.21,	average 4.52
Sphagnum-Carex peat	pH	4.43 - 4.59,	average 4.52

This writer has found that the pH values of Sphagnum peat may go as low as 2.50 in extreme cases. It was found that the pH values in a number of bogs in central Finland, according to measurements carried out by the author, varied from 3.00 to 5.50 in peat with Sphagnum as a dominating constituent and up to 7.50 in Bryales (Hypnum) peat. The author's conclusion is that the reaction of the underlying mineral terrain here has particular significance in the initiation of the bog. This means that if it is acid, only plants which favour that type of environment will invade the area and begin paludification. Thus Sphagnum mosses are the most likely to form the bulk of the peat in an acid environment while Bryales mosses, which favour neutral or even alkaline conditions, will be more important in paludifcation of basic alkaline areas. Later, effect of underlying rock will also be intensified on Sphagnum peat since the Sphagnum peat has higher acidity than the acid bedrocks and this is a result of the functions of the living Sphagnum mosses themselves.

In the soils as well as in the plants there are colloidal acids called acidoids. The acidoids in peat soils are stronger than those in the mineral soils and the exchange capacities of peats are high resulting in the fact that the plants in peaty soils thrive well at low pH values. Furthermore, Sphagnum shoots continually form more acidoids in their apices. These also create the required electrical potential between the moss and its foundation and this forces base cations from the peat to pass into the moss towards its upper parts since the potential difference between the moss and the peat increases towards the upper parts of the moss (Puustjärvi 1959 a and 1959 b). Functions such as this tend to accentuate the acid conditions in peat.

The acidity of peaty environment contributes to the slow breakdown of the plant material because this environment is not favourable to micro-organisms decomposing organic litter.

Thus, despite relatively slow vegetal growth and accumulation of dead plant matter in the relatively cool and humid climates, the slow breakdown of plant and other organic material guarantees that peat deposition ensues.

The Mode of Formation of Peat - Factors Affecting the Rate of Growth of Peat Deposits

The mode of formation of peat varies. Mainly it is formed by Sphagnum mosses as one major component and the sedges and other mosses as the other component group. When the peat is composed mainly of sedges and structurally related plants it has been formed from the dead individuals, which initially have formed only thin layers of litter on which younger individuals have grown and the thickness of which they have augmented with their remains. However, the peat is composed rarely only of sedges; it also almost invariably contains some Sphagnum. Most frequently Sphagnum actually is the major component because in most cases it is the major contributor to paludification of large areas. As an individual Sphagnum plant grows, it extends from its apex and dies at its base which is incorporated into the mass of remains of neighbouring Sphagnum. Because of factors already described, the resulting mass does not decay but forms peat instead. Depending on the degree of moisture the living parts of the Sphagnum descend to varying depths from the surface. In wet areas the moss is dead about 5 to 10 cm under the surface while in drier, more aerobic conditions it may show signs of life even at depths of 30 to 50 cm.

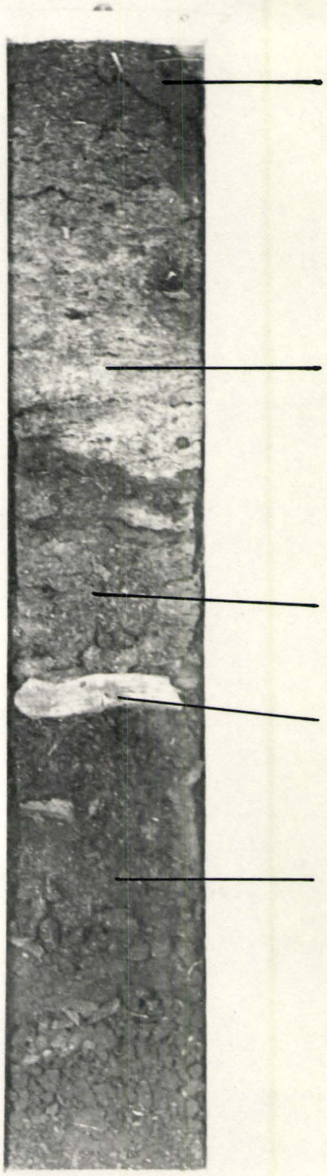
The rate of increase in depth of peat deposits depends on many factors. Also these factors as well as the rate of plant growth affect the structure of peat deposit and, since the insulation capacity of peat is a function of the structure, a brief account of the rate of growth will be presented here.

It is known that some Sphagnum species can grow 2 to

3 cm a year (Kivinen 1948). This fast growth affects only the surface and when the peat layers are formed and grow in thickness their own weight will press the lower layers together and the actual growth in thickness is only a small fraction of the growth of the Sphagna on the surface. Lukkala (1929) in Finland has measured the growth of thickness of peat in different kinds of muskeg and gives the following values. Wet treed muskeg with thin layers of peat (korpi - cf. Glossary) grows about 0.1-0.2 mm a year. Treed muskeg with large shrubs and Sphagnum (räme - cf. Glossary) increases about 0.2-0.3 mm a year. Treed Sphagnum muskeg increases about 0.8-1.2 mm a year (Sphagnum räme - cf. Glossary). Open muskeg with large sedges and Sphagnum (suursaraneva - cf. Glossary) increases about 0.4-0.6 mm a year. Open muskeg with hardly anything but Sphagnum mosses and only sparsely distributed small sedges (kalvakkaneva - cf. Glossary) increases about 0.5-0.7 mm a year. These are averages for large, thick deposits. During the development of muskeg there have been stages when the increase has been considerably faster than these figures show and stages when it has been slower. Generally, when the climatic conditions have been cool and humid, the peat has developed rapidly and then it usually contains large amounts of Sphagnum mosses. This is due to slower humification of peat in these conditions. Rather 'raw' peat formed this way appears commonly as light brown or even yellowish in colour.

Structurally this kind of peat is very fluffy and light and does not show as high a degree of consolidation as other types discussed below. In Figure 104 a peat profile of about 90 cm (3 feet) thick deposit shows layers of slightly humified predominantly Sphagnum peat as annotated. These light coloured layers were formed in the above-mentioned manner. They show large air spaces which contribute to high capacity for water retention as well as high insulating capacity especially in the dry state. In this case, "dry state" alludes to the degree to which peat may dry on the surface of muskeg seasonally (in extreme cases its moisture content might be only 250-300 per cent of dry weight). It does not mean that peat would dry up totally, to a degree where the cells of plants would start to release their moisture. This good insulating capacity of peat has significance in the formation of features which contribute to airform patterns and preservation of ice in peat.

In drier conditions of the climate muskeg acquires trees and commonly shrubs and lichen. Also the surface environment is more aerobic than during moist climatic conditions since the ground water table is lowered. The bacterial activity is increased and humification is much more thorough resulting in degenerated peat. Also the proportion of Sphagnum will be smaller in the composition of the peat. This all results in fewer air spaces because of



Moderately well humified *Sphagnum*-shrub peat. Degree 6 in v. Post's system

Quite raw, predominantly *Sphagnum* peat. Degree 2 in v. Post's system

Predominantly *Sphagnum* peat Humification degree 5 in v. Post's system

Block of wood embedded in peat

Well humified peat containing a large amount of remnants of shrubs and some *Sphagnum* and sedges. Degree 8-9 in v. Post's system

Fig.104. Peat profile showing variations in peat and degree of humification in a deposit due to differentials in the past history of the environment.

greater degree of consolidation. Peat of this constitution would have relatively low water holding and insulating capacities. This kind of well humified peat is dark in colour as Figure 104 reveals. In the literature, these recurring dark layers showing ameliorated climatic conditions are called recurrence surfaces (for example, Tolonen 1967).

Insulation Capacity of Peat

1. Structure of Sphagnum Moss: Its Significance As An Insulation

To aid in understanding the properties of peat, a brief detailed description of the structure of *Sphagnum* moss is given. Figure 105 (from Paasio 1935) shows the structure of *Sphagnum* moss. The cross-section of the stems reveals (C) that there are three kinds of tissues: "pith" (c), and an outer cylinder of two zones (sk), (c). The "pith" acts as a storage place for reserve nutriments and as a transport system. The thick walled cells (sk) give support to the plant. The outer zone is made of one to four layers of cells. These are recipients of nutriments and water and also transport them to the upper parts of the plant.

There are two types of leaves: branch and stem leaves. The leaves (B) are composed of one cell layer. There are two types of cells in the leaves both of which are

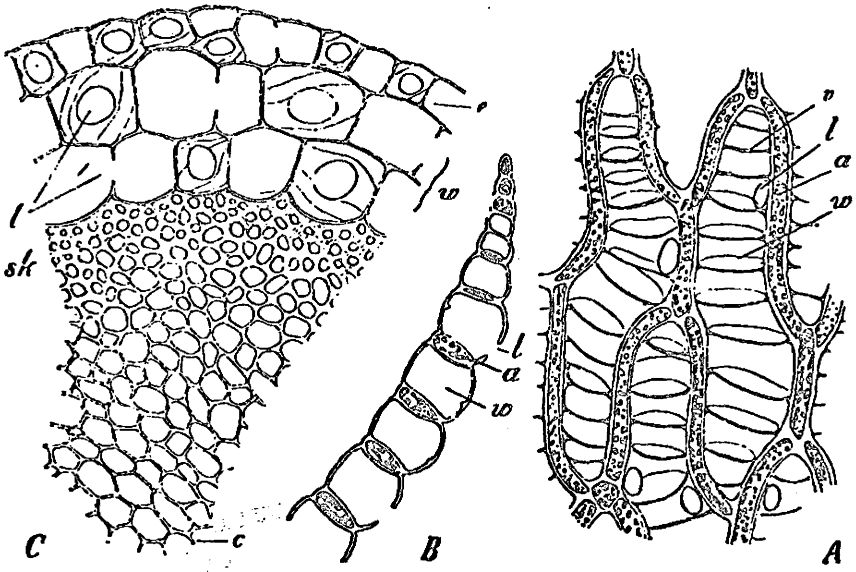


Fig. 105. Structure of Sphagnum moss (after Paasio 1935).

A - horizontal view of leaf containing one cell layer.
a - living chlorophyll-rich cell.
w - dead water water cell.
l - pore in water cell.
v - supporting ring in water cell.
B - cross section of a leaf.
C - cross section of a stem.
c - "pith".
sk - schlerenchyma.
e - water cells of outer cylinder.

visible in both cross-section (B) and horizontal section (A) of a leaf. The most conspicuous cells are dead water cells (w). These cells are either filled with water or air. They contain a number of pores (l) and supporting rings (v). The living cells contain chlorophyll and are narrow, elongated in form, and form a network (a) in the meshes of which the dead water cells are situated. Collectively the water cells when empty in the dry state of peat, may contain considerable amounts of air thus rendering peat that contains much Sphagnum a very good insulator.

Peat which contains only Sphagnum plants would not probably be the best insulator, since these plants are quite easily compressed if any pressure is exerted on them. In nature pure Sphagnum peat is uncommon, but contains large amounts of fibres derived from other common muskeg vegetation constituents such as sedges or grasses, other mosses and shrubs. These fibres give a framework for Sphagnum in which it may exist in a relatively loose form. Also, the framework of fibres itself contains large spaces which can be filled with air or water depending on seasonal fluctuations in water regime. In detailed image a typical fine fibrous peat which is composed mainly of Sphagnum, sedges and remnants of small shrubs would show arrangement of woody and non-woody fibres of shrubs and sedges respectively and the remnants of Sphagnum occupying the spaces of this fibrous network. There is an impression given of large pore space, if one can so say, of peat, and how peat in a dry state can act as an insulator and also how it can serve as an aquifer during freezing periods facilitating the formation of ice lenses in peat. It is important to note here that if the peat is dried to such a degree that the water is evaporated from the water cells, it is extremely difficult to wet it again since the pores in the water cells are so small that the refilling of them with water is virtually impossible because of the surface tension of water. Wetting depends upon inhibitional properties, too.

2. Effect of Moisture on the Insulation Capacity of Peat

Peat has a low co-efficient of heat conduction, which is dependent on its porosity and moisture content.

The moisture content of soil affects strongly the heat capacity. It is generally expressed in calories per degree centigrade (Hodgman, 1963). The specific heat of a dry soil is only about one-fifth of that of water. The specific heat of water is 1.0, that is one calorie is needed to raise the temperature of one gram of water from 14.5° C to 15.5° C. The higher the water content of a soil the higher its specific heat due to raised heat capacity. At the same time the heat conductivity (expressed in cal/sec sq. cm °C cm) (Hodgman, 1963) is raised since the heat conductivity of water (about 0.001348 at 0°C) is higher than that of the air which has been replaced by water in the soils. Thus, saturated cool soil changes in temperature slowly due to high heat capacity. This applies even to artifically dried peat which increases in temperature twice as fast as sand or gravel as compared with slow warming up of wet peat in its natural condition (Ohlson 1964). In natural conditions, dry peat is a good insulator and it has been proven that if its volumetric water content is doubled, its heat conductivity is more than doubled (McFarlane 1969). Table 2 below shows the effect of moisture on soil temperature according to Johnson (1952). It shows clearly that the wetter the soil is the higher are its heat capacity and specific heat and more heat is required to raise its temperature.

Table 2

Effect of Moisture Content of Soil on its Temperature (according to Johnson 1952)

	Moisture content %	Specific heat	Temperature increase in a naturally moist soil by application of one hundred units of heat
Sand	16.96	0.1915	0.005876° C
Gravel	10.45	0.2045	0.006520
Silt	29.16	0.2059	0.005790
Clay	40.7	0.2154	0.004848
Peat	256.5	0.2525	0.002127

There are two major variables which affect the insulating characteristics of soils. One is heat capacity. From the above, it appears that the higher the heat capacity or specific heat of a soil is the better insulator it is initially since it takes some time to warm it up and to start the flow of peat through it. In Lapland, according to measurements carried out by Kaitera and Helenelund (1947), the yearly frost reached a depth of 86 cm in gravel, 71 cm in sand, 57 cm in clay, and 58 cm in peat. The shallow depth of frost in the wetter soils was regarded as a result of its higher heat capacity. An example may explain this phenomenon. The heat conductivity of sand is about 0.00093 (Hodgman 1963) and specific heat about 0.19 (Johnson 1952). The heat conductivity of wet unfrozen peat is 0.00125 (McFarlane 1969) and specific heat 0.96 (McFarlane 1969). According to the heat conductivity values, sand should conduct heat much slower than wet peat but the great difference in the values of specific heat in favour of peat ensure that sandy soil in this case will warm up faster and freeze up faster and deeper than peat because much heat is required to heat the peat itself before any heat flows through it. This means that, if the temperature difference above the soil and in it remains constant, a large portion of heat is conducted rapidly deep into the sand since sand itself heats up fast. In peat the flow of heat from the atmosphere into the peat is faster than into sand but, due to high heat capacity of wet peat, a large amount of heat is required to warm peat near the surface, resulting in a slow penetration of heat into greater depths.

Now the characteristics of peat in its dry state in contrast to wet state conditions can be considered. As has been shown above regardless of high heat conductivity peat even in its wet state is a better insulator than sand or gravel in their normal condition as shown in Table 2. The coefficient of heat conductance of peat depends on the moisture content and also on the porosity. In its wet state peat pores are filled to a great extent with water. Since the heat conductivity of water is high and that of air negligible, dry peat will act as a more capable insulator than wet peat. In this case the low heat conductivity of a dry peat as a reducer of heat transfer through peat overrides the effect of high specific heat of wet peat.

The knowledge of the thermo-physical characteristics of peat is not yet very accurate since the literature gives quite varying values. According to Brown (1966), the heat conductivity of peat is approximately the same as that for snow, which is 0.00017. The heat conductivity of saturated peat is 0.00011 and unsaturated is 0.0007. According to Hodgman (1963) the heat conductivity for compact snow would be 0.00051 and for wet snow 0.00033. There are unexplained discrepancies in these comparisons. However, figures given by McFarlane (1969) are more specific and can be relied upon. According to him, the specific heat of peat can be calculated by assessing the heat capacities of volume fractions of water (C_{vw}), air (C_{va}), and solid matter (C_{vs}) and taking their sum. C_{va} can be omitted because it is so small. Table 3 gives calculated values of specific heat for unfrozen peat with different C_{vw} and C_{vs} values.

Table 3

Calculated Values of Specific Heat for Unfrozen Peat (after McFarlane 1969)

C_{vw} \ C_{vs}	0.10	0.20	0.30
0.5	0.56	0.62	0.68
0.6	0.66	0.72	0.78
0.7	0.76	0.82	0.88
0.8	0.86	0.92	0.98
0.9	0.96	1.02	1.08

This table shows that the specific heat of unfrozen peat is fairly high depending on the moisture content. Peat used for these calculations must contain much water since the specific heat for a peat containing 256.5 per cent of water on a dry weight basis has a specific heat value of 0.2525 (Johnson 1952). This table reveals that temperature change in the peat when it is wet is slow due to high heat capacities.

The table below shows calculated values of thermal conductivity for unfrozen peat (McFarlane 1969).

Table 4

Calculated Values of Thermal Conductivity for Unfrozen Peat
(after McFarlane 1969)

C_{vs} C_{vw}	0.10	0.20	0.30
0.5	0.66	0.72	0.79
0.6	0.79	0.86	0.93
0.7	0.94	1.01	1.09
0.8	1.08	1.17	1.25
0.9	1.25	1.35	1.45

The values in Table 4 are expressed in millicalories/sec/cm^2/cm/^{o}C and are larger than the estimate of Brown (1966) probably because of high water content. In dry porous peat it is quite low (0.00066) and this implies that in much dryer peat it would be much lower. Unfortunately, there are no direct indications of the moisture content of the peat used in the calculations in either of the references cited but from the figures one can conclude that the figures given by Johnson (1952) may be for dry peat with water content somewhere near 200 per cent of dry weight while the figures given by McFarlane imply water contents nearer 600 per cent (or over) of dry weight. In nature water constitutes about 85 to 95 per cent of the wet weight (850 to 950 per cent of dry weight) of peat. Naturally there is a large variation and on the surface under certain conditions the water content may be as low as 250 per cent (of dry weight) and in wet conditions up to several thousand per cent of dry weight. If the heat conductivity of peat in its dry state below 0.00066 down to 0.00033 is compared with that of water which at -10° C is 0.001348 or with that of wet peat, 0.00145, one can understand the great difference in the insultation capabilities of dry peat and wet peat. Also this shows that the low heat conductivity of dry peat acts as a more significant factor in its good insulating capacity than the high heat capacity of wet saturated peat by slowing down the transfer of heat very effectively through a given depth of dry peat. As compared with other soils, for example, sand and gravel, these properties work together so that peat forms an especially good insulator whether it be against heat flow from the atmosphere into peat or the reverse. Thus, a relatively dry peat on the top of muskeg hinders the transfer of heat into the underlying peat. The high heat capacity of the wet underlying peat further slows down the penetration of heat into and out of greater depths. The heat conductivity of even dry solid mineral soils is always considerably higher than that of dry peat. The heat capacity of mineral soils in their wet condition, on the other hand, does not attain values as high as those of peat because they cannot absorb as much moisture as peat can because of its special macro- and microstructure. Thus, the coefficient of heat conductance of peat remains rather low as compared with that of mineral soils, a fact that is of high significance in the thermal exchange between peat and the atmosphere. It acts to preserve ice in peaty soils even when the climate is not very favourable to severe ice conditions in the soils.

In the north where peat never thaws deeper than 10 to 20 inches below the surface, and also in the south where ice may stay in the peat into late summer, the characteristics of frozen peat as compared with those of unfrozen peat are of high significance as to the insulating properties of peat. The specific heat of ice at -10° C is 0.530 and heat conductivity 0.005 (Hodgman 1963). This means that the specific heat of ice is only about half that of water and twice that of peat containing about 250 per cent of water of dry weight. The heat conductivity of ice is four times higher than that of water and about ten times higher than that of dry peat. In general, thermal conductivity of a frozen soil is about four times that of unfrozen soil (McFarlane 1969). However, this is a very general statement and has to be qualified when dealing with peat the water content of which varies greatly. The thermal conductivity is about four times higher only if the peat is really well saturated. In dry peat, there is not enough water to increase its thermal conductivity which remains quite low even when the peat is frozen. Table 5 shows calculated values of thermal conductivity for frozen peat.

Table 5

Calculated Values of Thermal Conductivity for Frozen Peat (McFarlane 1969)

C_{vs} C_{vw}	0.10	.20	0.30
0.5	2.2	2.3	2.4
0.6	2.7	2.8	2.9
0.7	3.3	3.4	3.5
0.8	3.9	4.1	4.3
0.9	4.6	4.8	5.0

These figures indicate that the thermal conductivity of frozen peat is about four times higher than that of unfrozen peat. However, the calculations deal with saturated peat and show higher values than they would show if the peat were dry.

Also there is another complicating factor, the formation of ice lenses and the resulting suction of moisture from the peat adjacent to the crystallization surfaces. This renders the peat quite dry and thus keeps its thermal conductivity low although the pressure exerted by the growing ice lenses on peat will squeeze it into more compact layers resulting in lost pore space and increased thermal conductivity as compared with the pre-frozen condition. There may be some unfrozen water under high pressure between ice lenses which may keep the total heat conductivity lower than it would be were the whole mass to be frozen. Table 6 shows the calculated specific heat values for frozen peat.

Table 6

Calculated Values of Specific Heat for Frozen Peat
(after McFarlane 1969)

C_{vw} \ C_{vs}	0.10	0.20	0.30
0.5	0.29	0.34	0.39
0.6	0.33	0.38	0.44
0.7	0.37	0.42	0.48
0.8	0.42	0.46	0.52
0.9	0.46	0.51	0.56

This table shows that the values of specific heat for frozen peat are only about half of those of unfrozen peat. In this circumstance approximately the same principles apply as when dealing with the complications concerning thermal conductivity of frozen and unfrozen peat.

As a summary of the thermal characteristics of peat dealt with above, the following conclusions can be drawn. In addition to the fact that peat is a better insulator than most mineral soils, there are differences in this capacity depending on its moisture content and physical state. It appears from Tables 4 and 5 that frozen peat is not nearly as good an insulator as is unfrozen peat. This is due to relatively low heat capacity of frozen water (ice) which facilitates rapid change in temperature as compared with unfrozen water in peat. Also the frozen water (ice) of the peat deposits has quite high thermal conductivity as compared with the liquid water in unfrozen peat, a fact which enhances the flow of heat into or out of peat. This, however, is complicated by factors such as formation of ice lenses in peat and resulting dehydration of peat layers between ice lenses. Once ice lenses have been formed, the insulating dehydrated peat layers alternating with them may insulate the ice from the heat of the sun during the following warm season and thus enhance preservation of ice in peat. This subsequently will result in the build-up of ice in the peat and build up of formations such as palsas as will be seen in the following section.

These special physical features of peat together with vegetal cover, especially lichenaceous cover (H-factor) snow and water content help develop features which contribute to the development of airform patterns which in turn imply existence of marked sub-surface ice conditions. In the following section the possible dynamics of the development of the secondary features which associate to provide for airform patterns are advanced as related to the special physical characteristics of peat. In this respect the insulation properties of peat and the characteristics of various groups of muskeg plants and how they affect formation of peat mounds will be considered. Enquiry into effect of differential increment of peat deposits and its bearing on the preservation or deterioration of ice also will be considered.

FORMATION OF VARIOUS OBJECTS CONTRIBUTING TO DEVELOPMENT OF AIRFORM PATTERNS RELATED TO EXISTENCE OF SUB-SURFACE ICE IN MUSKEG

It is reasoned that the physical characteristics of peat, the mode of peat formation, the degree and rate of humification, the differential response of different plant species to varying environmental conditions and the interpreted effect of all these factors on the sub-surface ice factor result in the various secondary microtopographic features appearing on muskeg. These are thought to affect the development of airform pattern.

At this point, when the basic requirements for paludification, basic developmental processes in the pattern evolution and the main biotic and abiotic intereferences in the pattern development have been accounted for, there arises the need to evaluate the details of certain aspects of pattern development. This is required in order to establish the ultimate evidence justifying the use of airform patterns as a prediction method adopted to interpretation of sub-surface ice conditions in muskeg from aerial photographs. This section deals mainly with the genesis of certain formations which occur in muskeg as a product of the factors discussed previously and which are inherent to paludification and to the properties of peat itself. These formations, such as mounds, hummocks, tussocks and peat plateaus are the basic constituents of Marbloid airform pattern and are referred to in the following chapter as object indicators (or form objects). Their formation through the interaction of biotic and abiotic influences is expressed as the present author has interpreted it from the data collected in the field and from aerial photographs.

Interaction of Ice, Vegetation and Peat in Generating Topographic Indices on Muskeg

A common microtopographic feature found in areas of initial muskeg is the hummock (Figure 69). The hummocks have a mineral core which often remains frozen through the summer. In small hummocks the cover thaws, as does the surface of adjacent mineral soil. Depth of thaw is ten inches in Area 1. Regelation has already been recorded as the cause of the phenomenon which now offers two kinds of environment to which muskeg vegetation must adapt. One is comprised of the slightly drier locations on the hummocks and the other is the wet low lying depressions or trenches between these hummocks. If there is no muskeg vegetation in the location, the *Sphagnum cuspidatum* group will invade the depressions along with certain sedges while some *Eriophorum*, *Sphagnum fuscum* and small shrubs will adapt to the higher elevations. The colonization may be accompanied by a process of buckling in the vegetation (initially FI).

This is because of frost lift which initiates differential development whereby hummocks increase in height faster than the depressions. Actually, this happens in both cases. The shearing action of the surface of the water in the depressions tends to mechanically damage the plants and slow down the growth in the depressions. The ice on the surface of the depression exerts a pushing force against the sides of hummocks and squeezes them still higher in the course of time. In larger depressions, the forces acting through the ice on the vegetation may be so strong that hummocks located near each other tend to become contiguous. The differential increase from the onset leads to faster formation and deeper peat on the hummocks. Figure 107 is an example of a hummock which does not stay frozen in the summer (A) and of a larger, better developed hummock (B) which already is large enough to retain ice later. The latter one (B) has already acquired a considerable layer of peat as compared with the smaller one (A). When a hummock has passed the initial increase its further increase is assured and will be faster.

The hummock in Figure 107 begins to indicate presence of H-factor on it (lichen). From this time on, the further development of the hummock will correspond quite closely to that of tussocks and mounds and for this reason their early development will be discussed before going further.

Fig. 107. Hummocks in initial muskeg, Cambridge Bay, Victoria Island, N.W.T.

A - small hummock which thaws in the summer
B - larger hummock which may retain ice throughout the summer.

Tussocks are a result of special growth habit of certain plants. Figure 108 shows a well developed tussock with height of about 26 inches, from a more southerly latitude. This figure shows clearly that the tussock is the effect of growth habit rather than the result of ice thrust. Several plants in the sedge family grow this way. Examples are Carex nigra and Scirpus caespitosus. Figure 76 reveals half tussocky-half hummocky growth of muskeg vegetation in Area 1 in Cambridge Bay, N.W.T. Several species in the sedge family grow in ill-defined tussocks in watery areas as in Figure 76. Figure 108 shows that the dead parts of a tussock may cling to its exterior. But a great portion of the dead material stays inside the tussock and humifies there. When these dead remains humify, they become looser and the base of a large tussock tends to sag and become wider. Adjoining tussocks may join and between themselves present a good location for other muskeg vegetation to colonize, notably Sphagnum mosses.

The formation process of mounds develops whereby the constituents increase in the same way as hummocks. There are, however, peat mounds which are primary formations on initial muskeg. For instance, in a uniform FI area of initial muskeg, there are forces which tend to disrupt homogeneous development and cause differential growth. A strong factor is the underlying frozen mineral terrain. Ice thrust frequently disturbs the surface and breaks the existing peat

Fig. 108. Well developed tussock in senescent Marbloid, Manitoba.

Fig. 109. Massive ice lense under initial Marbloid peat plateau north of Churchill, northern Manitoba. Note the crack in the peat suggesting a possible mode of formation of polygons in peat plateaus. This figure also reveals the effect of ice lenses in the construction of peat plateaus and large mounds.

mat and forms earth mounds. A good example of this is seen in the foreground of Figure 62 where a silty frost boil has pierced the peat mat. Also the different rate of growth of different plant species will sooner or later cause depositional differences in the surface. This is assisted by differential distribution of moisture on the surface due to microtopographical features of the terrain. On the moister areas, Sphagnum cuspidatum (coll.) will thrive but Sphagnum fuscum occupies drier areas. The former will form loose vegetation while the latter will grow somewhat faster and form firmer vegetation. Thus in the wet areas peat in this case will not accumulate as fast as in the dryer areas. This is further enhanced by other plants which grow better on the dryer areas than wetter ones. A notable group is composed of small shrubs as can be seen from those growing on a small hummock in Figure 107. The differential growth once it has been initiated tends to be accentuated later. In Figure 64 mounds can be clearly seen. The depressions are occupied by FI and the vegetation in them is fairly loose. The mounds frequently have EI and EFI cover with firmer vegetation. Here, as well as in the areas of hummocky and tussocky growth, the physical activity of water in the rather open depressions has marked effect as a growth deterrent.

Once the development of hummocks, tussocks and mounds has reached the state shown in Figure 64, 76 and 107 respectively, the course of development of these formations will persist on the same plan but will be more closely tied to the sub-surface ice than before. At this stage the presence of an accumulated thin deposit of peat will have effect. The physical properties of the peat, discussed in the previous section, will impinge on the genesis of peat formation by regulating the build-up of sub-surface ice. In turn peat formation and growth trends of vegetation will be regulated by the sub-surface changes in temperature distribution.

In the case of unpatterned mineral terrain the tussocks, and tussock groups, hummocks or hummock groups and mounds following the stage shown in Figures 64, 76 and 107 will in turn coalesce and form larger expanses of muskeg where the depth of peat is increasing steadily. The formation of first, irregular and later, regular strings of peat mounds ensues and contributes to Microreticuloid pattern. Initiation of this is shown in Figure 112.

The state in Figure 70 is conducive to a formation of initial and featureless peat plateaus which soon will acquire polygonal or Microreticuloid pattern. In flat areas when peat is thick enough, polygons are formed in a peat plateau of this type as is seen in Figures 74 and 75. Microreticuloid pattern is dominant in gently sloping areas as in Figures 66 and 112.

Peat becomes established on mineral terrain having both initial and later stages of developing pattern. Examples of initial peat plateaus with transgressed polygonal and other patterns are shown in Figures 67 and 73, for instance. It is notable that ice is preserved more persistently and in greater depth and quantity in peat plateaus of these dimensions than would be the case if the organic overburden were lacking. Further south though ice is encountered in peat of peat plateaus it is not found in the spaces between them, not even where there is peat in these clefts. A small developing mound which originated as a hummock, tussock, or a small mound, once optimum in size develops in accordance with related properties of peat.

In areas comparable with that in Figures 70 and 112 the following processes happen to different parts of the developing peat ridges and plateaus. If the water regime is as high as it is in these areas (photos were taken in September just before the onset of continuous sub-freezing temperatures), the water in the depressions, small mounds, and plateaus will freeze rapidly. If the freezing is relatively slow in the peat, ice lenses will be formed. This means that the peat will be in layers and quite dry because the water is drawn from it to satisfy the need for water at the crystallization surfaces of the ice lenses. Also more water is drawn from the active layer below the peat. This means that the mounds and peat plateaus will grow in height at the expense of the water added to the deposit from the ground. Also, the peat itself will be relatively dry. The difference in height of the mounds and the depressions is accentuated since the peat in the depression is highly saturated and loose in structure as compared with the peat in the mounds. Some of the water from the depressions may be drawn into the mounds to augment ice lens formation. The entire set of processes will tend to increase height differentials across the terrain.

By the time the whole surface is frozen, the snow cover will play a contributing role. If the snow covers everything, it will insulate the soil from the effect of cold climate since, according to earlier conclusion, the heat conductivity of snow is low. In many cases, however, the snow is often blown from the mounds and they are left exposed. If now there still were some unfrozen peat in the mound it would freeze soon because the heat conductivity of frozen peat is quite high. However, the surface peat may become very dry through sublimation and effect of winds.

This sequence of behaviour will affect the fate of the mound or peat plateau in the following spring. If the mound has gained enough in height and has enough peat in it and if the summer is not warmer than usual, even the relatively small mounds and plateaus will begin to harbour an ice core. This is jointly because of moisture conditions and insulation capacity of peat. If the tops of the mounds are not already exposed with warmer weather in the spring, they will be the first to be exposed. This will cause fast drying up of the surface peat. As temperature increases, the rest of the snow will thaw and the water will gather in the depressions which will stay wet although the mounds and small plateaus which have gained height by the growth of ice lenses in them, will stay dry. The wet peat in the depressions will warm up very slowly due to the high heat capacity of water and the thaw will proceed through the wet peat more slowly than through the adjacent mineral soil which cannot retain as much water as peat having thus a lower heat capacity than the peat. Also the lower heat conductivity of the wet peat intensifies the contrast. However, the ice eventually thaws in the shallow wet peat of the depressions. It will be preserved in the mounds where the exposing agent has thawed and dryed the surficial peat before the heat had time to penetrate deeply. By the time when the weather gets very warm, there is a layer of dry peat. Only four to eight inches is enough to insulate the underlying peat from further energy absorption. Also even the deeper, though more compact zone of peat is relatively dry as a result of ice lensing. By high insulation effect this relatively thin dry peat layer will preserve ice throughout the summer in the same way as blocks of ice are preserved by dry sawdust. In the small initial relatively shallow peat plateaus in the north, the ice lenses are neither as plentiful nor as massive as those encountered in the deeper peat deposits of the well-developed Marbloid further south. With the repetition of the cycle described above there will be a considerable accumulation of ice in the peat. Figure 109 is an example of a massive ice lens in young Marbloid.

There is a limit to increase in height of a single small mound. As the peat increases in depth in the mound it also increases in the depressions and if the mounds are not very large to start with, it will not take long before adjacent ones join and form initial peat plateaus like those in Figure 70. Also the peat mounds developed on sorted circles and steps or stripes coalesce to a certain extent and when the peat deposits are deeper, the depressions between adjacent mounds become correspondingly shallower and dryer than in the beginning of paludification but still generally stay lower than the original centres. In large areas polygons are transposed into muskeg. In the case of channel type polygons, the drier centre paludifies faster than the wet trenches between two polygons in a manner similar to paludification of areas with mounds formed in the centres of sorted circles. In the latter case the process is on a larger scale and the result is a wide area covered with peat plateaus bearing polygonal pattern.

Often polygons are formed in initial peat plateaus without benefit of initial pattern in the mineral sublayer. (Figures 74 and 75). Here small peat plateaus were formed by regelation in mounds and by their amalgamation to form plateaus. The dry surface of peat insulated the ice core and then the peat layers cracked either by contraction forces during seasonal climatic variations or by other forces which form polygons in the soils on which the investigators cannot agree yet (cf. Washburn 1956). Note the shearing of the peat in the crack between two adjacent polygons and how the raw peat is exposed. (Figure 75). The peat appears quite dry and uncompacted in the trench implying good insulating properties.

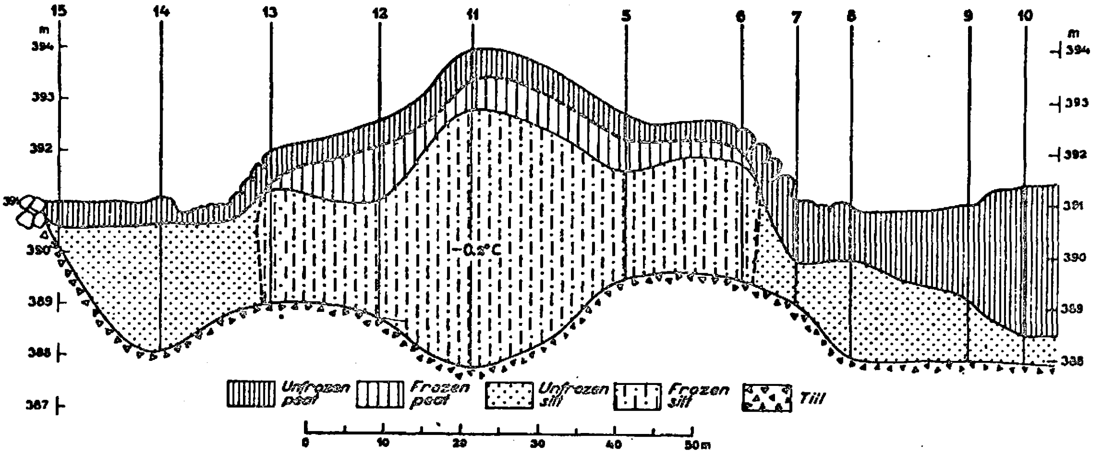
Palsa is a topographic phenomenon peculiar to muskeg. The expression "palsa" is derived from Finnish and means a large peat mound the width of which varies from about 20 feet (6 m) up to 1000 feet (300 m), and the height from 2 to 3 feet (50 cm to 1 m) up to 25 feet (7.5 m). There are two kinds of palsas. One has a frozen mineral terrain core under a rather deep deposit of peat which also remains frozen (Salmi 1968). Figure 110 shows a diagram of this type of palsa.

Another type consists of a deep mound of peat which lies in a depression in the mineral soil and rises above the level of the muskeg (Salmi 1968). The peat thaws only on the surface while the core remains frozen. In Finland, it has been noticed that in this case the underlying mineral soil is unfrozen or frozen only a few feet below the peat. Figure 111 shows a diagram of a palsa of this type. This type seems to be more common than the one with a mineral

Fig. 110. Diagram of a palsa with frozen mineral soil core in Finnish Lapland (after Salmi 1968).

Fig. 111. Diagram of a palsa with frozen peat core in Finnish Lapland (after Salmi 1968).

1 - seasonally frozen peat.
2 - permanently frozen peat.
3 - alternating layers of ice and frozen peat.
4 - fine sand, silt and clay.
5 - frozen silt with layers of ice.
6 - till.
7 - large stones and/or bedrock.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388
387
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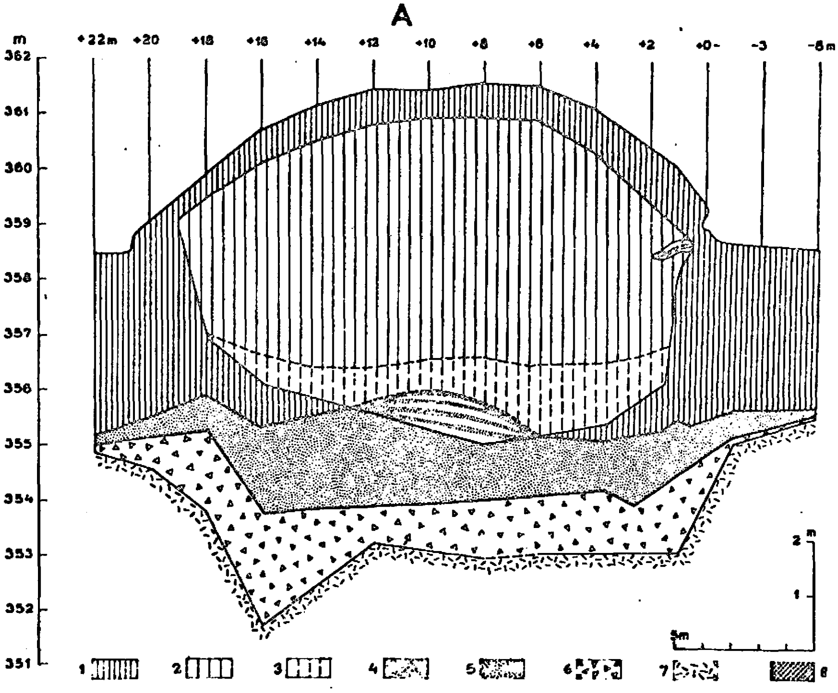
Frozen peat
Unfrozen silt
Frozen silt
Till
0
10
20
30
40
50 m


A
m
362
361
360
359
358
357
356
355
354
353
352
351
+22 m
+20
+18
+16
+14
+12
+10
+8
+6
+4
+2
+0
-3
-6 m
2 m
1
5m
1
2
3
4
5
6
7
8

soil core.

The author maintains that the regelation which makes the mounds can in some locations result in palsa formations. A palsa is composed of alternating layers of quite clear ice and layers of peat (Salmi 1968). Pollen studies reveal that a palsa is not a result of any migration of peat since the pollen profiles from a palsa and from the adjacent unfrozen peat deposits do not show any disturbances in the spectrum (Ruuhijärvi 1960). Also the peat profile is continuous from the surrounding areas into the palsa with the only difference that in a palsa peat is divided into layers of peat and ice. Age determinations have revealed that in palsas layers over three meters thick correspond to layers only about 10 cm thick in the surroundings showing that the growth in thickness of palsas is due to accumulation of ice lenses rather than to vegetal growth (Salmi 1968). The surface peat in a palsa is fairly dry and in many cases composed mainly of remnants of shrubs and secondarily of Sphagnum mosses. The surface vegetation of a typical palsa is often shrubs, lichen and Sphagnum, (EHI or HEI). A palsa is therefore a large scale example of the effect of dry peat on preservation of ice and on the interaction of ice and peat to produce object indicators pertinent to Marbloid airform pattern. Figures 84 and 85 are examples of palsas in mature Marbloid and initial Marbloid respectively. These figures also show how palsas join to form peat plateaus.

Some authors have expressed uncertainty about when a palsa becomes a peat plateau. In a way these two are the same phenomenon because the peat plateau may have been formed from palsas through coalescence. Thus it can be stated that a palsa is a definite, relatively small formation with limited extent, generally with a definite form, and distinguishable as a single formation. A peat plateau, on the other hand, is a large formation with either regular or irregular borders and may extend over several square miles of terrain. It also may show a considerable variation in vegetal cover due to its large area. Peat plateaus generally form networks of plateaus of deposits deeper than those in the meshes of this network.

For the initial peat plateaus, like those in Area 1 and Flight Line 2, development ensues associated more with the ice in the peat than during early development of its components, the mounds. Other strong factors are the hydrology and differential growth exhibited by various groups of muskeg vegetation as they respond differently to various local conditions. These conditions on the other hand are functions of peat and ice and water, so that the whole development, in fact, is a complicated feedback system.

In contrast to the situation for typical and also senescent Marbloid, the initial peat plateaus do not cover the total muskeg area but large areas remain lower lying with shallower peat and do not form an actual part of a peat plateau. However, they are an integral part of the airform pattern. Firstly large areas acquire Microreticuloid pattern early in the development as Figure 66, among others from Flight Line 1, shows.

The development of Reticuloid pattern is greatly dependent on the action of ice, on the differential growth of muskeg vegetation and on the general hydrology. Figure 76 shows a typical example of the initial Microreticuloid pattern. Here one can see how the small mounds and hummocks and occasional tussocks have started to group. What is significant in the grouping is that they form ridges which are parallel to each other. In Figure 112 there is quite a well developed ridge. Ridges like this probably start as slight promontories along the water's edge where peat has been pushed up by the ice of the wider open surface of the pond. At the same time, there will be intermittent but weaker thrust exerted by smaller open pools behind the initial ridge formation. This results in an initiation of a ridge with higher and lower places. Later the differential growth of plants on the higher ridge, as contrasted to the lower lying depressions in this initial state, further tends to accentuate the height differences. Still later the ice, as insulated by thicker peat, will cause the ridge to grow thicker and wider and also join with some adjacent ridges to form larger ones. Spaces between the ridges remain generally wet and display predominantly FI (sedge-moss) cover

Fig. 112. Initial Microreticuloid ridges in Cambridge Bay, Victoria Island, N.W.T. Dominating cover is FI.

Fig. 113. Low altitude (200') oblique view of Marbloid in northern Manitoba.

A - small palsa with EH cover and frozen peat core.

B - peat plateau with EH understory and very stunted B class trees (Picea mariana).

C - areas of regressive permafrost development with FI cover and unfrozen peat and in some locations even unfrozen clay deposits under peat.

D - thawing edges of peat plateaus.


D
A
C
D
B
C

while the ridges quite early acquire EFI, EH and HE cover. It is notable that if there is any gradient, the ridges tend to be parallel with each other and perpendicular to the gradient, that is against the flow of water thus hindering drainage. This is especially clear in ombrogenic raised bogs as revealed by Figure 102 and 127. This tendency is encountered both in the north and farther south in the typical Marbloid area. It can be observed in Figure 66 as well as in Figures 88 and 103, high altitude views of different stages of the Marbloid and Reticuloid and Terrazoid.

There are different hypotheses to explain the tendency but none of them is satisfactory alone. According to the author, in a major number of cases this tendency commences in the initial muskeg by combination of the following processes. In an extensive and featureless, gently sloping area, water may flow down the slope without always following the same rills but changing its route from time to time and even flowing in a sheet. Small obstacles then will collect material carried with water and ripple-like elongated accumulations of debris are formed. These areas are more likely to support vegetation initially than are the more barren spaces between them. Thus small, more or less parallel ridge formations will be formed. Paludification will ensue with increasing vigour and soon narrow, tortuous ridges will be seen on the slope roughly perpendicular to the water flow. They will slow down the already poor drainage and the land between them will start paludifying resulting in muskeg with ridges (Figure 66).

Another possibility is the solifluction in existing thin layers of peat. A large uniform area of muskeg with FI cover and frost underneath would form ridges ("wrinkles") perpendicularly to the water flow as the peat, which has thawed in the spring and rests on the still frozen deeper intermittent deposits is torn by solifluction. The gravitational pull down the slope will make the surface mat slide on the wet and slippery surface of the frozen peat layer causing the surface mat to tear into parallel strips which would be more or less perpendicular to gradient. It is more probable that this and the first type of formation may together form this pattern initially. To be able to accurately analyze the initial genesis requires extensive pollen and other microfossil studies to determine possible disturbances in the peat layers. Whatever the initial genesis, once the ridges are formed and have gained some thickness, the sub-surface ice is preserved in the peat as explained in the beginning of this section and by reason of the insulating capacities of peat. The initial Microreticuloid pattern in many cases develops into Macroreticuloid just by growing larger so that adjacent ridges by growing wider will join to form larger ridges. The spaces between the ridges are maintained mostly because the ice enhances the vertical growth of the ridges and partly also because in the environment of the ridges the peat tends to grow faster than in the depressions as long as the availability of moisture is sufficiently high. One can see how this is possible if one keeps in mind how Salmi (1968) found that in ice laden peat deposits like palsas, a 3 metre deep layer of ice and peat actually corresponded to only 10 cm of actual peat in the adjacent unfrozen peat. Figure 109 gives evidence of the existence of large amounts of ice in the peat of Marbloid area.

The parallel ridge Microreticuloid in areas comprising a mixture of Marbloid and Reticuloid is secondary on the large and regressive peat plateaus which used to be larger Marbloid plateaus. In Figure 103 the Microreticuloid pattern, which shows parallel ridges as in location (I), is secondary and a result of solifluction on the sloping peat plateau. The Microreticuloid and Macroreticuloid in Area (H) are secondary too. Only Macroreticuloid of the type seen in locations (C) is primary. The last mentioned secondary Macroreticuloid patterns are due to recessive development of the Marbloid peat plateaus due to warmer climate. This development is caused by accumulation of water in depressions where it is retained in the absence of suitable drainage channels. The high heat capacity of these accumulations of water will cause underlying permafrost to thaw. Thaw ponds are formed which thus transform the appearance of a former peat plateau of typical Marbloid into irregular Macroreticuloid pattern.

Maturing of Initial Peat Plateaus to Form Typical Marbloid Peat Plateaus

The discussion of the development of a peat plateau was left at the stage shown in Figure 70; in other words, at the early stage of peat plateau. Following this stage, development is closely associated with ice and differential increase as was projected in connection with the genesis of Reticuloid features.

Initial peat plateaus now known to reflect the underlying pattern of the mineral terrain thus have irregular microtopography. The transgressed form of the mineral terrain features to a great extent affects the drainage conditions of the plateau and this, in its turn, affects the growth of muskeg vegetation and indirectly the preservation of ice in the peat. As has been seen, the typical Marbloid peat plateau is not a smooth, even, continuous plateau but is dissected with drainage channels of various sizes and is ornamented with mounds, hollows and small narrow channels. These features appear in Figures 36 to 44. The peat plateau as a formation in its own right is a result of various processes. These small formations on it are a reflection of the similar processes which originated in the muskeg in its initial state.

Figure 70 shows a young peat plateau with its surface.

This irregularity is retained through its development and leads to formation of small channels and to shifting of mounds. The differential growth, as accentuated by ice in the peat, is the major factor in the advanced development of muskeg towards mature Marbloid and towards its senescence. In terms of small features it maintains the smaller scale rough topography. On a plateau the water originating from rain as well as from thaw accumulates in small depressions, which thus remain quite wet. As is now known, certain muskeg plants favour these wet places over drier ones which harbour other plants. When the moisture differences between these two environments are not too accentuated, the dryer areas increase faster than the wet ones because they have a more vigorous vegetal growth but are not dry enough for accelerated humification and thus accumulate peat fast. The insulating capacities of peat, the effect of the snow on the heat balances in the mounds and the depressions, and ensuing severe ice conditions also accentuate the faster growth of the mounds and ridges. If this differential growth remains small in scale there are limits to it imposed by biotic factors. It is reasonable to suggest that when the mounds or ridges attain heights which are large enough, say one to two feet in the conditions seen in Figure 70 (the height in this respect is dependent on the water regime), the mounds acquire more and more small shrubs and lichen on them (H-factor) at the expense of <u>Sphagnum</u> mosses and their growth in height decreases. Furthermore the increased dryness enhances bacterial and fungal activity in the peat which thus humifies relatively fast if compared with rate of humification in the adjacent depressions. Now the growth of Sphagnum plants, and thus also the formation of peat, goes on in the depressions at a slightly higher rate than in the dry higher areas. This means that the depressions slowly overtake the mounds. When the former depressions and the mounds are at about the same level, the water starts accumulating on the former mound areas. This also accounts for the fact that very often there are lichens on muskeg growing in slight depressions and because of these relics not all the lichenaceous growth is concentrated on high and dry areas. When these newly formed depressions have continuously free water in them, the lichens and also the shrubs tend to die off slowly. At the same time the water in them appears greenish and slimy. This is due to certain algae which thrive in this kind of location in muskeg. Furthermore, these algae, frequently sphagnophagous, hinder the regrowth of Sphagnum for a considerable length of time. These algae chiefly belong to in the family Desmidiacea. In addition to this group there are also representatives from Cyanophyceae and Diatomae (Kivinen 1948). By this stage the former depressions have acquired a cover which is common on mounds and ridges and the cycle may begin again. In some cases the depressions are also started by very small and local extremely wet conditions, for example, around the stems of small dead trees where rain water running from the tree trunks into the muskeg creates a local wet spot where sphagnophagous algae start displacing the Sphagnum, forming a slimy hollow which then spreads into the surroundings.

The stretching caused by the growing ice lenses in the peat mounds causes shearing of the muskeg surface if the growth of the peat is not fast enough to accommodate the stretching. Resulting separations tend to take place adjacent to the mounds and occasionally on the mounds, and water accumulates in them. This in turn leads to wet local conditions, decelerated accumulation, and formation of new depressions in the manner described above.

The initial peat plateaus, like that in Figure 70, develop in the manner described above towards maturity. They continue preserving some of the features shown in the initial state. By comparing Figure 70 with Figures 39 and 40 the basic similarity of the surface features can be seen. It should be observed here that the alternate growth of depressions and mounds is not the rule everywhere. Often shift of location is gradual and eccentric. One side of a mound starts lagging and the other side invades the nearby depressions. Thus the preservation of transgressed mineral terrain features and others which show so clearly in Figures 91 and 93, is explained. In some cases there may be no shifting at all as peat profiles testify. To obtain more accurate evidence would require a large amount of detailed pollen and peat investigations beyond the scope of this work.

It is also noticeable that the initial muskeg as well as the mature Marbloid and other airform patterns show occurrence of peat plateaus containing fairly large lower and wetter areas. The preservation and development of these areas without incorporation into a plateau system is dependent on local hydrology and the muskeg vegetation to a great extent.

The smallest drainage channels in the typical Marbloid peat plateau have been derived in many cases from the original depressions between soil circles, steps, stripes and polygons as figures showing these formations under paludification in the north illustrate (Figure 50, 51, 57, 68 and 75, etc.). Many of these depressions will be covered with peat in the course of the development of a peat plateau but an earlier account and Figures 42, 90 and 91 reveal, quite a few of them remain open and act as drainage channels for the peat plateaus. In these narrow channels, the surface of the permafrost table is lower than in the adjacent peat plateaus in absolute elevation and in wider channels with more FI cover like the one in Figure 38 there is no permafrost in the channel. The same holds true also for smaller confined areas of FI found in typical Marbloid. As an example in the area shown in Figure 113, there was no ice in area C with predominantly FI cover. The depth of peat in it was 10 feet (3 m) with clay (also unfrozen) underlying it. On the other hand, the small palsa (A) and the peat plateau (C) with HE and BHE cover have permanently frozen cores. The permafrost table in this case was only about one foot below the surface. Some of these FI areas within typical Marbloid were formed initially in young muskeg and some of them have been formed later.

Through the reasoning it is plausible to suggest that in the case of an initial FI area and in its preservation, the hydrology and the differential growth together have played a prominent role. In initial muskeg many of the depressions between polygons and other mineral soil formations are covered by peat but quite a few of them are not. These narrow channels will tend to stay open to provide the forming peat plateaus with drainage channels. In the case of a narrow channel in a strongly developing peat plateau the increased amount of water to be drained from the ever-widening peat plateaus will tend to fill the depression with water for longer periods of time since most of the paludified areas are almost flat and thus naturally poorly drained. As a result of the water in the channel paludification is retarded in it and also along its edges. Eventually this retardation gradually results in a widening channel with predominantly FI cover. At the same time peat is accumulating in this channel too but more slowly than in the adjacent peat plateaus which slowly grow above the FI channel and leave it with a shallower peat deposit. In areas of discontinuous permafrost, these FI areas do not generally contain ice as contrasted with the plateaus surrounding them.

There are also large FI areas even in initial muskeg which will retain this cover indefinitely regardless of the ice factors. This in most cases is a result of excess water from the adjacent lands which are higher in elevation. Thus an area, like the one seen in Figure 62, could retain its FI cover if the surrounding higher areas would paludify and form peat plateaus and later would act as aquifers to this lower lying area. The same may happen in the case shown by Figure 63. Here the narrow area which has paludified initially in the centre and also in the background will act later as a drainage channel and tend to retain FI and later DFI when drainage intensifies and DFI-FI drainage channels seen in Figures 36 and 37 form features of typical Marbloid. Figure 83 further reveals the widening of a polygonal fissure system into a drainage channel by retaining water and by the erosion of the banks by high winds.

Many FI and DFI drainage channels are also formed in typical Marbloid by the joining up of polygonal fissures. Figure 60 is an example of this as seen from the air near Chesnaye. The polygonal fissures form parallel drainage channels oriented along the gradient as marked with arrows.

At this stage of the discussion the relation of H-factor to the distribution of ice in peat should be presented. There has been a description of this factor earlier and in several connections this factor when in abundance has been referred to as an important feature symbolizing sub-surface ice conditions of muskeg. While there certainly is need for discretion and for simultaneously accounting for other factors, the presence of H-factor can, nevertheless, be used as an indicator of existence of possible ice in peat. This is based on the simple observation that lichens such as <u>Cladonia</u> spp. generally do favour drier habitats to wet ones (Ahmadjian 1967). This means that lichens grow abundantly on mineral terrain and also on muskeg when the surface of muskeg is dry enough. Radforth who coined the expression "H-factor" never insisted that muskeg with lichen on it must inevitably contain ice. It is common to see lichen on muskeg far south of the southern limit of permafrost and it would show poor judgment were the observer to deduce from this that there must be permafrost under the location of lichens or that there will be permafrost in future in those locations because of lichens. But the observer would not show poor judgment were he to suspect the lingering of ice under cover with lichen in peat even south of permafrost areas if the lichens are in abundance. There are numerous references to this effect in the literature by many authors who have mentioned the lingering of the seasonal frost in the peat under lichenaceous (H-factor) cover. Thus, for instance, Auer mentions this about some Canadian bogs as early as 1928 (Auer 1928). It is referred to by Radforth (1954). During the present study much attention was paid to this phenomenon and it was noticed that ice tends to linger late into the summer under lichenaceous cover as contrasted to its early disappearance from under other cover types in areas south of permafrost such as various parts of Newfoundland, Manitoba and Ontario. It is easily seen that in peaty areas lichen cover is considerably more prominent in areas with permafrost than in areas without it and that where HE abounds, sub-surface ice is predictable.

What are the reasons for the apparent favouring of H-cover for permafrost or any sub-surface frost areas? First, this favouritism is only apparent. All is based on the fact that lichens grow in relatively dry locations. If, for instance, one considers Figures 79, 71 and 75 in the initial muskeg area, and Figures 41 and 42 in the typical Marbloid area, or Figures 93, 94 and 100 in areas of senescent Marbloid, one can readily see that lichens grow on the highest elevations of muskeg in each location. The low-lying wet areas with predominantly FI cover are devoid of lichenaceous growth. There are of course exceptions with lichens growing in small wet depressions due to differential growth of the surface of muskeg but in this case they are in areas of regressive development of muskeg as explained earlier in this section. This confirms that the appearance of H on muskeg arises initially only on suitable arid microsites in this generally wet environment. These dry locations are offered by the formation of mounds following the interaction of ice and differential growth of other types of muskeg vegetation.

Studies of the albedo of lichen cover show that it reflects about 13.55 per cent of solar radiation in the range of 0.3-2.0 in treeless areas. Treed lichen areas reflected 11.67%, spruce bog 6.52%, and Sphagnum muskeg, 9.78%, and a closed forest about 11.13% of the radiation (I. C. Jackson 1959). Thus lichen covered muskeg shows a high albedo. However, Brown (1966) maintains that Sphagnum and lichen covered muskeg keep the permafrost table at about the same level. In many cases this may be true since Sphagnum moss acts like a sponge under favourable evaporation conditions and imbibes water from deeper regions with which it is in direct physical contact through its own stems and thus efficiently cools down the peat layer. Lichen does not do this as efficiently since it is not in direct physical contact with the deeper layers but still even it with rapid evaporation from near the surface helps in lowering the temperature. Thus lichen with its strong albedo and Sphagnum with its marked assistance to evaporation promote cool conditions and favour the presence of ice in the peat. This high albedo of lichen explains how ice is still preserved quite well even in lichen-covered mounds in which the formation of peat has slowed down and where peat has humified more strongly than in the surrounding areas causing the insulating capacity of the ensuing denser peat to decrease. In some phase in the development, the lichens are favourable to formation of ice in peat but due to their slow growth and resulting retardation of peat formation they, at some point, become detrimental to the build-up of ice. The differential growth of other muskeg vegetation, however, is conducive to the preservation of ice on a larger scale in large peat plateaus as was described earlier.

There is a definite difference in the ice preservation capacities between lichen and Sphagnum cover on one hand and FI cover on the other. Studies have shown that FI cover evaporates more than the other two but regardless of that the permafrost table under FI cover is low due to the low insulating values of this cover and type of peat formed under it (Brown 1966).

Also in areas of continuous permafrost, FI areas are generally frozen because the conditions are just too rigorous and soil freezes and stays frozen regardless of its properties. But, in the zone of discontinuous permafrost, ice very often tends to concentrate in peaty soils (Brown 1965 and 1966) because of various factors characteristic of peat as has been discussed in the present work. Also in the peaty soils, it tends to be discontinuous. As has been seen in the typical Marbloid, peat is frozen in the peat plateaus and in the palsas although it quite commonly stays unfrozen in the FI areas which, in many cases, also act as drainage channels. The discontinuous distribution of ice in this zone on a larger scale depends on the warmer climate which still can favour permanently frozen ground but where the heat balance is very easily upset either in favour of ice or to its detriment. Discontinuity of ice depends thus to a great extent on the characteristics of the soil in different locations. In the discontinuous zone of permafrost the interaction of water content and the insulation capacities of the peat thus will play an important role in the preservation of ice and in the forming of airform patterns. In areas where there are as yet no trees on muskeg as in Areas 2 and 3, one can already, in a few cases, see degeneration of ground ice but it is not yet prominent here, and shows only on the ground and not from the air. Figure 42 shows examples of an early stage of degeneration. It indicates the initial deterioration of the ice between polygons to form narrow drainage channels. This thaw is due partly to erosion caused by running water and partly to the effect of standing water in the cracks on the ice beneath. Another example of this is Figure 82, where thaw lakes have emptied or are being emptied.

Here the thawing of the ice is caused mainly by the moderating effect of a large water body on the temperatures. This results in thaw near the lake and in the formation of better drainage channels to be followed by complete drainage of these lakes. In some cases these empty or half empty lake beds paludify and form initially FI areas with corresponding sedge-dominated peat with high water regime. Also the growing in of thaw lakes, as in Figure 44, forms FI areas. FI channels in Figure 38, and an extremely poorly drained area of depressed centre polygons in Figure 41, also represent FI areas with high water regime and poorly developed ice in them. All these are features of typical Marbloid.

The differences in the ice conditions between Marbloid peat plateaus and these other features can be explained by the effect of moisture on peat and on the insulating properties of peat. The discussion earlier shows trends towards development of an environment suitable for the preservation of ice. The FI areas, on the other hand, are wet and low-lying with peat which does not have the same structure as that of plateaus. The high permanent water regime tends to eliminate extreme temperatures in these wet areas. The FI areas have mostly sedge peat with lower insulating values than Sphagnum peat permitting deeper thaw in the summer and thus disappearance of ice. This fact that FI areas have a low permafrost table as compared with lichen-Sphagnum areas has been recorded by Brown (1963) and Radforth (1954). Auer, as early as 1927, noticed the preservation of ice under HE (lichen-shrub) cover long into summer as opposed to FI (sedge) cover.

In considering the development of the peat plateaus from the initial stage on Area 1 to the typical Marbloid stage in Areas 2 and 3, one could claim that in the latter case the peat plateaus have reached their largest extent since up to this stage the peat plateaus have been growing and FI areas have been diminishing. From this area south the climate becomes more favourable and the regressive development in permafrost obtains. The Marbloid starts losing its typical features and becomes tree-covered; thaw lakes become less numerous and FI areas along with B and A cover become more extensive. In typical Marbloid, the permafrost table in the summer is only about 12 to 20 inches below the surface as Figure 49 shows in Chesnaye on a Marbloid peat plateau. In typical Marbloid, and further north, the ice lenses in the peat may sometimes become quite massive and it is quite understandable that the landscape will change its form drastically when this massive ice, of which Figure 109, near Churchill is an example, will start thawing.

Where trees appear on Marbloid thawing associates to change its appearance. Ice tends to melt first on the southern slopes of the peat plateaus. Thus, for example in Figure 114, the ice has regressed considerably at the place marked (A) which is the south-facing slope of the peat plateau

(B) in the background. Also quite early the ice starts regressing in the channels of the channel-type polygons as in those marked with (C) in Figure 114. The reason for this is that the peat in the centre of the polygons is dryer and has better insulating capacities than that in the depressions. Figure 115 reveals that the permafrost table under polygon-covered peat plateaus follows the surface contours and is higher in the centres than in the depressions. In the older Marbloid, (cf. Figure 114), the stagnant water or slowly flowing water enhances deeper thaw in the depressions and the waste of permafrost in them because of the higher heat conductivity and other related factors of the peat in the depressions. As a result of the thawing out of the ice in the peat plateaus, the edges slump and break down and actually sink deeper than the surrounding FI areas in many cases as can be seen in Figures 86 and 88 and 116. In Figure 116, in places marked with (A) the broken down edges of peat plateau (B) show clearly with free water in them. These areas now have greatly diminished insulating capacities as compared with the peat on the plateaus and the breaking down of a plateau in many cases proceeds very quickly. Free water collects in the areas too and this favours the growth of sedges over that of Sphagnum with resulting large FI areas with lowered insulating capacities and lowered potentials for preservation of ice. In Figures 114 and 116 in places (D) and (C) respectively, there are formations

Fig. 114. Marbloid under regressive conditions. Low altitude (150') oblique view, Manitoba.

A - markedly slumped peat plateau resulting from the thawing of permafrost in peat.

B - old Marbloid peat plateau with signs of regressive development of permafrost.

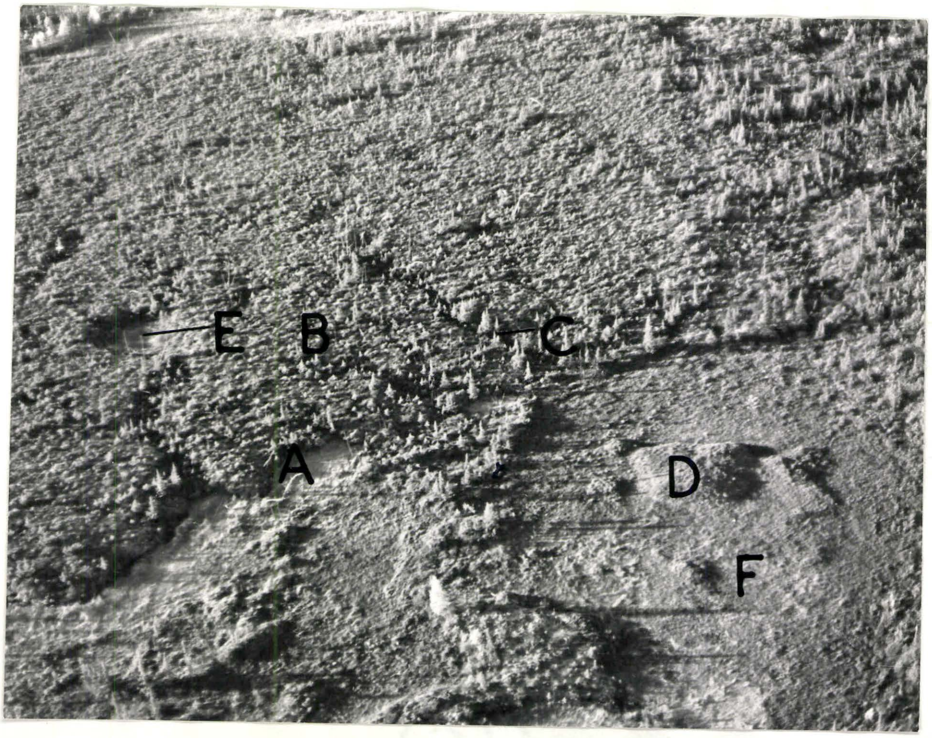
C - enlarged and deepened trench between ice wedge polygons.

D - small palsa.

E - slumping of the surface of peat plateau due to localized waste of permafrost (thermokarst).

F - FI area with unfrozen peat.

Fig. 115. Illustration of permafrost table (white line) under ice wedge polygons in typical Marbloid condition near Churchill, northern Manitoba. Predominant cover in this location is HE (lichens and Sphagnum mosses).


E
B
C
A
D
F

which are to be regarded as palsas. The question which arises here is whether these palsas are formative or degenerative. If one, however, takes into consideration other evidence of the regressive development of sub-surface ice, it is a reasonable hypothesis that these palsas are undergoing deterioration. To be sure of this, pollen profiles and carbon (C14) datings would be required from these formations.

The trees which begin to appear in this type of old Marbloid, or on treed Terrazoid, grow mainly in the depressions between adjacent polygons where the ice is not as near the surface as it is in the centres of the polygons. Further south the situation changes somewhat where the depressions get increasingly wider and wetter and start forming FI areas which, in most cases, are too wet for trees to exist. Here when the permafrost table has been lowered also in the peat plateau themselves, the trees start growing on them too. The tree growth on the plateaus is conducive to making them drier than before due to higher transpiration. This kind of pumping action of trees, especially of deciduous trees, has been noticed in many cases to check advancing paludification (Heikurainen 1960). The dryer peat will humify faster but the increase in the insulation capacity of this dry peat and the interception of solar radiation by cover will compensate for the loss of insulating capacity resulting from higher humification. Thus ice will persist

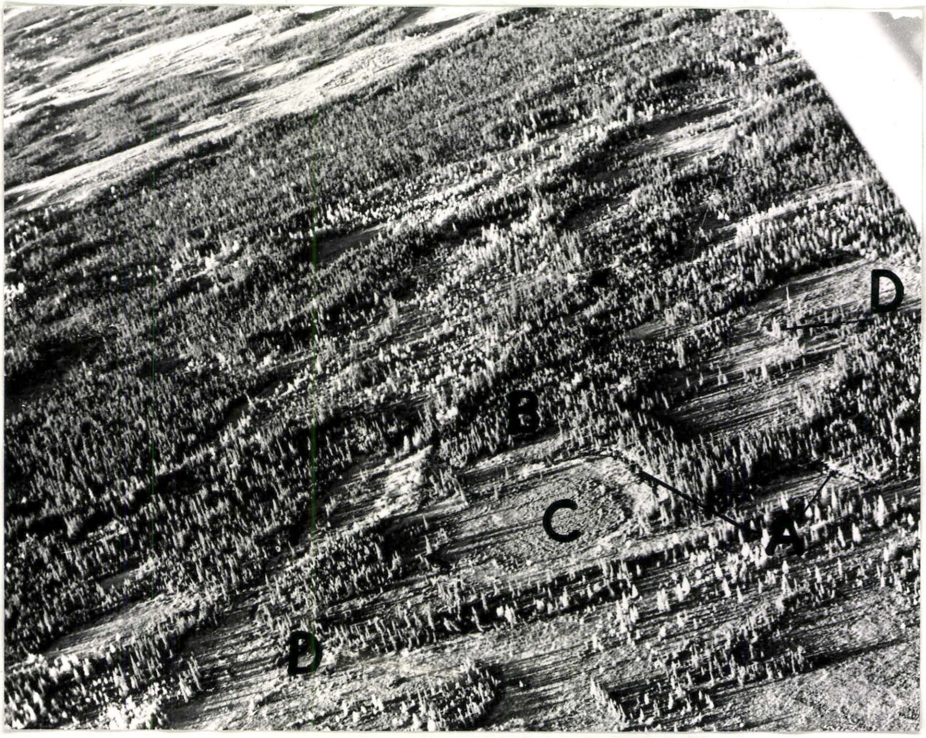


Fig. 116. Low altitude (1500') oblique view of senescent Marbloid near Ilford in northern Manitoba, showing disappearance of permafrost.

A - disintegrated edge of peat plateau displaying free water.
B - senescent peat plateau with BEH cover.
C - medium sized palsa with EH cover.
D - angularity of wasted peat plateaus indicating regressive development of permafrost.

in these islands of BHE, AHE, BEI and AEI cover constituting senescent Marbloid and treed Terrazoid. Good examples of this condition, where ice is still preserved due to the factors mentioned, are in Figures 95, 97. Formation of peat proceeds rather rapidly on these plateaus. Because ice is wasted slowly in the areas near Norway House the growth of peat in the plateaus compensates for the consolidation of peat layers where the existing ice disappears slowly so that there will not be any marked signs of this thaw in the form of slumped down edges of peat plateaus with exposed raw peat profiles as in Figures 114 and 116. It is interesting to notice that these peat plateaus may preserve their identity far south of the southern limits of permafrost as do those in Figure 17. It has been claimed that these formations are initial ombrogenic areas in Areas 15-16 (Figure 17) (Sjörs 1959). The author, however, suggests that they are remnants of old Marbloid peat plateaus, but to be sure of this more detailed ground studies would be required.

There is plenty of evidence supporting preservation of ice in peat mounds and other thicker formations of raw peat south of the southern limit of permafrost. Frequently areas where the ice lingers longer in peat in these cases have stronger than average lichen (H) cover. This was observed as early as 1927 by Auer (1927) in his studies of bogs of eastern Canada. It has been reported for instance by Ruuhijärvi (1960) in Finland and by Radforth (1962b) in Canada.

The present author has encountered ice on several occasions even in central Finland late in the summer in large mounds of raw Sphagnum peat with general cover of small shrubs and Sphagnum mosses (EI) and commonly with lichen on the mounds but not in areas around them which were wetter. During this study similar occurrence of ice was encountered in Newfoundland in many cases. Most notable was the distribution of late ice (sometimes called climafrost, Radforth 1954), in muskeg in the Avalon Peninsula near Colinette. There in some muskeg FI cover alternates with EHI cover so that a few square meters of FI are interrupted with a few square meters of EHI cover (Figure 7). The latter is slightly elevated above the surface. It seems that the use of H-factor as an indicator of ice conditions, even in areas of seasonal frost, is feasible if carried out with discretion. This discretion becomes more important if one is to consider possible differential growth cycle of the vegetation. But appearance of H (on dry high mounds) signifies locally drier and more aerobic conditions, faster humification of peat, and slower peat deposition which also is enhanced by decreased amount of Sphagnum in the cover. This will result in a depression with H still in it for some length of time and this might give wrong indications about the possible distribution of sub-surface ice. Also this cycle is faster in areas without permafrost and it is quite common there to have lichens (H) growing in shallow depressions in muskeg due to this cycle. Apparently this situation has been a source of strong objections for using H-factor at all as an indicator of sub-surface ice. However, that part of the cycle where H-factor appears in the depressions is short-lived (and H is not predominant) as compared to the other parts of the cycle. Thus in the overall picture and especially on aerial photos, the significance of H in depressions is not very high. One reason for this, in addition to the above, is that due to its lower intensity in the depressions it just does not show on aerial photos as markedly as when it is on mounds and peat plateaus.

A more reliable set of conditions for predicting lingering ice in peat in the areas south of permafrost would be possible H cover with EI cover on peat mounds of peat plateaus. This is based on the fact that the mounds mostly contain poorly humified Sphagnum peat with low heat conductivity. Also the higher lying mounds in the fall and winter remain saturated with water and later freeze and remain above the snow for a longer time than lower lying areas do. They thus become totally frozen and also conduct heat readily from the ground thus cooling the ground severely. In the spring they are first to shed their snow cover and thaw initially on the surface. Due to better drainage conditions, they also dry up quickly. The unfrozen layer of dry peat thus formed insulates the inside of a mound and the ground under it for a longer period of time from radiation and tends to keep the ice preserved in the peat.

It should be pointed out that in almost no case can lichen and permafrost or other lingering frost conditions be related without considering association of other factors. The author wants to point out that in the Radforth classification system there should be at least a 25 per cent coverage of H before it can be included in the cover formula; this 25 per cent coverage is not a criterion for permafrost or some other ice condition study and was never intended as such by Radforth. This coverage of 25 per cent was basically created for engineering purposes as was the whole Radforth system and naturally an adjustment is required if one wants to use this system for other purposes. The author would suggest that more than 25 per cent of H should cover the ground to indicate permafrost. In some other conditions, on the other hand, even less than that percentage of the total coverage could give indications of a possible severe short term ice condition and thus not necessarily a permafrost condition, as was found in Newfoundland. The author's experience in Finland has shown that in large areas of muskeg in central and southern Finland in the places where there was ice found in peat in late summer, in most cases the areas was covered even with extensive EI (Chamaemorus-Sphagnum fuscum) mounds and plateaus with some lichen (Cladonia spp) on them but not nearly to the extent of 25 per cent of the total cover. There was no lichen in the surrounding peat areas which did not contain ice.

Brown maintains in one of his recent studies (1968) that lichen and Sphagnum cannot be used as permafrost indicators since they grow extensively in areas without permafrost, and that there are areas with lichen covering over 25 per cent of the surface without permafrost. "H" is a permafrost indicator when used in connection with certain peat formations, such as palsas and peat plateaus, which, by the way, are the main features contributing to the Marbloid airform pattern. In these circumstances "H" appears as HE or EH and the factor is much greater than 25 per cent of cover which is the essence of Radforth's and the author's contention. Brown (loc. cit.) in another context notes that palsas and peat plateaus in the area which was under study in that work, always indicated permafrost. Since the major cover in the peat plateaus and palsas is HE to HEI, it becomes apparent that Sphagnum and lichens after all, according to his studies, have some connection with sub-surface ice. He also contends that in northern Manitoba in the southern part of discontinuous permafrost, the only areas with permafrost are peatlands. He further refers to the fact that sedge areas do not often have a frozen core in contrast to the peat plateaus (loc. cit.). This means that areas with lichen and Sphagnum are the only ones really to have permafrost.

Brown also refers to the fact that in the small areas of FI cover containing stagnant water there is no permafrost as contrasted to the surrounding plateaus and palsas (Brown 1968). He only seems to account for difference on the basis of poor drainage and the effect of water on the heat balance and leaves out the biotic influence. Difference in structural constitution of peat (due to different plants growing in the wet areas) providing for different heat capacities and heat conductivity of this peat as compared with the peat in the plateaus and palsas gets no consideration.

No single factor can be isolated as an indicator in the application of best judgement. The interpretation of aerial photos and muskeg features from them thus involves identification and application of a deductive process enabling conclusions to be drawn from conditions seen on the photos. Deduction in this instance is based on the knowledge, gained from ground level investigation and comparison such as attempted in this work, that the development of the airform patterns among which Marbloid is especially prominent has central significance in relation to detection of sub-surface ice.

MACRORETICULOID PATTERN AND ITS SIGNIFICANCE IN SUB-SURFACE ICE PREDICTION

It was developed earlier in connection with Reticuloid that in the zone of continuous permafrost the ridges in the Macroreticuloid pattern are permanently frozen throughout the year. Also in the Microreticuloid pattern, many larger ridges stay frozen permanently. But the situation appears to be different in the discontinuous permafrost zone. The Microreticuloid ridges (elements) are too small and are surrounded by large volumes of quiescent water which has an effect on the thermal condition of the peat and does not allow it to remain frozen permanently. In the literature this has been noted by other investigators who describe muskeg with negligible gradient, possessing ridges, flarkes and stagnant water and claim that it does not contain permafrost (Brown 1968a). The description reveals that the terrain in this case was Reticuloid.

In large areas the typical Marbloid airform pattern is infested with Reticuloid pattern. In the case of Microreticuloid, for example, in areas marked with (D) in Figure 103, there is no sub-surface ice due to the factors which are a function of the high water regime, properties of wet peat, and botanical response to this environment, as has been discussed on earlier pages. In the case of Macroreticuloid invading the Marbloid as marked with (C) in Figure 103, the matter is vastly different from the case of Microreticuloid. This type of Macroreticuloid which appears in connection with the Marbloid pattern indicates two things. One is poor drainage and another is ameliorating climate with ensuing regressive development of sub-surface ice in peat plateaus. In the first case the pattern probably never attained the stage of pure typical Marbloid and probably never was heavily frozen if the development took place in the discontinuous permafrost zone. In the case of ameliorating climate, as applying to Figure 103, the peat plateau once was part of a near-typical Marbloid pattern but, due to poor drainage and increasing warmth, water started accumulating in the depressions which originally, in numerous cases, were created by the thawing of ice in peat.

This thawing started generally in the places where peat plateaus originally were not as well developed as in the immediate vicinity and where the peat had slightly higher coefficient of heat conductance. Once the initiation for the thaw lakes was established, the development went forward quite quickly through the added heat capacity of the water bodies represented by the thaw lakes. The result is a peat plateau riddled with numerous ponds and lakes like those in Figure 103. Some of them also have been formed by solifluction especially near the edges of the peat plateaus as in areas marked (H) (Figure 103). In these sites the deepening thaw every summer has created deeper and deeper layers of saturated peat which has been lying on the frozen permafrost table. When the weight of these peat layers became sufficiently great they have slid along the permafrost table causing shear planes in the surface and forming parallel elongated lakes. (I in Figure 103). The development along these lines suggests that areas marked with Reticuloid Marbloid are not as reliable as pure Marbloid pattern in the prediction of sub-surface ice, since the ice is more patchy under this type of pattern and often is missing beneath features which are identical to those of the Marbloid pattern where ice is always encountered.

The development of treed Terrazoid pattern from, or on the Marbloid pattern, is a clear indicator of ameliorating climate since this pattern in most cases involves the growth of trees on the Marbloid components where ice has started degenerating as the growth of the trees commences along the cracks of polygons and sorted circles. (Figures 90 and 91). Also the formation of large FI areas in this type of treed Terrazoid-senescent Marbloid condition is due to the degenerating ice in peat and suggests where there is no ice and where there still is ice to be encountered. FI areas are formed as a result of the thawing of the ice and ensuing collapse of the plateaus. In the remaining plateaus and palsas ice is still preserved, and, as was shown further south, the tree cover which invades the centres of old polygons and other patterns favours further preservation of ice. Thus the treed Terrazoid in areas where the Marbloid has disappeared or is about to do so will form a basis for sub-surface ice prediction from the air once one understands the course that has led into this pattern and how tenuously its development is tied to that of Marbloid which is the prime pattern in the prediction of sub-surface ice.

ANALOGY IN STRUCTURAL COVER AND AIRFORM PATTERN OF MUSKEG COMPARING FINNISH AND CANADIAN CONDITIONS

It is hoped that this final section on the analogous muskeg conditions in two widely separated countries, Finland and Canada, will be a test of universal application of the principles discussed earlier. It also is hoped to reveal possibilities offered by this type of investigation to fill the gap left by the lack of comparative muskeg studies in this sense.

The Effect of Abiotic Factors (climate, geology) on Paludification Comparing Finnish and Canadian Conditions

Climatically Finland is very much the same as that part of Canada where Study Areas 2 to 16 are situated. Only Areas 1 and to a lesser degree 2 and 3 are colder and drier than any part of Finland. Area 14 is somewhat warmer than Finland while Areas 17 to 19 exhibit much higher humidities than encountered in Finland. Thus most of the Canadian study areas enjoy approximately the same climatic conditions as does Finland and in this respect are closely analogous as to the climatic controls of paludification. The temperatures, humidity, and evapotranspiration values are within about the same limits in both areas.

Geologically Finland is simpler than the total area of Canada encompassed by the study areas. Practically the whole of Finland is in the Fennoscandian Precambrian Shield area. This ensures a rugged topography in smaller scale while large mountains, except in Lapland, are missing. Only the western coastal areas are very flat and featureless in the same way as is a large portion of the Hudson Bay Lowland Area in Canada. Also in Lapland between mountains there are large flat areas. The rest of the country is very similar to most of the rocky Precambrian Shield country of Canada and offers, as far as topography is concerned, about the same conditions for paludification.

Soils in Finland are largely till. There are some clay areas especially in the south and various glaciofluvial soil types formed during the last glaciation. They thus also conform to the Canadian soil types in the areas where the Canadian study areas are scattered.

The closely analogous abiotic conditions affecting paludification in Canada and Finland ensure that the result of paludification in both countries is also very similar as will be seen later. There are small differences in certain aspects of paludification in Finland as compared with Canada, however. In Finland unconfined muskeg is not nearly as widely distributed as it is in Canada. Mainly this is so because of the lack of extreme humidities such as those found in Newfoundland, and because of the lack of large areas of flat country such as the Hudson Bay Lowland. Thus in most parts of country confined conditions prevail.

A Summary of Effects of Climate and Other Abiotic Factors on Paludification in Finland

According to Figure 117 the most humid climate is in eastern Finland as well as in smaller localities in southwestern Finland with moisture index values 40 to 50. The climate appears to be the least humid on the western coast and in Lapland. Only in the case of two eastern Finnish areas with value of 50 is there unconfined paludification. There also the frequency of occurrence is high reaching values greater than 40% of total land area (Figure 118).

The largest muskeg areas are found along the coast of the Gulf of Bothnia being from 40% up to over 60% in the northern part of the coastal area. Another centre of high frequency is in Lapland where in large areas frequency of muskeg is over 50% of the land area. However, these areas have moisture index values as low as 20 as compared with some areas in the central parts of country with values over 40.

There are several reasons for this apparent contradictory situation in Finland where the moisture index values and frequency of occurrence of muskeg do not seem to coincide as well as in Canada. The first reason presumably lies in the fact that the calculation for the values concerning Finland were based on the older system rather than

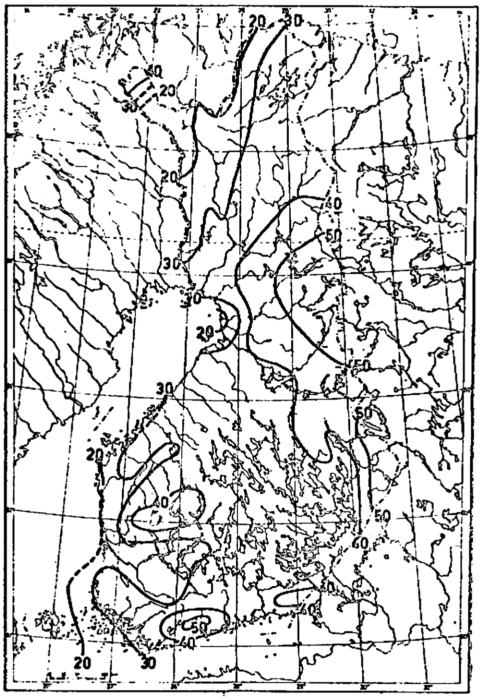


Fig.117.Moisture indices in Finland (After Hare 1955). Calculations based on 100 mm soil moisture storage capacity.

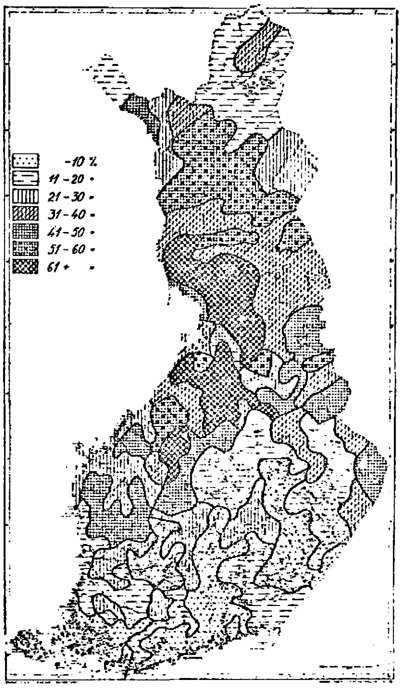


Fig.118.Percentage of muskeg area of total land area in Finland (After Ilvessalo 1960).

on the reassessed method used for those dealing with Canada. (cf. page 75). This may cause some inaccuracy in the values and probably does not always reflect the true state of affairs. These circumstances have been recognized also by Thornthwaite who maintains that the system, to be reliable and more accurate, needs further development and above all more data collected in the field (Thornthwaite 1948).

The major reason for contradiction is caused by other abiotic factors, such as topography, overriding the effect of climate in the control of paludification. The effect of topography is felt strongly in the form of varying run-off values in various parts of the country. Thus in central Finland (Lake District) good drainage conditions compensate for the relatively high humidity of climate (high moisture index values), so that frequency of paludification remains lower than one would expect from the moisture indices. In the east the run-off is not as good as in the central parts of the country and this shows in the paludification which is quite well developed there. This area forms part of a watershed, Maanselkä by name (Granö 1952), and has a poor drainage condition typical of watersheds. In addition to this, favourable edaphic conditions and humidity of climate (Figure 117) favour paludification which reaches in some areas unconfined expansiveness on slopes comparable with muskeg in Areas 17 to 19 in Canada in outer appearance but not in genesis which is ombrogenic in the Canadian counterpart while in Finland it is minerogenic.

The same topographic reason (watershed) causes high concentration of muskeg in Lapland in areas with very low moisture indices. The author judges that here also the inherent inaccuracies in the calculation methods play a prominent role resulting in too low values. Inaccuracies as a reason are more evident if one considers the effect of low potential evapotranspiration values in the north (300 mm) as compared with high values in the south (500 mm). Humidity of climate is closely dependent on these values, and their smallness in the north suggests that the climate there is actually more humid than it is according to the moisture indices.

The major concentration of muskeg along the Gulf of Bothnia with the lowest moisture index values shows strong evidence of the effect of drainage and soil conditions and how they can override the effect of climate. The southern part of this concentration of muskeg on the western coast (Figure 118) is partly due to the effect of a watershed (Suomenselkä watershed; Granö 1952) which curves across the country just south of area with over 61% muskeg (Figure 118) to the east and joins Maanselkä watershed. High frequency here is partly caused by the poor drainage so that 60% of the total land area, around the northern end of the

Gulf of Bothnia is muskeg. Poor drainage conditions here are caused by the same factor as in the Hudson Bay Lowland area. The western coast of Finland too was depressed by the continental ice sheets during the latest glaciation. After they were released from the ice they initially remained inundated and acquired impervious sediments. Then crustal lift has resulted as the surface of the earth attempts to reach equilibrium. The emerging land with flat topography, impervious sediments and differential lift (which is faster near the sea than inland) offers very suitable circumstances for paludification with resulting unconfined muskeg regardless of the climate which would be better for this strong paludification in other parts of the country.

The above mentioned features cover the main major aspects of general characteristics of paludification in Finland and show that conditions for paludification in this respect are quite analogous to those in Canada.

Major Vegetation Regions

According to some sources the major vegetational regions in Finland and Canada are the same. (The Times Atlas of the World 1967). Thus the northernmost part of Finland belongs to the tundra zone as does northern Canada where only study areas 1 to 3, or strictly according to Figure 18, only Area 1, belong to this zone. Most of Finland belongs to the Boreal Coniferous Forest Zone and only a narrow strip of the southwestern coast belongs to the Mid-Latitude Mixed-Forest Zone with broadleaf and coniferous trees. In Canada Areas 2 to 13 and 15 to 19 belong to the Boreal Zone and only Area 14 to the Mixed-Forest Zone (Great Lakes - St. Lawrence; Figure 18). Certain authors maintain that there is no proper Tundra Zone in Finland because only the summits of the highest mountains in the north are treeless, and are called "fjelds" instead of tundra (Kujala 1952).

The small differences of opinion on the Tundra Zone are not significant if one considers muskeg vegetation as compared with that in Canada. There are features of tundra in large open unconfined muskegs of Lapland. The vegetation is composed mainly of the same type of plants there as in northern Canada. Even a large portion of species is the same and almost all genera and families on muskeg such as *Sphagnum*, *Eriophorum*, *Scirpus*, *Ericacea* (family), etc. are the same.

In the Boreal Zone muskeg acquires tree covers. The main difference is in the species. Black spruce (*Picea mariana*) is replaced with Scotch pine (*Pinus silvestris*). Only in western Canada is there pine commonly on muskeg (*Pinus contorta*). Cedar (*Thuija occidentalis*) and Tamarack (Larch; *Larix laricina*) are replaced with Norway spruce (*Picea abies*) and in some cases Birch (*Betula pubescens*).

Of the large shrubs species such as *Chamaedaphne* calyculata, Myrica gale, some Vaccinium species are encountered both in Canadian and Finnish muskeg. Ledum palustre in Finland replaces Ledum groenlandicum which is common in Canada. Genus Kalmia is totally absent from Finland as on the other hand is Calluna vulgaris from the Canadian muskeg.

Other muskeg vegetation is approximately the same in both countries at least with respect to the families and genera and, to a great extent, to species. In this context it would be too irrelevant to consider more details of muskeg vegetation, an aspect which belongs to a floristic investigation.

Briefly summarized one can state that there are minor differences in the species composition of muskeg vegetation between Finland and Canada but as to structure and texture the vegetation shows analogous features, an aspect which will be discussed more extensively in the following chapters.

STRUCTURAL AND PATTERN ANALOGUES IN FINNISH AND CANADIAN MUSKEG

Cover Classes

The analogous conditions of physiography, climate and major botanical features as explained above suggest structural analogues in muskeg. As structural features, the cover formulae and classes of muskeg are more conspicuous than the peat deposits.

As the preceding chapter suggests, the main differences in cover between Canadian and Finnish muskeg are minor differences in the species while the larger groups such as families are predominantly the same. Comparative investigation has revealed that the species differences are not significant if one concentrates on structural aspects of the cover. Thus if one has learned to use the Radforth cover classification in Canada he is actually also capable of using it in Finland without any additional training. This is so because the cover classes in Finland are grouped together in a way analogous to that in Canada and combine to give approximately the same frequencies of various cover formulae.

Ground views of a few main cover formulae of Finnish and Canadian muskegs described in the following material will show that the analogy in structure is striking.

Fig. 119. A ground view of a Finnish muskeg showing FI cover formula in the foreground. F is composed mainly of Carex filiformis and I of various Sphagnum species.

Fig. 120. A ground view of a Finnish muskeg showing intermixed FI and EI cover formulae. F consists mainly of sedges, I of various Sphagnum species with Sphagnum fuscum predominating on the ridges. E is mainly formed by various Vaccinium species and Rubus chamaemorus (cloud berry, salmon berry, yellow berry).

Figure 119 from central Finland gives an example of FI formula where Carex filiformis is the major component forming class F and various Sphagna are the main components of the I class. This compares favourably with Figure 36 of northern Manitoba. In this figure the FI cover in the foreground is formed by sedges and various Sphagnum mosses.

In both cases also the properties of the peat at least near the surface are very similar in structure. In depth there may be structural variations due to the different developmental histories of the muskegs.

Figure 120 is another example of muskeg in Finland with a general FI cover intermixed with smaller areas of EI cover on the mounds. In this case F is not as strongly developed as in Figure 119 and consists mostly of Carex. I is more prominent in FI areas as well as on the mounds with EI cover. It is formed by various Sphagna of which Sphagnum fuscum predominates on the mounds with Vaccinium and Rubus chamaemorus forming class E. This figure compares quite well with Figure 109 in Manitoba. Even the species, except Rubus chamaemorus, are basically the same in both locations. These two figures are examples of an area with lower amounts of FI and EI than those in the previously mentioned figures (36 and 119). The peat here is also slightly deeper than in the previous cases.

Fig. 121. A view of a muskeg in northern Finland (Lapland). The main cover formulae are EI - EFI. E is formed by <u>Betula nana</u>, <u>Ledum palustre</u> and various <u>Vaccinium</u> species. F is formed by various <u>Carex</u> and <u>Eriophorum</u> species while I consists mainly of Sphagna.

Fig. 122. A view of a muskeg in central Finland showing an abrupt pond edge formed by a peat plateau. Cover in the background is BEI, EI cover on the slope with some H and FI in the foreground near the water. B is formed by <u>Pinus silvestris</u>, E mainly by <u>Ledum palustre</u>, I by Sphagna and F by <u>Carex</u> species.

Figure 121 from northern Finland (Finnish Lapland) shows a muskeg with EI-EFI cover formulae very similar to those in Figure 8 and somewhat similar to those in Figure 7. In the Finnish example E is formed mainly by Betula nana (dwarf birch) with small amounts of Ledum palustre and various Vaccinium species. In the Canadian counterpart (Figures 7 and 8) E is largely Chamaedaphne calyculata. In both cases F is formed by various representatives from the Cyperaceae family and I is formed by Sphagna. Both of these cover types are very common both in Finland and Canada.

Treed muskeg is quite common in both countries too. In Finland there is proportionally more treed muskeg because of the intensive drainage of muskeg for forestry. Natural treed muskeg is about as common proportionally in Finland as in Canada.

Figure 122 from central Finland is an example of an edge of a peat plateau by a pond in muskeg and reveals BEI cover in the background, EI cover with some H on the slope and FI in the foreground near the edge of the water (which was behind the photographer in this photo). This compares quite well with Figure 123 from Manitoba. Here the cover is BEI in the background and EI in the foreground. FI was behind the photographer at the water's edge in the same way as in Figure 122. Structurally these two areas are analogous although the species composition is different. In Figure 122 B is formed by Pinus silvestris (scotch pine)

Fig. 123. A view of a muskeg in northern Manitoba showing BEI cover (Picea mariana, Chamaedaphne calyculata and Sphagna) in the background and EI in the foreground.

Fig. 124. A view of a Finnish muskeg showing localized H-factor (Cladonia aplpestris) on the ridges bearing BEI cover.

E predominantly by Ledum palustre, I by Sphagna and F by Carex (with some G intermixed, note Cicuta virosa in the foreground). In the Canadian counterpart B is formed by Picea mariana (black spruce). E is formed by Chamaedaphne calyculata predominantly. In Finland this species appears on muskeg only in the north and even there never to such a great extent as in Canada. I and F are formed by Carex and Sphagna in both countries.

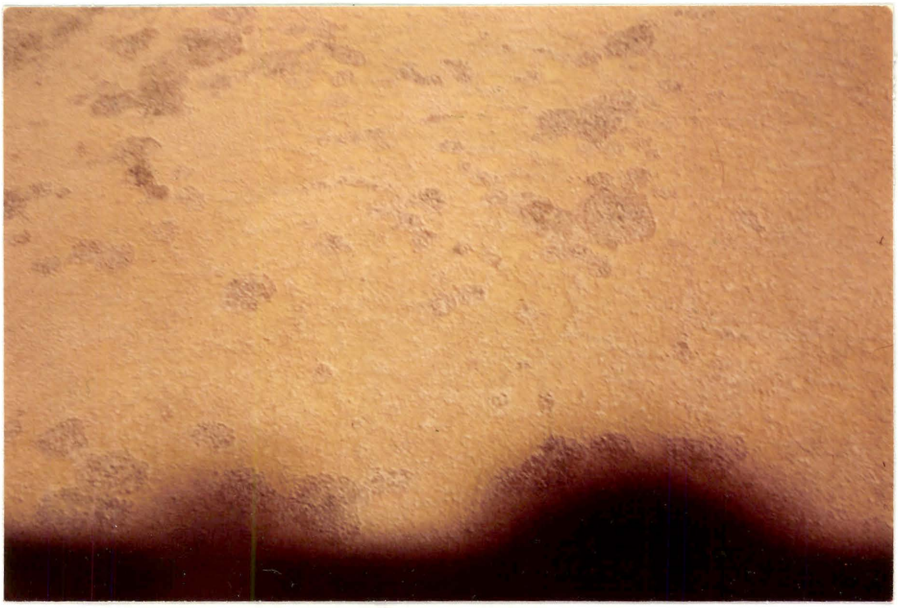
Figure 122 is also quite similar to Figure 45 which shows an abrupt pond edge in a Marbloid area in northern Manitoba. The main difference is in the amount of H which is negligible in Figure 122 which was not obtained from a permafrost region.

There is also H on muskeg in Finland but localized in the same manner as in Newfoundland since both these areas are outside permafrost regions. Figure 124 from the northern part of central Finland reveals well developed H-factor on peat ridges. This is, however, quite localized and is not evident in aerial photos taken at higher altitudes. The only areas with more H are in northernmost Finland and there it occurs mostly on palsas which are representative of discontinuous permafrost.

In summary one can state that the cover classes and formulae and their frequencies in Finland and Canada are approximately equal. The major difference is the lack of extensive areas of HE and EH cover formulae in Finland to

Fig. 125. A low altitude (500') oblique view of a muskeg in southern Finland showing Planoid low altitude airform pattern. Cover is mainly FI (pale green flecks) intermixed with pure I cover (light green) and some E (circular brown areas) invading locally.

Fig. 126. A low altitude (500') oblique view of a muskeg in southern Finland showing low-lying FI areas (pale green to black) and higher contorted peat ridges with EI cover with some H (white flecks) in it. This is also an example of low altitude airform pattern called Vermiculoid I.



the extent that they are encountered in Canada. This is due to the lack of large areas of permafrost in Finland, which as has been shown previously, is quite closely related to extensive distribution of H cover.

Airform Patterns

The similarities in the cover formulae and cover classes as described in the previous section suggest that there may be similarities also in the airform patterns. Airform patterns are basically formed by the cover formulae and their distribution and distributional frequencies strongly affect the appearance of airform patterns. Therefore, because the frequency and distribution of various cover formulae and cover classes in Finland are approximately the same as in Canada one could presume that the airform patterns have about the same appearance in both countries.

Figure 125 taken at an altitude of about 500 feet in southern Finland shows an area with Planoid low altitude airform pattern where the major cover formulae are FI (pale green"flecks") intermixed with nearly pure I cover (bright green areas). Circular darker brownish areas have been invaded also by E-cover. This figure compares favourably with Figure 15 from Manitoba.

Figure 126 is a low altitude (500') oblique view from southern Finland of a muskeg with low flat-lying FI (light green to black areas) and contorted peat ridges with

Fig. 127. A high altitude (30,000') vertical airphoto of a raised bog in eastern Canada showing the typical almost concentric ridges of this type of bog.

EH and EI cover (brownish ridges with light flecks). This figure compares well with Figure 99 from Manitoba just by the southern limit of permafrost. The pattern and the cover are analogous and also indicate similar sub-surface ice conditions for reasons already explained in previous sections.

The term raised bog (ombrogenic) and the special reticuloid pattern with concentric ridges have already been dealt with in detail. This pattern shows as Macroreticuloid even from high altitude and is fairly common in the maritime areas of both Finland and Canada. Figure 102 from south-eastern Finland is an example of the Macroreticuloid pattern of a raised bog, and compares quite well with Figure 127 from eastern Canada. The former is a low altitude (1000') and the latter a high altitude (30,000') view. In both cases the ridges bear EI to BEI cover. This pattern indicates the very humid and quite cool climatic conditions common to both regions.

Of the high altitude airform patterns Dermatoid, Stipploid, and Reticuloid patterns are proportionally as common in Finland as in Canada. Marbloid in its typical form is lacking in Finland and although it appears in its old form in northern Lapland it never occurs to such an extent as in Canada. The same may be said of the Terrazoid pattern. Also large expanses of typical Macroreticuloid are less common in Finland than in Canada. All this results

Fig. 128. A high altitude (30,000') vertical airphoto of a muskeg in northern Finland (Lapland).

D - Dermatoid

M - Microreticuloid

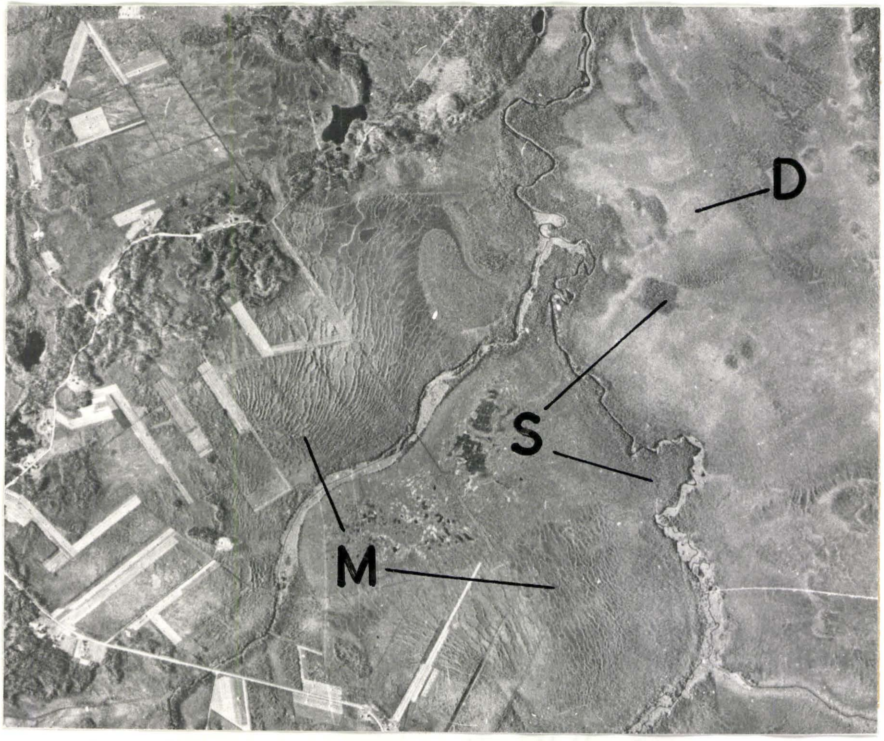
S - Stipploid.

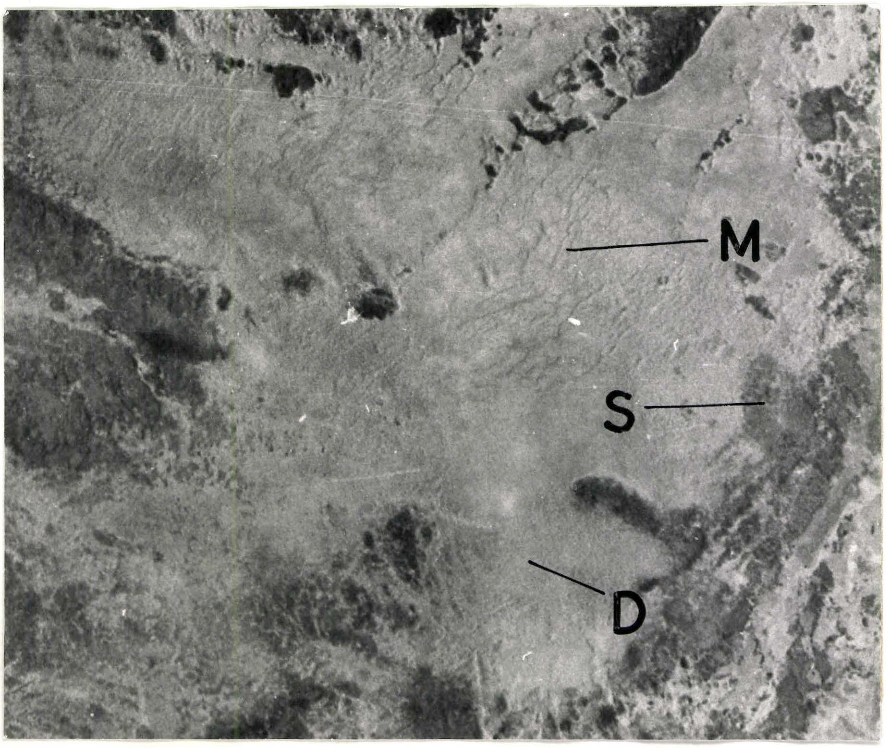
Fig. 129. A high altitude (30,000') vertical airphoto of a muskeg in central Manitoba.

D - Dermatoid

M - Microreticuloid

S - Stipploid.


D
S
M


M
S
D

from the lack of extensive areas of continuous permafrost in Finland as contrasted with large permafrost areas of Canada.

Figures 12 and 127 are examples of high altitude aerial views of muskeg in northern Finland and northern Manitoba respectively. They both reveal large areas of Dermatoid (D) and some Stipploid (S). There are also quite extensive areas of Microreticuloid (M) which is not always easily detected without visual aids such as stereoglasses. In the Finnish muskeg this Microreticuloid is often formed by peat ridges with BEI cover. In the Canadian muskeg it is predominantly composed of Sphagna. In both cases there is no sub-surface ice during the summer.

These pairs of photos reveal that the airform patterns are quite analogous in Finland and Canada with respect to muskeg and therefore the analogies can be applied to aerial interpretation of muskeg in several aspects of investigation of muskeg problems.

Application of Airphoto Interpretation to Planning for Muskeg Utilization

The discussion above on the analogies between the Finnish and Canadian muskeg cover reveals that the prerequisites environmental conditions, climate, geomorphology, etc. and the resulting cover structure and airform pattern are, in their main features and in some cases even in small details, analogous. This implies a possibility of utilitarian application of the analogous condition. Thus it would be possible to use airphoto interpretation of analogous cover and airform pattern features as an aid in determining suitable use for various muskeg areas in Canada based on the utilization of similar areas in Finland.

In Finland muskeg has been utilized to a considerably greater degree and for a longer time than in Canada and the properties of peat under certain kinds of cover and now also under certain kinds of airform pattern are well known. With this background information the properties of peat in Canadian muskeg can be quickly determined.

For example, if forestry and agriculture are contemplated, areas with stipploid cover are the most suitable for forestry in Finland. Thus, in Figure 129 the stipploid (S) areas would be the best ones for forestry purposes. Figure 128 from Finland shows that large areas have been used for agriculture. The pattern in those areas is predominantly Dermatoid with some Microreticuloid. This implies that in the Canadian area (Figure 129) areas marked with (D) would be best for agricultural purposes.

Normally in this type of analysis, airphoto interpretation results are verified by checking conditions on the ground. Detailed knowledge, obtainable only from the ground studies, is needed to determine suitability of the muskeg for agricultural reclamation. In this case it is known that in the Finnish muskeg, class I is formed by Bryales mosses which indicate more neutral conditions than those in the Canadian area where I is formed by more acid Sphagna. This means there are differences in the fertilization procedure for the areas in their preparation for agricultural use.

Figures 102 and 127 showing a raised bog Reticuloid pattern indicate that the peat under the surface is very probably predominantly raw Sphagnum peat and thus suitable for peat moss production and other horticultural use, but not at all useful for forestry and very rarely for direct agricultural purposes. Here too as elsewhere detailed ground surveys are needed to determine the final type of utilization but, aerial interpretation is a convenient and rapid preliminary survey method which greatly reduces the amount of ground study required. Also the same approach can be used for more purely scientific studies, such as for investigating and explaining past development of muskeg features, and for predicting future ecosystem behaviour in muskeg regions as previous sections have revealed.

SUMMARY AND CONCLUSIONS

In order to summarize the foregoing discussions it is necessary to think of the various factors discussed as simultaneous influences which combine to generate specific sets of conditions conducive to paludification and development of airform patterns. All these factors which take part in an interplay can be thought of in terms of causes and effects (responses). The degree of various effects depends on the sensitivity of various properties of terrain and plants to environmental influences which bear on them. Furthermore because the process (paludification; pattern development) is time-dependent and because there is interplay between causes and effects the relative magnitude of the causes are in turn influenced by the magnitude of effects.

To facilitate the understanding of the process *in toto* it has been put into the form of a diagram which reveals the feedback mechanism involved and also a certain kind of three-dimensional nature of the process. After the explanation of the basics of the diagram the components and their place in the diagram are dealt with.

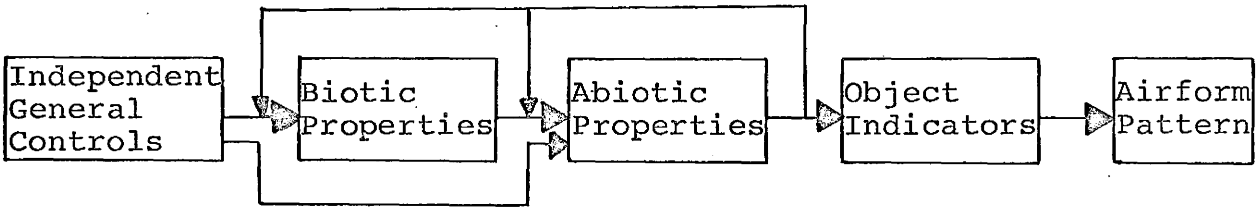


Fig. 130. Diagrammatic representation of the interplay of causes and effects in paludification and pattern development.

The following points are necessary for understanding the working of the system in Figure 130:

1) The diagram represents a system.

2) The system is made up of components represented by rectangular compartments.

3) The interrelation of causes and effects among the components is represented by lines and arrowheads joining the rectangular compartments.

4) The response of a component to a given influence (cause) is denoted by a line (lines) attached to the right-hand side of compartment with the arrowheads pointing away from the component.

5) The action of an influence (cause) upon a component is represented by a line (lines) attached to the left-hand side of compartment with arrowheads pointing towards the component.

6) Branching of interconnecting lines allows the depiction of the distribution of individual actions to several components simultaneously.

The following is a brief summary of factors which take part in the process and which have been described in detail in the discussions earlier. They can be grouped under the headings for components in the different compartments.

Independent general controls: These are the basic ultimate controls of paludification and certain related factors affecting it. The most influential in larger scale paludification are the physiographic (geomorphology, geology, topography, edaphic factors) and climatic influences. Together, and in some cases alone by overriding each others effect, they determine the main cause of paludification and thus lay the basis for pattern development. Whenever they are conducive to unconfined paludification there is a good chance for development of a high altitude airform pattern. In the case of confined paludification this not possible because of the scale factor. On this more local scale the significant features are crustal uplift and moisture regime as described earlier.

Biotic properties: While the properties themselves are intangible in a way, their response to the independent general controls takes the tangible form of certain biotic features. The one of particular interest in this context is muskeg vegetation. As depicted in Figure 130 this (or these) biotic response in turn acts upon the abiotic properties of the system to further the process of paludification.

Abiotic properties: These may be divided roughly into two sets. The first one arises from the direct influence of biotic response and in this work comprises peat with its various physical properties as the function of muskeg vegetation. Some of the physical properties of peat (e.g. insulation capacity) arises from the structure of plant constituents (see chapter on the structure of Sphagnum mosses) and some from the mode of formation of peat and physical factors affecting it.

The other set comprises abiotic properties which are partly a direct result of the function of the independent controls and partly a result of the interplay between biotic and abiotic properties as revealed by the feedback channel in figure 130. Properties in this category are features such as soil steps, circles, polygons, water and ice taking part later in the paludification processes, certain drainage features etc.

In Figure 130 there is one line going directly to the compartment representing object indicators from the abiotic compartments while another line turns back into biotic and abiotic components. This second line represents the feedback system in this process. It is evident that the current state of abiotic properties can affect their future change. It is also evident that through abiotic and biotic interplay there is mutual enhancement for generation of both these components with resulting accelerated development towards object indicators and ultimately towards airform patterns.

Object indicators: These are a result of the direct action and interplay of various components which precede them in the system (Fig. 130). Object indicators (mounds, peat plateaus etc.) are the ultimate constituents of airform pattern. Thus they are a response to the function of all the other factors preceding them which thus fundamentally contribute to the generation of airform pattern.

To avoid duplication the above account of various components of the Figure 130 has been left brief. The following is an example how this diagram can be used to interpret the result and the points of contribution.

If one first considers the general controls one observes that to create conditions conducive to paludification the following specific conditions must be obtained. The climate, geomorphology (topography) and soil conditions have to be such that the basic suitable set of conditions is obtained for paludification to proceed. Briefly, that set of conditions comprises a cool, humid climate to start paludification, flat smooth topography to proceed towards unconfined conditions and preferably impervious soil. The biotic properties of the system respond to these conditions and the response is expressed as muskeg vegetation starting to cover the ground. This response can cause development of various types of peat formations. Let it be assumed that formation of peat starts on an area with permafrost (abiotic property) with soil circles (independent general control). As has been described earlier a certain chain of events occurs. One result is that there is formation of peat with certain physical properties. Thus another set of abiotic properties has been generated. The high insulation capacity of peat (abiotic property) will ensure growth of ice lenses in the peat. This may alter the muskeg vegetation on it or enhance its growth. This represents feedback from the abiotic component to biotic properties component. Enhanced growth of peat at the same time may also increase acidity of the environment which further enhances growth of peat. Thus the response of the abiotic component through feedback to the biotic properties has an indirect bearing on the abiotic component. At the same time the enhanced growth of peat also facilitates growth of ice in peat and the feedback path from initial (permafrost, soil circle) and secondary (ice lenses in peat) abiotic properties directly back to the same component is obtained. This process leads to fast growth of object indicators and through them to airform pattern.

The explanation here also reveals how various factors described in detail earlier are a part of the whole system starting with the general accounts of climatic and geologic conditions and proceeding through detailed accounts of structure of peat and related features. This example is a simplified single representation of the process and it is to be remembered that one can start at any point in the diagram, take any property (for instance acidity, insulation capacity of frozen peat, some drainage features in muskeg, mode of formation of peat) in the system and follow its influence in the manner described above by applying the detailed principles described in the earlier part of this work.

The following will summarize briefly the main points of principle developed in this investigation.

1. The significance of mechanical and physical influences as factors contributing to pattern development has afforded new approach in exposing and explaining the role of abiotic contribution. These influences are clearly a result of edaphic and climatic interplay and also their interplay with biotic factors thus being expressions of both the biotic and abiotic effects (Fig. 130). The extent to which these influences act and their direction can be concluded as contributing to the initiation of the development of pattern. In certain cases either biotic or abiotic expression alone may follow the independent general controls in initiation in the system of all stages of pattern development. Thus theoretically the mature patterns are reflections of mass vegetal adaptation and the variability is an expression

of different degrees of incomplete adaptation.

2. The genesis of object indicators as based on the study and evidence derived from the biotic-abiotic interplay serves to account in part for the adaptational trends. The genesis of structural expression of the covering vegetation also discloses object indicators, and it is the collective presentation of these object indicators that signifies the physiognomy of adaptational trends. Thus the object indicators in terms of total physiognomy of pattern are the units which provide the basis of interpretation of terrain conditions. This is so because they are the elements of adaptational expression, the objectively devised true reflection of organization in terrain.

3. The implication inherent to the above principles is that there is an organization in organic terrain pattern. This enables prediction of terrain states to be made facilitating, for instance, assessment of presence, form and distribution of sub-surface ice.

4. The investigation of development of airform pattern arising from development of object indicators has established that there is an evolutionary trend in the development of patterns.

5. Objective study of various aspects in airform pattern genesis and analysis of its various features has shown that recurring patterns exist. Contribution in the present work in this connection arises from the developed

principle that muskeg vegetation associates with effect of changing mechanical and physical relationships in the terrain (mineral and organic) to promote geomorphic values, the basic constituents of airform patterns.

6. These patterns thus can be accounted for as objective features rather than subjective ones. Ultimate patterns conform essentially to the airform patterns of Radforth (1955b and 1958) who subjectively selected them, because they were conveniently recognizable, without explaining them.

7. Analysis of airform pattern evolution has established that there are variations of Marbloid pattern which deviate in certain degree from the typical mature Marbloid.

8. These variations recur in a characteristic way and recurrence is controlled by several interplaying factors. The basic cause for the variations is the interplay of local biotic and abiotic factors, and independent general environmental controls.

9. Variability of airform pattern is dependent also on the differing levels of influence of biotic and abiotic interplay which vary in characteristic ways depending on latitude, one of the independent general controls (Fig. 130).

10. There is also a gradient not only in accordance with latitude but also with the maritime-continental axis. Here the variability is affected by minerotrophy or ombrotrophy of the environment and has a strong influence on the

development of patterns. Some features arising here can be used for prediction of seasonal (climafrost) in peat from the air.

11. The investigation on the effects of certain abiotic soils, topography, geomorphology) and biotic influences has established that the confined - unconfined state of muskeg is largely determined by geomorphic characterization of major geological phenomena such as the Precambrian Shield and Palaeozoic formations. Thus geology affects sub-surface ice prediction in the large scale sense because the extensive use of Marbloid airform pattern in prediction requires unconfined or near-unconfined conditions of muskeg to develop to an extent in which the characteristic features of Marbloid are visible from the air.

12. Further, the history of the development of pattern coincides with the development of characteristic drainage systems which are therefore an inherent part of pattern evolution as it changes with latitude.

13. The rationalization accounting for formation of object indicators and the establishment of the effect of edaphic factors on character of airform pattern involves the establishment of the principle that pattern dynamics relates to presence, distribution and topography of sub-surface ice. Thus object indicators have a relationship in a symbolic sense to sub-surface ice conditions.

14. In terms of principles established in this work,

Marbloid and to a certain extent Reticuloid and Terrazoid have developed from interplay of biotic and abiotic factors. Various frost (ice) features are especially prominent in this development. This justifies and gives extended value to the use of this (these) pattern(s) for reliable prediction of sub-surface ice from the air or aerial photographs.

15. These principles established on evidence from the investigation allow for implementation of a system of reliable interpretation of organic terrain conditions. The method of interpretation must accommodate repeatability of characteristic developmental stages, a principle arising from the establishment of recurrence of airform patterns and their variations. Such a system is evident in Figure 130, which reveals the interrelationships in pattern development diagrammatically.

16. Certain abiotic (soil patterns, temperature conditions) influences on paludification establish symbolic secondary patterns (for example, polygonal pattern) in muskeg. Polygonal pattern in Marbloid especially forms a reliable indicator of sub-surface ice, its distribution and condition from the initiation of Marbloid through its various stages to eventual degradation.

17. The evidence derived from the investigation on the biotic and abiotic factors affecting formation of object indicators establishes that, despite abiotic influence,

prediction can be made on the basis of reference to vegetal structure alone. This implies that vegetal structure, cover formulae or even cover classes, can be used as sub-surface ice indicator symbols (cf. H-factor). Use of symbolic vegetation alone in the prediction process, however, requires a higher degree of discretion than use of airform patterns.

18. The details of the biotic and abiotic interplay producing object indicators further confirm the feasibility and reliability of predicting sub-surface ice conditions beyond the permafrost region. This involves the use of symbolic vegetation as object indicators.

19. Establishment of the fact that it is possible to predict the presence of sub-surface ice in muskeg from the air and even to determine its condition, whether it is seasonal or permanent, and whether it is continuous or discontinuous, creates various possibilities for application of this capability for utilitarian or scientific purposes. Only a few major aspects of application will be discussed.

A. The influence of the underlying mineral soil, especially when patterned, on the development of Marbloid suggests that it is possible to predict the conditions prevailing in the mineral sublayer and even the type of soil under the peaty overburden. As an example of this possibility, comparison of Figure 50 with Area (A) in Figure 91, and Area (A) in Figure 68 with Area (B) in Figure 91 indicates interpretation relationship (cf. different developmental stages). This would not be possible if evolutionary trends of pattern development as they now have been disclosed here were not known. There is still a need for more work in this field to increase prediction accuracy.

B. Another form of application arising from understanding of pattern dynamics is the prediction of the future of certain muskeg conditions. This involves comparison of a selected location and its pattern features with the total image of pattern evolution to determine the stage of development in that location. This being accomplished, one is able to predict the possible future conditions in that location as based on evolutionary trends as they are influenced by prevailing biotic-abiotic interrelationships and external environmental factors (independent general controls).

C. The knowledge of the mode of influence of biotic and abiotic factors on the evolution of muskeg environment suggests that it is possible to influence the course of this development by manipulation of the controls. Manipulation could be effected in various ways, such as draining the muskeg or stripping the insulating peat cover to cause differentials in the thermal and biotic characteristics, resulting in changes in the trends of development. Careful manipulation could be used for engineering purposes to encourage better use of land. If desirable, manipulation could be used to retard development and thus to conserve certain conditions.

D. The possibility of predicting sub-surface ice conditions in muskeg from the air is important in reclamation for forestry and agricultural purposes. It is very significant for effective reclamation to predict occurrence, distribution and conditions of sub-surface ice especially in the zone of discontinuous permafrost. Increased human population and new discoveries of natural resources, such as petroleum have raised interest in northern development. Reclamation for agriculture, forestry and construction is imminent. Therefore accurate and economic prediction of muskeg conditions is of high importance in the national economy.

E. The problems involved in the reclamation of muskeg are partially the same as for certain engineering problems, especially transportation over trackless expanses of muskeg. The aerial prediction system, knowledge of the controls of paludification and their effect on environmental change are of prime importance for route location, construction methods and for economic planning for engineering projects. The problem is more acute in areas with discontinuous permafrost where interpretation is needed because permanently frozen ground is not ubiquitous as in the zone of continuous permafrost. There the problem of how to build without disturbing permafrost is less difficult. In connection with road location, behaviour of the terrain for the anticipated engineering needs and design for adjustment because of the peculiarities of the now predictable characteristics of the sub-surface ice can now be considered scientifically. The knowledge of the biotic and abiotic controls facilitates modification of normal methods of construction either to achieve minimum disturbance of the environment or to manipulate it for best results. The interpretive system which now affords reliable prediction has also provided a reliable foundation for mapping procedures without fear of subjectivity.

F. A theoretical and partly practical application of this work relates to the hydrological needs of this continent. The growing population and rising level of technology have brought about an increasing demand for fresh water. There are projected controversial suggestions for diverting to the south Canadian rivers now draining into Hudson Bay, to satisfy this demand. While these projects are relatively simply realized as far as the engineering is concerned, their impact on the land environment as interpreted in the present work is almost totally unknown. The largest remaining almost untapped reservoir of fresh water on this continent is the terrain under the dominating influence of muskeg as the Cambridge Bay - Lake Winnipeg aerial traverse suggests. Large areas of the water source are covered by various kinds of muskeg. Structural and microenvironmental differences now objectively interpretable should be assessed and mapped in relation to proposed scheme of diversion. Flooding and diversion of water flow (natural or artificial) on a localized or widespread scale generates a structural response within the peat in different ways and degrees depending upon peat type and its extent. In addition, alteration of thermal regimes influencing development of airform patterns would have massive effect on the dynamics of sub-surface ice now controlled by the peat in different ways as evidenced by characteristics of the patterns and their distributional phenomena.

G. The distribution of ice can be predicted even in small scale from the airphotos. Its role in terms of muskeg pattern evolution is now known and one can now reasonably speculate as to what would happen if the waters were diverted by basing some of the speculation on the disclosed characteristics of muskeg development. As based on the interrelationships of biotic and abiotic influences in Marbloid development it can be suggested that these large muskeg areas would act as collection areas for fresh water where permafrost is undergoing regressive development. They would act also as release sources for ground water. Thus new and widely influential problems would arise if the well balanced muskeg systems were disturbed by manipulations of unassessed effect. In some areas as yet unmeasured muskeg would dry out on the surface with ensuing better insulation properties in the superficial peat thus resulting in progressive development of permafrost and diminishing available water which would be retained by formation of ice. In other cases the dryer superficial peat would be more vulnerable to wind erosion and increased microbial activity with increased degree of humification and with ensuing loss of insulation capacity of peat which would result in faster thaw of permafrost. This in turn would cause floods and rapid release of water with sudden volume changes in the resources. To predict accurately the new dynamics of water balance and loss more investigation of controls of paludification and management methods on muskeg hydrology is required.

20. Finally an aspect of contribution lies in the possible universal application of aerial photographic interpretation system as evidenced by short account of the analogous conditions concerning Finnish and Canadian muskeg. This section emphasizes the impact of the independent general control on paludification and consequently on the structural cover and airform pattern.

These, only a few of the possible applications arising from the principles disclosed in this work, reveal several new problems. New, more sophisticated aerial remote sensing methods may in the future be of great help in solving the problems especially because the areas are remote and conventional methods are cumbersome and time consuming.

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APPENDIX A

TABLE 7

SUMMARY OF PROPERTIES DESIGNATING NINE PURE COVERAGE CLASSES
(From Radforth 1952)

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

PLATE I

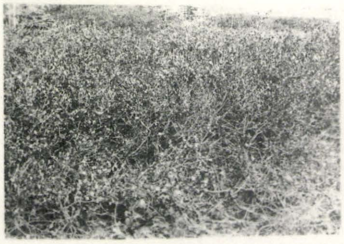
THE RADFORTH COVER CLASSIFICATION SYSTEM
(Radforth 1952)

CLASS A

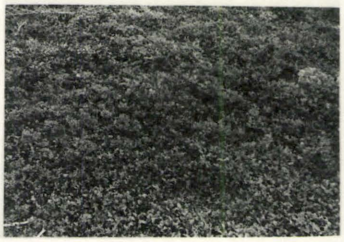
CLASS B

CLASS C

CLASS D



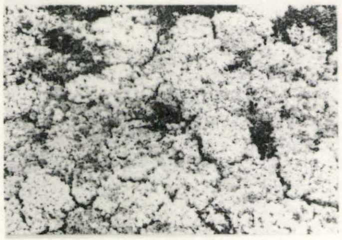
CLASS E



CLASS F

CLASS G

CLASS H



CLASS I

APPENDIX B

TABLE 8

LOW ALTITUDE AIRFORM PATTERNS
(Radforth 1958)

Pattern	Description	OBJECT INDICATORS Topographic Vegetation
Planoid	An expanse lacking textural features; plane	flats, ridge FIE hummock, FEI mound, EFI rock gravel, EFH plain E, EF gravel bar, closed pond, rock enclosure, open pond, exposed bolder, hidden bolder, extensive plateaus
Apiculoid	Fine-textured expanse; bearing projections	plateau slopes, AHE flats, AEH, BEF gravel bar
Intrusoid	coarse textured expanse, caused by frequent interruptions of unrelated, widely separated, mostly angular "islands"; interrupted	closed pond, FI, I rock enclosure, EH, EF open pond, FE exposed bolder, hidden bolder
Vermiculoid-1	Striations webbed into a closed net and usually joined	flats, EH/FI

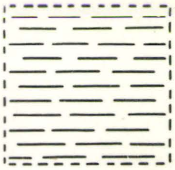
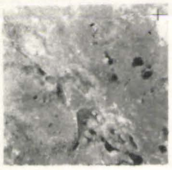
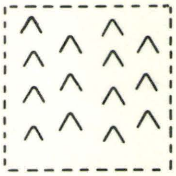
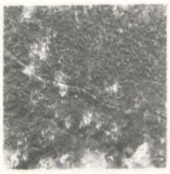
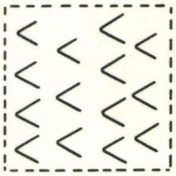
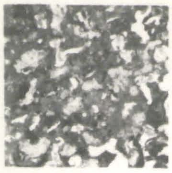
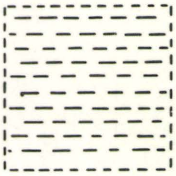
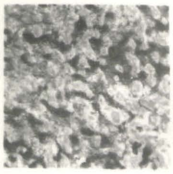
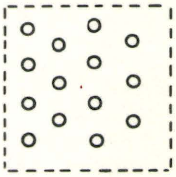
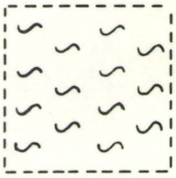
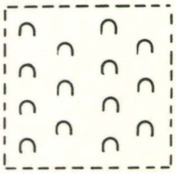
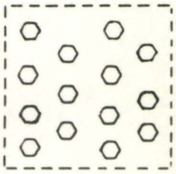
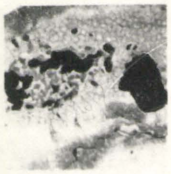
TABLE 8 - continued

LOW ALTITUDE AIRFORM PATTERNS
(Radforth 1958)

Pattern	Description	OBJECT INDICATORS	
		Topographic	Vegetation
Vermiculoid-2	Striations in close association, often foreshortened and rarely completely joined	hummock,	E/FI
Vermiculoid-3	Striations webbed into an open net, usually joined and very tortuous	mound, ridge,	FI/FI FI in water
Cumuloid	Coarse textured expanse with lobed or finger-like "islands" prominent; components shaped like cumulus clouds	even peat plateau, irregular peat plateau,	HE, EH EHB HEF
Polygoid	Coarse textured expanse cut by intersecting lines; bearing polygons	polygond,	EH, HE E

PLATE II

LOW ALTITUDE AIRFORM PATTERNS
(Radforth 1958)

MAPPING SYMBOL	PATTERN	PHOTOGRAPH
	PLANOID	
	APICULOID	
	INTRUSOID	
	VERMICULOID-1	
	VERMICULOID-2	
	VERMICULOID-3	
	CUMULOID	
	POLYGOID	

APPENDIX C

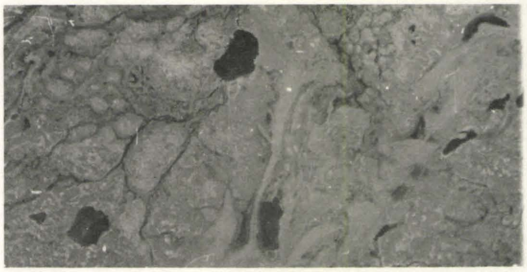
TABLE 9

HIGH ALTITUDE AIRFORM PATTERNS
(Radforth 1956)

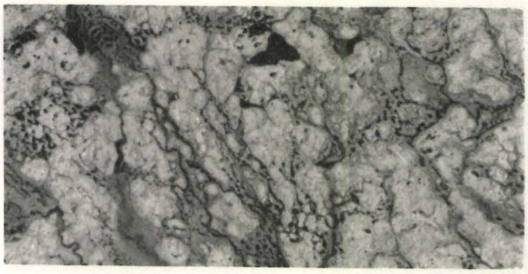
Pattern	Description	Designation (common cover classes)
Dermatoid	Chiefly textureless and plane; a simple covering lacking ornamentation (skin-like in the fundamental and literal sense)	FI,HE,EH
Marbloid	Polished marble effect	AH,AEH,EH,DBE,HE,FI
Reticuloid	Net-work	FI,EH,D,DBE
Stipploid	Constructed of closely applied dots	AEH,AH,HE,D,FI
Terrazoid	Patch-work quality	FI,EH,HE,D,AEH,DBE,AH

PLATE III

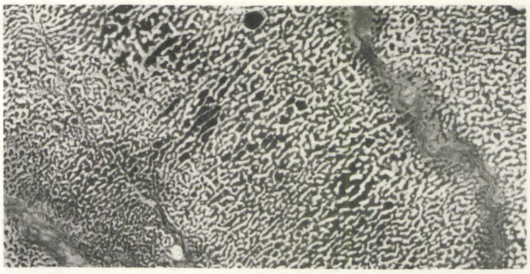
HIGH ALTITUDE AIRFORM PATTERNS
(Radforth 1956)



DERMATOID

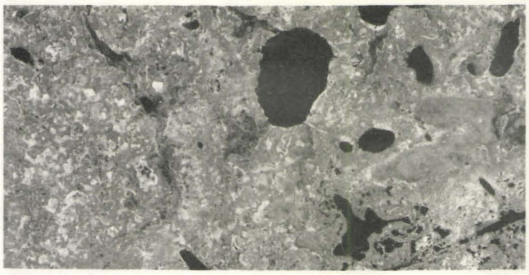


MARBLOID



RETICULOID

STIPPLOID



TERRAZOID

APPENDIX D

GLOSSARY

A - Cover class. Woody, 15 ft. or over in height.

AAPAMOOR (aapabog, aapamuskeg) - Mostly treeless subarctic sedge bog with rimpis and peat ridges and sometimes flooded in the spring. (Aapa (Finnish) = open, wide).

AAPAMOOR COMPLEX - System of aapamoors.

ACTIVE LAYER - Layer of ground above permafrost which thaws in the summer and refreezes in the winter.

ABRUPT POND EDGE - Steep banked edge of pond in muskeg. Occurs frequently in unconfined northern muskeg as well as in raised bogs.

AERIAL INTERPRETATION - Evaluation of terrain character by direct observation from the air or by examination of aerial photographs.

AIRFORM PATTERN - An arrangement of shapes, apparent at a particular altitude, which is characteristic for significant terrain entities and their spatial relationship and thus useful in the application of aerial interpretation.

ALBEDO - Reflective power (reflection of the light).

APICULOID - A descriptive term designating a 5000 ft. airform pattern characterized by "fine-textured expanse" bearing minute projections.

ASYMMETRICAL VALLEY - An east-west valley with asymmetrical cross profile due to differential erosion of the north - and south-facing slopes of the valley resulting ultimately from the differential exposure of these slopes to the elements.

B - Cover class. Woody, 5 to 15 ft. in height, young or dwarfed tree or bush.

BEADED STREAM - A stream with enlarged, more or less round pools spaced irregularly along a narrow stream giving an image of a string of pearls. Characteristic of permafrost regions.

BOG - The usage of this term varies greatly. In this work it is used to mean confined muskeg the limits of which are imposed mostly by topographical features of mineral terrain. Thus it is differentiated from the general term muskeg mainly in terms of area and also often for more frequent changes in cover and peat structure than in extensive muskeg areas. Commonly used in connection with ombrogenic conditions; raised bog concept.

C - Cover class. Non-woody, 2 to 5 ft., tall grasslike.

CHANNEL TYPE POLYGON - Cf. ice wedge polygon.

CLIMAFROST - A very localized frozen area mostly in peaty soils lasting one or more summers but thawing eventually. Sometimes included with the terms 'scattered and sporadic permafrost'. Occasionally confused with active layer.

CONFINED MUSKEG - Cf. muskeg.

CONCENTRIC RAISED BOG - Cf. raised bog.

CONTINUOUS PERMAFROST - Cf. permafrost.

COVER CLASS - A subdivision of vegetal cover based upon difference in properties such as woodiness, non-woodiness, stature, texture (where required) and growth habit.

COVER FORMULA - A combination of two or three class letters arranged in descending order of prominence of cover classes as estimated by an observer at ground level (classes with an apparent representation of less than 25 per cent are excluded from the formula).

CUMULOID - A descriptive term applied to a 5000 ft. airform pattern characterized as a "coarse textured expanse with lobed or finger like islands prominent"; components shaped like cumulus clouds.

D - Cover class. Woody, 2 to 5 ft., tall shrub or very dwarfed tree.

DENDRITIC DRAINAGE PATTERN - A very common drainage pattern characterized by irregular branching of tributary streams at almost any angle, although usually at less than a right angle. Shows notable lack of structural control.

DEPRESSED CENTRE POLYGON - Cf. ice wedge polygons.

DERMATOID - A descriptive term applied to a 30,000 ft. airform pattern characterized as "chiefly featureless and plane", a simple covering lacking ornamentation (skin-like in the fundamental and literal sense).

DERANGED DRAINAGE PATTERN - A drainage pattern with complete lack of structural or bedrock control and with such a variation between the components as to be impossible to describe as conventional drainage patterns. Often too 'young' to have developed any integration and common in periglacial areas. Characterized by 'boggy' interstream areas.

DISCONTINUOUS PERMAFROST - Cf. permafrost.

DRUNKEN FOREST - A forest characterizing some areas of a permafrost region where trees are tilted in a haphazard way due to differential slumping of the ground resulting from local changes in the distribution of permafrost.

DRUMLIN - A streamlined hill or ridge of glacial drift with its long axis paralleling direction of flow of a former glacier and often with a small rocky depositional core (hog's back).

E - Cover class. Woody, 0 to 2 ft., low shrub.

ESKER - A long narrow sinuous ridge of glaciofluvial origin deposited in a large crack or tunnel in the former glacier.

EUTROPHIC - Of high nutrient content. Conditions in which a certain kind of peat was formed referred to as eutrophic peat. Condition also where muskeg vegetation is very varied due to high nutrient content as opposed to oligitrophic conditions.

ECCENTRIC RAISED BOG - Cf. raised bog.

F - Cover class. Non-woody, 0 to 2 ft., mats, clumps or patches sometimes touching each other.

FEN - Muskeg consisting of organic terrain with water previously in contact with mineral soil. If area is large this condition arises from the contact with mineral subsoil rather than from the waters flowing from the surrounding mineral soil areas.

FLARKE - Cf. rimpi.

G - Cover class. Non-woody, 0 to 2 ft., growth habit singly or loose.

H - Cover class. Non-woody, 0 to 4 in., leathery to crisp.

H-FACTOR - The effect of H cover class on aerial views and aerial photographs of muskeg of giving them a light tone due to high albedo it possesses.

HOCHMOOR - Cf. raised bog.

HOTSPOT - The destruction of fine image detail on a portion of wide-angle aerial photograph. It is caused by the absence of shadows and by halation near the production of a line from the sun through the exposure station.

HORSETAIL DRAINAGE - Non-integral drainage pattern common in Marbloid muskeg areas giving the image of a partially open horsetail.

HUMMOCK - A microtopographic feature. In this work it is separated from tussock having in its initial stage commonly a mineral soil core covered with vegetal matter. The core may remain frozen permanently in larger hummocks while it generally thaws in the smaller ones during the summer.

I - Cover class. Non-woody, 0 to 4 in., soft or velvety in texture; growth habit often continuous mats, sometimes forms mounds and hummocks.

ICE WEDGE POLYGON - Patterned ground with polygonal mesh and characterized by bordering ice wedges. The borders may be depressions (channel type polygon) or ridges (depressed centre polygon).

INTEGRATION (of drainage pattern) - Refers to the degree of unity exhibited by a drainage pattern.

INTRUSOID - A descriptive term applied to a 5000 foot airform pattern characterized by a coarse textured expanse caused by frequent interruptions of unrelated widely separated mostly angular 'islands'.

IRREGULAR PEAT PLATEAU - Cf, peat plateau.

KERMI - Parallel or concentric peat ridges of raised bogs. (Finnish origin)

KORPI - A treed muskeg with spruce (Picea abies) and birch predominating. Near neutral reaction. Various kinds of herbs and eutrophic, mostly Hypnum and Mnium mosses forming the bulk of vegetation. Peat depth rarely over three feet (Finnish origin).

LAGG - Wet marginal part of muskeg and especially that of a raised bog or another type of confined muskeg (Swedish origin).

LETTO - An open muskeg characterized by general neutrality or even alkalinity of peat and water and by mosses other than Sphagna forming class I (Finnish origin).

MACRORETICULOID - Cf. Reticuloid.

MARBLOID - A descriptive term applied to a 30,000 foot airform pattern showing a polished marble effect.

MARSH - Low-lying tract of land usually covered with grass and sedge type plants growing often directly on mineral soil. Due to high water table and poor drainage marshes often are precursors of muskeg.

MASS WASTING - A general term for a variety of processes by which large masses of earth material are moved by gravity either slowly or quickly from one place to another.

MESOTROPHIC - Of medium nutrient content. A muskeg may be mesotrophic if it displays species which do not require eutrophic conditions but which would not thrive in oligotrophic conditions either.

MICRORETICULOID - Cf. Reticuloid.

MINEROGENIC - A muskeg is minerogenic if it is supplied with nutrients received from the surrounding mineral terrain or from the mineral subsoil (minerotrophic).

MOUND - A microtopographic feature of muskeg with a fairly thick layer of peat. The shape and size may vary but it is generally rounded on top and often elongated horizontally.

MULTISPECTRAL SENSING - Isolation of electromagnetic energy reflected from a surface in a number of given wavelength bands and recording of each spectral band with various devices. The result may be displayed photographically or magnetically.

MUSKEG - The term designating organic terrain, the physical condition of which is governed by the structure of peat it contains and by its related mineral sublayer, considered in relation to topographic features and the surface vegetation with which the peat co-exists. Muskeg may be confined when its area is confined by topography (bog) or it may be unconfined when it covers large expanses of terrain without strict limitations.

NEVA - An open muskeg characterized by general acidity of peat and water and by predominance of Sphagna forming the class I. (Finnish origin).

OBJECT INDICATOR - Entities such as Hummock, tussock and mound are object indicators.

OLIGOTROPHIC - Of low nutrient content. A muskeg may be oligotrophic, for instance, when it gets all of the required nutrients from the atmospheric water.

OMBROGENIC - A muskeg is ombrogenic when it receives all the mineral nutrient matter from the atmospheric water; thus it generally is also oligotrophic (e.g. raised bog).

OMBROTROPHIC - condition in which nutrients are received from the atmosphere.

ORGANIC TERRAIN - A tract of land comprising a surficial layer of living vegetal matter and a sub-layer of peat or fossilized plant detritus of any depth existing in association with various hydrological conditions and with various underlying mineral foundations.

PALUDIFICATION - 'Marshifying', 'swampifying', turning of drier land into wet land. More exactly: the process of formation of muskeg.

PALSA - A large peat mound with permanently frozen peat or mineral soil core. Palsas occur most commonly in the zone of discontinuous permafrost (Finnish origin).

PEAT - A component of organic terrain consisting of more or less fragmentary remains of plant matter sequentially deposited and fossilized.

PEAT PLATEAU - An extensive rather homogeneous tract of muskeg lying slightly higher than its immediate surroundings. Peat plateau may be regular or irregular with sudden breaks and contortions.

PERMAFROST - A thermal condition of earth materials such as rock, peat or other looser soils when their temperature remains below $0^{o}C$ for a number of years, which may be as few as two, or as many as tens of thousands. Permafrost may be continuous when it stretches continuously without breaks over large areas or discontinuous when it is distributed in smaller localized pockets and then often in peaty soil only.

PINGO - A large earth mound with frozen core and often a thin layer of peat on the surface. Are larger than palsas and may attain heights over a hundred feet.

POUNU - Almost identical to hummock with the difference that it always has a mineral soil core and forms a large field of these microtopographic features. Pounikko: plural of pounu, a field of pounus (Finnish origin).

POLYGOID - A descriptive term applied to a 5000 foot airform pattern characterized by a coarse-textured expanse cut by intersecting lines; bearing polygons (polygonoid).

PRIMARY PALUDIFICATION - Paludification of land directly after its emergence from the sea in areas of crustal uplift.

RAISED BOG - A confined muskeg with ombrogenic origin. Displays commonly a centre which may be raised several feet higher than the surrounding terrain. Is oligotrophic and also commonly has a well defined lagg in its periphery. Is characterized by concentric peat ridges (kermi) and intervening hollows (concentric raised bog). In some cases the ridges are only in half circles and curve paralleling each other (eccentric raised bog). German equivalent is Hochmoore.

RECTANGULAR STREAM - A stream with nearly right-angled curves implying control by ice wedge polygons.

REGULAR PEAT PLATEAU - Cf. Peat plateau.

REMOTE SENSING - Detection, recognition or evaluation of objects or terrain features by distant sensing or recording devices such as cameras, radars or infrared sensors.

RETICULOID - a descriptive term applied to a 30,000 foot airform pattern characterized by a network effect. Reticuloid may either Macroreticuloid or Microreticuloid, depending on the scale factor, Macroreticuloid is visible without visual aids (e.g. the Reticuloid pattern of a raised bog) while Microreticuloid is discerned only with the aid of stereoglasses (e.g. the Reticuloid pattern encountered in fens).

RIDGE - A topographic feature similar to mound, but extended, often irregular and numerous; vegetation often coarser on one side.

RIMPI - A wet hollow, either with a scarce muskeg vegetation in it or without, between shallow ridges of initial muskeg or those of an aapamoor.

RÄME - A treed muskeg characterized by acidity of peat and water and by thick peat deposits, Sphagna as the main component of I class and Scotch pine (*Pinus silvestris*) as the main tree species (Finnish origin).

SHEET WASH - erosion through the action of rain wash on the sides of a valley.

SIDE LOOKING RADAR (SLAR) - An airborn radar which scans the terrain from underneath the aircraft to one side to the horizon.

SLOPING POND EDGE - Gently sloping pond edge in muskeg showing often the effect of the overgrowing of a pond by muskeg vegetation.

STIPPLOID - A descriptive term applied to a 30,000 foot airform pattern characterized by closely applied dots.

SWAMP - Similar to marsh but usually with higher water table and interrupted vegetal cover. Also a precursor of paludification.

TELMATIC PALUDIFICATION - Paludification at least partially above ground water table.

TERRAZOID - A descriptive term applied to a 30,000 foot airform pattern that shows a 'patchwork' quality.

TERRESTRIAL PALUDIFICATION - Paludification above ground and flood water tables.

TOPOGENOUS - Adjective term meaning that the source of water for a bog is the water table in the place where it has collected in a pre-existing depression.

TUNDRA - Treeless arctic expanses with widely spread thin peat layers and arctic low vegetation (Russian origin).

UNCONFINED MUSKEG - Cf. muskeg.

VERMICULOID - A descriptive term applied to a 5000 foot airform pattern characterized as striated, mostly coarse-textured expanse featuring tortuous markings. Subdivided into three configurations: Vermiculoid I, II, III.

APPENDIX E

APPENDIX E

Data on Distribution of Ice in Relation to Cover Formulae and Peat Formations in the Study Areas

NOTE: Values indicate the frequency of occurrence.

Area 1. Permafrost ubiquitous appearing four to ten inches below the surface (August).

Area 2. Analysis made at the end of August at the transition from continuous permafrost into the discontinuous zone. The depth of peat varied, the maximum being four feet.

Set A between Churchill and missile base east of Churchill

	Ice Absent	Ice Present
FI flats	10	0
EFI flats	6	2
EI mounds with some H (high water regime)	5	12

Set B southeast of Churchill

	Ice Absent	Ice Present
FI flats with faint reticuloid pattern	16	4(climafrost)
HE peat plateaus (Initial)	2*	18
AHE peat plateaus (near Churchill River)	0	12

* Less than one foot of peat

Area 3. Investigations made within the discontinuous permafrost zone at the end of August. Depth of peat varies up to five feet.

Set A - a transect of 800 meters west of the Hudson Bay Railway. The depth to the permafrost varied from 30 to 35 cm on polygons and 25 to 35 cm in the "cracks" between polygons.

	Ice Absent	Ice Present
HE (EH) peat plateaus with polygonal pattern	0	28
FI, shallow drainage channels, flats bordering ponds	11	4*

* Very near (two feet) the edge of peat plateau

Set B, a transect of 1000 meters east of Hudson Bay Railway

	Ice Absent	Ice Present
HE (EH) peat plateau with polygonal pattern	0	12
HE peat plateau with EFI - FI in the centers of depressed centre polygons	2*	8
FI drainage channels and flats	15	2#
DFI drainage channel	6	1#

* Centre of a depressed centre polygon
# At the edge of peat plateau

Area 4. Tests made within the discontinuous permafrost zone in confined muskeg at the end of August.

In 40 probings under coverage AEI, BEI, BEH, EI and FI ice was encountered only twice in deep (over 3 m) peat mounds with BEH coverage and woody *Sphagnum* peat. Depth to ice was 60 cm.

Area 5. Area situated at the claimed southern limit of permafrost. Muskeg coverage was FI, EI, and BEI. No ice was encountered at the end of August in eight probings.

Area 6. Situated in the discontinuous permafrost zone. Study was made at the end of August. Depth of peat varied up to seven feet. Ice was encountered 60 to 80 cm under the surface.

	Ice Absent	Ice Present
AEI (a shallow depression)	4	0
BEH peat plateau	0	5
HE peat plateau	0	11
FI depression	6	0

Area 7. Situated in the discontinuous permafrost zone. Peat depth varied up to seven feet. Ice was encountered 50 to 60 cm below the surface.

	Ice Absent	Ice Present
BEH peat plateau	0	6
HE palsa	0	2
FI depression	12*	0

* (unfrozen peat up to seven feet underlain by unfrozen clay.)

Area 8. In the discontinuous permafrost zone, muskeg was lacking. No ice was encountered in the mineral terrain which bore signs of polygonal pattern. Past ice activity was observed in the soil profile across an ancient polygonal "crack" in the disturbance and bending of the horizons. Profile was brown woody type.

Area 9. At the southern limit of discontinuous permafrost zone where testing was done in muskeg with BEI and EI coverage. Depth of peat 3 m with 0.7 m of clay and sand bottom. No ice was encountered in six borings.

Area 10 to 12. Non-permafrost area where predominant coverage was FI with smaller areas of AEI, BEI and EI. No ice was discovered at the end of August. Depth of peat varied up to eight feet. Predominant peat type Carex-Sphagnum peat (24 borings).

Area 13. Situated in the non-permafrost zone with coverage FI, AEI, AI, BEI, EI where no ice was encountered in 20 borings at the end of August.

Area 14. Non-permafrost zone. Coverage variable.

	Late June		Early June	
	Ice Absent	Ice Present	Ice Absent	Ice Present
AEI	8	0	0	0
BEI	6	0	0	0
BEF	2	0	0	0
DFI	3	0	0	0
EI	20	0	0	12
FI	9	0	0	0
EFI	23	0	0	0

Ice in EI mounds represents climafrost existing in the late spring.

Areas 15 and 16. Situated in the non-permafrost zone. Ice was encountered in two of 50 borings in the beginning of August. Ice was under BEH cover 60 cm from the surface and consisted of only about 10 cm thick lenses. No ice under AEI, BEI, BFI, DFI, DI, EFI and FI cover.

Area 17. Situated in the non-permafrost zone.

Set A. 15 miles south of St. John's. Borings made at the beginning of June.

	Ice Absent	Ice Present
EI mounds with some H in cover.	0	6
EFI depressions	8	0

Ice in the mounds was 20 to 50 cm from the surface (climafrost).

Set B. Colinette, Avalon Peninsula

	Ice Absent	Ice Present
HE - very low mounds	0	10
FI flats	8	0

Ice was also encountered in three large (about 70 cm high) mounds in an experimental area that was cleared of shrubs for cultivation. Ice in low EH mounds was 10-20 cm from the surface, and was about 10 cm thick lenses of climafrost.

Area 18. Situated in non-permafrost zone. Small confined muskegs with FI, EI and BEI cover. In ten probings no ice was encountered.

Area 19. Situated in non-permafrost zone. Ice in the form of lenses about 10 to 30 cm from the surface (climafrost).

		Ice Absent	Ice Present
EH	very low mounds	2	15
FI	flats	10	0
EI	very low mounds	12	0
EFI	flats	6	0

ADDENDUM A detailed survey of Bull Pasture Bog in the Fredericton area of New Brunswick in June 1969, showed retention of ice beneath EI and also where peat ridges and mounds covered by EI with patches of H occurred. Ice was approximately 20 cm from the surface. No ice was discovered under FI coverage. Ice disappeared in July.