Terrain Disturbances Associated with Tracked Vehicle Movement and Diamond Drilling Activites, Nogash Lake, South Central District of Keewatin

By

J. Larry Marshall

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Table of Contents

page

1. Introduction

2. The Physical Setting

3. Physical Tests and Observations

4. Vehicle Testing

List of Figures

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ABSTRACT

The movement of diamond drills by tracked vehicles and drill trailers in south Central Keewatin was studied during the summer of 1980. Tests of the physical ground strength showed that the ability of the terrain to resist disturbance from tracked vehicle operations depended on two main physical factors: the type of surficial material and the presence of water. Moisture contents varied throughout the summer so that the response of till and peat to compression and shear was not constant. As the summer progressed, the increasing depth of thaw and gradual surface drying caused strengthening of both major types of surficial material. As a result, vehicle trafficability gradually increased throughout the summer. While surface rutting increased the depth of thaw compared to an undisturbed site, especially in peat, after the first few weeks of the thaw this had little apparent effect on vehicle trafficability. In many cases the vehicle disturbance was largely aesthetic giving the impression that the terrain disturbance was much more serious than it actually was.

Although the load distribution of the vehicle tracks concentrated much of the longitudinal stress directly beneath the bogie wheels, in most cases the performance of the tracked vehicle itself was adequate. However, problems caused by the drill trailer wheels resulted in unnecessary mechanical strain on the vehicles and created marked increases in terrain disturbance.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In recent years, the District of Keewatin in the Northwest Territories has received increased attention from various mining companies and as a result government interest in resource development has also intensified. The increased exploration activity has led to the discovery of potentially economic deposits of uranium and other metal deposits. However, numerous problems to resource exploitation exist. These include the isolation from the larger population centres to the south, the inaccessibility of much of Keewatin and the extremely high costs of development that result from these factors. In addition, mineral extraction is made more difficult by the ubiquitous occurrence of continuous permafrost throughout Keewatin. Although much has been learned in the past ten or twenty years about the behaviour of permafrost from road, pipeline and drill rig construction in the western Arctic, many of the engineering properties of permafrost are still not well understood.

In most of the more recent mineral discoveries, the current work is still in the early "step-out" stages whereby grids of holes are drilled in order to delineate the extent of the ore body. Drill cores are analyzed to determine ore grades and depths of occurrence. However,

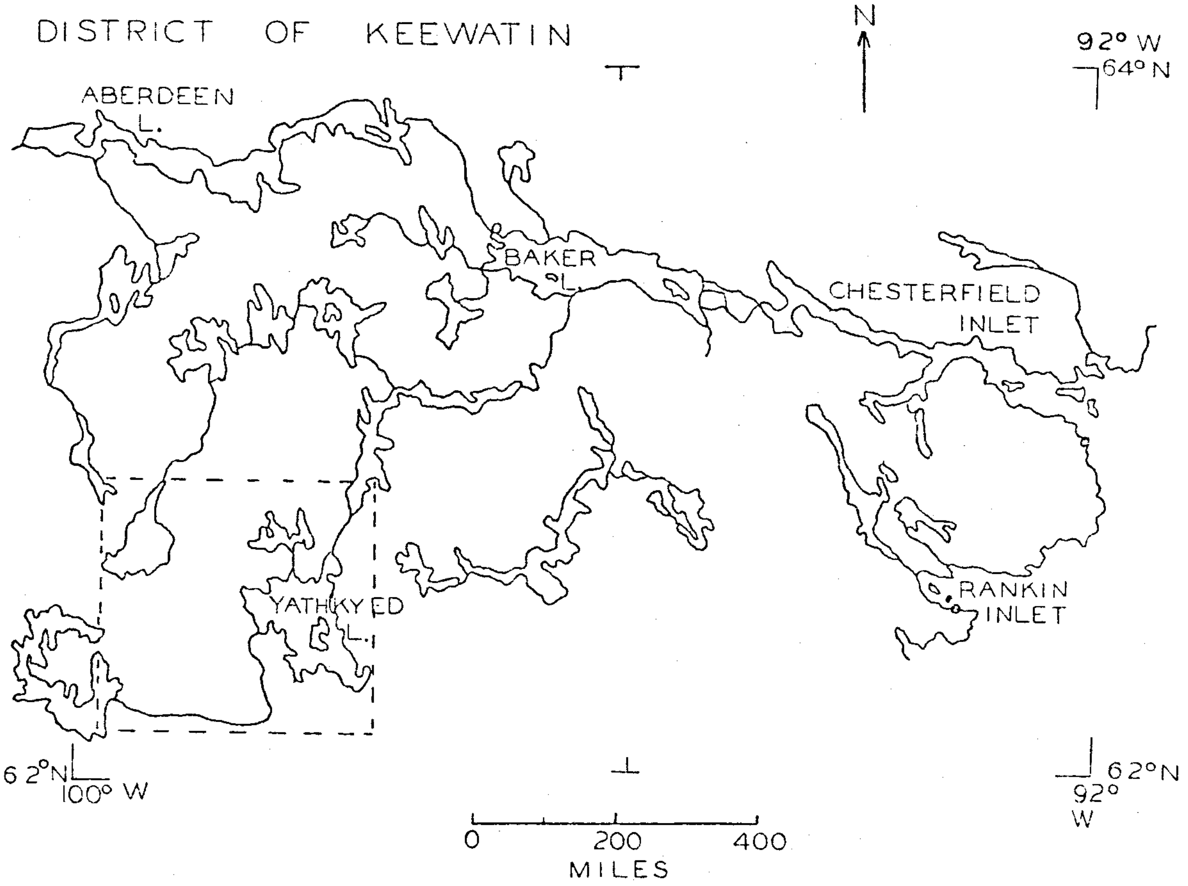


Figure 1.1 Location Map of South Central Keewatin.

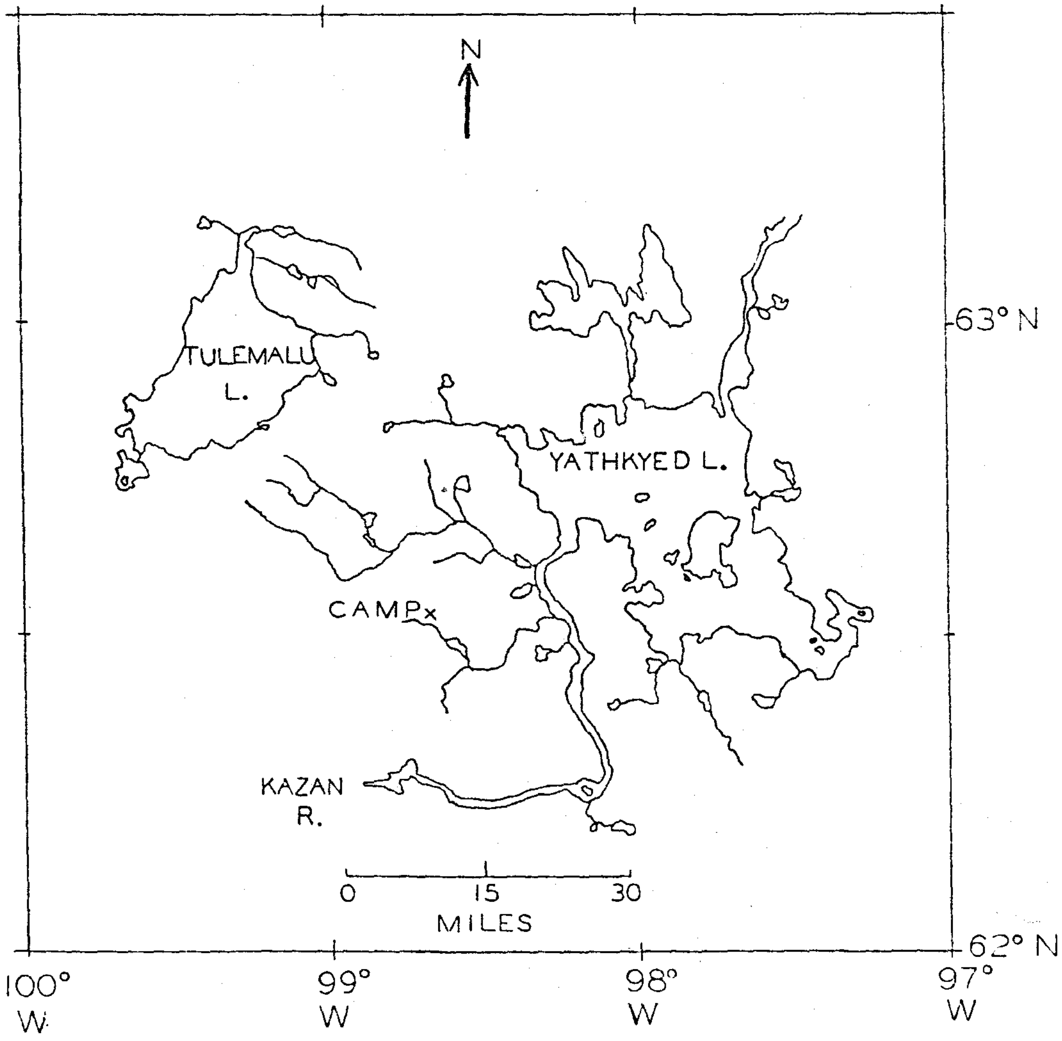


Figure 1.2 Yathkyed Lake Area showing the location of the Nogash Lake camp (62° 31'N, 98° 40'W).

should some of these deposits become economic to mine, in every case some sort of an environmental site study would be necessary - both from a government regulation point of view and a mine engineering aspect. When such a site assessment study is conducted simultaneously with a delineation drilling program, the findings of both operations can be considered together with an eye towards future mineral extraction. It is in this context that the monitoring program at Nogash Lake was initiated.

1.2 Purpose of the Thesis

At present, the use of tracked vehicles to support a drilling program in Keewatin is a relatively recent undertaking. However, should such vehicles perform as anticipated in this respect, the potential for expanded vehicle use in a mining operation is enormous. Given the isolation and lack of sufficiently stable overland transport routes, the tracked vehicles must be highly efficient in order to support mineral exploitation activities. Therefore, it is the general purpose of this thesis to discuss the effect of tracked vehicle use in Keewatin both in terms of the efficiency of the vehicle itself based on its use in the drill operations and the degree of environmental disturbance this use created. In addition, this thesis attempts to provide general impressions of vehicle trafficability throughout Keewatin while eliminating some of the misconceptions regarding tracked vehicle use that have resulted from previous studies, particularly those of the Mackenzie delta region. The final aim is to suggest recommendations to reduce the level of disturbance resulting from vehicle traffic. The main purpose of these recommendations is to aid the government in adopting regulations which, while protecting the environment, are not so restrictive that the guidelines would discourage resource development in the area. A continuous problem is the definition of just what an acceptable level of disturbance is, but since this will probably vary between sites, each site must be examined individually to determine the probable impact of vehicle use.

1.3 Methodology

Much of the summer of 1980 study was directed at providing basic measurements of the conditions which were thought to control the response of different surficial materials to the vehicle movement and drilling operations. The tractor zone was mapped on the basis of characteristic surficial materials which in turn were partly subdivided according to vegetation characteristics. Since vehicle passage exerted compressional and shear stresses which tended to deform the material beneath the tracks, the ability of the materials to withstand these stresses would be expected to change over the summer with changing physical conditions such as moisture content. As a result, many of the tests were designed to detect these changes and what affect these changes had on ground strength. The physical tests and observations could be subdivided into two separate categories.

(a) The determination of factors that control the vehicle impact at various locations throughout the summer. These measurements included those of water table levels, ground temperatures, bearing strengths, vane shear, drop weight penetration and moisture contents in till and peat.

(b) The results of the vehicle use in terms of such things as accelerated degradation of the frost table, increased erosion and destruction of the vegetation cover. The monitoring of surface and frost profiles provided most of this information.

The methodology of each individual test is further discussed in their respective sections in Chapters 3 and 4.

1.4 General Program and Location

The terrain monitoring program carried out at the Nogash Lake Camp of Pan Ocean Oil Ltd. was initiated as part of an ALUR (Arctic Land Use Research) Program to document the response and performance of the terrain resulting from the use of tracked vehicles in a delineation drilling program. The program attempted to define some of those properties which influence vehicle trafficability as well as to provide an estimate of the degree of disturbance and the time required for natural recovery of the disturbed surfaces.

Located at Nogash Lake (62° 31' N latitude, 98° 40' W longitude, approximately 200 km southwest of Baker Lake, Figures 1.1 and 1.2), the drill program involved 17 men and the operation of three Longyear 38 diamond drills (Figure 1.3) 24 hours a day for approximately 11 weeks.

The main use of the two tracked vehicles (Bombardier Muskeg tractors) (Figure 1.4) was to move the drill rigs which were mounted on a two wheeled metal sloop with a wooden drill platform (Figure 1.5). However, the use of the vehicles was restricted by DIAND (Department of Indian Affairs and Northern Development) to a tractor zone 2 km long and 1/2 km wide, which was located at Pan Ocean's discretion. For any drilling outside of this vehicle use area, the rigs were dismantled and moved by helicopter from one set-up to the next. The vehicles were used on several different types of terrain, from thick peat accumulations to areas of till exposed in the form of mudboils. The response of these different areas to the drilling operations and vehicle movement forms the basis of this thesis.

1.5 The Tracked Vehicle (Figure 1.4)

The tracked vehicle used at Nogash Lake was a Bombardier Muskeg tractor having the following basic specifications:

length 3.62 m
height 1.99 m
width 2.22 m
ground clearance 36 cm
basic vehicle weight 3200 kg
maximum speed (no track slippage) 22.5 km/hr
inside turning radius 3.66 m

Theoretical ground pressures produced were 1.47 psi (0.103 kg/cm^2) and 1.16 psi (0.082 kg/cm^2) at the surface and 15 cm depth respectively. Experimental results from the tractor zone were much different, as will be discussed later (see pages 48 to 52). The tracks consisted of endless belts of rubber fabric and re-enforcing steel cable joined by steel crosslinks which were indented to pass smoothly over the drive sprockets and bogie wheels. Each track was 71 cm wide with one rubber belt 14 cm wide on each side of the bogie wheels and another belt 15 cm wide between the wheels. In all there were 20 wheels, 8 pneumatic and 2 solid (drive sprockets) for each track. Besides towing the drill trailer, the vehicle was also used to move small equipment such as drill rods and water pumps and to gather empty fuel barrels and other garbage.

The suitability of any vehicle in terms of minimizing disturbance depends largely on the interaction between vehicle weight distribution and track design. The Muskeg tractor was designed so that in a non-loaded state the majority of the vehicle weight is located near the front of the vehicle, the centre of gravity being approximately at the rear of the cab. As a result, the greatest longitudinal stresses in an unloaded state are generated by the second set of bogie wheels, which are located underneath the cab. Laterally, the dual bogie wheels spread the stresses sideways, rather than concentrating the force directly under the wheel as in a single bogie wheel track. This causes the track edges to be more aggressive than the centre, increasing the load supporting characteristics of the track and reducing the potential disturbance.

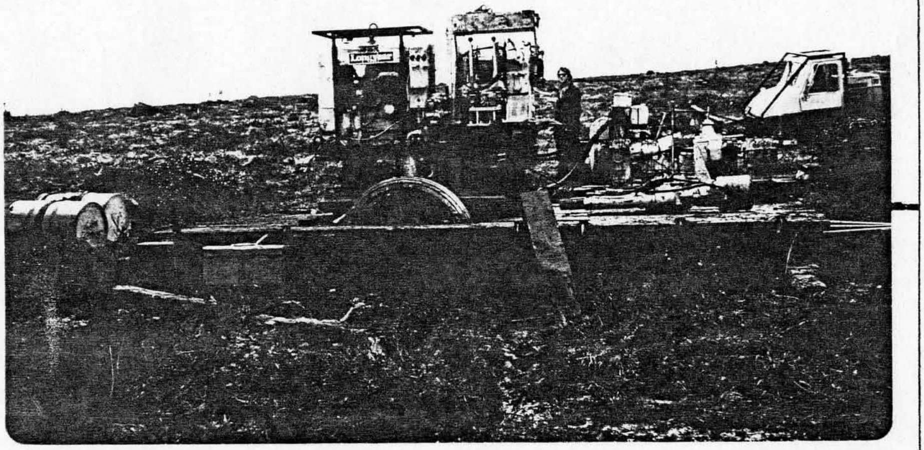


Figure 1.3 Longyear 38 diamond drill partially disassembled.

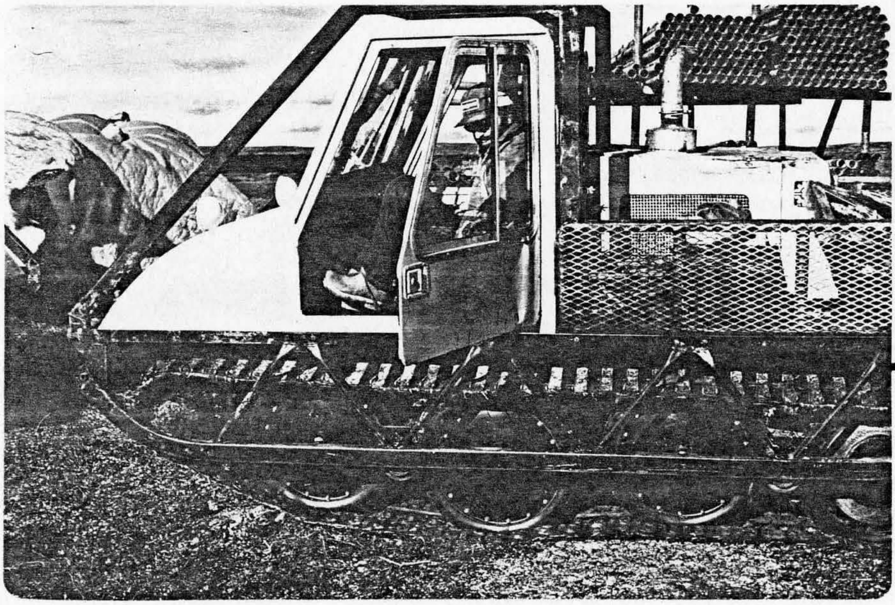


Figure 1.4 Bombardier Muskeg Tractor.

1.6 The Drill Trailer (Figure 1.5)

The diamond drills themselves were mounted on a 2 wheeled wooden platform which rested on a steel sloop base. The tires were DC-3 retreads which were mounted on the trailer base at the middle of the sloop. The purpose of the trailer was to: 1) reduce the time required for a drill move by eliminating the need to "tear down" and re-assemble the rig as would be required for a helicopter move, and 2) to reduce the amount of expensive helicopter time required for the drilling operations.

The first advantage was especially important in that much of the drilling was done using closely spaced holes (10-30 m apart) so that the actual move itself (1-2 hrs) took very little time compared to helicopter moves, which often took about 12 hours from the beginning of "tear down" to the start of drilling at the new site, regardless of whether the drill move covered 30 m or 300 m. Much of the success of the drilling program was based on the significant time and money savings involved in using the tracked vehicle and drill trailer.

1.7 Previous Research

Much of the previous research in northern Canada concerning the use of tracked vehicles has taken place in the Mackenzie Delta or the Arctic Archipelago. Due to the exploration for oil and gas reserves in and around the Mackenzie Delta, the effect of various types of tracked vehicles on the terrain in this area has been especially well documented

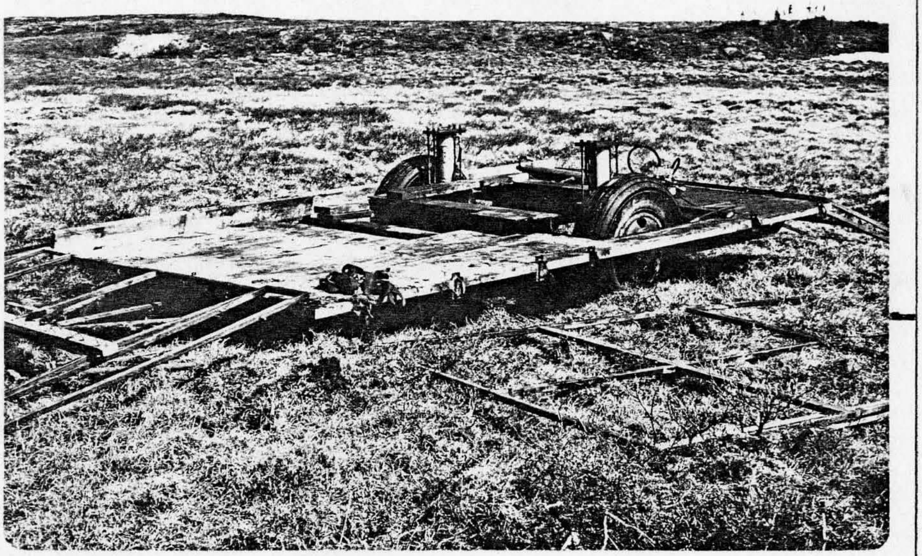


Figure 1.5 Drill Trailer.

over the past 20 years.

One of the more exhaustive studies in this region was that of D.E. Kerfoot (ALUR 1971-72). This program involved the study of over 40 seismic line profiles created in the summers of 1970 and 1971 in the Parsons Lake area holdings of Gulf Oil Canada Limited. In addition, winter seismic operations were also studied over the same period. In fact, for many years almost all seismic activity was confined to the winter months by both government regulations and technological problems. Kerfoot selected several sites where detailed profiles and/or maps were surveyed and frost table depth measurements obtained. From these profiles, estimates of the volume of surface material removed or displaced by the disturbance were compiled. Frost table data provided estimates of the amount of permafrost degradation attributable to vehicle disturbance. Core soil samples were measured for ice content in order to assess the potential amount of thermokarst subsidence that would result if thawing of the ice occurred. The following is a summary of several of Kerfoot's vehicle traffic related findings with regard to oil exploration in the Mackenzie Delta area.

1. In most cases the sensitivity of the tundra environment to vehicle traffic has been overestimated while natural re-vegetation capabilities have been greatly underestimated.

2. Damage to the vegetation cover is most severe in areas where there has been repeated vehicle traffic over relatively short periods of time. Yet, even in cases of extreme destruction of the organic layer the existance of the shredded vegetation retards surface runoff, continues to

provide some insulation for the frozen soil below and may act as a suitable substrate for re-vegetation.

3. Winter operations produce lower levels of disturbance than the same amount of vehicle activity would produce during the summer months. However, winter roads should be used for one season only to prevent extensive damage to the organic layer. Studies have shown that it is better to create a new winter road than to risk the severe increase in disturbance levels resulting from a second season of use.

4. Erosion caused by the action of runoff channelling into vehicle tracks is rarely significant. The only exception is on steep gradients where deep vehicle ruts tend to channel the natural runoff, thereby increasing erosion.

Another study carried out in the Mackenzie Delta region was that of Bellamy, Radforth and Radforth (1971) where several tracked vehicles were used near Tuktoyaktuk. They recognized a strong correlation between the severity of surface damage and the moisture content of the material. In addition, three main processes of damage were identified:

1. destruction of the living vegetation
2. destruction of the secondary terrain structure
3. production of ruts, destroying the active layer and exposing the frost table.

It was also found, from the study of older tracks in the area, that long term regeneration was most efficient in the areas of poorly drained vegetation. Three different vehicle types were tested and variations in disturbance levels were largely a function of the different vehicle weights.

However, the vehicle equipped with smooth, pliable rollers generally created less disturbance for a given number of passes than did the other two vehicles, which were equipped with more conventional tracks (Bellamy et al., 1971).

A group that has been very active in tundra disturbance studies is the Muskeg Research Institute of the University of New Brunswick. In 1970 this group conducted extensive testing of the Albee Rolligon (a vehicle which rides on low pressure inflated bags) and several other vehicles in the vicinity of Tuktoyaktuk. The Rolligan testing involved three separate sites - a low lying level, moist area, a well drained slope having a gradient of 10 per cent, and the plateau at the top of the aforementioned slope. The focus of the study was to conduct multiple vehicle passes along test lanes at each site under various load conditions. Measurements of disturbance and photographs were taken after 1, 5, 10, 20, 60, 80, and 100 passes along the test lanes, although in some cases the tests were terminated prematurely due to mechanical breakdowns or vehicle immobilization. Vehicle disturbance was classified according to the Radforth "Vegetation and Structure Disturbance Classification System" (Table I), which relates structure and vegetation characteristics to a numerical scale of disturbance levels. Although this system is very subjective, it did allow the authors to define an upper limit of what they deemed to be an acceptable level of disturbance. This limit was taken to be level 4, characterized by mound top destruction with the vegetation torn and scattered, 10 per cent of the vegetation having been destroyed. Other studies included drawbar pull tests to measure the

Table I

Vegetation and Structure Disturbance Classification System

Disturbance Level	Structure	Vegetation
1	Undamaged	Undamaged
2	Slight damage	Shrubs broken, leaves knocked off
3	Mound top scuffing/ flattening	Cutting and/or flattening of all vegetation
4	Mound top destruction	Tearing and scattering of vegetation - 10% destroyed
5	Ruts start to form, less than 50% structure destroyed	25% destroyed
6	Ruts slightly deeper, more than 50% structure destroyed	50% destroyed
7	Ruts half bare	90% destroyed
8	Ruts entirely bare	100% destroyed
9	Ruts to permafrost	

towing efficiency of the Rolligon and turning radii tests.

As expected, the degree of disturbance was directly related to the amount of vehicle traffic, however, the rate at which the disturbance progressed was found to be dependent on several other factors. These included vehicle weight, inflation pressure of the bags, vegetation composition and ground moisture content. In general, rutting was slow to develop but eventually became more pronounced in low-lying moist areas. Drawbar pull tests showed that little slip occurred between the inflatable bags and the ground surface, even under conditions of maximum drawbar pull. The only exception involved travel in wet peat and silt mixtures where slip was greatly increased by soild adhering to the inflated bags. As well, the ability of these bags to conform to the surface microtopography was found to greatly reduce the disturbance level relative to other more conventional tracked vehicles.

A similar study based on multipass test lanes was also conducted by G. Abele near Barrow, Alaska. In this case, an air cushion vehicle (ACV), a tracked "Weasel" and a four wheeled Rolligon were all tested on different terrain types. The first two vehicles made 1, 5, 25 and 50 passes over the test lanes while the Rolligon made only 1, 5 and 15 passes due to vehicle immobilization. Visual observations, photographs and thaw depth measurements were made during and after each test, but these measurements were also repeated 1, 2, 3, and 4 years after the original tests. Since the use of an ACV is impractical in the context of the Nogash Lake diamond drilling program, the emphasis will be placed on the results of the Weasel and Rolligon tests.

The Rolligon was found to be very inefficient as the wide, low inflation and low rigidity tires caused significant surface disturbance. After only 15 passes the live organic mat was sheared from the peat subsoil, whereupon the tires began to cut deeply into the subsurface. Although 50 Weasel passes created an initial surface depression of 15 cm (14 cm of which rebounded after one year), the organic mat remained relatively intact.

Abele's findings supported the relation between moist areas and increased disturbance discussed earlier. However, the author found that in some cases surface disturbance actually stimulated regrowth of some plant species through surface darkening and increased heat absorption. This produced a "green belt" effect - that is after a few years the tracks remained visible due to a darker,more dense vegetation cover rather than the existence of deep black ruts. Abele determined that although the visibility of a vehicle track began to decrease within a year and continued to decrease gradually, the thaw depth continued to increase for one or two years after the test before recovery began. But, once the frost table began to aggrade toward the predisturbance level, this recovery of the subsurface thermal regime proceeded relatively quickly. As a result, the surface visibility of previous vehicle traffic often remains long after the frost table has returned to its original level.

The author concluded that the aesthetic (visual) impact of vehicle traffic is more pronounced due to the "green belt" effect than the effect on the thermal regime. Also, as long as vehicle traffic compressed the surface without excessive shearing, the surface should recover to a near pre-disturbance state within several (2 to 5) years, depending on the initial degree of disturbance.

Although the effect of tracked vehicles has been extensively studied in several areas of the north, monitoring of vehicle disturbance in Keewatin is a relatively recent undertaking. While some of the results from vehicle studies elsewhere can be applied to Keewatin, the majority of the research has to be repeated due to the different physical characteristics of the Barren Grounds. For instance, one of the major differences between the Mackenzie Delta and Keewatin concerns the surficial materials. The delta is dominated by fine silts having a high moisture holding capacity and as a result segregated ground ice of various forms is common. In contrast, much of Keewatin is covered with varying depths of relatively coarse grained sandy and bouldery till. The ground ice is a less common feature and thermokarst development is less likely to occur following disturbance. In addition, climatic variations affect the density and strength of the ground cover, as well as the revegetation capabilities of disturbed sites. Due to these suspected differences between Keewatin and other areas previously studied, an ALUR study was initiated at Lone Gull Lake, a Urangesellschaft Canada Ltd. camp 80 km west of Baker Lake. Mechanical difficulties with the tracked vehicle concerned, a Nodwell RN-75, resulted in minimal vehicle use. However, some of the early results will be discussed.

One of the major concerns of the program was the description of the vehicle stresses produced on the tundra surface. Normal stress tests indicated that topographic irregularities (ice wedge polygons, hummocks) could cause normal stresses up to 500 per cent higher than those recorded on a flat surface (Ferris, 1980). Also, it was found that the load was not evenly distributed over the entire track. The bogie wheels acted as pressure points, generating stresses up to 300 per cent higher than those produced under the rest of the track. Horizontal stresses were greatest under the track centre due to the single bogie wheel design of the track which increased track flexibility.

The greatest vehicle disturbance occurred during start-up under load where large sheets of vegetation were sheared from their roots. Tight vehicle turns also produced significant shearing by one, if not both, tracks. Track measurements in till showed that up to 15 cm of the active layer was removed by vehicle rutting which resulted in an average permafrost degradation of 8 cm (Ferris, 1980). Only limited thermokarst development was associated with this degradation, however massive ground ice is unusual in the till of the Lone Gull area. However, travel through low-lying areas of thick peat overlying marine or alluvial deposits produced localized frost table degradation of 300 per cent and some thermokarst subsidence. Such areas were especially sensitive due to the significant quantities of ground ice contained therein (Egginton and Ferris, 1980).

Throughout these and other studies concerned with tracked vehicle use in the north the importance of several factors is repeatedly stressed. Factors such as ground moisture contents, vegetation density and composition and depth to permafrost appear to exert a major influence on the level of disturbance created, regardless of vehicle design or location. Seasonality of the vehicle use has also been shown to be an important consideration in terms of disturbance and re-vegetation capabilities. The variety of vehicles tested exhibit variations in disturbance levels due to different vehicle weights and track designs. However, it must be remembered that the multi-pass test lanes on which several studies were based are not representative of the usual conditions of vehicle use. At Nogash Lake, for instance, neither main track experienced more than five or six passes per day and almost always the time delay between passes exceeded one hour. Multiple pass tests involved 5, 10, 20, 40 or more consecutive vehicle passes, increasing the level of disturbance markedly due to the amount of traffic and short recovery period between passes. Therefore, although these tests are useful indicators of general vehicle trafficability, such experiments are not typical of most resource oriented uses in the north. In contrast,the study at Nogash Lake involved the monitoring of vehicle movement in day-to-day drilling operations and as such represented a more realistic approach to vehicle disturbance studies.

Another observation supported by most researchers is that the tundra surface is generally more resistant to vehicle traffic than had been originally thought. Perhaps an undue emphasis on the aesthetic appearance of vehicle tracks, especially the high visibility of the dark tracks from the air, has created the false impression that minimal traffic will cause severe disturbances in all cases. In Kerfoot's opinion over-publicity of areas of severe disturbance has contributed greatly to this misunderstanding. As a case in point, the summer seismic lines created on the Tuktoyaktuk Peninsula in 1965 is one of the most often cited examples by opponents to tracked vehicle disturbance in the north. Kerfoot's description of this area is:

> "... miles of summer seismic lines bulldozed across the tundra landscape ... the complete removal of the active layer, and the insulating cover in particular, by the bulldozers, exposed high ice content sediments in the upper part of the permafrost and subsequent thermokarst development has transformed the original seismic lines into shallow trenches or canals over much of their length. This is unquestionable evidence of unnecessary, excessive damage to the tundra..." (Kerfoot, 1972, p. 62).

As such, the above is a rare example of extreme disturbance. In the more usual cases of disturbance, substantial recovery often occurs in as little as one or two years provided that the rooting systems have not been extensively damaged and that further disturbance does not occur.

1.8 Summary

Having a general overview of the monitoring program and the previous research concerning tracked vehicle use, the following chapter discusses the physical setting of the study area. The setting is described both on regional (geology, Quaternary geology, climate) and local scales (physiographic regions and terrain units). The discussion of the various terrain types within the tractor zone is especially important, for it was these surface differences that determined the location of the physical test (Chapter 3) and track profile (Chapter 4) study sites.

CHAPTER 2

THE PHYSICAL SETTING

2.1 Introduction

The purpose of this chapter is to briefly describe the regional setting of the study area. The first three sections provide a background discussion of the geologic, glacial and climatic influences which have affected the area and how these have interacted to produce the general terrain characteristics at Nogash Lake. The last two sections deal more specifically with the tractor zone, both in terms of terrain types and physiographic divisions, as studied and mapped by this author.

2.2 The Geologic Environment (Figure 2.1)

The geology of the region west of Yathkyed Lake has been studied by many different authors including Lee (1953), Wright (1967), and most recently K.E. Eade who reported on the Tulemalu map area (1976, 1977), wherein the study area is located. The following is a summary of the regional geology of the area, stratigraphically from oldest to youngest.

Basement Rocks (Wright, 1967; Eade, 1976)

All of the basement rocks are intruded to some degree by

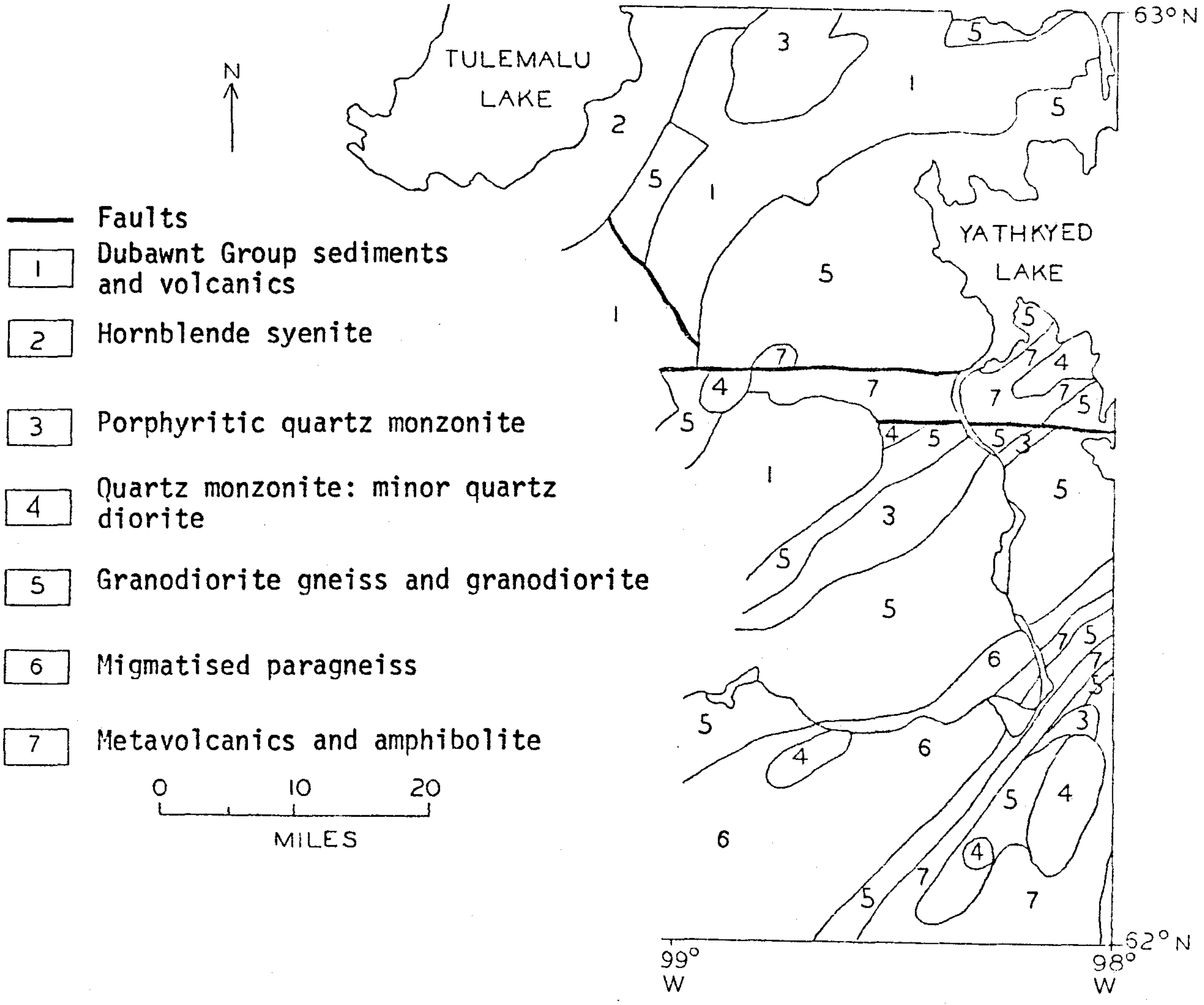


Figure 2.1 Geological map of the area west of Yathkyed Lake (Map 65J east half) based on the work of Wright (67) and Eade (76).

stringers, veins or irregular bodies of medium grained to pegmatitic pinkish quartz monzonite. Inclusions are only found close to the contacts, where cleavage and local faint foliations may also be seen.

(a) Archean Metavolcanics

Located south and west of Yathkyed Lake and south of the Kazan River, these metavolcanics consist of flows and pyroclastic rocks of basic composition with lenses of acidic to intermediate composition. Intrusions of granodiorite to quartz monzonite plutons are also present.

(b) Archean Migmatized Paragneiss

Containing garnet and minor sillimanite, white pegmatitic bands are common. Derivation was from greywackes and tuffs which were metamorphosed to mid-amphibolite grade. Often the paragneiss is cut by veins or small plutons of granodiorite or quartz monzonite.

(c) Archean Granodiorite Gneiss and Granodiorite

This unit is a broad grouping of igneous and metamorphic rocks having an average composition of granodiorite. Gneissosity varies from pronounced layering to slight mineral foliation though in places the rock may be massive. The granodiorite gneisses contain dark bands and inclusions are rare.

(d) Late Aphebian Porphyritic Quartz Monzonite

Unlike the Archean quartz monzonite, this unit is almost undeformed. Generally medium to coarse grained and pinkish feldspar phenocrysts are dominant, with only minor hornblende and biotite as mafic accessories.

(e) Hornblende Syenite

Pinkish medium grained and massive, this unit is probably correlative with the Martell syenite (Donaldson, 1965), however, the exact age relationship with the overlying Dubawnt group has not yet been established. Often the syenite intrudes the Archean quartz monzonite and may form small dykes which cut the granodiorite gneiss.

The Dubawnt Group

(f) Basal South Channel Formation

The South Channel Formation is a massive, poorly bedded polymictic conglomerate containing rounded blocks to angular fragments of locally derived basement rock. These felsic gneiss and granodiorite clasts are set in a fine to medium grained maroon to reddish brown chloritic matrix. The bedding is defined by interbedded lenses of sandstone and pebbly sandstone.

(g) The Kazan Formation

The lower portion of the Kazan Formation is made of fine to medium grained pinkish laminated and cross-bedded sandstone. The upper section is a maroon to reddish brown siltstone and mudstone showing well developed mud cracks and ripple marks. Overlying the siltstones and mudstones is a thick sequence of fine grained maroon coloured rocks, possibly tuffs.

(h) Christopher Island Formation

Dark green porphyritic lavas, probably of andesitic composition, with biotite, feldspar and pyroxene phenocrysts compose the lower part of the formation. The upper section contains purplish red porphyritic lavas, agglomerates and tuffs with phenocrysts of phlogopite, pyroxene and feldspar. In the Nogash Lake area, the Christopher Island Formation outcrops as prominent hills but is variable in thickness (generally greater than 100 metres) due to deposition on an irregular topography.

Structural Deformations (Eade, 1976)

Two periods of deformation can be recognized in the basement rocks. The earlier deformation produced a northeast trending foliation and folds plunging gently in the same direction. The second deformation formed broad open folds striking approximately 150° with steep dips. Following this deformation several gabbro and metagabbro dykes were emplaced, most trending between 85° and 115° while showing variable metamorphism. A few earlier dykes may be seen but these are much less common and more highly metamorphosed.

The regional structure is also distinguished by east trending faults, eight of which have been mapped in the northern portion of the map area. Thought to represent old faults that have experienced periodic activity, these faults cut the Dubawnt group rocks and along with younger northwest trending faults control the distribution of Dubawnt outcrops. A major regional shear zone is inferred from a cataclastic zone five miles wide in the granodiorite west of Yathkyed Lake. This northeast trending zone of shearing and faulting is believed to have experienced periodic movement since its initial activation.

2.3 Quaternary Geology

In terms of the Quaternary geology of the southern District of Keewatin, the Nogash Lake area experienced a varied glacial history due to its proximity to the northwest edge of the Keewatin Ice Divide, as defined by Lee et al. (1959). The author defined the divide "as the zone occupied by the last glacial remnants of the Laurentide ice sheet west of Hudson Bay". The divide was further described as a linear zone stretching from Hudson Bay at 66°N latitude to a point 150 miles inland at 61°N latitude. The Keewatin Ice Divide was originally defined as the zone wherein evidence of ice movement in both easterly and westerly directions was found. To the west of the divide, glacial features indicated westward ice movement only; to the east, only movement trends to the southeast were found (Lee et al., 1959).

This author measured 35 glacial striae in the vicinity of Nogash Lake and when the data was plotted as a rose diagram at 10° intervals, two general orientation sets were apparent (Figure 2.2).

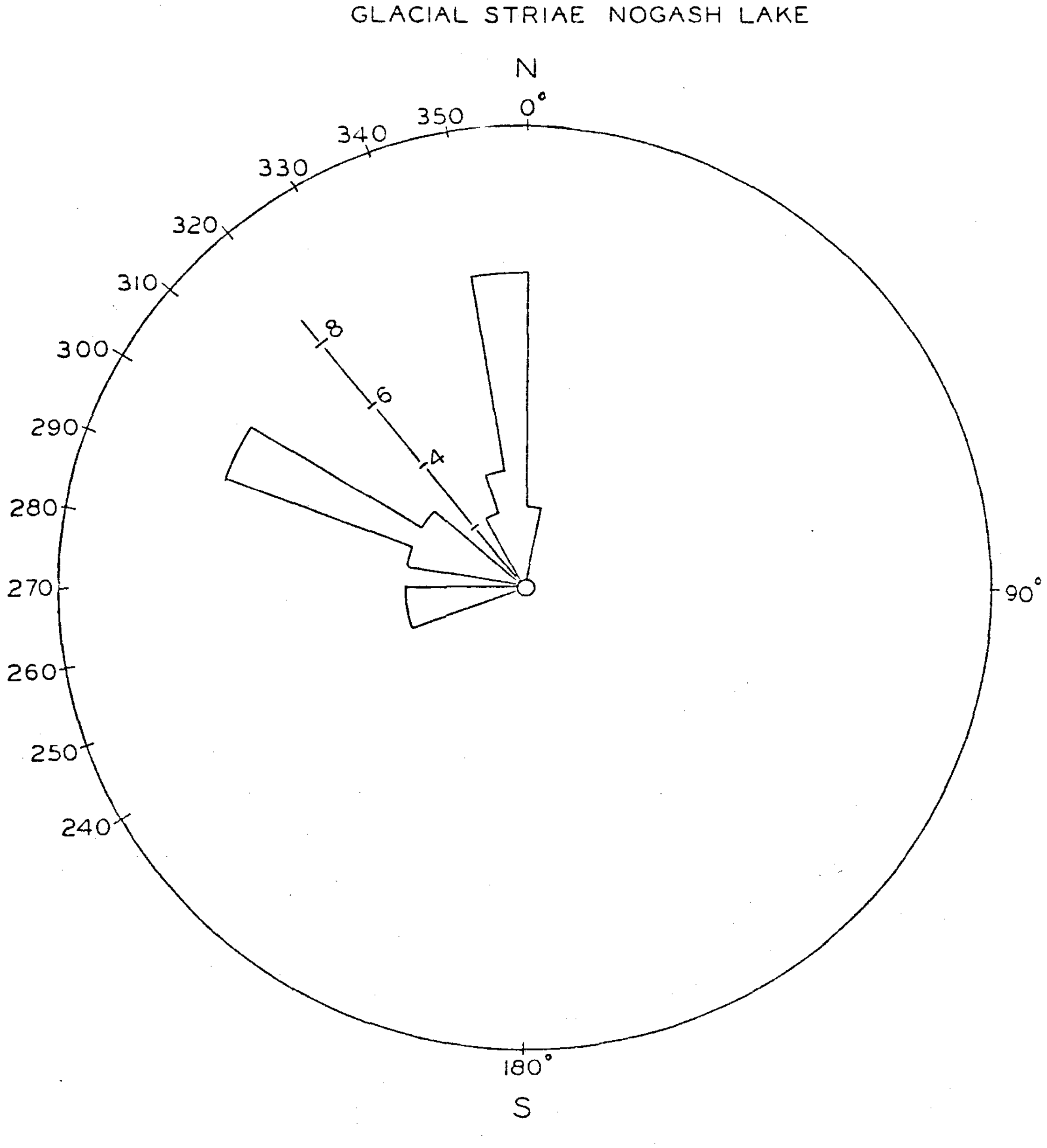


Figure 2.2 Glacial striae orientations based on 35 separate measurements in the Nogash Lake area. The data shows two periods of ice advance, the earlier trending in a WNW direction and the latter in a NNW direction.

The first set trended in the range 330° - 10° (150° - 190°) and was superimposed on striae of the second set which had orientations in the range 280° - 310° (100° - 130°). As these measurements indicated lines of movement only, other features such as crescentic fractures and crag and tail features were used to determine the directions of ice movement. From these features, ice movement to the WNW was indicated by the older striae set while the younger set suggested glacier movement to the NNW and N. These results conform reasonably well to both the position of Nogash Lake with respect to the Keewatin Ice Divide and the work of Lee et al. (1959). Lee's investigations revealed two directions of ice advance in the area; an earlier advance to the west followed by a second advance toward the NNW.

While glacial striae are the most obvious small scale indicator of previous glacial activity in the area, several other glacial features are also present. Perhaps the most spectacular feature from the ground is a large kame moraine located at the foot of a narrow valley northeast of camp. A few miles east of the kame moraine is a large outwash plain. From the air the sandar can be identified by the deep ice wedge furrows cutting across the deposit while on the ground a sudden change in ground vegetation cover reflects the sandy nature of the underlying deposits. The outwash deposit is in sharp contrast to the general surficial material of the area which consists of 1 - 10 metres of loosely compacted glacial till. The depth of till varies greatly with topography but the figures listed represent the ranges in till thickness encountered during the drilling program. The till characteristically contains pebbles of granodiorite, gneiss and granite and an average contains 90% sand and only 10% silts and clays, although there is often an increase in the finer size fractions with depth in the till. These figures are based on 25 particle size analyses of till samples from several locations within the tractor zone. In many areas the till is overlain by up to a metre of peat and in these situations the till is often gleyed.

2.4 The Climatic Environment

The climate of southern Keewatin depends for the most part on the interaction of four main climatic factors: the amount of solar energy input, the nature of the receiving surfaces, the topography and its influence on weather systems and the location with respect to large water bodies. Due to the high latitude location, the absorption of solar energy per unit area is relatively small compared to the more southerly latitudes. However, a portion of this energy deficiency is offset by the increased sunlight duration during the summer. As a result, the total solar energy input for June and July is comparable to several areas further south. Yet, the annual heat absorption in Keewatin is usually less than 50% of the total energy input due to the high reflectivity (albedo) of the surfaces. Since most of southern Keewatin is covered by ice and snow for approximately nine months of the year, heat loss by sunlight reflection forms a sizeable portion of the total heat budget. Also, the interaction of these factors with the temperature influences the weather systems that influence the region.

However, as Keewatin is relatively flat, topographic effects are minor compared to the District of Mackenzie, where the Mackenzie Mountains and the funneling effects of the Mackenzie River valley exert a considerable influence on weather systems moving through the area.

Another climatic consideration, especially in Keewatin, is the proximity to large water bodies. Although Ennadai and Eskimo Point are located at roughly the same latitude, Eskimo Point is located on the coast of Hudson Bay while Ennadai is 220 miles inland. Due to the effect of continentality, Ennadai experiences a much more severe climate than Eskimo Point, where conditions are greatly moderated by Hudson Bay. This example illustrates the general increased severity of climate experienced with movement westward into the interior of Keewatin. In addition, the interior lacks lakes large enough to have a significant moderating effect on more than a local scale.

Southern Keewatin experiences long severe winters with generally clear skies due to the influence of the Mackenzie high pressure system. As a result, circulation is mainly anticyclonic and precipitation is light because of low humidities. Some snowy periods do occur, usually associated with southeasterly winds and atmospheric troughs that cross Keewatin. Of the snowfall that does occur, most falls in October and November. Keewatin is noted for the severe blizzards and windchill factors experienced, with snow driven by gale force north or northwest winds.

The summer period, although short lived, remains relatively clear and cool as Arctic air continues to dominate. However, areas in southern Keewatin often experience daily high temperatures exceeding 10°C through much of the summer and short lived warm periods with highs exceeding 20°C occur in most summers. Precipitation is light with most storms associated with depressions in the Arctic front.

Given the harsh climate, a great deal of emphasis in almost all terrain studies is given to the ability of the disturbed surfaces to recover to their pre-disturbance state. Early studies indicated that the cold climate resulted in low biologic productivity which, while partially offset by the longer sunlight duration, caused complete natural recovery to be a slow process. However, several more recent studies suggest that the natural recoverability of disturbed vegetation actually proceeds at a much faster rate than previously thought. While the rate of recovery is directly related to the climate, and as a result will vary slightly from area to area, several other factors related to the climate are involved. These include soil acidity and nutrient supply, active layer depth and disruption of the root systems by freeze thaw heaving. The shallow active layers force the vegetation to develop horizontal rather than vertical root systems. The shallow frost table especially discourages the growth of low bushes and shrubs which cannot be supported by the shallow root network. As well, the shear strength of the vegetation mat is reduced so that the surface is more susceptible to disturbance. Wet conditions during the spring thaw decrease soil aeration and interrupt the function of nutrient supplying micro-organisms . In areas of silty soils with high moisture contents and on many slopes freeze-thaw action may produce significant disruption to root systems, weakening the vegetation cover.

Examination of weather data from the two nearest weather stations to Nogash Lake, Ennadai and Baker Lake, shows that the climate of the study area is similar to that of much of central Keewatin, that is, a relatively cold and dry environment with long winters and short cool summers. From the Canadian Normal Weather Data publication, the climatic averages for the years 1941-1970 are as follows:

	Baker Lake	Ennadai
Mean Yearly Rainfall (mm)	123.9	164.5
Mean Yearly Snowfall (mm)	98.0	120.6
Mean Total Yearly Precipitation (mm)	213.0	285.4
Mean Daily Maximum (°C)	-8.4	-5.4
Mean Daily Minimum (°C)	-16.1	-13.6
Mean Daily Temperature	-12.3	-9.5
Number of Days with Frost	279	263

Comparison of the summer 1980 data with the previous four years is shown in Figure 2.3. The daily maximum and minimum temperatures (Figure 2.4) were recorded by a 170 hour continuously recording drum thermograph, which also recorded relative humidity. Precipitation totals were also recorded twice daily (Figure 2.5) as were the relative humidity (wet bulb - dry bulb technique) and wind velocity (anemometer). As the temperature curves of Figure 2.3 show, the local temperature climate appears to reflect the latitudinal position of Nogash Lake between the Baker Lake and Ennadai stations. Summer precipitation totals are generally quite variable with the summer of 1980 no exception. Compared to both Baker Lake and Ennadai, June was unusually dry, July was average, and August was

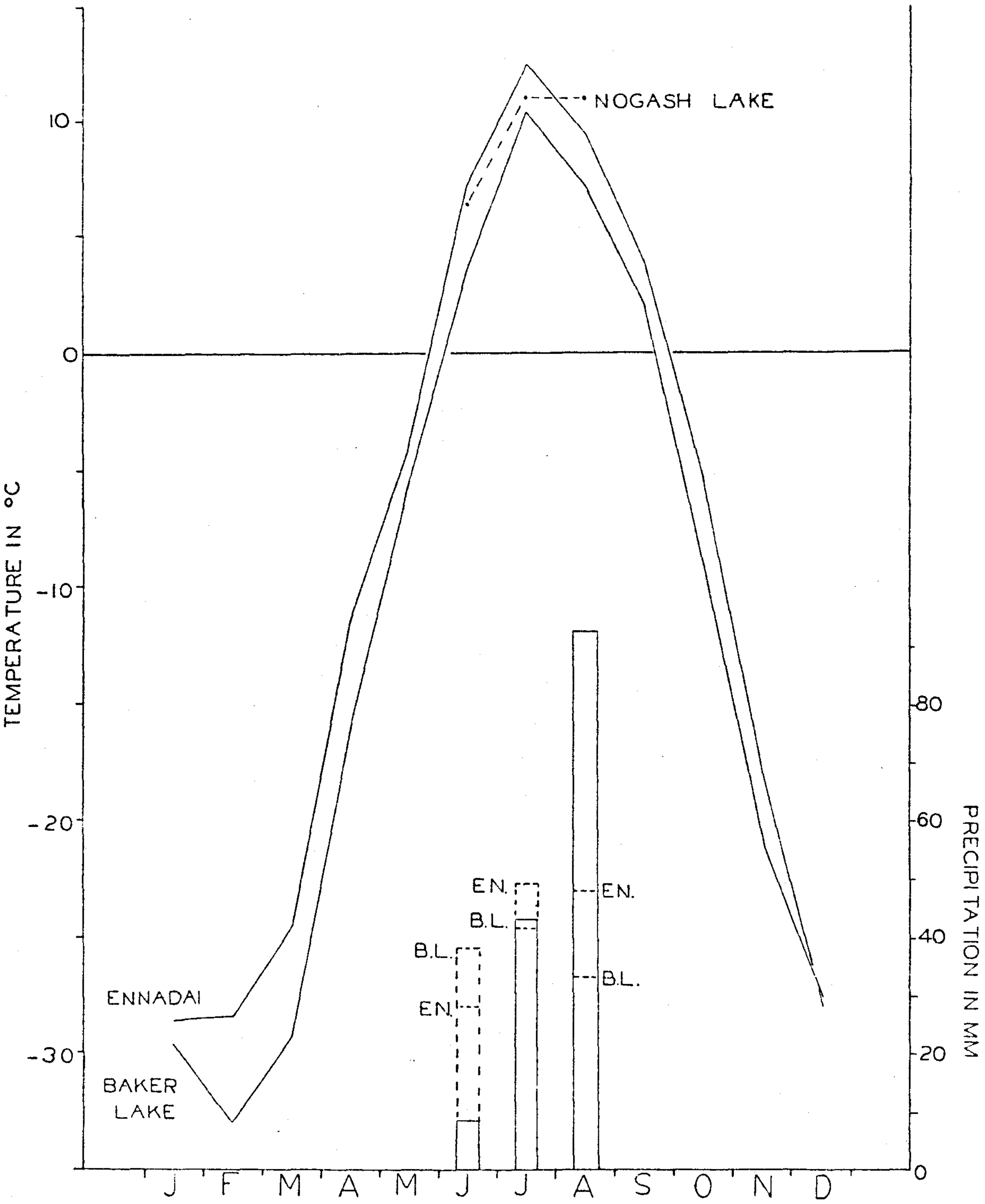


Figure 2.3 Climatic data for Baker Lake (B.L.) and Ennadai (EN.) based on the 1975-1979 average monthly temperature and precipitation values. Climatic data acquired at Nogash Lake in the summer of 1980 is represented by a dotted line for the average monthly temperature and a solid line for total monthly precipitation.

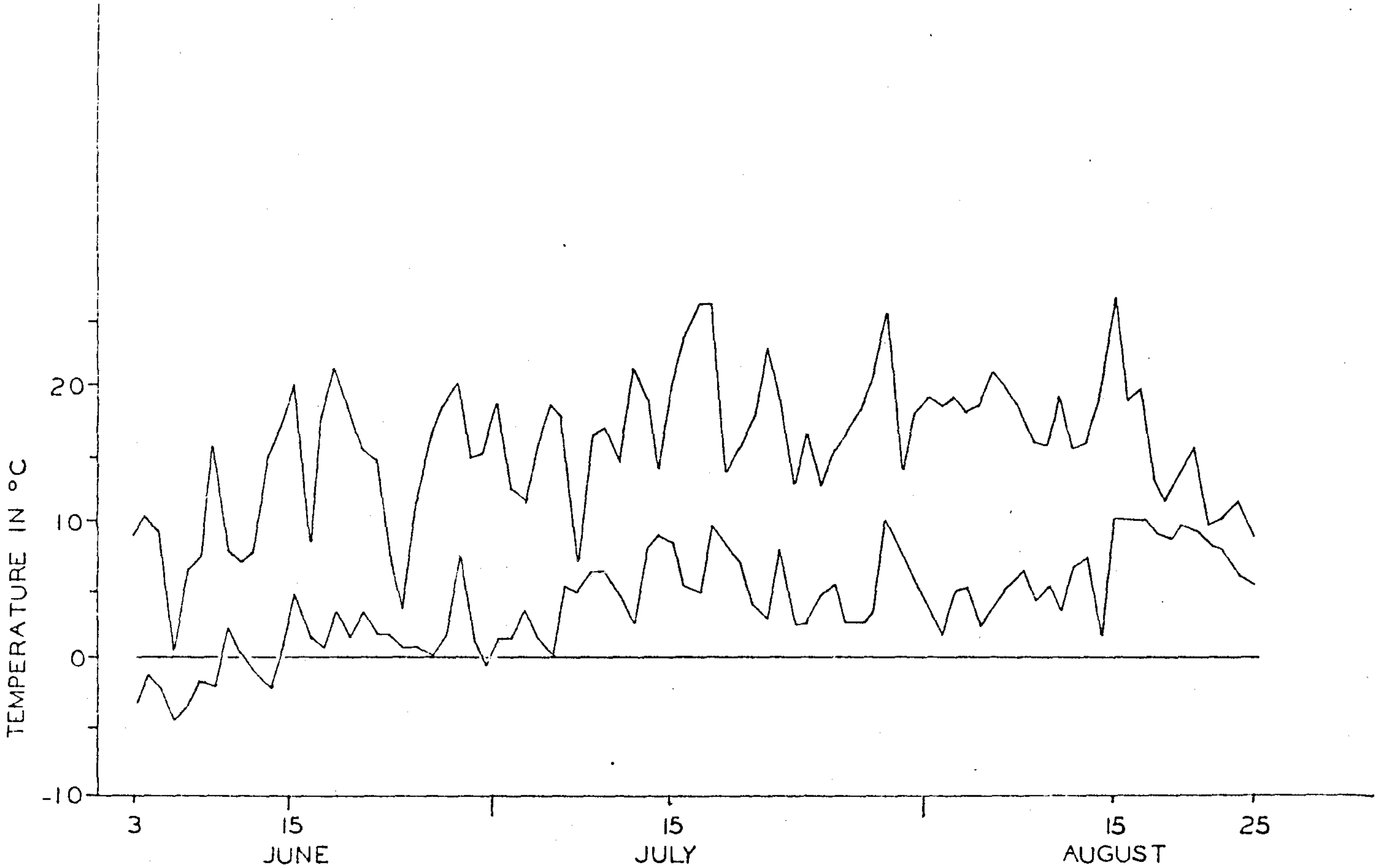


Figure 2.4 Daily maximum and minimum temperatures (°C) as recorded by a continuously recording drum thermograph from June 3 to August 25, 1980 at Nogash Lake

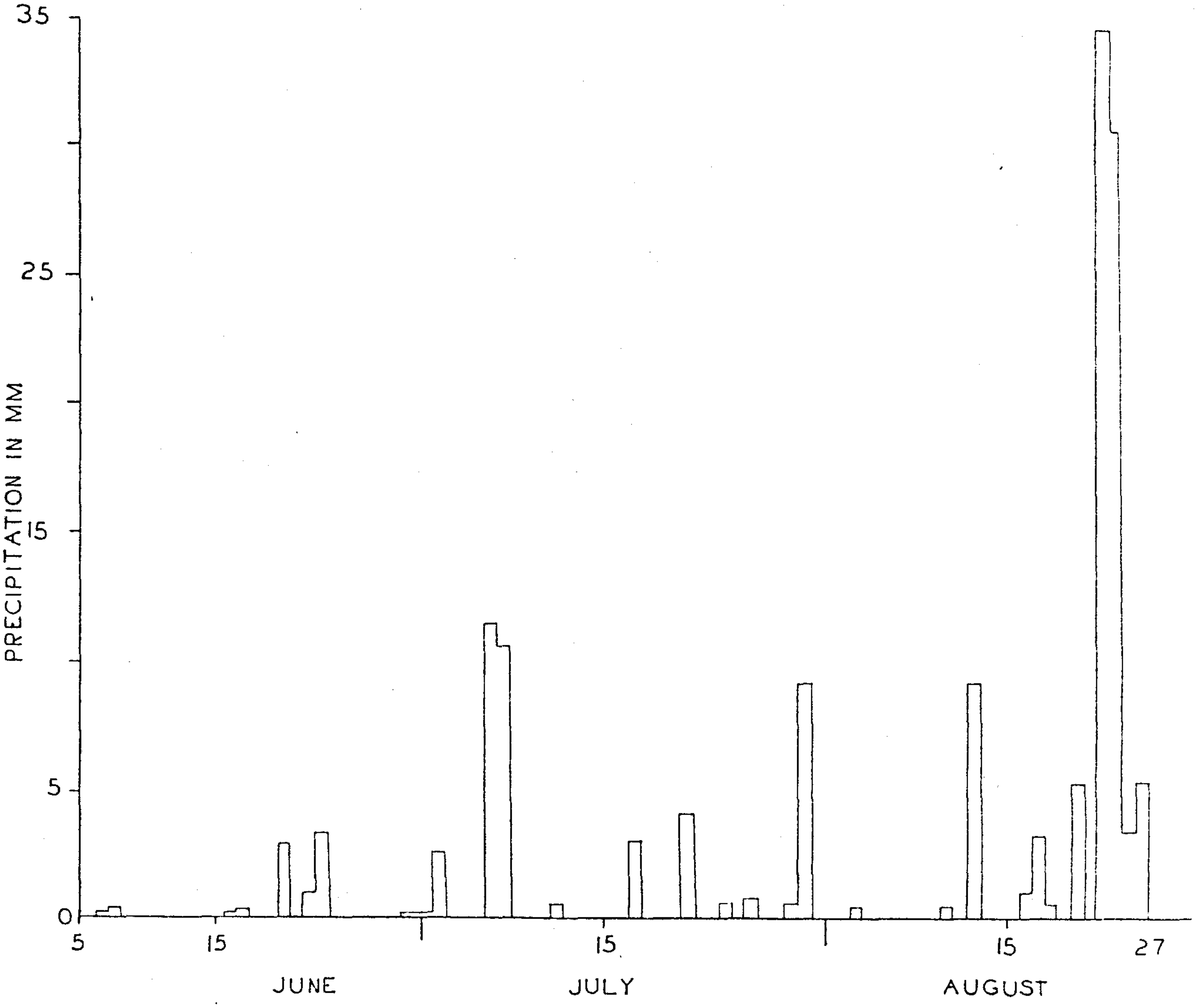


Figure 2.5 Daily precipitation totals (mm) for the period June 5 to August 27, 1980 at Nogash Lake.

unusually wet at Nogash Lake, the latter due to a large late August storm. Analysis of the 1941-1970 climatic data shows that in this time period the largest summer storm generally occurred in July at Baker Lake and August at Ennadai. The return interval of these large storms (greater than 3 cm rainfall in 24 hours) is about 1.7 years and 1.9 years for Baker Lake and Ennadai respectively. As July and August 1979 were relatively dry in both locations, it was probably not unusual to experience a large storm such as the 36 hour rainfall of 65 mm at Nogash Lake. While the magnitude of the storm was unusually large, the occurrence of a large storm, based on previous weather data, may have been expected.

2.5 Terrain Types (Map 1)

The vehicle zone was mapped in terms of terrain type in order to provide a better understanding of vehicle response in different materials. Mapped on a scale of 1:2500, nine different terrain types were classified.

1) bedrock with shallow till cover, the till being less than 1 m thick
2) well drained, shattered bedrock boulder fields with lichens the only vegetative covering
3) well drained light brown to reddish till, generally covered by a thin vegetation layer (2-10 cm thick) of low ground plants such as crowberry (Figure 2.6); mudboils are locally common within this unit, especially near bedrock outcrops

4) well drained, well vegetated till with boulders at or near the surface; mudboils are rare
5) well drained hummocky sedge meadow with peat thicknesses less than 30 cm, found in gently sloping areas
6) poorly drained hummocky sedge meadow containing abundant sedge hummocks (10-50 cm high, 15-70 cm diameter) surrounded by moist depressions, lichens and mosses found mainly on the drier hummock tops
7) poorly drained level sedge meadows with thick peat accumulations, most are seasonal ponds covered by thick sedge growths on the bottom
8) high centre peat polygons of various sizes, occuring as complexes of several polygons with 10-20 cm of vegetation above the frozen core
9) well drained areas of vegetated rock polygons characerized by dense growths of low shrubs, scattered mosses and other low ground plants.

2.6 Physiographic Regions (Figure 2.7, Map 2)

The tractor zone was further grouped into three distinct areas in terms of location and slope.

1) The central valley contains the upper and lower sedge meadows and is characterized by wet, spongy, and on the macroscale, relatively flat terrain. Peat thicknesses are variable from 30 cm to 1 m thick over till which is often gleyed. Other common features

include peat mounds and small moss or grass hummocks, which provide what little relief there is. The former rarely exceed 80 cm in height, while the hummocks are generally 50 cm high or less. This unit trends in a southeasterly direction from Lac Cinquante before turning to a more easterly direction near camp. Throughout the summer this region remained permanently moist, partly due to the moisture holding capacity of the peat, but also to the fact that the valley occupies the main drainage course of the tractor zone. This was obvious after heavy rains in late August, as the runoff could be traced for more than a kilometre from near Lac Cinquante towards the camp.

2) The northern plateau is dominated by surface or near surface glacial till, with occasional bedrock outcrops. Although there are some areas of sedge and moss, most of the area is well drained and remained dry throughout the summer. The vegetation thickness over till rarely exceeds 5-10 cm in the till areas while greater thicknesses were found in moist areas associated with snowbank accumulations. The terrain is quite flat with exceptions in both the NW and NE corners of the tractor zone.

3) The southern slope in gently sloping except for the SW corner where the gradient steepens towards a large bedrock and exposed till complex. Although similar to the northern plateau in terms of large areas of exposed or near surface till, this area is more moist, and as a result, well drained sedge meadows predominate over till. Within the tractor zone, the southern slope occupies the largest area

Figure 2.6 Typical Profile in till with overlying organic layer 10 cm thick.

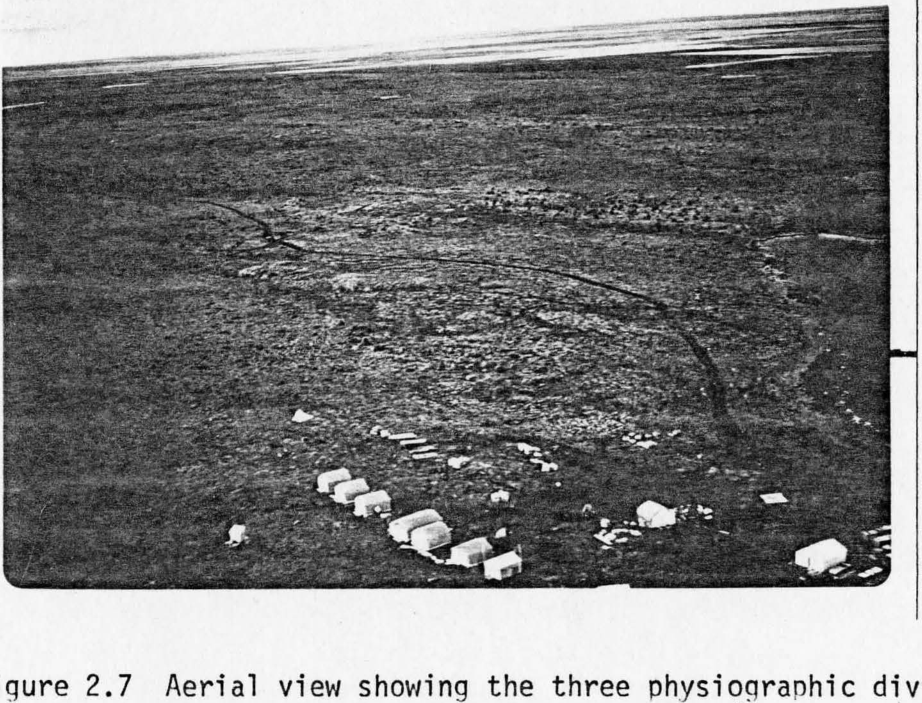


Figure 2.7 Aerial view showing the three physiographic divisions at Nogash Lake: the central valley (darker green area leading to lake on right) which separates the northern plateau (top of photo) from the southern slope (left side). Also visible is the dark main track 1 (MT 1) developed in late May and June and the faint MT 2, used in July and August. It leads diagonally to the upper left corner from the campsite.

of the three physiographic divisions.

2.7 Summary

The two most important physical characteristics on a regional scale are the existence of continuous permafrost and the thick blanket of till that covers most of the area. This reflects the importance of glaciation and climate in the development of the area. The interaction of these two controls is well illustrated by the tractor zone. Here, several different terrain types are defined on the basis of distinct vegetation assemblages which reflect variations in till depth and proximity to the frost table. Having defined these different terrain units, the following chapter discusses some of the physical tests used to quantify the strength of these various surficial materials.

CHAPTER 3

PHYSICAL TESTS AND OBSERVATIONS

3.1 Introduction

As stated previously, one of the purposes of this study was to measure some of the physical properties of the surficial materials and later to apply this knowledge to explain variations in vehicle disturbance levels. As this study will show, thick peat accumulations are often quite susceptible to vehicle disturbance. For this reason, a general summary of some of the physical properties of peat is included as a useful aid in the understanding of peat behavior under the different tests. Although pressure bulb tests were only performed in peat, the later two tests (vane shear and drop weight penetrometer) were done in both peat and till areas and are discussed in the pages following.

3.2 The Physical Properties

Peat is a spongy, dark brown or black material consisting largely of organic residues accumulated by the incomplete decomposition of dead plant constituents such as mosses or sedges (Stanek, American Geological Institute, 1976). Inherent in this definition is that enough of the original plant structure is preserved so that the peat can be identified as originating from certain plants, such as sphagnum peat. In addition, peat has a cellular structure with the root systems of the living surface vegetation forming a matrix for the peat subsoil. Peat development is most common in marshes and other wet areas, including much of the Arctic tundra.

In the classification of peat, several factors are involved, however, the fibre content of the material may be the most useful criterion (Frazier and Lee, 1971). The System of Soil Classification for Canada classifies peat on the basis of an arbitrary fibre size of 0.15 mm. Fibric materials are defined as those having 67 per cent or greater of the fibre content larger than 0.15 mm, mesic materials if 33 to 67 per cent and humic materials if less than 33 per cent of the fibres are larger than 0.15 mm. This classification is useful in determining the degree of decomposition,which has an important effect on the response of peat to stresses. For instance, the degree of decomposition exerts a major influence on the water retaining capability of the peat. Several authors (Feustal and Byers, 1936; Amoryan et al., 1966) have shown that the degree of decomposition is inversely related to the water content. Similarly, bulk density is also used as a measure of decomposition as well as compaction. Elzen (1961) found that as bulk density increases, the pore size distribution changes radically although the total pore volume changes only slightly. Sturges (1968) discovered that low bulk density peats contain several large pores which release water easily, whereas high bulk density samples have smaller pores which retain more water at higher suctions.

As decomposition occurs, fibre breakdown reduces the pore size so that permeability decreases and moisture contents increase.

The ability of a peat to retain large quantities of water depends largely on porosity and permeability. Pore size considerations involve such concepts as the void ratio (the ratio of the volume of spaces to the volume of soil solids) and the total porosity (the total volume of water contained at saturation). The void ratio provides a measure of the compressibility of the peat, ranging from 25 for fibrous peats to as low as 2 for amorphous peats (Hanrahan, 1954). Porosity values average 92 per cent for most peats, but may vary between 80 and 97 per cent. Although the porosity of peat is high, the permeability is relatively low. The main influences on permeability are: (i) the degree of decomposition, (ii) the degree of compaction, (iii) the amount of mineral contamination. The result is that open fibrous peats are, at least initially, more permeable than granular peats. Colley (1950) and Miyakawa (1960) found that the permeability of peat is greater in the horizontal direction than in the vertical direction. This relation tends to keep peats permanantly moist, especially in low-lying flat terrains where the topographic gradient is too low to allow significant horizontal or vertical drainage.

Another important property of peat is the ability to shrink when dried and swell when rewetted. Observed values show that shrinkage of up to 87 per cent of the original peat volume may occur on drying (Walmsley, 1973), producing a hard, firm peat. As with the other properties of peat, the amount of shrinkage and volume recovery is largely dependent on the peat type. However, once a peat has dried, it will be unable to hold as much water upon rewetting as it held before drying. Maas (1972) found this relation to strengthen with depth in the peat profile, suggesting the dangers of draining peats to excessive depths. Since rewetting would not compensate for the shrinkage, net surface subsidence would result. Also, given two dried samples Feustal and Byers (1930) found that sphagnum peat will have an average re-absorption of 55 per cent of the water the original sample could hold, while heath peat will only absorb 33 per cent of its initial water holding capability before drying.

3.3 Physical Properties and Vehicle Traffic Considerations

Probably the most important property of peat in terms of the engineering aspects is the ability to hold an amount of water equal to 50 to 2000 per cent of the dry weight of the solid particles. This enormous amount of water is held in three main ways: as water between the individual peat particles (free water), as water within the cells, and as absorbed water around the cells (Wilson et al., 1965). When the peat is subjected to a stress, such as tracked vehicle passage, the free water is expelled from between the particles, reducing the void volume. As well, compaction will expel a certain amount of water from within the cells. Since the permeability of peat is low, these expelled waters are capable of creating high pore pressures. Should the pore pressures become high enough, the cells will rupture, releasing the cellular water and tending to lubricate the shearing surface. Under repeated (cyclic) loading, peat exhibits both elastic and plastic components of deformation (Wilson, 1976). Provided the vehicle stresses are below a certain "threshold limit" so that cell rupture does not occur, the peat will rebound after the stress is removed so that further loads can be supported. Part of this rebounding effect is due to the re-absorption of expelled waters after load removal. Therefore, the goal in vehicle design is to maintain vehicle stresses below this general "threshold limit" for peat so that deterioration of the peat is minimal.

PHYSICAL TESTS AND OBSERVATIONS

3.4 Compression of Thawed Peat - Pressure Bulb Tests

Procedure and Purpose. Tests were performed to measure the ground pressures exerted by the tracked vehicle at different depths in the subsurface. Two pressure sensors were used, one each buried at depths of 10 cm and 25 cm in a level wet sedge area. The sensors themselves consisted of a balloon filled with water which was connected by Tygon tubing to a pressure gauge. Care was taken to ensure that no water leaked from the system between the balloon and pressure gauge, that is the pressure exerted by the vehicle on the balloon would be the pressure recorded (within the limit of accuracy of the device). Misleading results could occur if the tubing or balloon became crimped or if the vehicle path over the sensor varied from pass to pass. Each test involved multiple passes (8-12 per test) over the sensors with the maximum pressures recorded for each pass. The pressure bulb test was done four times throughout the summer and an attempt was made to correlate the differing results with the physical conditions at the time of the tests.

Results. In the general test area, several standpipes were installed which gave an indication of the water levels at the time of testing (Figure 3.1) and from these it was apparent that the water levels had a significant effect on the compressibility of the peat. Throughout the summer, as the water levels dropped in the control standpipes, measured bearing pressures also decreased indicating decreasing compressibility of the peat. Conversely, late in the summer as the water levels slowly rose, the bearing pressures recorded also increased (August 14 test). This suggested a direct relationship between the amount of moisture in the peat and the compressibility. By analogy, the water levels were similar to increasing the volume of drill cuttings and fluids discharged around the drill sites, as both situations reduced the bearing strength of the ground. As expected, the deeper gauge recorded lower pressure values than the shallow gauge in all tests. Also, the maximum bearing pressures recorded showed a general decline throughout the test in all but one case (Figure 3.2). These tests were quite useful in providing some data on just what ground pressures would be produced by vehicle traffic in the sensitive peat areas.

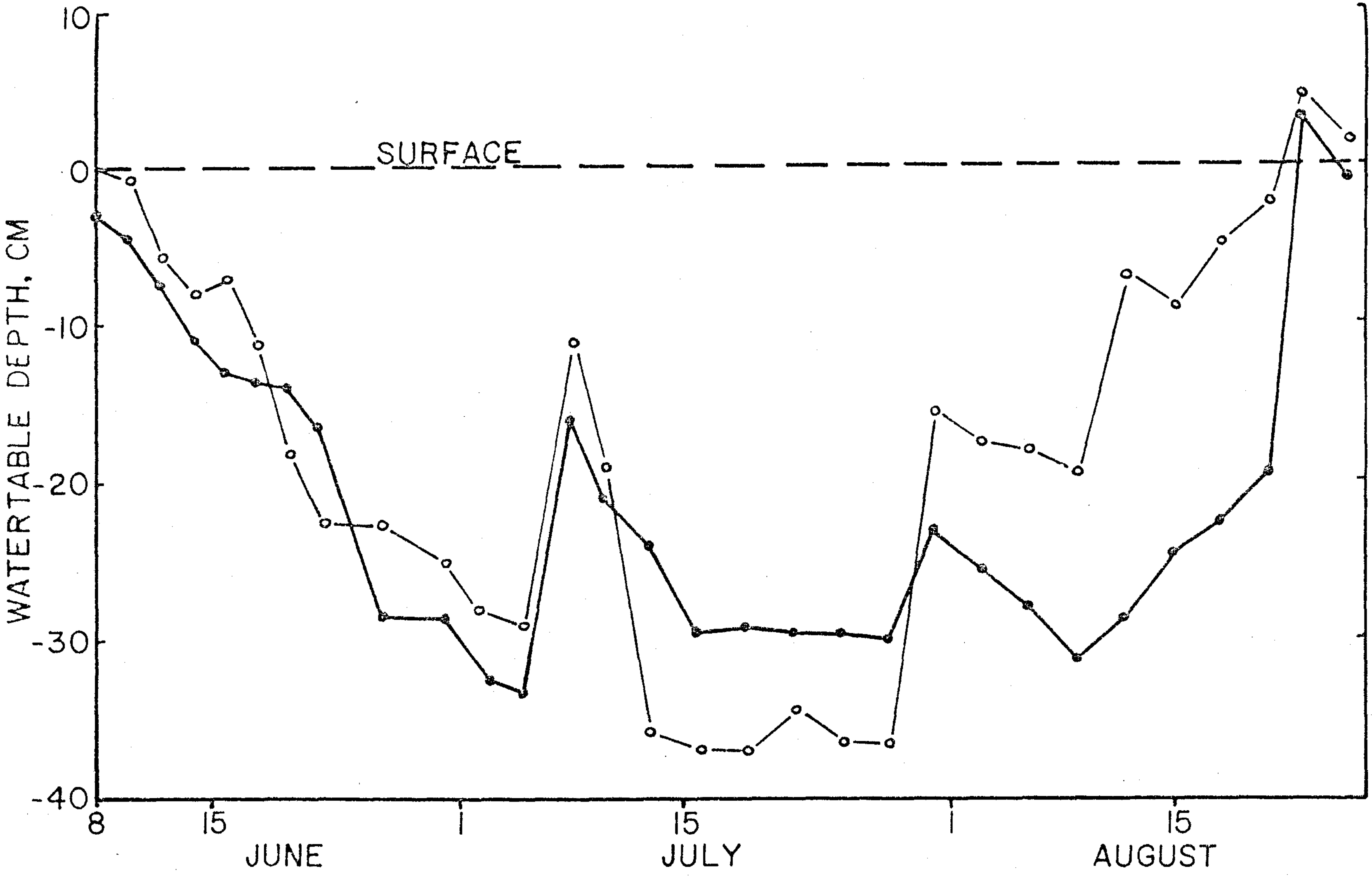


Figure **3.1** Water table levels for one site in the central valley (solid dots) and one site on the northern plateau (circles). Steady decrease in levels throughout June appears to correlate with increases in shear and compressional strengths of peat during this period.

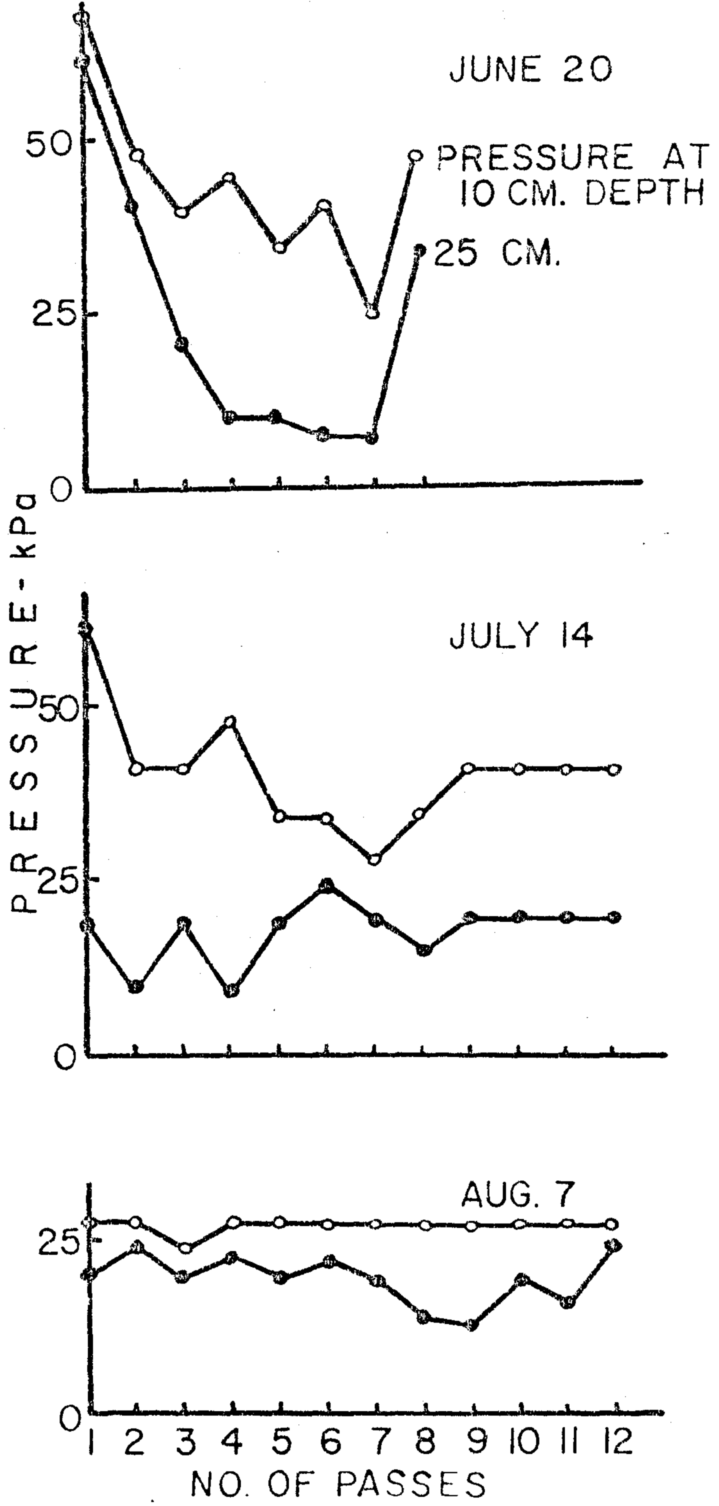


Figure 3.2 Maximum pressure recorded at depths of 10 and 25 cm. for each of several passes at three times over the summer. Tests were performed on sedge meadow. Tendency until early August was toward lower pressure drops during each test, indicating that the ability of peat to resist compression is increasing as the peat dries out.

Interpretation. Close examination of the bearing pressure results reveals two common trends in the data.

The first is that on the first vehicle pass, the pressure readings tend to be quite high compared to values for subsequent passes. The probable explanation is that on the initial pass, much of the water is squeezed out from the peat so that on subsequent passes, the peat around the balloon had stiffened due to the water loss and compaction. By stiffening, the peat should be better able to resist the force of the vehicle on further passes,resulting in lower bearing pressures.

In contrast, the August 7 test showed almost no variation in shallow bearing pressures throughout the test as only two of twelve readings were not 28 kPa. At the time of the test, water levels were low and presumably the peat was about as dry as it would get at that depth, so that after one pass the peat was almost in a state of maximum compaction. As a result, further passes produced essentially the same bearing pressure.

The second pattern evident is the periodicity of the results. In the majority of the tests, the rise and fall of pressure values seems to follow a forward-backward pass pattern. In fact, in 70 per cent of the cases where the bearing pressures changed from one pass to another, the pressures produced while the vehicle moved forward exceeded those values as the vehicle moved backwards.

The explanation is probably related to changes in the behavior of the peat due to the weight distribution of the vehicle itself. On a forward pass, since much of the vehicle weight is in the front, the peat experiences a large force "shock" immediately, producing high pressure values. However, on the backward pass, the peat is compressed more gradually and stiffens for a few seconds before the major weight of the vehicle passes over the gauges. In the first case the peat is not allowed to stiffen appreciably before the major force is applied. However, backing up stiffens the peat, making it more resistant to the greater weight of the front end of the vehicle when it passes over the gauge.

The data reflects a consistent pattern of decreasing ground pressures throughout the test, and successive vehicle passes often show some variability. Part of the variation is probably a function of the amount of time between passes. The reason for this is that between passes, water would be re-absorbed by the peat after the compressive force (the vehicle) was removed. While most of the water originally present would not likely be re-absorbed, enough water would probably be taken up to weaken the peat somewhat for the next pass, causing increased ground pressures. In the case of August 7, very little water must have been re-absorbed, otherwise the pressure readings would not have been so constant. If the compression and rebounding of the peat has a major influence on the ground pressures, then the time variations between passes must contribute at least partially to the differing results from pass to pass.

3.5 Vane Shear Tests

Procedure and Purpose. Several vane shear surveys were taken throughout the summer in the wet sedge areas and along the main track from camp (MT 1). The main purpose was to give an indication of the shear strength of the surface throughout the summer and attempt to relate this to the trafficability of the surface. Measurements were taken with a Geonor vane shear device, then averaged. The vane itself consisted of four sharpened blades which were pushed into the ground surface, with the amount of force required to turn the vane recorded on a rotating collar near the T-shaped handle. Care had to be taken so that the vane did not catch on stiff roots or pebbles, both of which would give misleading results. In most cases three shallow (5 cm) measurements were taken at specific distances along a survey line, but for both the upper and lower sedge meadows, three deep readings (10-15 cm) were also taken. The measurements were then averaged and converted to vane shear strengths in kilopascals (kPa).

Results. An examination of the water levels in the vicinity of the vane shear surveys showed that as the water levels dropped, the shear strengths tended to increase. The largest increase in shear strength between readings occurred early in the summer (mid June to early July) during a period when the water levels showed a marked decline. The surveys of the main track (0-350 m) and the upper and lower sedge meadows indicated this relationship clearly, while a survey taken in late July only showed a small increase in shear strength, suggesting that part of the major period of strengthening had already passed. Moisture contents by weight along the main track also showed significant declines in this period. Conversely, as the water levels began to rise significantly in mid to late August, the average vane shear values decreased slightly, again indicating an inverse relationship between shear strengths, water levels and associated moisture contents of the materials (Figures 3.1, 3.3).

Interpretation. The results of the vane shear measurements further support the conclusions resulting from the bearing pressure tests, namely that as the peat dries, the stiffer and more resistant to imposed stresses the peat becomes. Just as the decreasing moisture contents lead to peat stiffening and lower bearing pressures, the resistance of the surface to shearing is also increased with moisture loss. Water levels and moisture contents were initially high due to the shallow frost table, which restricted meltwater drainage to a few centimetres of thawed ground. As a result, the thawed zone held a large volume of water early in the summer, but as the thaw progressed the water could flow through a thicker thawed layer. This allowed water previously trapped by frost between hummocks to gradually drain away. Improved drainage allowed the surface to dry, with higher shear strengths the result. Similarly, the position of the frost table also had a major influence on vehicle disturbance early in the summer. While the frost table was shallow and the thaw zone extremely wet, the shear force of the

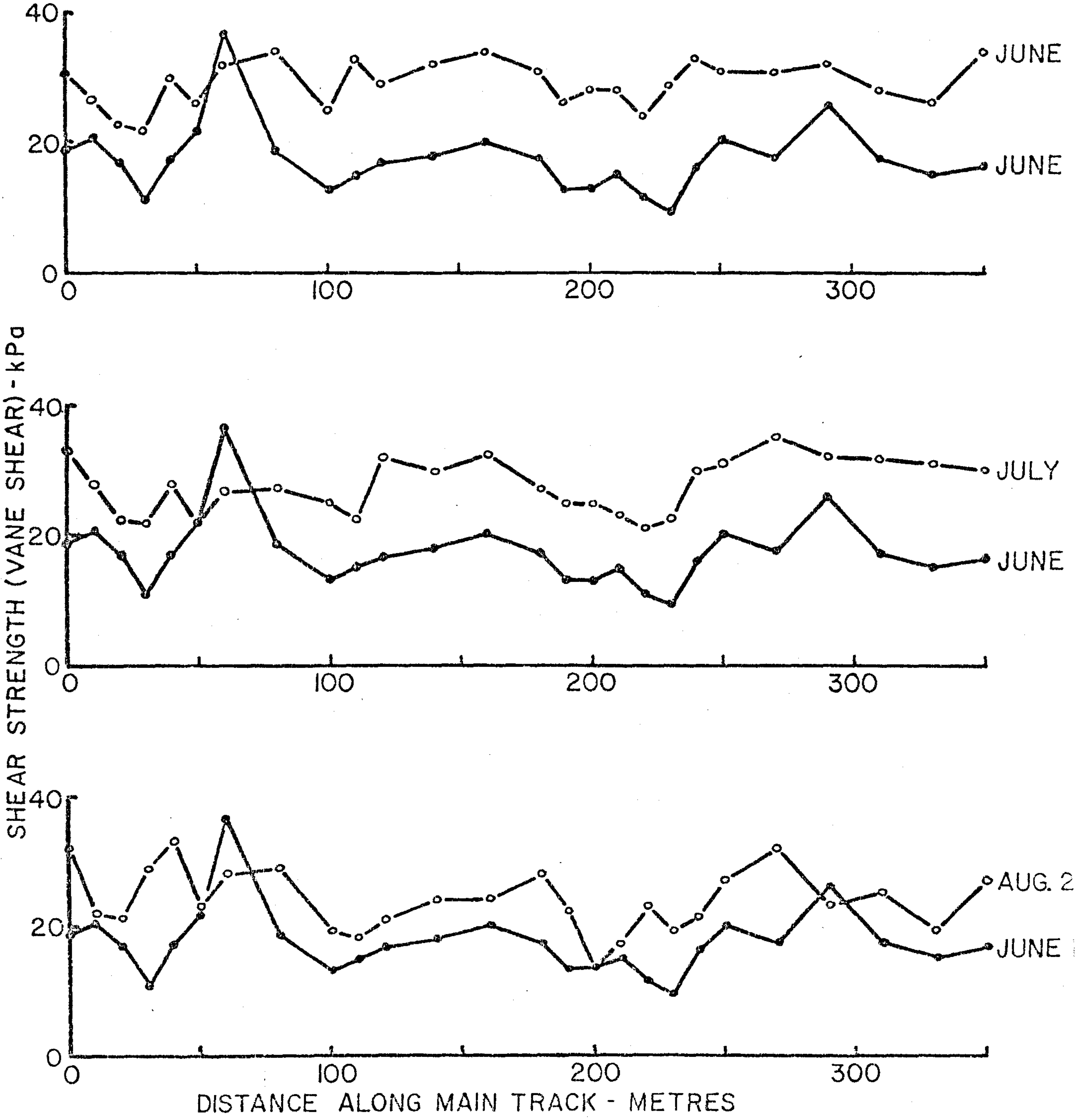


Figure 3.3 Shear strength measurements taken at intervals along the main track (MT 1). Profile for June 11 is repeated on each graph for comparison. June 27 and July 30 profiles show attainment of near-maximum shear strengths while August 24 profile shows the return to early summer values immediately after a heavy rain. For further comparison, the tracked vehicle pulling a conventional drill rig mounted on skids would exert a shear stress of approximately 10-15 kPa.

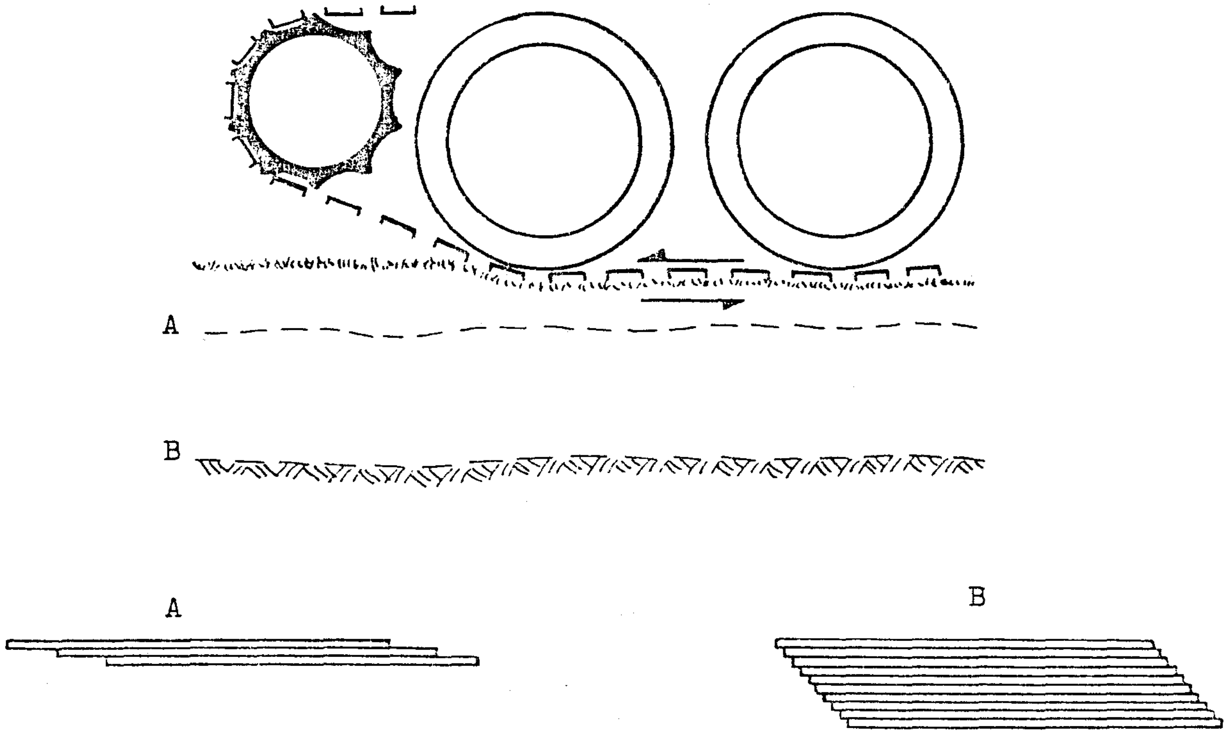


Figure 3.4 As the depth of thaw increases (two positions of frost table represented by dashed lines) shear deformation is distributed over a greater thickness, i.e., shearing along any one surface decreases as shown by stacks of cards.

vehicle moving across the surface is only distributed over a depth of a few centimetres to the frost table. Therefore, shear stresses per unit area were high and in some cases the tracks of the vehicle sheared the surface vegetation off almost to the frost table. However, as the thaw progressed, the same shear force is distributed over greater depths, resulting in lower shear deformation near the surface and an increase in trafficability (Figure 3.4). Heavy rainfalls such as in late August were observed to return shear strengths toward early thaw values in peat to a greater extent than in till areas.

3.6 Drop Weight Penetrometer Surveys

Procedure and Purpose. The drop weight penetrometer surveys were designed to give a numerical estimate of the resistance of the surface materials to compression throughout the summer. Measurements were made by way of a steel rod with a 2 Kg weight which was dropped onto a metal collar welded to the rod. The force of this dropping weight was then transmitted to either a one inch or two inch square metal foot attached to the bottom of the rod. Two pressure feet were required due to the presence of wet areas of slurried peat where almost no resistance was offered to the small pressure foot. The surveys were carried out across the main track (MT 1) at specified distances. Five sets of measurements were usually taken at each station along the track: two in undisturbed areas on either side of the track, one in each of the ruts and one between the ruts. In other cases, for instance, the N-S extension of the main track, measurements were only taken in undisturbed areas outside of the main track. In most cases 5 drops of the weight were used and the depth of penetration measured.

Results. As a measure of ground strength similar to vane shear, the drop weight penetrometer results also show a correlation with moisture contents and thaw depths. Early in the summer (June 4) high moisture contents allowed an average penetration of 4.2 cm when 10 drops and the large pressure foot were used in the area 0-350 m along MT 1. On June 21, the average penetration was 10 cm from 450-780 m along MT 1 using the same experimental procedure. In both cases the tests were performed under the wettest ground conditions excluding the late August storm. For contrast, the penetrometer surveys were repeated on August 7 during which time the ground surface was almost in its driest state of the summer. At this time, the average penetration was 3.6 cm for both portions of MT 1 (Figure 3.5). As expected, the till areas showed the least strengthening due to their relatively low loss of moisture. Unfortunately, no solid frost occurred after arrival at camp so no penetration values were obtained for the tracks while frozen. Also, a measurement in late August was prevented when the tracks became flooded.

Interpretation. Similar to the vane shear results, the drop weight penetrometer surveys also show a good relationship with moisture contents of the material. Throughout the summer the drop weight surveys continually showed that as moisture contents decreased, the resistance

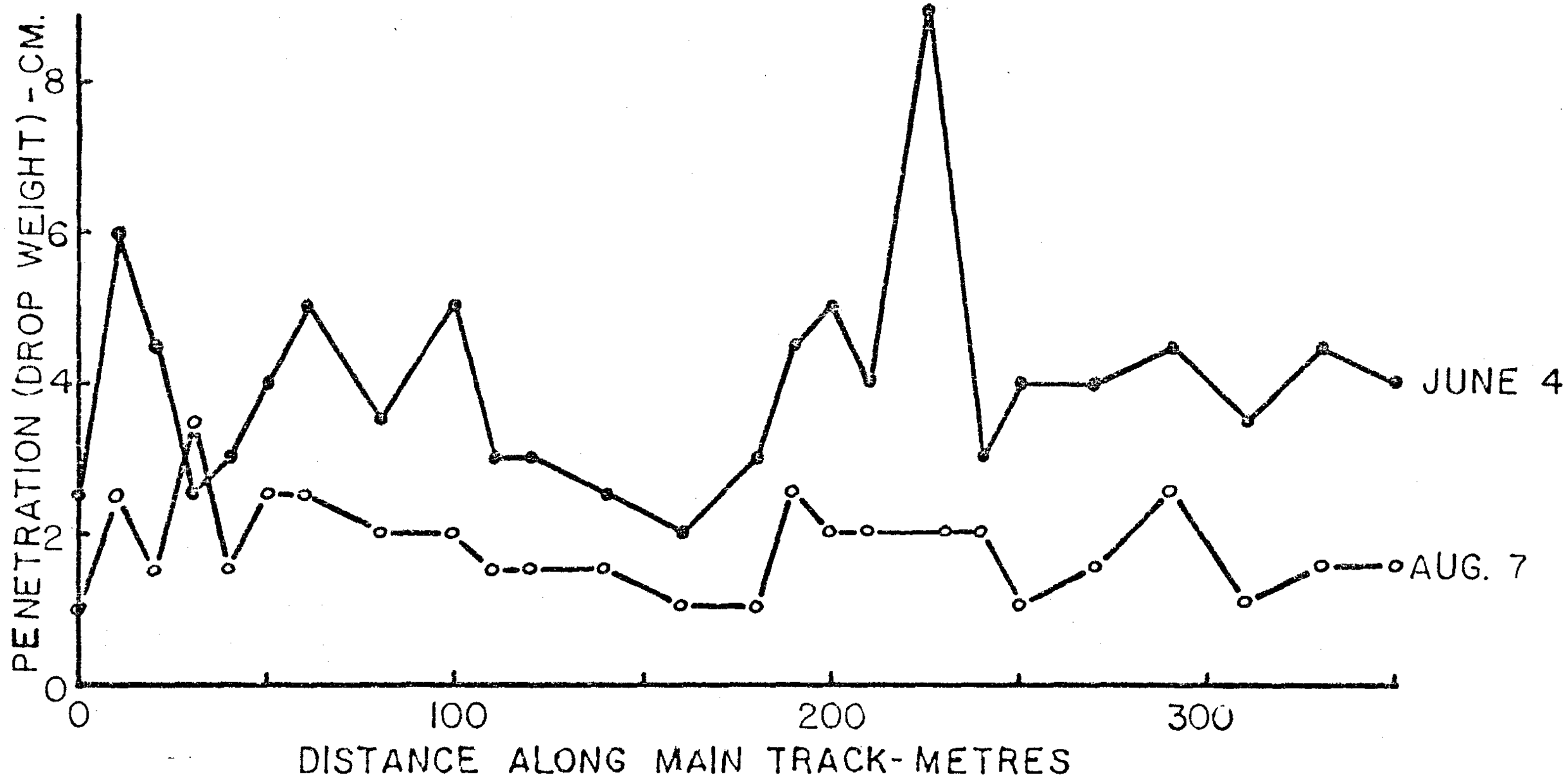


Figure 3.5 Penetration of drop weight implement after five blows of weight for locations along main trac (MT 1). Note that despite greatly increased depth of thaw by August 7, penetration is much less than for test shortly after beginning of thaw.

to compression and hence penetration of an object increased. Conversely, high moisture contents increased the compressibility, especially in peat, allowing deeper penetration of the pressure foot, vehicle tracks or drill trailer. In undisturbed peat, the fibrous form of the material resisted penetration. However, in the slurried organic muck of the tracks, the fibrous nature had been lost so that penetration of an object became easier. The results suggest that some threshold limit of vehicle passes exist whereby "X" passes can be made on peat without destroying the structure and reducing the strength. In this state, drop weight penetrations were small. However, further passes result in a breakdown of the fibrous peat structure after which penetration increases rapidly as the peat is churned into an organic muck. This was the condition early in the summer when shallow frost table depths and high moisture contents near the surface led to deep rutting. In contrast the till shows less change in compressibility and penetration values as it dries since the till is much less compressible to begin with. While the vegetation over the till may be easily disturbed early in the summer as was peat, the compactness and stoniness of till prevented deep rutting even under moderately wet conditions. When dry, the till became even stronger, as evidence by low penetration values of 1 or 2 cm. In general the drop weight tests showed that the drier the surface, the less compression by, and penetration of, the vehicle tracks that will occur.

3.7 Summary

The physical tests undertaken concentrated on two main physical effects of vehicle traffic, these being surface compression and shearing. As can be seen, moisture contents, which show seasonal variations, play an important role in surficial material strengths, especially in peats. Having investigated these physical properties, predictions can be made about what effects a given amount of vehicle traffic will have on a certain terrain type. These aspects are further considered in the following chapter where track profiles and vehicle trafficability are related to seasonality and the physical properties of the two main material types.

CHAPTER 4

VEHICLE TESTING

4.1 Introduction

The monitoring of track profiles in various terrain types provided a realistic approach to tracked vehicle performance in terms of day to day drilling activities. Measurements of ground surface and frost table profiles were made at weekly intervals from June 10 to August 25 and are discussed in the first part of this chapter. The study of the vehicle tracks was designed to provide an estimate of vehicle trafficability based on three main factors: the surface material type, the amount of traffic and the seasonal distribution of the traffic. The importance of these factors is particularly well illustrated in section 4.6 by the comparison between main tracks 1 and 2 (MT 1 and MT 2). The latter part of the chapter concentrates on vehicle trafficability in several situations where disturbance is greatly increased above normal levels.

4.2 Track Profiles and Frost Table Measurements

Procedure and Purpose. Profiles of the vehicle tracks were monitored throughout the summer of 1980. The main purpose was to examine what effect vehicle traffic had on the surface profiles and the pattern of frost degradation in areas representative of the tractor zone. The device used for these measurements, referred to as a bedstead, had one of three forms. In the first two cases, the bedstead consisted of two or more metal rods which were driven into the permafrost by means of a Cobra drill. Aluminum pipes were installed between the rods and levelled, providing a datum to which the measurements were referred (Figure 4.2). The main disadvantage of this method was that once the pipe bedstead was installed, further traffic along the track at that point was prevented. However, this did provide some information on the behaviour of the ground when further traffic did not occur. An alternative method was based on the same principle except that a taut string was levelled between notches on the rods, the profile measured, then the string removed (Figure 4.17). This allowed further passes to be made across the profile between measurements, giving information on the response of a track in continual use. This would have proved a useful comparison with the "abandoned track" profiles discussed earlier, had not the string bedstead been destroyed by the vehicle in mid-July. These pipe and string bedsteads were used mainly in the wet sedge areas, with two located across the tracks in the upper sedge meadow and one across a track in the lower sedge meadow. In addition, a control bedstead in undisturbed vegetation was installed in the upper sedge meadow. Two bedsteads (one across the track and one in undisturbed terrain) were set in stony till near camp. In these cases, the copper rods could not be driven in to sufficient depths, so platforms of notched 2 X 4s were used with the level of the aluminum tube checked at each measurement (Figure 4.6). In all cases profile measurements were made at 20 cm intervals along the length of the bedstead.

The measurements themselves consisted of surface profile and active layer depth measurements, with the datum taken as the top of the aluminum tube or string. The surface profile was easily measured by a tape measure while a metal rod was used as an active layer probe. The probe worked well initially but as the active layer depth increased, measurements became more difficult due to the stony nature of the subsurface. However, in most areas the measurements were probably quite accurate as the difference between boulders and the frost table was usually apparent.

4.3 Results. Tracks vs Undisturbed Area in Wet Sedge Meadows

Frost Profiles. The first measurements of track profiles were taken on June 10 and 11. At this time both bedsteads across the track showed thaw depths of 15-25 cm along the sides while the frost table was at 20-30 cm depth below the ruts themselves (Figures 4.1 and 4.2). In undisturbed areas (bedstead No. 3) the frost table varied between 12-18 cm below the surface (Figure 4.4). As time progressed, the frost table showed accelerated degradation across the tracks, but most notably beneath the ruts. Under the ruts, the frost profile became roughly V-shaped (especially if water remained in the rut) while under the organic muck the frost table exhibited a wide U-shape. The undisturbed areas across the track profile showed smaller increases in thaw depth

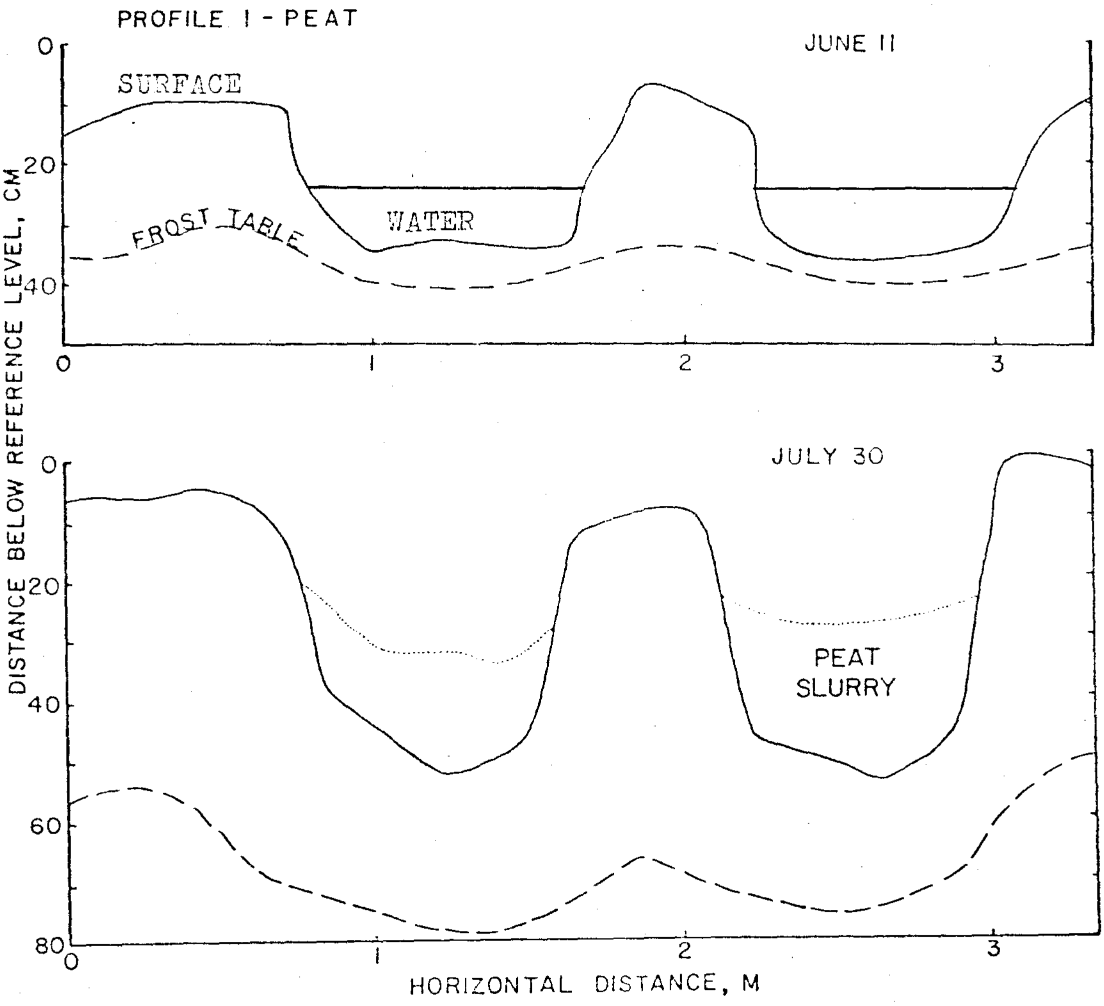


Figure **4.1** Thaw profiles at bedstead 1 through thick peat in upper sedge meadow.

Figure 4.2 Bedstead 1, June 11. The slurried peat has formed after approximately 35 vehicle passes between late May and early June.

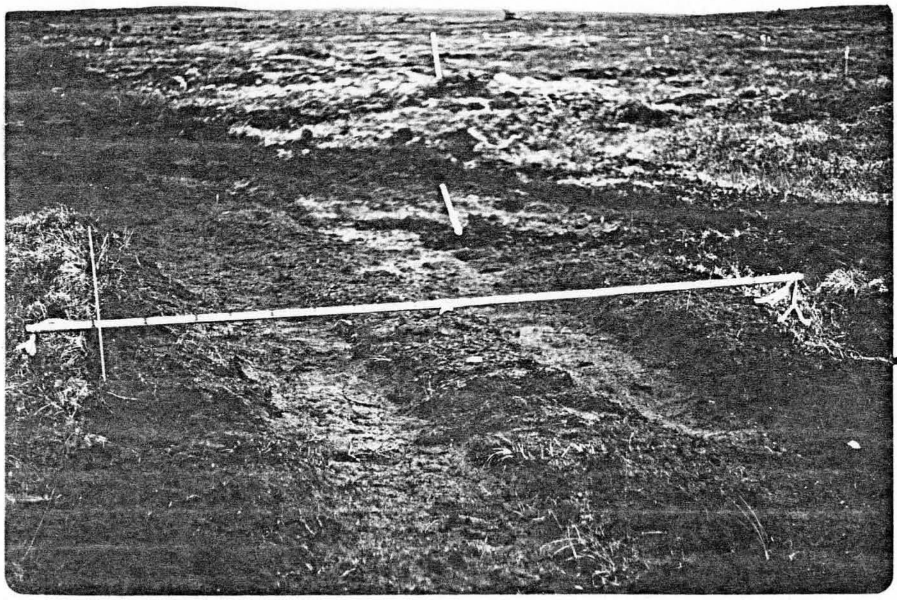


Figure 4.3 Bedstead 1, July 30. The peat shows increased strength due to moisture loss and sedge growth up through the peat along track edges.

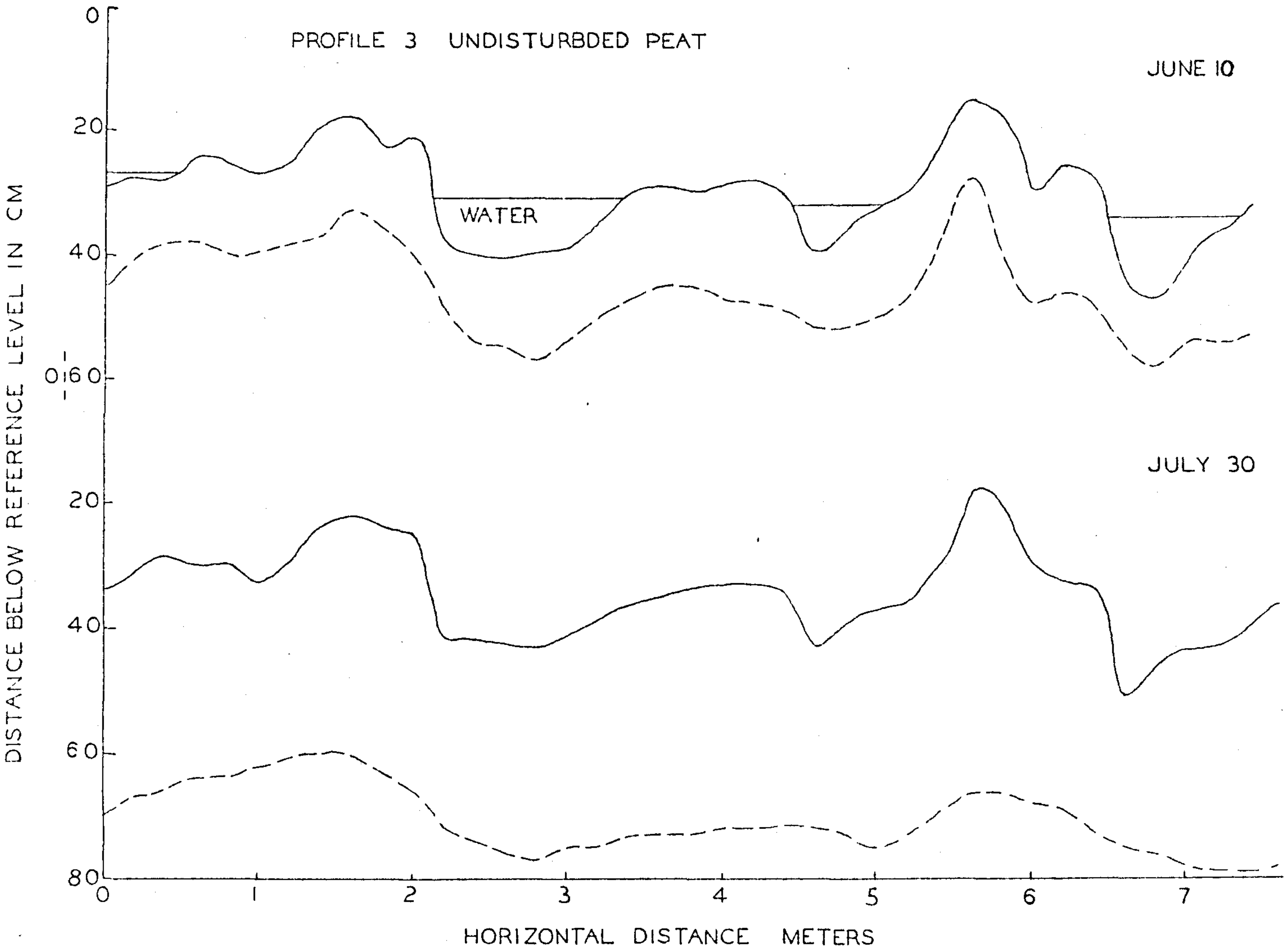


Figure 4.4 Surface (solid line) and frost table profiles (dotted lines) measured on June 10 and July 30 in undisturbed peat in the upper sedge meadow.

but little change in the frost profile. At the same time, the depths of the ruts were increasing without further traffic (the bottom of the rut was defined as the depth to which the probe would settle, through the muck, under its own weight). By July 30, frost depths at bedstead 1 had reached 70-75 cm under the ruts and 50-55 cm beneath the track centre and sides (Figures 4.1 and 4.3). In comparison, the maximum thaw depths at bedstead 3 were 30 cm (Figure 4.4). In fact, even by the end of the summer frost depths in undisturbed peat were only in the order of 50-55 cm, compared to 80-85 cm beneath the ruts and 65-70 cm elsewhere across the track profile. In disturbed peat the frost table showed the most vertical variation, mainly under the ruts where the frost table expression varied between steep V- and U-shapes to shallow troughs. Both disturbed and undisturbed terrains showed a tendency towards a levelling out of the frost table over time. This is especially evident under the vehicle ruts or hummocks where the initial irregularities gradually smooth out, producing a more regular profile.

Surface Profiles. The general trend of the surface profiles in both disturbed and undisturbed areas was towards net subsidence. Along bedstead 3 the net subsidence measured was approximately 5 cm. In disturbed areas the subsidence averaged 8-10 cm along the sides, slightly more between the ruts. The ruts themselves were the most variable part of the profile due to periodic flooding, with average subsidence values of 8-12 cm (Figure 4.1).

4.4 Results. Tracked vs Undisturbed Till Areas

Frost Profiles. Two bedsteads were installed in stony till near camp, one each in disturbed (No. 6) and undisturbed (No. 7) situations. The first measurement of the track profile on June 15 showed marked deepening of the frost table beneath the ruts. On average, the frost was 25-30 cm deeper under the ruts than for the rest of the profile (Figures 4.5 and 4.6). Measurements of bedstead No. 7 showed the frost table to be between 15-30 cm below the surface at this time (Figure 4.8). Within a week the frost table under the ruts had deepened to 40-45 cm, changing from a V- to U-shaped profile. Within this time span the frost depths also increased markedly along the rest of the profile by an average of 20 cm, producing a more gentle frost profile than earlier. Yet in undisturbed terrain, the frost depth increased 20-30 cm also. This suggested that the deepening frost table underneath the tracks was mainly the result of increased natural thaw, not strictly the result of vehicle traffic. This general pattern persisted through the summer, namely the elimination of irregularities as the frost table deepened. By the end of the 1980 summer, there were only 9 and 12 cm variations in frost table depths along bedsteads No. 6 and No. 7 respectively, illustrating the decreasing influence of surface irregularities (Figures 4.5, 4.7 and 4.8).

Surface Profiles. For bedstead No. 6, subsidence along the profile sides only amounted to 2-3 cm for the summer, while between the ruts the average was 10 cm (Figure 4.5). While the ruts themselves

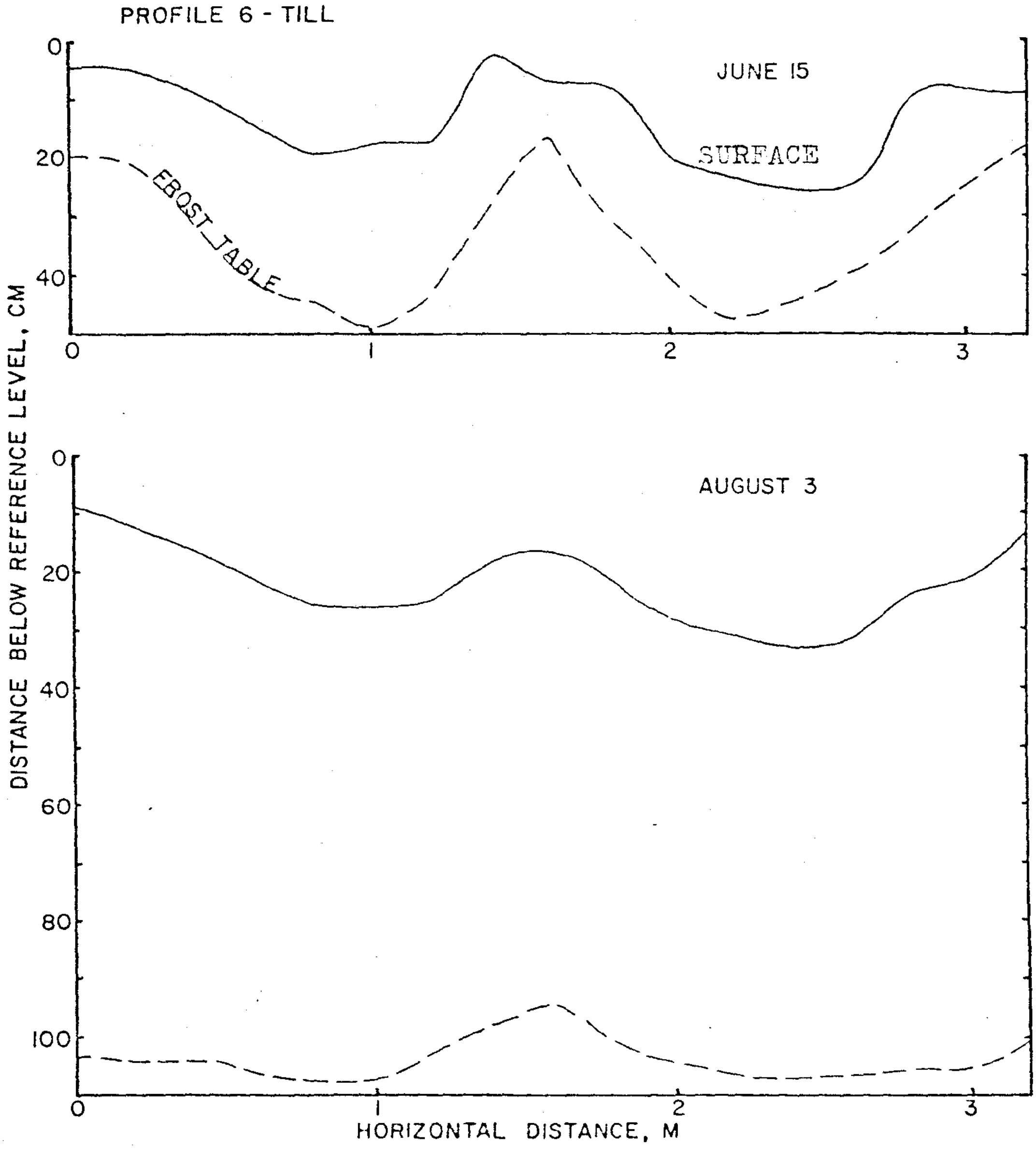


Figure 4.5 Thaw profiles at bedstead 6 through stony till.

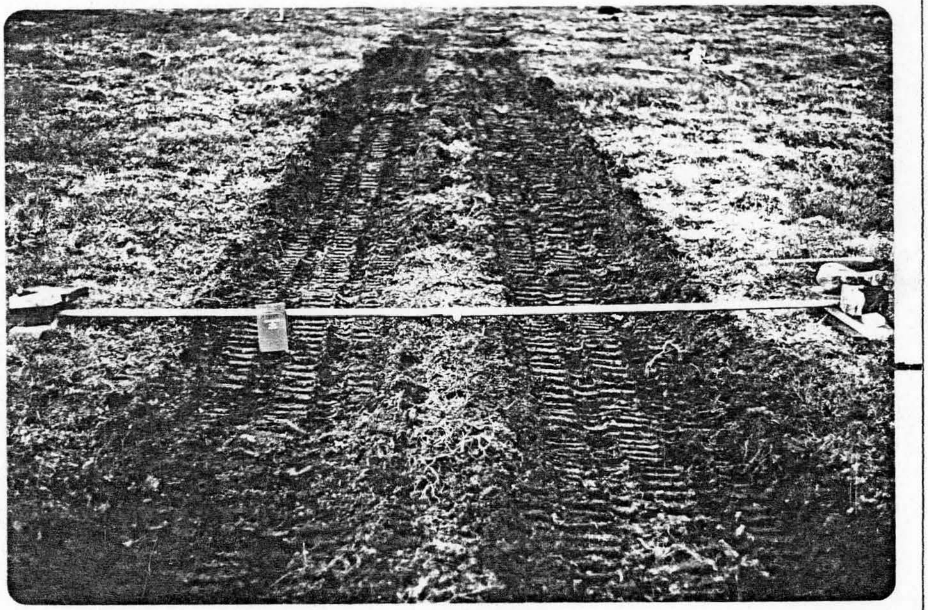


Figure 4.6 Bedstead 6, June 15. Shallow ruts are developed in thin peat over till. Note that the peat has not slurried as in the upper sedge meadow even though both areas have experienced the same amount of traffic.

Figure 4.7 Bedstead 6, August 3. No increase in depth of rutting has occurred after 20 more passes since June 15.

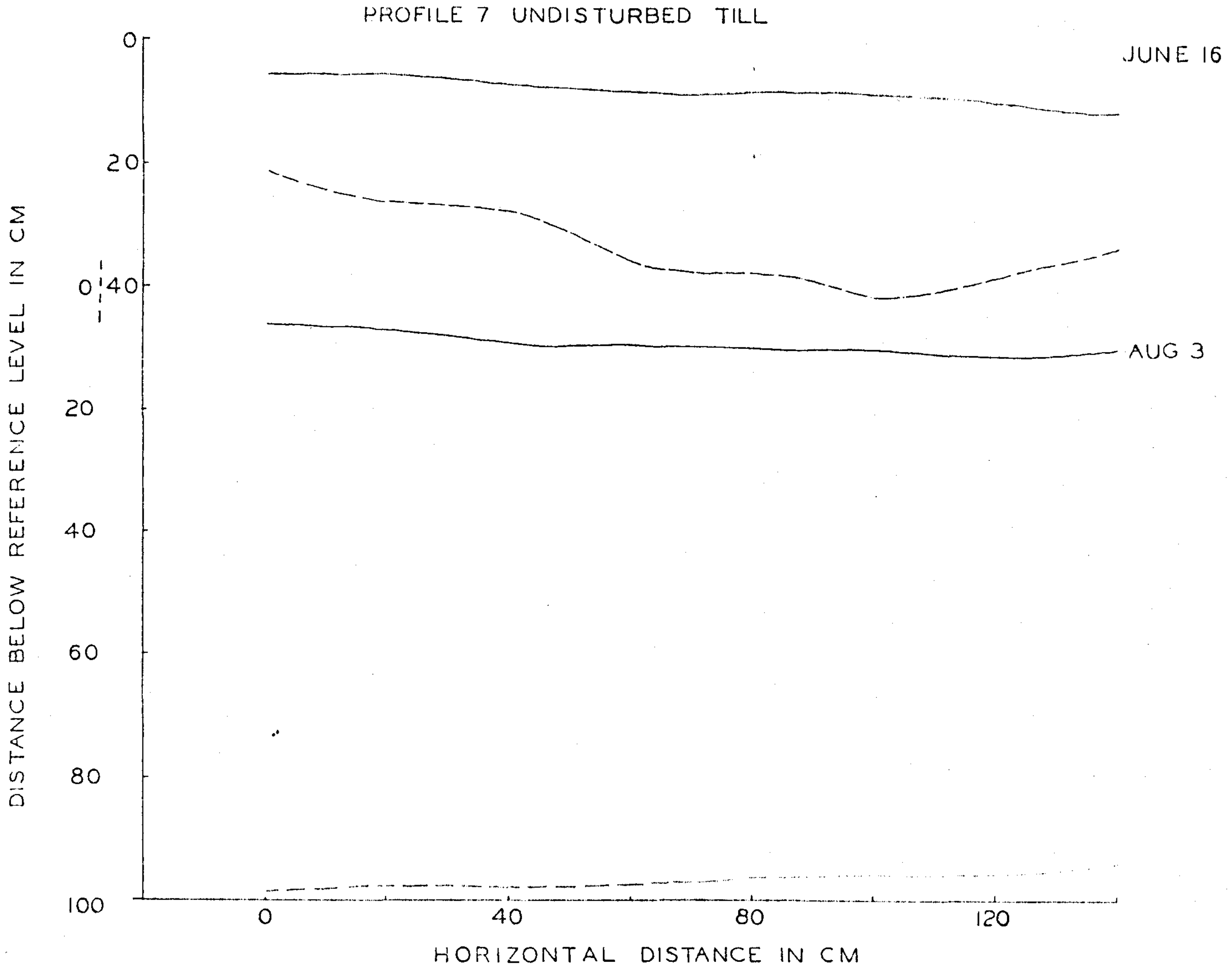


Figure 4.8 Surface (solid lines) and frost profiles (dotted lines) measured on June 16 and August 3 in undisturbed till near camp.

subsided an average of 7 cm, this figure was misleading in that sporadic vehicle passes in July and August and washing of material into the tracks from the sides would both influence the apparent net subsidence. In contrast the points along bedstead No. 7 averaged a total subsidence of only 1 cm (Figure 4.8).

4.5 Interpretation. Frost and Surface Profiles

The various bedsteads indicate several examples of the differences in response to rutting between peat and till areas. First, thaw depths extended to deeper levels in the till areas, probably due to the thin vegetation cover, relatively high thermal conductivity of a mineral soil, lower moisture contents and better drainage, which would encourage earlier drying and warming of the till. Thermistor measurements showed that the till warmed faster at depth than the peat (Figure 4.9). As the thaw extended to greater depths, the effect of the surface profile on the frost profile would be expected to be least in till. Although differences in heat absorption between a black organic muck, till and undisturbed vegetation exist at the surface, these differences are dampened out by the thicker thawed zone in till. Differences in thermal conductivity would also contribute but again would have the greatest influence on the shallowest frost tables. All frost profiles showed an initial similarity to the surface irregularities but as the thaw deepened these irregular portions gradually levelled out.

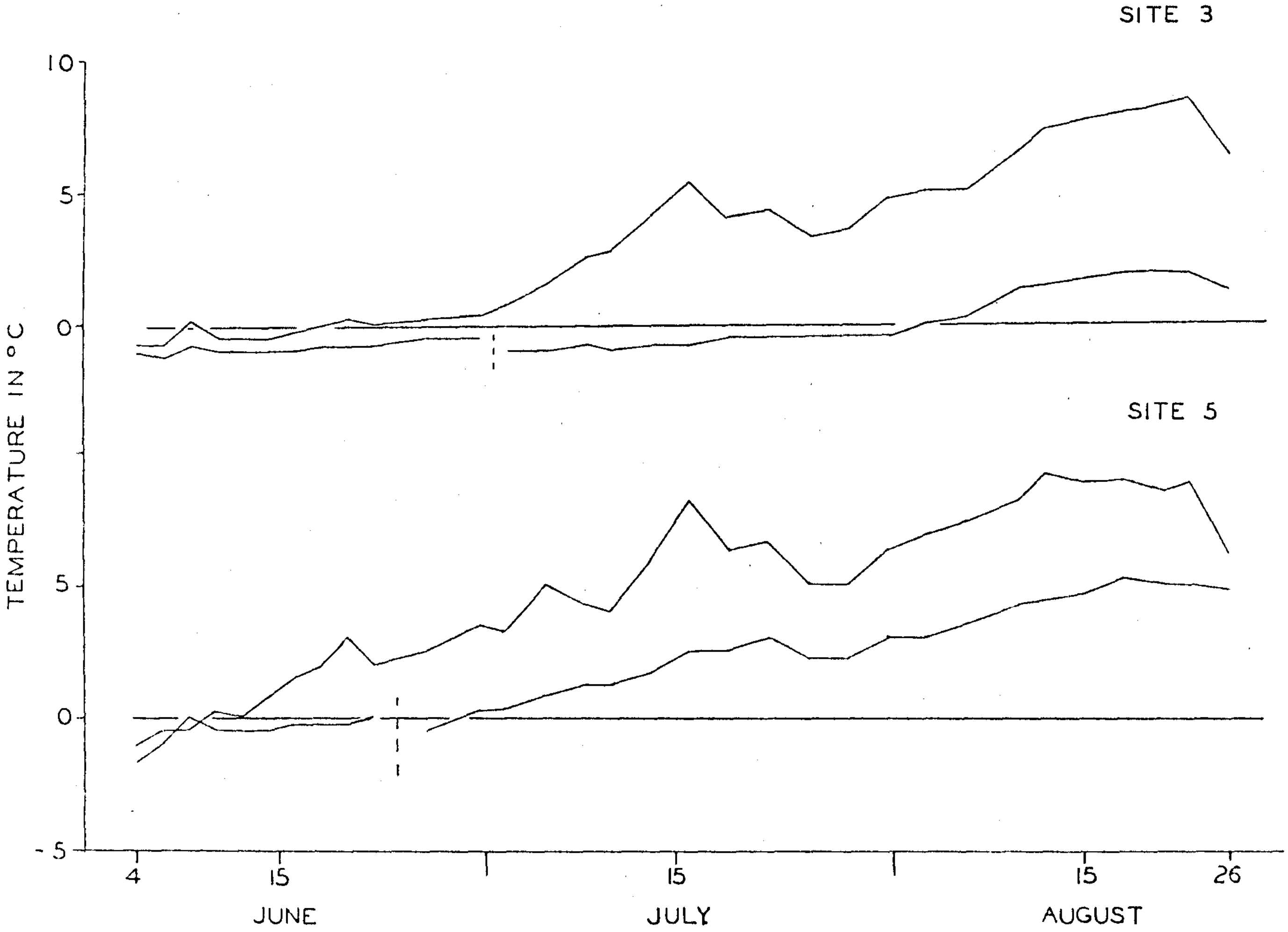


Figure 4.9 Temperature curves for sub-surface warming in peat (site 3) and till (site 5). The upper line represents the shallow probe (10 cm depth), the lower line the deep probe (60 cm depth) for each site. A dashed vertical line indicates the re-installation of the deep thermistor probe at 60 cm depth.

4.6 Vehicle Performance Throughout the Summer

Upon arrival at camp, the main vehicle track (MT 1) from camp to the upper sedge meadow had already been well established after 35 to 40 vehicle passes. The track began at camp and covered about 450 m through till before it crossed roughly 150 m of overgrown rock polygon terrain, then continued on into the thick peat of the upper sedge meadow. Rut depths for the area 0-600 m along the track averaged 14 cm, however, there seemed to be a bimodal distribution of values, with concentrations in the 4-10 cm (shallow vegetation over till) and 20-27 m (thicker vegetation) ranges. In contrast, the average rut depth from 600-780 m (thick peat) was 25 cm. The shallowest rut depths were associated with very bouldery till, the boulders being at or near the ground surface. As the thickness of the organic soil over the till increased so did the average rut depth (Figure 4.10). In the upper sedge meadow several passes had cut relatively deep ruts in the peat. Apparently the churning action of the tracks had destroyed much of the structure of the peat so that the originally fibrous material had been transformed into a weak, black organic slurry. Along the edges, some of this black slurry was thrown out from the tracks by vehicle passage, forming a thin organic layer over the existing vegetation. However, in most cases the sedges were able to grow up through the organic coating, suggesting that eventually the ruts should recover to the pre-disturbance state, provided further disturbances did not occur (Figure 4.3). As several other observations have suggested, disturbance caused by the vehicle beginning a new route at any time during the summer decreased

Figure 4.10 The north-south section of main track 1 showing the susceptibility of peat (foreground) and till (background) to disturbance.

Figure 4.11 Main track 2 in early August where it crosses upper sedge meadow. Use of this track began in early July when thaw was well advanced. Rutting and slurrying is considerably less advanced than for MT 1.

for a given number of passes as the summer progressed. The degree of disturbance may have increased slightly in the late summer when water levels rose somewhat.

The second main track (MT 2) from camp was a good example of increased trafficability as the summer progressed because even though this track experienced roughly the same amount of traffic (from late June to mid August) as MT 1, the average rut depths were less than half of those produced in late May and early June (Figure 4.11). The seriousness of the rutting of MT 1 was further compounded by heavy rains in late August when the upper portion of MT 1 became a drainage channel estimated to have carried 100 gal/sec (455 litres/sec) during peak flow (Figure 4.12). This caused the ruts to deepen an average of 5.2 cm, yet the peat seemed quite resistant to erosion given the high rate of flow. Wherever localized areas of boulders or other obstructions cause sudden channel drops, accelerated erosion produced pools 50 to 80 cm below the ground surface. In most cases these pools were eroded through the peat into the till below (Figure 4.13). Where large boulders were present, the till appeared well protected from erosion but in other cases eroded sand had formed long stretches of asymmetric ripples, evidence of significant erosion and sediment transport. Part of the problem was that much of MT 1 ran through the main drainage area of the tractor zone. Had the track been located on either side of the main valley, the impact would not have been as great. While MT 2 carried some runoff, the effects were small relative to MT 1 as it was located out of the main drainage area. The heavy rains provided a good estimation

Figure 4.12 Runoff channelled by main track 1 during heavy rains in late August.

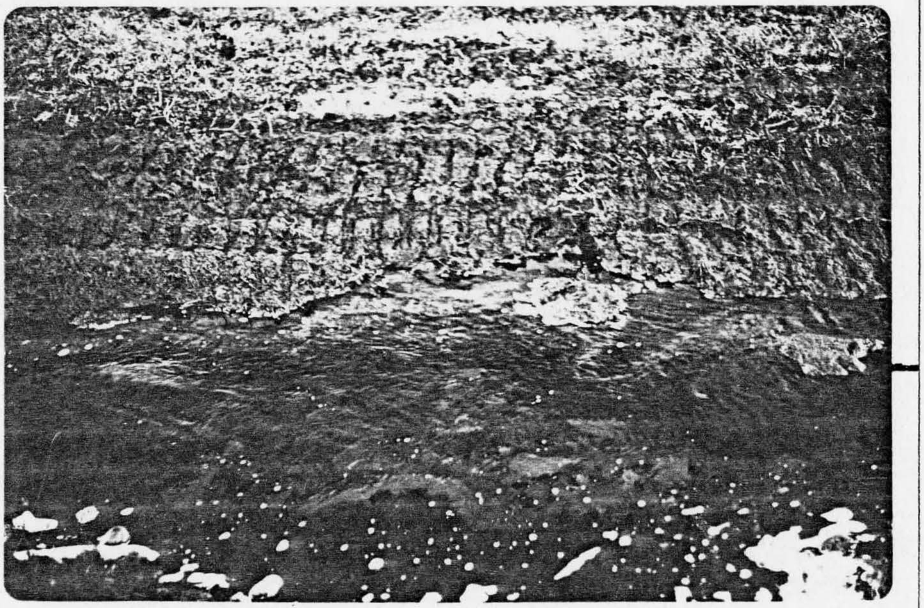


Figure 4.13 Erosion through 50 cm of peat to underlying till as a result of the late August storm. Water depth in centre of photo is 70 cm.

of the probable effects of the spring snow melt flood. Moreover, information was gained on the basic question as to whether the tracks are likely to erode and widen or stabilize and re-vegetate in the future. However, no firm answer to the above question can be supplied with the data currently available as another field season would be required for useful estimates of track re-vegetation capabilities.

4.7 Drill Trailer Performance

The trailer worked very well initially, however the efficiency of this system decreased as the thaw progressed. While the frost table was near the surface, the trailer tires were unable to penetrate very far into the ground, but as further thaw occurred the tires began to cut through the ground surface. Towing became more difficult as the drill trailer began to produce progressively deeper wheel ruts. By early July both vehicles were often required to move the drill rigs, as the trailer often settled into the ground and became stuck due to the reduction of bearing strength by drill fluids in the area immediately around the drill hole (Figure 4.14). Although these problems became much more acute in peat accumulations, tire rutting also occurred on till. Here, one of the trailer wheels often became locked when vegetation became packed between the wheel and wheel well of the trailer (Figure 4.15). As a result of these problems, the trailer method was much less efficient by August, requiring more time and causing much more disturbance than did drill moves in early June.

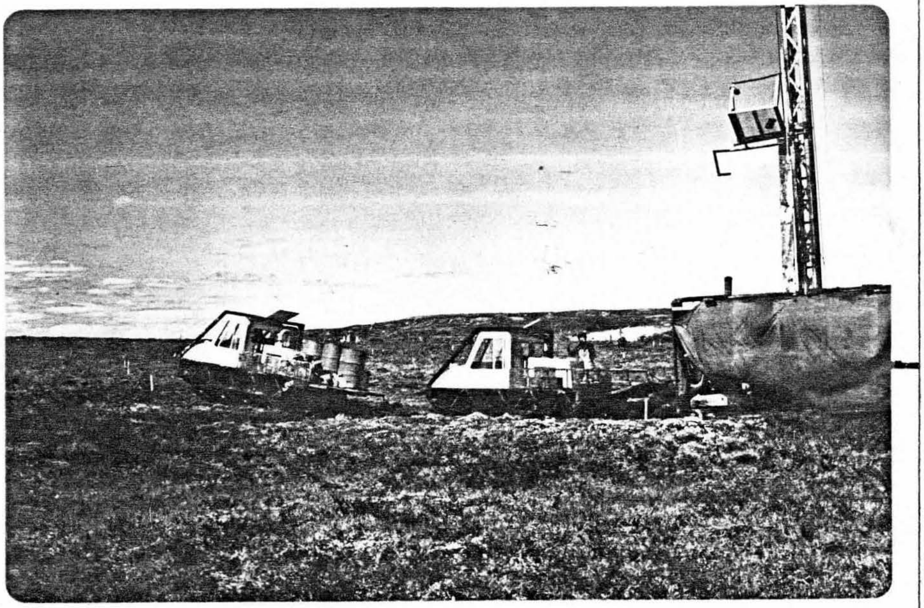


Figure 4.14 Both vehicles towing the trailer after it became stranded on a peat mound. Similar towing situations were most common near drillholes where drill water return reduced ground bearing strengths.

Figure 4.15 The gouge resulting from wheel locking on the drill trailer.

4.8 Problems in Vehicle Use

While the performance of the tracked vehicle was generally satisfactory throughout the summer, several situations which resulted in increased levels of disturbance were noted.

(1) The first situation involved vehicle travel in second or higher gears. Under such conditions, the track was visibly more aggressive, with vegetation shearing much more serious than when the vehicle travelled in low gear. This problem was especially serious early in the thaw where in several places the tracks removed the organic layer down to the frost table. As well, travel in higher gears accelerated peat slurrying and rut development. This is in contrast to some other studies (for example Wilson, 1976) which found that vehicle disturbance may actually be lessened by higher speed operation. Wilson hypothesized that when the vehicle is driven at full power, the tracks will deform less and therefore increase the load supporting capacity of the track. However, these tests involved vehicles with a flexible track, whereas the Muskeg tractors used at Nogash Lake were equipped with rigid tracks supported by steel crosslinks. While a flexible track may be sufficient for travel in a non-loaded state, experience from both camps involved in this study showed the rigid track to be more desirable. When pulling heavy loads such as drill rigs, the vehicles require as much traction as possible and under these conditions, the rigid track is much more efficient.

(2) As previously mentioned, in an unloaded state the longitudinal stresses were greatest under the second set of bogie wheels. However, as

the vehicle load increased, either directly (cargo area) or indirectly (towing), the weight distribution shifted towards the rear of the vehicle, thus concentrating greater ground stresses on a smaller track area. This increased the surface shearing drastically and in an attempt to generate enough tractive force to move, the vehicle developed a "bow-up" attitude. This resulted since the rear of the track, by exerting greater stresses, was more aggressive and cut more deeply into the surface than did the rest of the track (Figure 4.16). A similar result occurred without loading in the deeply rutted portions of MT 1. Here, the difficulty in generating enough tractive force in the peat slurry caused the rear of the vehicle to sink deeply into the muck. However, the most common occurrence of this type of vehicle behaviour involved towing the drill trailer. While the "bow-up" effect was minor early in the season when the drill trailer rolled smoothly on its wheels, as the summer progressed and the trailer wheels began to rut, the problem intensified. As the thaw advanced, greater pull was required to move the drill rigs and the vehicles began to travel "bow-up" in order to produce enough tractive force. The resulting disturbance increased markedly to the extent that both tracked vehicles were needed to tow a single drill rig. By using both vehicles, further surface shearing resulted as well as increased mechanical problems with the vehicles themselves. Although vehicle travel in this manner was more common in drill moves across peat areas, the same effect was observed in crossing till also.

(3) In addition, very tight vehicle turns resulted in increased surface shearing. In many cases such turns caused apparently limited

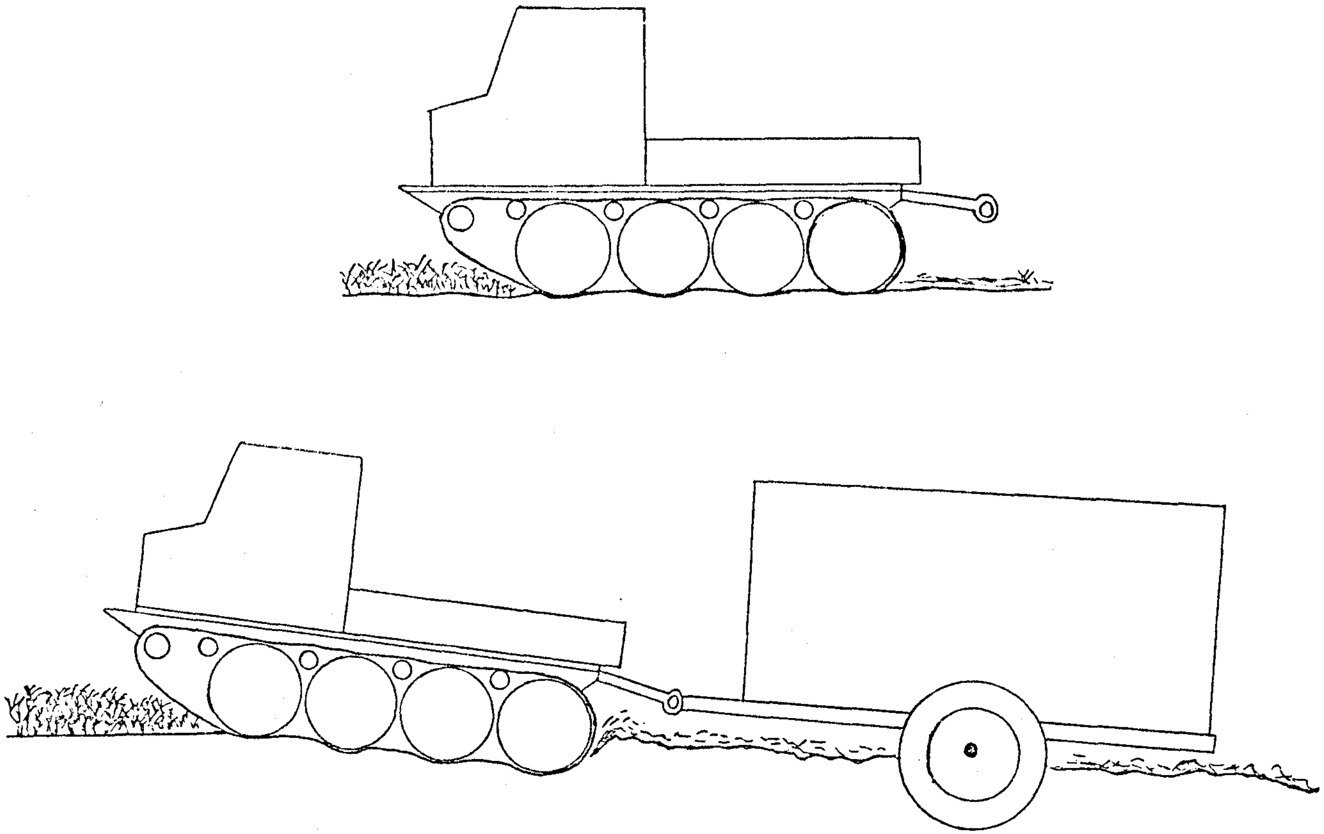


Figure 4.16 Sketch showing the tendency of the tracked vehicle to develop a "bow up" attitude when towing the drill rig especially when the trailer wheels are forming deep ruts. This "bow up" attitude was also apparent during vehicle travel through saturated, slurried peat.

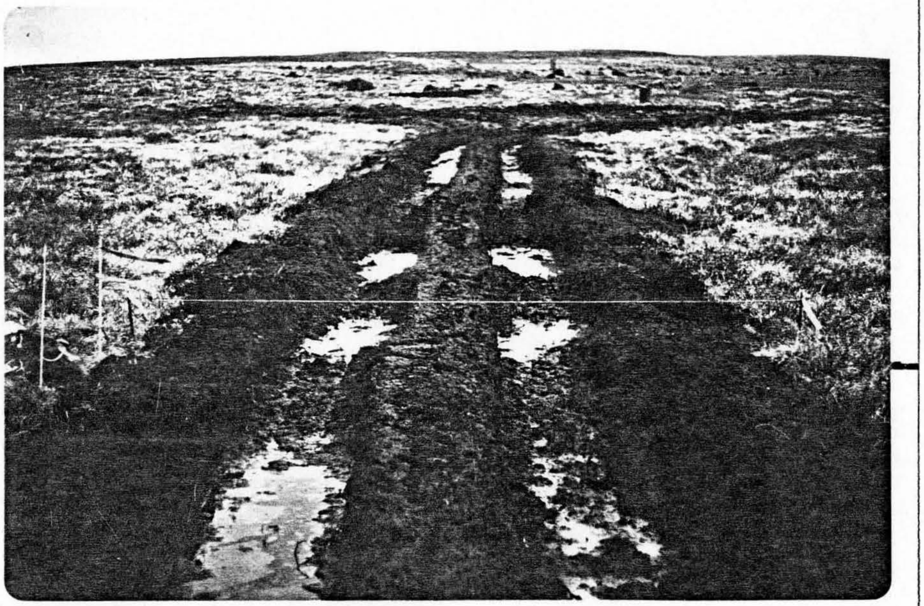


Figure 4.17 String bedstead profile used to measure the effects of continuous vehicle traffic in a wet sedge area in late June. The bottom of the vehicle has started to level the ridge between the ruts.

disturbance. However, close examination revealed that in several instances the vegetation mat had been severed at the root layer so that pieces of the mat could be turned over easily by hand. This problem was most common near drill set-ups where several sharp turns were made in hooking onto the drill trailer and gathering drill rods, fuel barrels and other drill equipment or supplies.

(4) Finally, continued use of the deeply rutted portions of MT 1 caused unnecessary disturbances. This resulted when the depth of the ruts exceeded the fording depth (height of the undercarriage) of the vehicle causing the undercarriage to level the peat ridge between the ruts (Figure 4.17). Deepening of the ruts and further track slippage often occurred, forcing the vehicle to list to one side in an attempt to gain traction. If allowed to continue, the centre ridge would probably be destroyed, forming a wider channel wherein erosion of the peat slurry would be further encouraged.

4.9 Summary

Perhaps the most important observation resulting from the study of vehicle tracks was that the level of disturbance is greatly affected by the seasonal distribution of the vehicle traffic. While in general the till was shown to be much more trafficable than the peat, early in the thaw both materials showed low resistance to vehicle rutting. However, as the thaw advanced both materials strengthened as evidenced by the increased trafficability of MT 2. In somewhat of a contradiction, this strengthening of the peat and till resulted in lower disturbance levels for normal (not towing the drill trailer) vehicle traffic but caused increased disturbance while towing the drill trailer due to a deeper active layer. This suggests that design modifications, especially to the drill trailer, must be made. This recommendation and others are further discussed in the following chapter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a summary of the entire tracked vehicle study and is intended to stress the main scientific conclusions resulting from the monitoring program. These conclusions are listed numerically, as are the recommendations regarding future vehicle use. The recommendations are subdivided into: (a) those concerning vehicle or drill trailer design and (b) operational considerations involving the amount and location of vehicle use. Finally, the economic feasibility of tracked vehicle drill support is discussed, as this is a prime consideration to the future use of tracked vehicles in Keewatin.

5.2 Scientific Conclusions

1) Areas of thick peat accumulations are the most susceptible to vehicle disturbance. This relation is shown by vane shear and drop weight measurements which indicated lower shear strengths and higher degrees of compressibility relative to till areas.

2) Peat strength is inversely related to the moisture content. High moisture contents, such as occurred early in the thaw due to the shallow active layer, caused the peat to be easily compressed and rutted.

Later in the summer when a deeper active layer allowed the peats to dry, disturbance levels were much lower as evidenced by MT 2.

3) Till areas showed lower moisture contents, higher shear strengths, less compressibility, deeper active layers and a greater resistance to disturbance throughout the summer than did organic accumulations. The only exception occurred in areas of poor drainage or some other permanent water supply, such as near lakes. In these cases if the till is near saturation, vibrations from vehicle passage may cause the soil structure to collapse so that the till becomes akin to a quicksand. In such instances, the vehicle may become mired, especially while towing the drill trailer. While till strength is also inversely related to moisture contents, only in the case described above would enough water be present to have a significant effect on vehicle trafficability.

4) The strength of the upper few centimetres of the vegetation mat is critical to the degree of disturbance, especially in peat. In peat this layer is relatively strong and includes the living vegetation and the fibrous, least decayed organics. However, once the vehicle tracks penetrate this layer, rapid slurrying of the peat is encouraged. As a result, surface strength varies according to the composition of the surficial material. On till the vegetation mats are much thinner and easily removed but the firmness of the till substrate prevents the formation of deep ruts.

5) Under normal vehicle traffic conditions in wet peat (standing water in the sedge meadows) especially early in the thaw, little

disturbance may occur for one or two passes. Above this amount of traffic peat slurrying often begins. As the thaw progresses, gradually more and more vehicle passes can be made along any given route before the slurried condition will develop.

6) In general, beyond the early portion (2 to 3 weeks) of the thaw, the disturbance created by multi-pass tracks is largely aesthetic, lessening is visibility as the surface dried out. In till areas tracks were only barely visible in July and August while tracks in peat were slightly darker and more obvious. Measurements of frost table depths in both till and peat showed that the surface rutting had little effect on the frost table profile by mid-summer. The only exceptions occurred in the deeply rutted portions of MT 1 which developed very early in the thaw.

7) Pressure bulb tests indicate that the amount of time between successive vehicle passes on peat has an important effect on the degree of disturbance. Several passes, one immediately after the other, encouraged breakdown and slurrying of the peat. However, the same number of passes spread over several days created much lower levels of disturbance. The time delay between passes allowed the peat to rebound and strengthen, resulting in less breakdown of the surface vegetation.

8) Pressure bulb tests showed that the track design caused the maximum lateral stresses to occur at the track edges. As a result, the track edges were slightly more aggressive than the track centre. Longitudinally, stresses were greatest under the second set of bogie wheels. Under load, the tendency for the position of maximum longitudinal stress to shift towards the rear of the vehicle indicated that increased

vehicle disturbance would result.

9) Vehicle tracks through shallow valleys, especially if deeply rutted, may collect surface runoff and channel flow away from the natural drainage course of the area.

5.3 Recommendations

A. Design.

1) That the drill trailer be fitted with wider, flatter tires such as floatation tires which should reduce wheel penetration into the ground.

2) That such a wider tire, or perhaps dual wide tires be installed outside of the drill platform on extended axels to prevent wheel locking from accumulations of surficial materials between the wheels and the wheel well of the trailer.

3) Removal of the blade on the front of the vehicle, unless necessary, to avoid gouging and scraping of large peat polygons.

4) Removal of the wheels from the trailer should re-designing fail to eliminate the problems connected with the trailer, so that the drill could be moved on the metal sloop as was done at Lone Gull this past summer (1980).

B. Operational Considerations.

(a) Vehicle Travel (not towing drill trailer).

1) As till was shown to be more trafficable than peat throughout the summer, vehicle movement should be across till whenever possible.

2) Required travel across thick peat early in the summer should consist of: a) no more than one or two passes along any given path to prevent unnecessary disturbance while the peat is very wet and structurally weak (Figure 5.1), and b) use of the shortest possible path across the peat at all times such as traverses across the sedge meadows, rather than travel along the length of these sensitive areas.

3) Avoidance of frequent traffic in known areas of unstable till such as around outcrops where snowbank melt leads to unusually high moisture contents or immediately south of Lac Cinquante.

4) The above conditions should be relaxed somewhat later in the summer when the effect of the thaw has decreased and the physical tests show improved strength and resistance of the surface materials to disturbance.

5) Should a track develop to the stage that the depth of the ruts approaches the fording depth of the vehicle, the use of this portion of the track should be discontinued.

(b) Planning of Drilling.

1) Any known drilling locations in the thick peat areas should be drilled as early in the season as possible while the frost table is near the surface to reduce drill disturbance (Figure 5.2).

2) When several holes are to be drilled in a certain area, drilling should proceed upslope such that each new set-up is not affected by the drill washings from the previous drill hole.

3) Consultation with the terrain monitor concerning upcoming drill

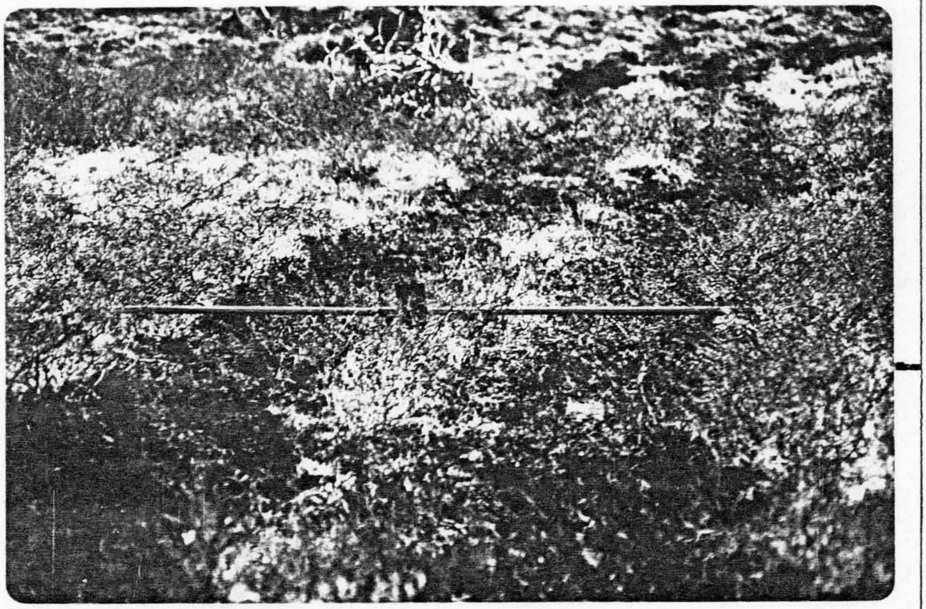


Figure 5.1 Two vehicle passes in mid-June have resulted in the initiation of peat slurry. This condition represents a warning sign that further traffic should be avoided, at least until the peat has dried.

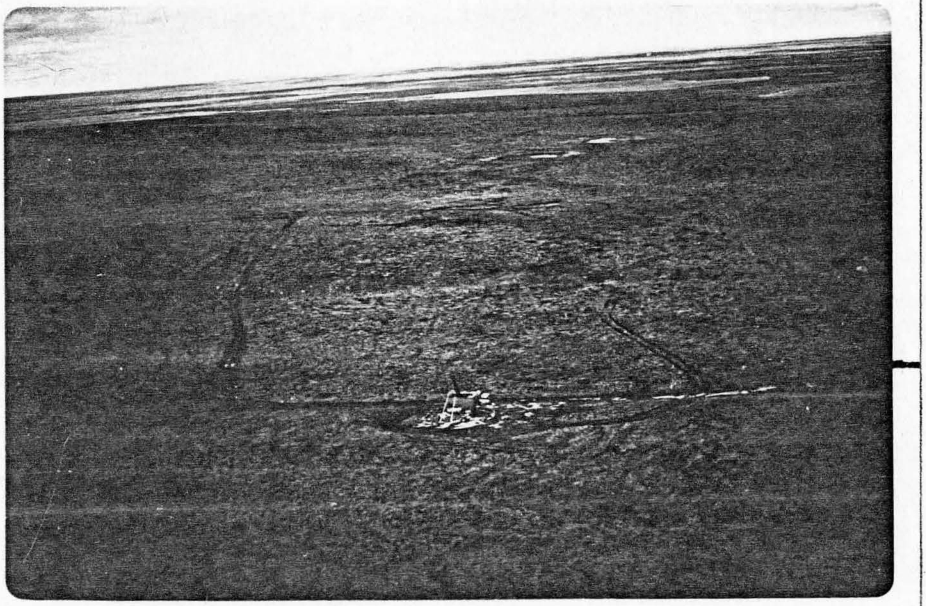


Figure 5.2 Aerial view of the differences in tracked vehicle and drill disturbances between thick peat areas (foreground) and areas of thin vegetation cover (background).

moves so that the monitor may be able to recommend a route that would avoid problem areas and keep disturbances to a minimum.

5.4 The Economics of Tracked Vehicle Drill Support

While the physical performance of the tracked vehicle is the major measure of its suitability, the economics of the vehicle-trailer system are also important. A cost study indicates whether it is feasible to use the present system again, or whether design or other modifications are required to make the system economic.

Cost analyses of the 1980 drilling program at Nogash Lake showed that 14 helicopter moves and 50 Muskeg vehicle moves occurred, at total costs of approximately $69,000 and $98,000 respectively (Hawkins and Stephen, 1980). In round figures, the average helicopter move most $5,000, the average vehicle move $2,000. In terms of the cost, tracked vehicle support represented significant financial savings over a drill program supported entirely by helicopters. Since vehicle moves are so much cheaper, the apparent goal may be to eliminate helicopter moves entirely. However, this is impractical for two main reasons. First, there exists some distance, probably about 600 metres, beyond which helicopter support becomes more economical due to the slow travelling speed of the Muskeg tractor. For any drill move or drill supply beyond this distance, the helicopter becomes increasingly more efficient as distance increases. The second reason is that most camps would require a helicopter for emergency situations whether for personal injury or in the event the vehicle(s) became immobilized by mechanical breakdown.

Since most helicopter contracts involve a minimum contracted flying time, these longer moves may be useful in accumulating helicopter time. Other advantages of the towing system include a greater independence of weather conditions and darkness whereby a helicopter may not be able to fly. Furthermore, Muskeg support is much more flexible over short distances, especially if daily re-supply trips to the drills are well planned.

In conclusion, the tracked vehicle-drill trailer system represents a viable alternative to helicopter support for short to medium distance drill moves. The time, and hence financial savings involved, far outweigh the relatively slow travelling speed of the vehicle. However, for long distance moves (greater than 600 metres) the helicopter becomes the more efficient method of drill support. This allows the operator to tailor the method of drill support to the nature of the drill program and drill hole spacings.

5.5 Summary

All of the physical tests performed the compressibility of thawed peat, drop weight, vane shear and track profile monitoring indicate that the degree of terrain disturbance is dependent on three main factors:

(a) the type of surficial material

(b) the seasonality of the traffic in terms of thaw depths and moisture contents of the surficial materials

(c) the number of vehicle passes and the amount of time between each pass.

The results of this study show that in most cases the performance of the tracked vehicle itself was adequate. This suggests that better planning, taking into account the factors discussed previously, should reduce vehicle disturbance significantly.

The study undertaken at Nogash Lake during the summer of 1980 provided several useful observations regarding the response of the tundra to tracked vehicle use. While it is hoped that these results will have general implications to the area beyond Nogash Lake, it must be realized that each site will require some sort of an individual site investigation. In this sense, the recommendations resulting from the Nogash Lake Study are intended to be a general guide to vehicle use in Keewatin and do not present specific recommendations applicable to other exploration sites in Keewatin.

BIBLIOGRAPHY

Abele, G., 1971, Effects of Hovercraft, Wheeled and Tracked Vehicle Traffic on Tundra: Report prepared for NSRDC, ARPA SEV Project, p. 186-215.

Bellamy, D., Radforth, J., and Radforth, N., 1971, Terrain, Traffic and Tundra: Nature, v. 231, no. 5305, p. 429-432.

Bird, J.B., 1967, The Physiography of Arctic Canada: The John Hopkins Press, Baltimore, 336 p.

Brown, R.J., 1970, Permafrost in Canada: Its Influence on Northern Development: The University of Toronto Press, Toronto, 234 p.

Eade, K.E., 1976, Geology of the Tulemalu Lake Map Area (65J) District of Keewatin: in Current Research, Part A, Geological Survey of Canada, Paper 76-1A, p. 379-381.

Egginton, P. and Ferris, P., 1980, Terrain Disturbance Resulting from Vehicle Movement, Lone Gull Lake, Central Keewatin: in Current Research, Part B, Geological Survey of Canada, Paper 80-1B, p. 69-74.

Ferris, P., 1980, Observations on Summer Vehicle Traffic and Drilling Operations in the District of Keewatin: Unpublished Report presented to DIAND, Yellowknife, 43 p.

French, H.M., 1976, The Periglacial Environment: Longman Inc., New York, 309 p.

Hare, F.K. and Barry, R.G., 1974, Arctic Climate: in Arctic and Alpine Environments: Meuthen, London, 999 p.

Hawkins, P. and Stephen, W., 1980, Cost Analysis of Helicopter versus Muskeg Drill Moves: Unpublished Report presented to DIAND, Yellowknife, 18 p.

Kerfoot, D.E., 1970, Thermokarst Features Associated with Tundra Disturbances Resulting from Oil Exploration Activities in the Mackenzie Delta Area, N.W.T.: Preliminary ALUR Report, 13 p.

Kerfoot, D.E., 1971, 1972, Tundra Disturbance Studies in the Western Canadian Arctic: ALUR Report on Summer Activities, 36 p.

Lee, H.A., 1959, Surficial Geology of the Southern District of Keewatin and the Keewatin Ice Divide: Geological Survey of Canada, Bulletin 51, p. 7-23.

Lord, C.S., 1953, Geological Notes on the Southern District of Keewatin: Geological Survey of Canada, Paper 53-22, p. 2-8.

Macfarlane, I.C., ed., 1969, Muskeg Engineering Handbook: University of Toronto Press, Toronto, 297 p.

Meteorological Branch, Environment Canada, 1976-1979, Monthly Record of Meteorological Observations in Northern Canada: Atmospheric Environment Service, Downsview.

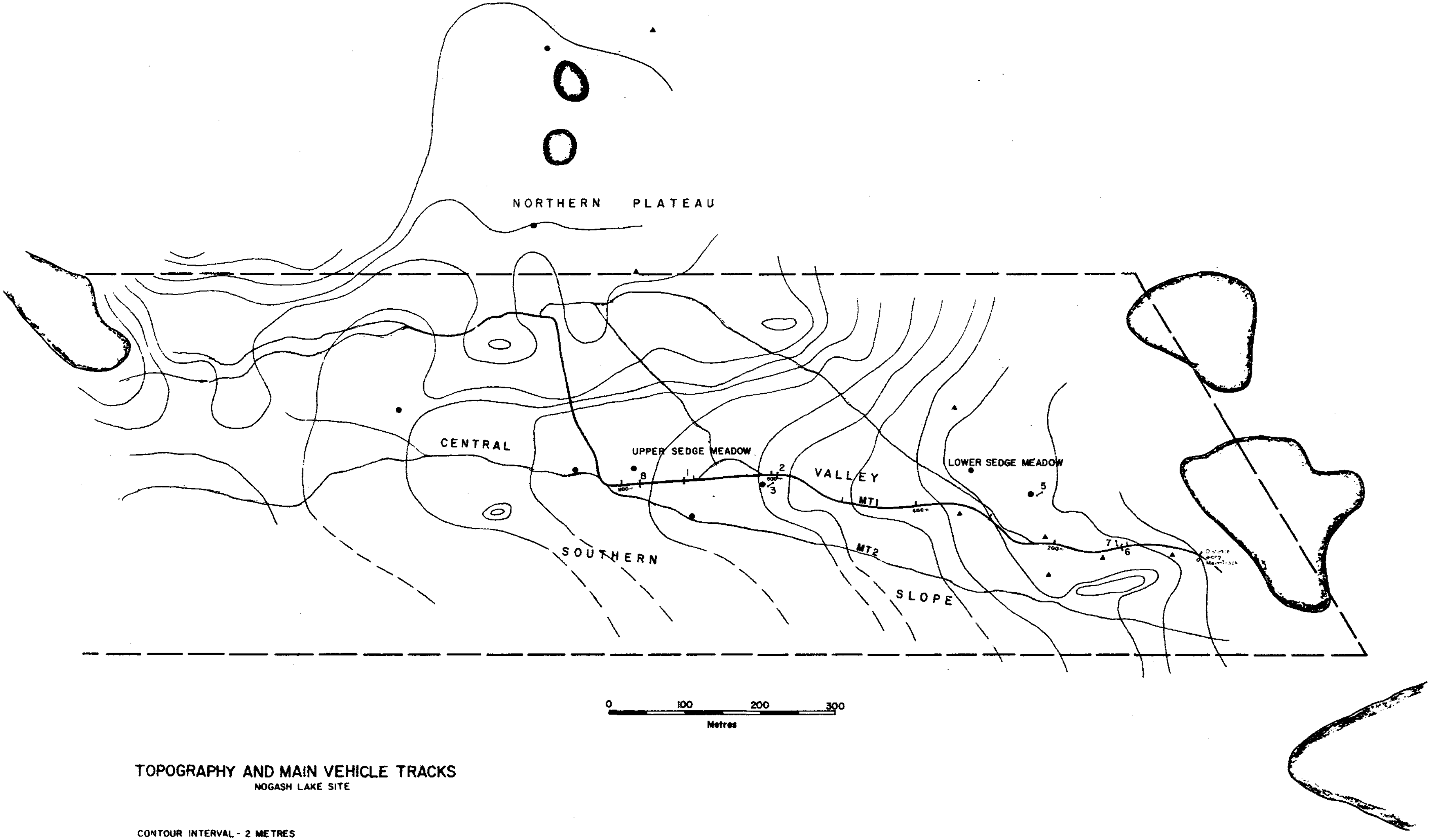
Radforth, J.R., 1970, Rolligon Tundra Disturbance Tests, Tuktoyaktuk: Muskeg Research Institute, University of New Brunswick, Report prepared for Bechtel Inc., 13 p.

Radforth, J.R., 1970, Tests to Define Levels of Terrain Damage by Tracked Vehicles Operating on Tundra: Muskeg Research Institute, University of New Brunswick, DIAND Report, 32 p.

Radforth, N.W. and Brawner, C.O., 1973, Muskeg and the Northern Environment: University of Toronto Press, Toronto, 399 p.

Wilson, N.E., 1976, Peat Under Cyclic Load: National Research Council Technical Memorandum No. 116, p. 144-150.

Wright, G.M., 1967, Geology of the Southeastern Barren Grounds, Parts of the District of Mackenzie and Keewatin: Geological Survey of Canada, Memoir 350, p. 26-67.

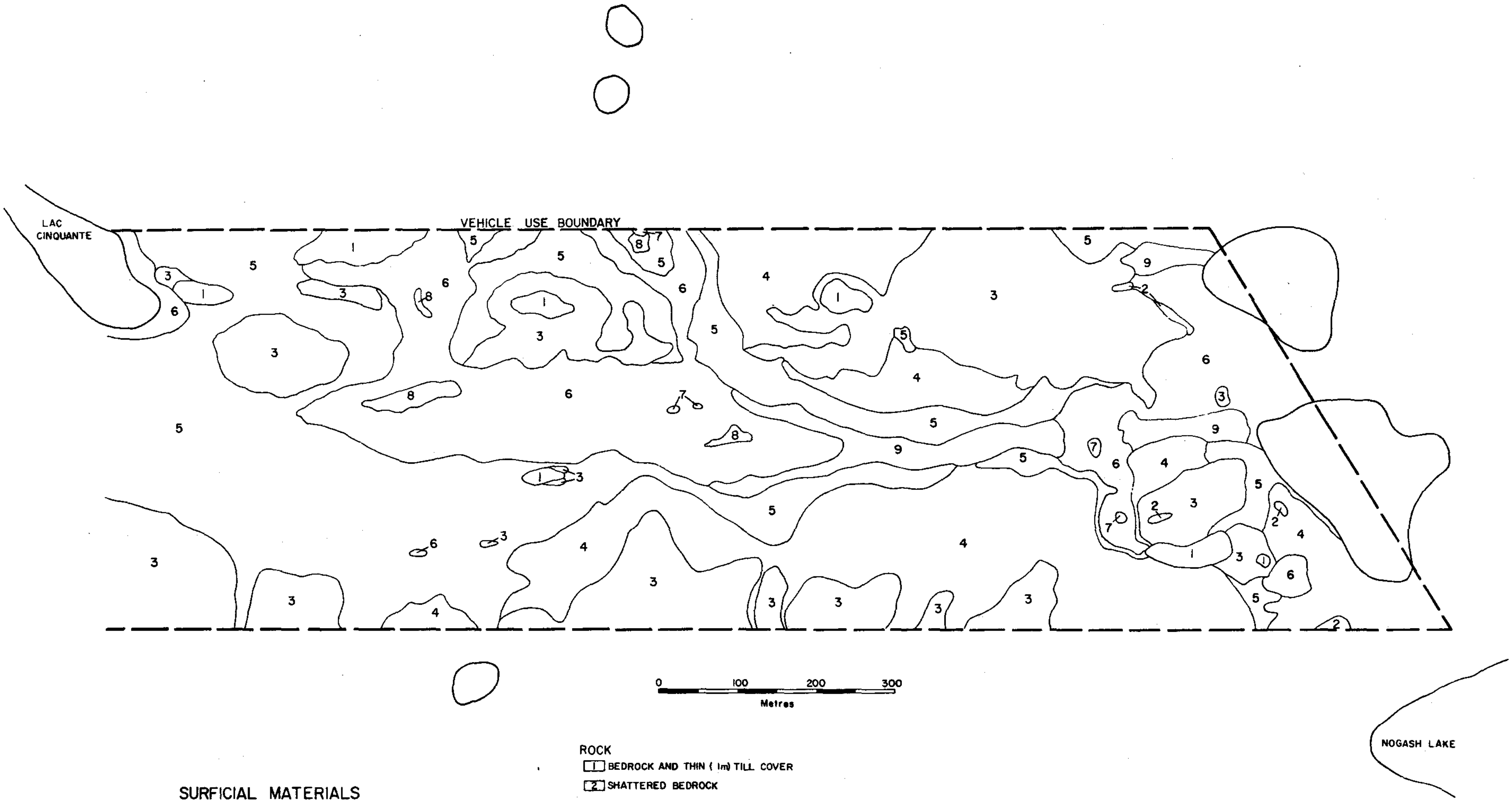


TOPOGRAPHY AND MAIN VEHICLE TRACKS

NOGASH LAKE SITE

CONTOUR INTERVAL - 2 METRES
● STANDPIPE LOCATION
▲ THERMISTOR LOCATION
— THAW PROFILES

DATA AND COMPILATION BY G. S. C.



SURFICIAL MATERIALS

NOGASH LAKE SITE

DATA AND COMPILATION BY G. S. C.

ROCK

1 BEDROCK AND THIN (1m) TILL COVER
2 SHATTERED BEDROCK

TILL

3 SPARSELY VEGETATED
4 WELL VEGETATED

PEAT

5 HUMMOCKY SEDGE MEADOW - WELL DRAINED
6 " " " - POORLY DRAINED
7 LEVEL SEDGE MEADOW
8 PEAT POLYGONS
9 VEGETATED ROCK POLYGONS