CLAY MINERALOGY

OF A CANADIAN SUBARCTIC SOIL

CLAY MINERALOGY AND MORPHOLOGY
OF SOILS AT THOR LAKE, N.W.T., CANADA

by

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ABSTRACT

Investigation of the morphology and mineralogy of a group of soils in the southern part of the District of Mackenzie, N.W.T. is reported. A uniform suite of clay-size minerals, reflecting locally reported bedrock, is observed with weathering of surface horizons resulting in the formation of vermiculite and montmorillonite from illite and chlorite. Kaolinite, attributed to pre-glacial formation, is illuviated downwards in these soils. Considerable quartz, feldspar, hornblende and anatase are also noted in the <2 micron fraction. Dominant soil types are Humo-Ferric Podzols and Degraded Dystric Brunisols. It is proposed that the use of Degraded Brunisol for these soils is inappropriate. The nature of fragic and placic soil horizons in this area is discussed.

RESUME

Une investigation sur la morphologie et la minéralogie d'un groupe de sols au sud de la Région Mackenzie, T.N.O., est relaté. Une série uniforme de minéraux argilleux, refléctant les roches génératrices obsérvées en cette localité, est notée avec la transformation des horizons surfaces résultant en la formation du vermiculite et montmorillonite par illite et chlorite. Kaolinite, attribué à la formation pré-glaciale, est lessivé de haut en bas dans ces sols. Beaucoup de quartz, de feldspar, de hornblende et d'anatase, sont notés aussi dans la fraction <2 microns. Les sols typiques de cétte région sont les Podzols Humo-Ferriques et les Brunisols Dystriques Dégradés. C'est proposée que l'usage du terme Brunisol Dégradé, pour ces sols, n'est pas justifiée. Les caractéristiques des sols avec les horizons fragiques et placiques de cette région sont discutés.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF COLOUR PLATES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION AND OBJECTIVES

Soil development in subarctic regions of Canada has received limited attention from pedologists. These areas mainly include the coniferous woodlands of Northern Quebec, Manitoba and Ontario and parts of the Districts of Mackenzie and Keewatin south of the tree line. Within these areas, the major soil groups present are Podzols and soils affected by podzolization processes. This thesis elucidates aspects of the morphology and genesis, as related by clay mineral analysis, of a number of soils examined at Thor Lake, Northwest Territories, a site in the southern District of Mackenzie.

Podzolic Soil Development

Podzolic soils develop under climatic and biological conditions favoring the formation of acidic decomposition products of organic matter. The downward leaching of organic material and sesquioxides of iron, aluminum and manganese and their accumulation in a B horizon are common to all soils in the Podzolic Group. This typically results in a light grey albic (Ae) horizon with overlying organic horizons (L, F, H) and underlying spodic (Bf, Bh, Bm) horizons. The criteria for horizon identification are outlined in the United States and Canadian systems of soil classification (United States Department of

Agriculture, U.S.D.A., 1967; Canada Soil Survey Committee, C.S.S.C., 1974). The precise morphology of such soils is somewhat variable depending on local environments and soil age.

The processes involved in the genesis of these soils is the subject of continuing debate, particularly in the Soviet Union where two major terms ("Podzolization" and "Illimerization") have been used to distinguish "true Podzols" from soils affected in some way by the podzolization process. These terms are discussed by Duchaufour (1951), Fridland (1958), Rode (1964), and Kremer (1969). Detailed literature reviews on Podzolic soil development include Muir (1961), Stobbe and Wright (1959) and Dudal (1970).

In subarctic environments, chemical and physical weathering processes are active to varying degrees, resulting in the alteration of parent materials (usually glacial drift) to soil. Fox (1975) has shown that the influence of weathering, as reflected by chemical mobilization, is limited to the uppermost 35 cm of Thor Lake soils. She has observed that all minerals are stable or unaltered below 80 cm depth except in poorly drained depressions. Tedrow and Hill (1961) have discussed the major processes observed in the Alaskan environment. Chemical weathering includes: (1) Solution which may cause the leaching of carbonates from calcareous sandy deposits, (2) Oxidation resulting in strong hues where ferrous to ferric ion exchange occurs, (3) Hydration of aluminum and iron liberated by crystal lattice alteration resulting in the accumulation of Fe_2O_3, $FeO(OH)$, Al_2O_3 and $Al(OH)_3$, and (4) Hydrolysis which can cause feldspar weathering. It is these processes that are most active in subarctic areas. This thesis is directed to the influence these processes have had on Thor Lake soils.

Weathering also includes mechanical processes such as the action of flowing water, grinding ice, and the freeze-thaw cycle. These have only indirect effects on soil development and have not been investigated in detail in this thesis.

Weathering of Clay Minerals in Podzols

The development and alteration of clay minerals play an essential role in the genesis of podzolic soils in the Subarctic. Clay minerals, also known as the "phyllosilicates", and clay-size minerals form the major part of the fine, non-organic, active material in soils. Clay-size materials are regarded as minerals and particles of less than two microns in diameter (<2μ) for soils investigations (Wentworth, 1922). However, the phyllosilicates exclude minerals such as quartz, feldspar and hornblende and organic matter and soluble salts all of which may occur as particles <2μ in size.

The clay minerals display a regularity in stability to weathering. Goldich (1938) was one of the first to establish a series (for silt and sand particles) relating weathering and bond strength. Jackson and Sherman (1953) and Jackson (1968) have established a similar series, attaching an index of stability to each of the clay and clay-size minerals frequently found in soils. Table I lists some of these minerals with their respective chemical formulae. The position of a mineral in this series relates directly to its structure and properties. For instance, kaolinite has strong interlayer hydrogen bon and is [illegible] res to [illegible] wea [illegible] min is

TABLE I

WEATHERING STABILITY OF SOME CLAY-SIZE MINERALS

(Jackson, 1968)

Stability	Mineral	Formula
MOST STABLE		
(13)	Anatase	TiO_2
	Ilmenite	$FeTiO_3$
	Corundum	Al_2O_3
(12)	Hematite	Fe_2O_3
	Goethite	$FeO(OH)$
(11)	Gibbsite	$Al(OH)_3$
	Boehmite	$AlO(OH)$
(10)	*Kaolinite	$Al_2Si_2O_5(OH)_4$
(9)	*Montmorillonite	$(Al,Mg)_4Si_8O_{20}(OH)_4 \cdot nH_2O$
(8)	*Vermiculite	$Mg_3(Al,Si)_4O_{10}(OH)_2 \cdot 4H_2O$
(7)	*Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_2$
(6)	Quartz	SiO_2
(5)	Feldspars:	
	Plagioclase	$NaAlSi_3O_8 - CaAl_2Si_2O_8$
	Microcline	$KAlSiO_8$
(4)	*Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$
	*Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$
	Serpentine	$Mg_3Si_2O_5(OH)_4$
(3)	Hornblende	$(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$
	Pyroxene	$(Mg,Fe,Ca)_2Si_2O_6$
(2)	Calcite	$CaCO_3$
(1)	Halite	$NaCl$
LEAST STABLE		

*Phyllosilicates

placed high in the series (10) and is frequently characteristic of older, well-developed landscapes. Minerals lower in the series, such as montmorillonite (9) and vermiculite (8), have "expandable" lattices which allow hydration and ionic substitution. The presence of these minerals often indicates soils in which more intense initial weathering has occurred. Hence, the identification of the clay minerals present in a soil can reveal considerable information concerning the intensity and nature of the weathering processes active in that soil.

Morphogenetic Horizons

The soils of the Thor Lake area are characterized by thin albic (Ae) horizons and weakly to well-developed spodic (B) horizons. Of particular interest as well, are the presence of indurated fragic and placic soil horizons in these soils. A review of the literature, outlined in Chapter Two, indicates that such horizons develop as the result of localized environmental effects not common to surrounding soil horizons. The morphology of such horizons has received considerable attention in other areas of Canada (De Kimpe, 1970; Valentine, 1969; Wang, et al., 1974) as discussed in Chapter Two. However, this author is not aware of any detailed reports of their occurrence in the Canadian Subarctic.

The term "fragic" has been proposed for classification of soils with fragipans (C.S.S.C., 1973). A fragipan (a Bx horizon) is a subsurface horizon of high bulk density, is firm and of brittle consistence when moist and hard to extremely hard when dry. Commonly, it has bleached fracture planes separating coarse prismatic units, frequently being of platy structure. It may be overlain by friable B horizons with a sharp textural boundary. These pans may be very thick (1-3 metres) and diffuse into parent materials usually different in structure, consistence and bulk density (C.S.S.C., 1973).

A placic horizon (usually Bfc) consists of a single thin band (about 5 mm thick) or a series of bands that are irregular or involute, hard, impervious, often vitreous and dark reddish brown to black.

Study Objectives

During the 1974 and 1975 field seasons, this author has had the opportunity to assist in the study of soil conditions in a spruce-lichen woodland environment in the Northwest Territories. The location and characteristics of this site are outlined in Chapter Three. Results of ecological research conducted in this location are reported in Kershaw, Rouse and Bunting (1975).

Considerable debate at the Ninth Annual Meeting of the Canadian Soil Survey Committee (C.S.S.C., 1973) focussed on the difficulty of classification of soils and the need for detailed research in the woodland areas of Northern Saskatchewan and the southern parts of the District of Mackenzie. A review of the literature of soils in spruce-lichen-woodland (Chapter Two) indicates that only a few papers have been directed towards mineralogy and soil genesis in this subarctic environment. This author and Fox (1975) have pursued the investigation of the genesis of Podzol and podzolized soils observed at Thor Lake, N.W.T. This thesis outlines a detailed semi-quantitative examination of the clay mineralogy of these soils.

The main objectives of this study can be listed as follows:

(1) To identify and sample a number of different soils developed under varying conditions of drainage, topography, vegetation cover, and glacial history.

(2) To determine, through field description, the profile characteristics of these soils in relation to criteria established by the Canadian Soil Survey Committee.

(3) To obtain chemical, physical and clay mineralogical data to characterize the soil types and horizons of varying texture and depth in this region.

(4) To trace the genetic processes which have led to the development of these soils by comparison of clay mineral suites and identification of weathered materials and resynthesis products therein.

(5) To provide detailed information on the soils of the region and possibly offer suggestions for improvement of classification of these soils.

Several assumptions regarding these soils must be made. It is assumed that the soils formed on the drumlins in the study area are derived from uniformly distributed glacial till parent material. Macroclimatic effects are also assumed to have had uniform influence on all parts of the region through time. The effects of fire, which have been an essential component in maintaining this environment for at least the last several thousand years (Kershaw, 1975), are assumed to have had a reasonably uniform effect on upland, well-drained sites. These effects would largely be restricted to surficial Ae horizons and organic layers.

Several hypotheses are proposed:

(1) That the clay minerals observed in these soils generally reflect the minerals noted in parent rocks of this area. In surface horizons, where chemical weathering is most active, *in situ* alteration of these minerals has resulted in the formation of secondary clay minerals.

(2) That there exist detectable differences in the suites of clay minerals present in different types of soil profiles within this area.

(3) That specific physical and chemical parameters affect the clay minerals present in these soils.

(4) That the morphology and genesis of these soils is similar to those observed in soils of similar environments elsewhere.

CHAPTER TWO

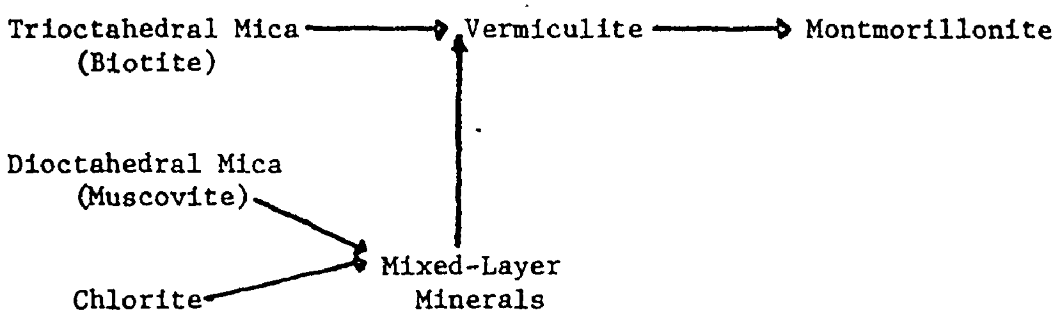
REVIEW OF CLAY MINERAL GENETIC SEQUENCES AND CANADIAN LITERATURE

A suite of clay minerals in a Podzolic soil can be identified which reveals considerable information regarding its development. Identification of these minerals and the establishment of a scheme for mineral genesis in Podzolic soils has been the subject of considerable research in several countries. In this chapter, several of the schemes proposed and a detailed review of the literature for soils north of 55° latitude in the Canadian Subarctic are discussed. In addition, Canadian papers concerning morphogenetic fragic and placic horizons are briefly examined.

Genetic Sequences of Clay Minerals

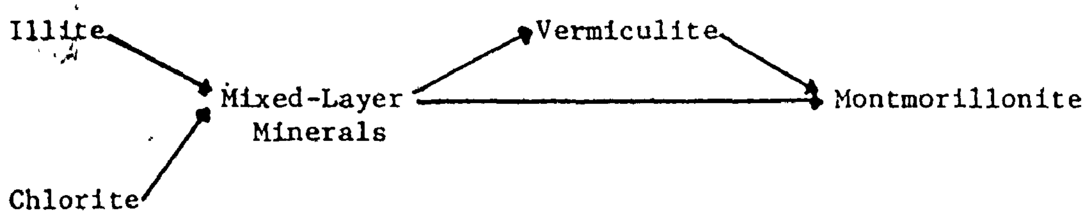
The high degree of uniformity in the pathways followed in the alteration of clay minerals in Podzolic soils in the Soviet Union, Canada and Norway indicates that the genesis of soils in the Podzolic Group proceeds in a similar fashion in geographically-separated regions.

In the Soviet Union, Sokolova, et al. (1971) and Belousova, et al. (1973) in studies of Podzols of the Aldan Plateau, report that chlorite is absent in the surface A2(Ae) horizons but increases with depth below the Bf horizon. Montmorillonite is noted to be common in the Ae but absent below the upper B horizon while vermiculite and mixed minerals accumulate in the Bf horizon. This indicates that chlorite in these soils is the main clay mineral being weathered to the expandable minerals, montmorillonite and vermiculite. Both studies attribute kaolinite, where observed, to preglacial origin. In a similar study, Zvereva (1968) noted that pH declines as soil development proceeds resulting in potassium loss and alteration of illite to vermiculite. She also noted that chlorite can alter to vermiculite where magnesium is extensively leached. Sokolova,et al. (1971) proposed the following weathering sequence for clay minerals:



Numerous other papers from the Soviet Union support this generalized sequence. Gradusov and Palecheck (1968), in a study of Sod-Podzolic soils from the Ob'-Vasyugan Watershed, Tomsk Oblast, attribute clay mineral distribution differences to variations in the aeration-water regime. Sokolova and Shostak (1969) note illite to vermiculite development in Podzols of the Yan-Alin Mountains, Siberia.

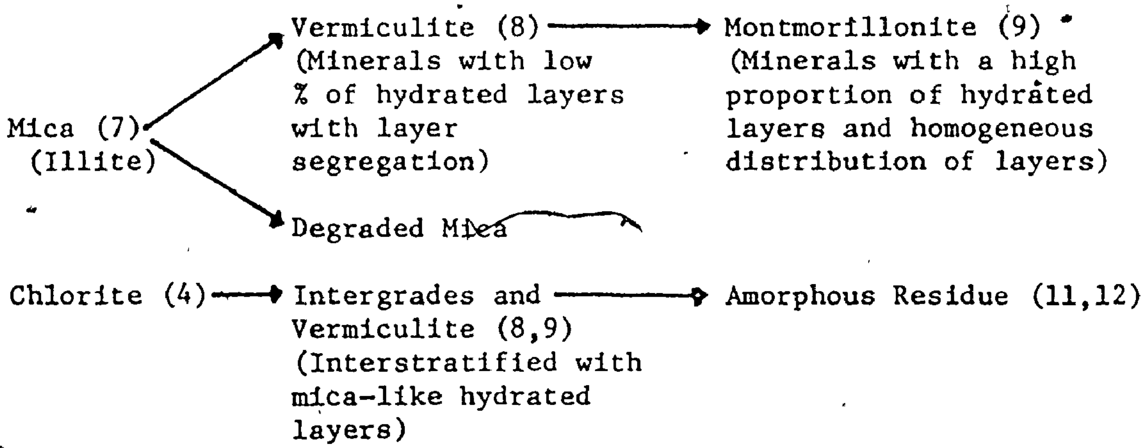
Gjems (1963, 1967) reports detailed studies of Podzol genesis in Norway. The presence of montmorillonite in Ae surface horizons is indicative of advanced weathering while the absence of chlorite in the Ae and its increase with depth show that, in Norwegian Podzols, a process similar to that observed in the Soviet Union is active. Environmental factors including pH, drainage, organic matter, vegetation cover and temperature are also shown to be strongly correlated with clay mineral suites present in these soils. As in the Soviet Union, Gjems' weathering sequence can be summarized as follows:



Gjems (1967) noted that his studies concur with earlier examinations of clay mineral suites in Podzols in Wisconsin (Brown and Jackson, 1958) and in Illinois (Droste and Thorin, 1958). The persistence or chlorite in the B horizon and its absence in surface horizons are attributed by Kapoor (1972), working in Norway, to protective FeOH and AlOH coatings on ped surfaces in the B horizon. He states that these coatings prevent the rapid decomposition of chlorite by impeding the uptake of H^+ and the release of Mg^{++} and Fe^{++}.

The mechanisms involved in the genesis of Podzols in Eastern Canada have also been studied extensively. Kodama and Brydon (1968) and Brydon, Kodama and Ross (1968) report clay mineral distributions similar to those observed in Norway. These authors also attribute the accumulation of chlorite in the B horizon to the protection by iron and aluminum hydroxides. In New Brunswick and Nova Scotia, C horizon clay minerals generally reflect the minerals noted in the bedrock of this region (Allen and Johns, 1960). De Kimpe (1974) has studied Podzols in New Brunswick, concluding that montmorillonite and vermiculite are the weathering products of dioctahedral illite (muscovite). This study also confirms that chlorite is readily decomposed in the acidic environment of surface Ae horizons as observed by Brydon, Kodama and Ross (1968) and Brydon, Clark and Osborne (1961).

A weathering sequence for clay minerals in Podzols of Eastern Canada has been proposed by Kodama and Brydon (1968) as follows:



The numbers associated with minerals in this scheme correspond to the indices of weathering assigned by Jackson (1968) as noted in Table I of the previous chapter. The more intensely-weathered minerals have higher index values.

Mineralogical Studies of Canadian Subarctic Soils

One of the first papers to provide mineralogical data on subarctic soils in Canada is that of Wright, Leahey and Rice (1959). Three calcareous materials displaying podzolic surface characteristics, in the Fort Simpson, N.W.T. region are described. Mixed montmorillonite-illite is prominent in these soils with extensive amounts of illite, quartz and some chlorite, kaolinite and montmorillonite. Concentration of clays in the B horizon was attributed to *in situ* deposition. Several soils in tundra and boreal environments along the Mackenzie River between Norman Wells and Inuvik are described by Day and Rice (1964). These soils were observed to contain a suite of clay minerals similar to the previous study by these authors.

A further study of soils in the Mackenzie Valley near Wrigley is reported by Lavkulich (1973). The vegetation, climate and geomorphology of this area is quite similar to those at Thor Lake. At Wrigley, vermiculite is the dominant clay mineral in 46 samples of Bm, BC and C horizons of mainly Degraded Dystric and Eutric Brunisols. Kaolinite and illite are also present in significant amounts while chlorite is noted in only 9 cases in Bm and C horizons. In four Bm or BC horizons, montmorillonite is a significant component. Surficial Ae horizons were not examined in this study. Lavkulich concluded that these soils contain a heterogeneous suite of little-weathered clay minerals reflecting the original geological materials (glacial till, colluvium and alluvium) from which these soils have developed. Table II outlines examples of the dominant clay minerals from sites described in this paper.

The geochemical properties of soils developed on eskers near Kaminak Lake, Keewatin District (62° 20' N, 94° 15' W), have been reported by Shilts (1972). Hydrolysis and oxidation of labile materials

TABLE II

DOMINANT CLAY MINERALS IN SOILS OF THE WRIGLEY AREA

(Lavkulich, 1973)

Geologic Material	Soil Type (CSSC)	Horizon	Dominant Clay Minerals Listed in Order of Abundance
Drumlinized Till	Degraded Eutric Brunisol	BC	Vm Kt Qtz Mt Vm-It
		C	Vm Kt Qtz It
Till Plain	Degraded Dystric Brunisol	BC	Vm Kt It Qtz Vm-It
		C	Vm Cht Kt It Qtz Vm-It
Drumlinized Till Plain	Peaty Orthic Humic Gleysol	Bg	Vm Kt It Qtz.
		C	Vm Kt It Qtz
Outwash; Esker and Esker Complex	Degraded Eutric Brunisol	Bm	Vm It Qtz
		BC	Vm It Qtz
		Cca	Vm It Qtz

Cht = Chlorite
It = Illite
Kt = Kaolinite
Mt = Montmorillonite
Vm = Vermiculite
Qtz = Quartz

have resulted in the formation of vermiculite and chlorite in these deposits. Illite and amphiboles are also noted in several samples. Although no profile descriptions are provided, the data suggest these soils are Degraded Dystric Brunisols.

Pawluk (1960, 1963) has examined Podzolic soils near Fort McMurray in northern Alberta. In these soils, illite, kaolinite and mixed-layer montmorillonite-illite are common in Ae and C horizons. The presence of chlorite in B horizons is attributed to *in situ* weathering of illite and montmorillonite. Pawluk felt that quartz/feldspar ratios reflect the degree of weathering of horizons, with highest values near the surface. Ratios for A, B and C horizons are noted to be 16, 10 and 6. The data show that, in northern Alberta, soil genesis is primarily of a chemical nature resembling that in other similar areas. In recent papers, Pawluk and Brewer (1975) and Brewer and Pawluk (1975), note that the major clay minerals in forest/tundra soils along the Mackenzie River (66° 43' N, 134° 32' W) are montmorillonite and illite with some vermiculite and kaolinite as described in earlier papers. These authors have attributed depletion of potassium in surface horizons to weathering of feldspar and illite.

A detailed study of the pedogenesis of soils in subarctic spruce-lichen woodland near Cambrian Lake, Quebec (56° 30' N, 69° 15' W) has been reported by Moore (1974). Orthic Humo-Ferric Podzols and Degraded Dystric Brunisols are the main soil types observed in this environment which is quite similar to that at Thor Lake. Soils with quartzite parent materials have been observed to be more developed than those derived from gneissic materials. A large degree of translocation of oxides and organic matter between horizons is noted but no data on clay mineral suites is included in the paper. The observation by Lavkulich (1973) that chemical weathering is minimal in subarctic woodland soils is substantiated by this paper.

A considerable number of studies of the mineralogy of Podzols in other areas is reported in the literature. Soils in Alaska have been examined by Douglas and Tedrow (1960), by Allen, et al. (1969), and by Everett (1971). In eastern Canada, Kodama and Brydon (1964, 1968); Brydon, Kodama and Ross (1968); Brydon (1958, 1965), Brydon and Shimoda (1973) and McKeague, MacDougall and Miles (1973) have dealt with aspects of the mineralogy of Podzols in Prince Edward Island, Nova Scotia and New Brunswick. Theisen, et al. (1959) examined clay minerals in soils on Vancouver Island. Coen and Arnold (1972) report a study of the mineralogy of Podzolic soils in New England.

Fragic and Placic Horizons in Canadian Soils

Review of the literature concerning fragic soil horizons indicates that considerable debate centres on the nature of the binding agents causing induration in these soils. Grossman and Carlisle (1969) proposed that specific clay minerals act as binding agents whereas Yassoglou and Whiteside (1960) had concluded that the accumulation and orientation of illite formed this agent in fragipans. De Kimpe (1970) points out that this is inaccurate since he has observed soils with fragipans in Quebec which do not have a significantly greater amount of illite in these horizons. A further study of fragipans in Quebec is reported by Rochefort (1969). Wang, et al. (1974), utilizing

Scanning Electron Microscopy, reveal that clay bridges are much more numerous in fragic Bx horizons of a Podzol in Nova Scotia. This indicates that the binding agent is a function of the total phyllosilicate (clay mineral) fraction in the soil. The exact nature of the material binding fragipans is probably variable, being a product of complex, local environmental conditions. The induration of such horizons can be quite extensive. De Kimpe and McKeague (1974) point out that the study of some fragic soils may require the use of powered excavation equipment. The occurrence of such indurated soil profiles at Thor Lake is discussed in Chapter Five (Site G). The difficulties involved in its excavation strongly support the view expressed by De Kimpe and McKeague. A detailed review of the literature on fragic soils, which are found in many soil types throughout the world, is presented by Grossman and Carlisle (1969).

The occurrence of placic soil horizons at Thor Lake is also reported in Chapter Five. Placic horizons have been sporadically reported in Canadian soils. McKeague, Schnitzer, and Heringa (1967), McKeague, Damman and Heringa (1968) report studies of placic soils in Newfoundland while Valentine (1969) and Lavkulich, et al. (1971) report similar studies for Podzols on Vancouver Island.

It is evident that there exists considerable literature concerning clay mineral genesis in Podzolic soils in Canada and other nations. The sequences observed are basically similar from region to region. However, the few papers dealing with soils from subarctic Canada suggest relationships but do not clarify the clay mineralogical processes in this region. This indicates that detailed examination of the mineralogy of subarctic soils is warranted.

CHAPTER THREE

STUDY AREA

Location

Pedological field work was undertaken at a research site in the southern part of the District of Mackenzie, Northwest Territories. The site, locally called "Thor Lake", is approximately 150 kilometers northeast of Uranium City, Saskatchewan at 60° 21' North latitude and 106° 54' West longitude. The position of Thor Lake relative to local settlements and the rest of Canada is delineated in Figure I. The area is accessible by fixed-wing float aircraft and by helicopter.

Climate of the Study Region

Data based on meteorological records from permanent stations at Fort Smith, N.W.T. and Uranium City, Saskatchewan, both of which are to the southwest of the area, indicate a subarctic microthermal climate characterized by cold winters with moderate snowfall and relatively short, cool summers with low rainfall. The area would be classified "Dc" according to the Köppen Climate Classification scheme (Longley, 1972).

Table III outlines summarized meteorological data for Fort Smith and Uranium City. A sample of 1974 field data from Thor Lake is included for comparison. It has been observed that the 1974 field season

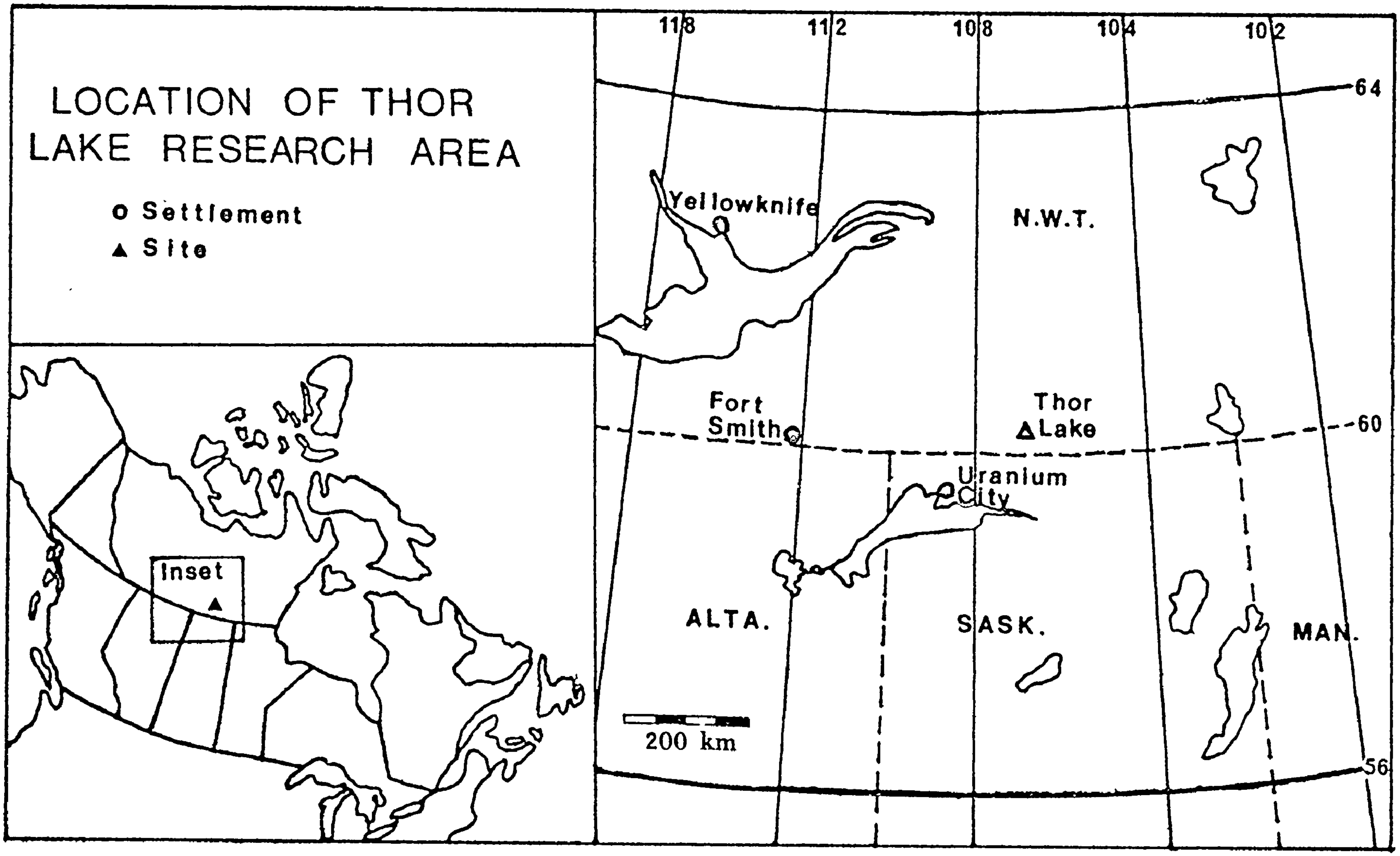


FIGURE I: Location of study area

TABLE III

CLIMATIC DATA FOR THOR LAKE AREA

Meteorological Station Data*	Fort Smith N.W.T.	Uranium City Sask.
Precipitation (mm):		
Mean June-August	127	127
Mean Annual	353	358
Mean Annual Snowfall	1530	1400
Mean Annual Soil Deficit based on 10 cm Soil Moisture	165	127
Temperature (°C):		
Average No. Days T max. >26°C	10	5
Mean July Temp.	16.3	16.7
Mean January Temp.	-25.0	-26.1
Extreme Low	--	-48.3
Extreme High	--	32.8

Thor Lake Data	July 4-31 1974	August 1-16 1974
Mean Daily Temperature (°C)	13.5	13.2
Extreme Low (°C)	3.0	1.4
Extreme High (°C)	27.4	31.0
Total Precipitation (mm)	109	55
Mean Wind Speed (m/sec)	1.9	1.8

*Longley (1972)

(May-August) was climatically abnormal for this region. Rainfall in the June-July recording period was above average and temperatures somewhat below average. During the same period in 1975 rainfall measurements were lower and temperatures slightly higher (Rouse, personal communication). Detailed study of the microclimate of burned and unburned woodland surfaces at the research site is reported in Kershaw, Rouse and Bunting (1975).

Local Vegetation

The Thor Lake region is dominated by spruce-lichen woodland along elevated, well-drained drumlin areas and by poorly-drained sphagnum swamp in inter-drumlin lowlands and along lakeshores. A list of the major flora observed by McMaster University botanists in the immediate Thor Lake area is given in Table IV. Scientific and common names, as well as a note on local abundance for each species, are provided (Maikawa, personal communication). Numerous species of moss and vascular plants restricted to swamp areas are not included in this list. A study of the vegetation in a similar environment at nearby Ennadai Lake, N.W.T. is reported in Larsen (1965).

The woodlands of this region have a distinctive fire history. It has been observed that relatively small areas may have evidence of a complex of fire events. Fire-scar analysis allows dating to as much as 200 years before present. The research drumlin has evidence of at least five significant burns in this period over an area of less than three square kilometers. A successional sequence for lichens on these burn surfaces has been identified by Kershaw (1975).

TABLE IV

FLORA OF THE THOR LAKE REGION

(VA)-Very Abundant (C)-Common (R)-Rare

	Lichens			Shrubs and Vascular Plants	
1.	*Cladonia alpestris*	(VA)	1.	*Arctostaphylos uva-ursi* (Bearberry)	(C)
2.	" *uncialis*	(VA)	2.	*Empetrum hermaphrodite* (Crowberry)	(C)
3.	*Cetraria nivalis*	(VA)	3.	*Geocaulon lividum* (Northern Comandra)	(C)
4.	*Stereocaulon paschale*	(VA)	4.	*Ledum groenlandicum* (Labrador Tea)	(VA)
5.	*Lecidia uliginosa*	(C)	5.	*Vaccinium vitis-idaea* (Cranberry)	(C)
6.	*Biatora granulosa*	(C)	6.	*Vaccinium myrtiloides* (Blueberry)	(C)
7.	*Cladonia amaurocrea*	(C)	7.	*Vaccinium uliginosum* (Bilberry)	(C)
8.	" *coccifera*	(C)	8.	*Lycopodium* spp.	(R)
9.	" *cornuta*	(C)			
10.	" *crispata*	(C)			
11.	" *gracilis*	(C)			
12.	" *mitis*	(C)			
13.	" *rangiferina*	(C)			
14.	*Cetraria islandica*	(R)			
15.	*Cladonia botrytes*	(R)			
16.	" *cristatella*	(R)			
17.	" *gonecha*	(R)			
18.	" *macrophylla*	(R)			
19.	" *subulata*	(R)			
20.	*Nephroma arcticum*	(R)			
21.	*Peltigera aphthosa*	(R)			
22.	" *scabrum*	(R)			

	Mosses and Liverworts			Trees	
1.	*Hylocomium splendens*	(C)	1.	*Picea mariana* (Black Spruce)	(VA)
2.	*Pleurozium shreberi*	(C)	2.	*Pinus banksiana* (Jack Pine)	(C)
3.	*Polytrichum juniperinum*	(C)	3.	*Betula papyrifera* (White Birch)	(C)
4.	*Polytrichum piliferum*	(C)	4.	*Populus tremuloides* (Quaking Aspen)	(C)
5.	*Dicranum* spp.	(R)	5.	*Larix laricina* (Tamarack)	(R)
6.	*Ptilidium ciliare*	(C)			

An infrared aerial photograph of the research area is provided as Plate I. The higher drumlin sites are dominated by black spruce (*Picea mariana*) and a range of lichen species. Lower, wetter areas are dominated by mosses, vascular plants and small trees. The light area in the centre of Plate I, labelled "1", marks an intense burn dated to 1951. Other spruce-dominated zones in the photograph, labelled "2", are estimated to have been subjected to severe fires, several times in some areas, between 38 and 110 years before present. The deep green zone in the lower centre of this photograph, labelled "3", marks an area subjected to an intense, uncontrolled burn during the 1975 field season. The large elongated lake, labelled "4", in the centre is Thor Lake. A ponded kettle, labelled "5", similar to those investigated, is noticeable on a drumlin crest in the lower right of this photograph.

Physiography and Geology of Study Area

The area in which the research site is located was completely glaciated during Wisconsin time as evidenced by extensive glacial landforms, deposits and bedrock modifications in the region. Such features are common to all of the eastern part of the District of Mackenzie. Rapid retreat of the ice sheet occurred between 6000-8000 years before present in this region (Nichols, 1967). The area is covered by gravelly glacial drift mixed with many boulders and lies within the Canadian Shield.

Drumlins are the most common feature in the Thor Lake vicinity covering about 3100 square kilometers. Many small elongated lakes connected by swampy streams in inter-drumlin areas drain gradually

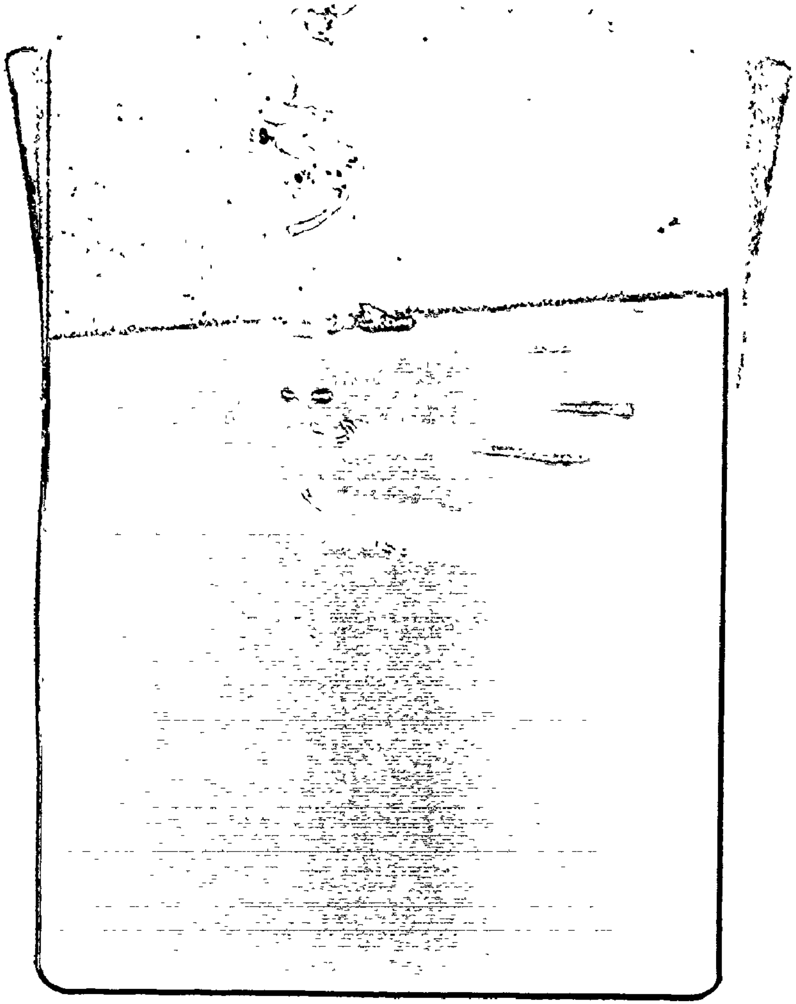


PLATE I: Infrared aerial-oblique photograph of Thor Lake Research Area eastwards through the region as part of the Hudson Bay basin. Shore areas of these lakes are generally swampy and underlain by boulder deposits. Direction of ice movement from northeast to the southwest is indicated by drumlin shape, eskers and glacial striae. Hoadley (1955) noted that many of these drumlins have rock cores and, in some cases, end in rock outcrops at the northeast point. Few bedrock outcrops have been observed in the immediate Thor Lake vicinity. Numerous eskers running southwest to northeast mark the loci of Pleistocene drainage channels. One esker approximately eight kilometers south of Thor Lake was visited. It is noted to have a boulder core, runs some three kilometers in length and ranges in height from 4 to 7 metres.

The research site encompasses two coalesced drumlins of about 1.5 kilometers in length. The maximum height of the feature was established by levelling to be 25.6 metres above lake level in July 1974. Heights of other drumlins in the area are generally less than 30 metres. Local lake elevations are approximately 480 metres above sea level. Like all drumlins in this area, the research site drumlin has a thick covering mantle of glacial till.

The area about Thor Lake is mainly underlain by migmatitic and gneissic rocks, rich in quartzite and plagioclase feldspar. Deposits of glacially transported till are of mixed volcanic and sedimentary origin. The bedrock has been classified as Archaean and/or Proterozoic (Precambrian) in age (Geological Survey of Canada, 1969). Coarse-grained granitic gneiss and paragneiss are indicative of a high degree of regional metamorphism with active granitization in the Thor Lake area. These materials vary widely in colour from pink to red and grey to white with variable texture, grain size and mineral composition. Hornblende-feldspar-gneiss in this region is indicative of medium grade metamorphosed volcanics. Igneous bedrock includes quartz, amphiboles and micas. Some potassic feldspar, chlorite, muscovite, epidote, magnetite and hematite have also been noted in this region (Taylor, 1963).

Geological studies in adjacent areas have been reported by Craig (1964) and Taylor (1959) to the north; by Taylor (1963) and G. S. C. Map #1199A (1970) to the east; and to the south by G.S.C. Map #20-1968 (1968).

Soils Observed at the Research Area

During the summer of 1974, an extensive investigation of the soils of this area was undertaken. Specific studies included the mapping of soil types; the examination of the relationship between fire history and development of organic horizons; profile genesis and moisture regime; and computer mapping of soil properties and horizons. Results of these studies are reported in Kershaw, Rouse and Bunting (1975).

The most common soils observed on drier upland drumlin areas are Humo-Ferric Podzols. Fox (1975) notes that in many cases soils that appear to be Podzols must actually be classified Degraded Dystric Brunisols. Such soils have illuviated Bm horizons in which the Fe+Al analytical criteria for a Bf horizon is not met. These criteria are defined by the Canada Soil Survey Committee (1973, 1974). In some areas where drainage is restricted, extensive mottling indicates the

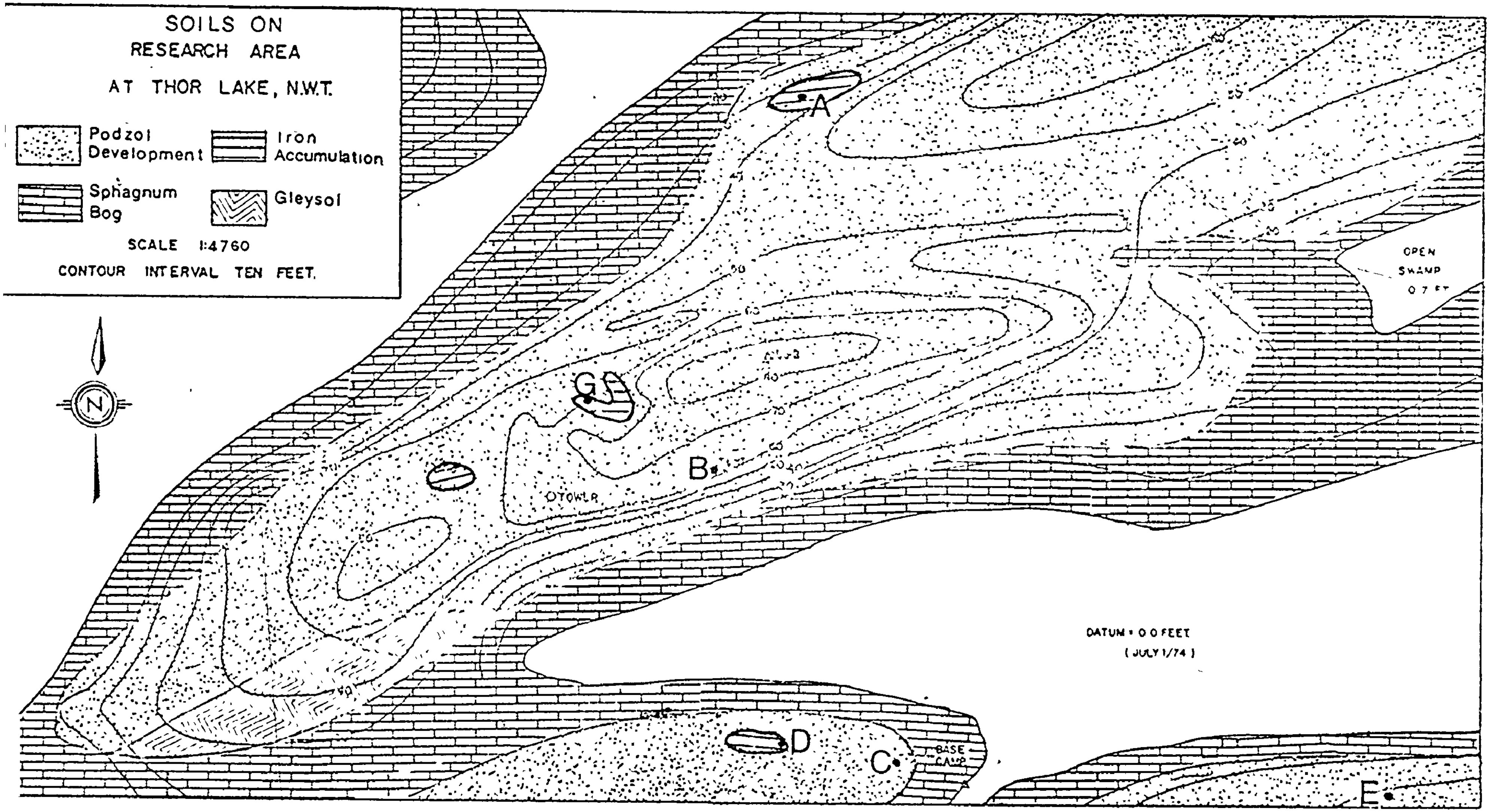


FIGURE II: Generalized soil map of research area and location of sampling sites presence of Fera Eluviated Gleysols. Along lakeshores and interdrumlin swamps, existing soils are classified Sphagno-Fibrisols. Some are underlain by frozen sandy gravel. Isolated humus-rich sediments have also been noted in numerous kettles along crests of drumlins in the area. A number of isolated earth hummocks similar to those described by Shilts (1973) and Pettapiece (1974) have been examined in the area, usually along drumlin crests.

Figure II is a generalized soil map of the immediate Thor Lake area. Areas labelled "iron accumulation" are local depressions where fragic and placic soils have been observed. The location of the sampling sites (A-E, G), as described in Chapters Four and Five, are also noted on this figure.

CHAPTER FOUR

SAMPLING AND ANALYTICAL METHODS

Soil samples from the research area have been analyzed for their chemical, physical and mineralogical properties. In this chapter, the procedures used in the sampling and analysis of these soils are briefly outlined.

Sampling Procedures

A total of twelve sites were originally sampled for detailed laboratory investigation. Only seven of these are directly discussed in Chapter Five as the remainder are of a repetitious nature. The selected sites are representative of varying local environmental conditions affecting soils such as drainage, aspect, topography and fire history. The seven sites described have been arbitrarily lettered "A" to "G". The locations of these sites are identified on Figure II, page 28.

In the field, profiles at each of these locations were described according to Canadian criteria (Canadian Soil Survey Committee, 1973, 1974). This includes notes on horizon development, soil colour, texture, structure, consistency, stoniness, local vegetation, slope, drainage and presence of roots and mottles. Soil colours reported in profile descriptions in Chapter Five represent standard Munsell colours for soils in the field (Munsell Color Company, 1954). An additional "d" or "w" is added to designate dry or moist-wet samples respectively. All samples were air-dried and the <2 mm fraction pre-sieved and stored in sealed plastic bags prior to shipment from the field to the laboratory where the analyses were conducted.

Particle Size Analysis

A particle size distribution analysis of the soil samples at all sites was undertaken using an Allen-Bradley model L-3 sonic sifter. Sieve specifications available with this device differ slightly from the size classes defined by the Canadian Soil Survey Committee (1974) and the traditional Wentworth system (1922). Table V compares the textural classes defined in this study, in the Canadian and in the Wentworth systems. Samples of air-dried <2 mm soil were pretreated to remove organic matter by ignition at 550°C for one hour. Samples were weighed on an electronic balance to ±1 mg and percentage textural distributions calculated.

Soil Reaction (pH)

A Fisher Accumet pH meter, model 210, was used to record the pH of all soil samples. Measurements were made using both a 2:1 distilled water to soil ratio and a 2:1 mixture of 0.01 M. $CaCl_2$ to soil. The latter mixture often more accurately estimates available hydrogen ions in soils.

Organic Matter

A slightly modified version of the standard Walkley-Black wet oxidation method (Jackson, 1958) has been utilized to estimate organic

TABLE V

A COMPARISON OF TEXTURAL CLASSES USED IN THIS STUDY, THE CANADIAN AND THE WENTWORTH SYSTEMS

This Study (microns)	Textural Class	Canadian (microns)	Wentworth (microns)
2000-500	Very Coarse and Coarse Sand	2000-500	2000-500
500-177	Medium Sand	500-250	500-250
177-105	Fine Sand	250-100	250-125
105-53	Very Fine Sand	100-50	125-63
53-37	Very Coarse and Coarse Silt	50-25	63-16
37-10	Medium Silt	25-10	16-8
<10	Fine, Very Fine Silt and Clay	<10	<8

carbon in these samples. The method measures the active, decomposable organic matter in soils because plant residues and humus are oxidized while carbon present as charcoal (which may be a significant portion in these soils with a history of recurring fire) is not measured. From 90-95% of total carbon is capable of being measured by this procedure. A standard conversion factor of "organic carbon" % x 1.34 for 0.50 gram samples is used to express the data as "soil organic matter".

Exchangeable Phosphorus, Potassium, and Magnesium

Pre-sieved and air-dried samples were sent to the Soils Testing Laboratory, Department of Land Resource Science, University of Guelph, for ionic analysis. This laboratory, regulated by the Ontario Government, provides a rapid, reliable service for analysis of available phosphorus, magnesium, potassium and calcium at no charge. Available phosphorus is measured by Olsen $NHCO_3$ extraction using a Technicon Auto-analyzer. Potassium and magnesium (and calcium which was not requested for these samples) are estimated by extraction with neutral ammonium acetate and measurement by atomic absorption spectrophometry (Techtron model 1000).

These analyses were requested since the atomic absorption apparatus in the McMaster pedology laboratory was not operational until September 1975. Several duplicates were submitted and an accuracy varying ±8% for values is noted.

Data on bulk and particle density has also been included for some samples. These values were separately calculated in analyses by Mr. Alquin Grubb.

Clay Minerals Analysis

Clay minerals identification in this study has been accomplished by the use of X-ray Diffraction Analysis. In the same manner that visible light can be diffracted by a series of glass gratings, X-rays may be diffracted by the planes of a crystal lattice. When X-rays fall onto a series of such planes, each a distance "d" apart, at an angle "θ", a diffracted beam is produced of wavelength "λ". This relationship, with constant "N", is known as Bragg's Law ($N\lambda = 2d\cdot\sin\theta$) and allows the identification of specific clay minerals since each have characteristic "basal spacing" values ("d").

For the analysis, powder slides were prepared with clay-size material, as outlined in Appendix A, and bombarded with X-ray monochromated Co Kα radiation with a Ni filter at 30kV and 16 ma. The slides were scanned at the rate of 1° 2θ per minute by a Norelco vertical powder diffractometer with wide range goniometer (2-200 2θ). The diffractograms were charted with a standard single-pen Rikadenki recorder at a speed of 2 cm per minute, with detector slits of 1° width and a full scale of 1000 arbitrary units. Three conditions were investigated: (1) Mg-saturated samples were recorded from 4-40 2θ, (2) Ethylene glycol saturated samples were recorded from 4-15 2θ, (3) Samples heated to 550°C were recorded from 4-15 2θ.

An identification scheme for minerals based on standard procedures by Warshaw and Roy (1961), Brown (1972) and notes by Vermuri (1967) and Rutherford (1973) has been adopted. The X-ray characteristics and behaviour of the major clay minerals are briefly outlined later in this section.

A semi-quantitative estimation of the presence of each mineral in each sample has been calculated. For each diagnostic peak on the diffractograms, under the three conditions outlined above, peak area was calculated ($^1/2$ base x height) and the area expressed as a percentage of total peak areas for the sample. This allows direct comparison of the behaviour of a mineral under different conditions and the calculation of the differences of clay mineral assemblages between samples. Treatment with glycol causes lattice expansion (greater "d" value) for some minerals. Gjems (1967) used the peak area technique extensively while Vemuri (1967) has expressed reservations, preferring the use of peak height alone for quantitative calculations. Area evaluation is more suitable for this study since it allows more direct comparison of a variety of samples without knowing the exact initial concentration of the total clay fraction used in the preparation of the powder slides. In this study, these initial amounts were quite variable and no attempt was made to calculate a concentration. Peak height evaluation would require equal concentrations of clays to be used for all samples. Also, the diffraction apparatus used has some internal electronic and mechanical variability undesireable for highly quantitative work (as required for the peak height method). The peak area method, while less rigorous, does allow accurate identification of minerals and acceptable estimation of their percentage occurrence.

Data for these analyses are outlined in Appendix B. Table XX lists the percentage occurrence of all peaks recorded on the 4-40 2θ range. Tables XXI and XVIII respectively express the occurrence of the major clay minerals on a base of 100% and in order of dominance in the samples.

The behaviour and occurrence of diagnostic peaks permit the identification of specific minerals. The criteria used in this study, for the clay and non-clay minerals, are outlined on page 37. Minerals which are present in the parent materials, those being translocated or altered in the profiles and those forming *in situ* can be identified by these analyses. Estimation of the amounts of each mineral present in samples identifies those soil horizons in which depletion or accumulation is occurring. The overall processes and nature of the soil horizons involved, in this way, becomes more clearly understood.

Statistical Analyses

In this study, 22 variables with 42 cases (28 of which are directly discussed in the text) were entered in the original data matrix. The variables include measures of sampling depth (1), soil reaction (2), texture (4), organic matter (1), exchangeable ions (3), and mineralogy (11). A list of the computer mnemonics used to identify each of these variables and details of each variable are outlined in Tables VII and VIII in Chapter Six.

A series of statistical analyses have been conducted using techniques described by Campbell (1974). These include SPSS library programs (Nie, et al. 1970) for multiple stepwise regression; orthogonal factor analysis with varimax rotation; and factor analysis using oblique rotation. In addition, a program called "Condescriptive"

Criteria for the Identification of Clay Minerals

Chlorite	A strong 14 Å peak distinguished from a similar vermiculite peak since it does not collapse to 10 Å on heating to 550°C (no dehydration occurs). The peak at 14 Å is not affected by glycol. A 4.79 Å peak may also be detectable.
Vermiculite	A strong 14 Å peak which is not affected by glycol but does collapse to 10 Å on heating to 550°C.
Kaolinite	A strong 7.1 Å peak which is unaffected by glycol but with heating the mineral loses crystallinity and the peak disappears. A 3.57 Å peak is often present as well.
Illite	A major 10 Å peak which is not affected by glycol or heating. Muscovite forms have a secondary peak at 4.98 Å, unlike biotite.
Montmorillonite	A peak present between 15-16 Å which expands to 17-18 Å with glycol treatment and collapses to 10 Å on heating.
Mixed Layer Minerals	Mixed vermiculite-illite will display a peak around 12 Å while mixed vermiculite-illite-chlorite has a peak at about 13 Å. Other mixed minerals are not easily identified using simple diffraction techniques.

Criteria for the Identification of Non-Clay Minerals

Quartz	Sharp major peaks are present at 4.27 and 3.34 Å with secondary peaks at 2.46 and 2.24 Å.
Amphibole	These are finely-weathered fragments of such minerals as hornblende and glaucophane with a characteristic peak at 8.42 Å.
Feldspars	A complicated group with characteristic doubled peaks at 3.18 and 3.24 Å, with moderately strong, single peaks at any or all of 2.81, 2.85, 2.90, 3.00, 3.66, 3.77, 3.85, and 4.04 Å. Also a broad peak from 6.4-6.5 may be present.
Anatase	This mineral is characterized by peaks at 3.51 and 2.38 Å (a peak which may be confused with a third order kaolinite peak).

has been used to generate a group of standard statistics for each variable (mean, standard deviation, skewness, kurtosis, range, etc.)

Multiple stepwise regression is based on a matrix of simple correlations between all pairs of variables. It identifies secondary relationships where a dependent variable is influenced by more than one other variable. Campbell (1974) points out that multiple regression along with factor analysis may simplify the examination of soil systems and identify interactions and dependencies.

With orthogonal rotation in factor analysis, all the variables are linearly dependent on the dimensions. The analysis produces only one factor matrix in which elements can be interpreted as pattern loadings or as correlations. Factors generated are linearly independent and uncorrelated.

When factor analysis is conducted using the more rigorous oblique rotation, new aspects must be considered. Factors are now allowed to become correlated which results in more information being generated in some cases. Clusters of variables may be better defined and variables central to a cluster identified by high loadings (which is not possible with orthogonal rotation). The analysis produces two factor matrices: the pattern matrix and the structure matrix. The pattern matrix is usually better for determination of clusters of variables defined by oblique rotation (Rummell, 1970). *Pattern matrix loadings* may be interpreted as measures of the unique contribution each factor makes to the variance of the variables. They measure the dependence of the variables on the factors and, in a sense, are regression coefficients of the variables on the factors. *Structure* *matrix loadings* are the product moment correlations of variables with the oblique factor. Each matrix must be interpreted separately since the information conveyed is different in each case. Correlations of oblique factors are outlined in a factor correlation matrix generated by the SPSS program.

CHAPTER FIVE

PROFILE DESCRIPTIONS AND DISCUSSION OF ANALYTICAL RESULTS

In this chapter, descriptions of each soil profile examined and the nature of the chemical, physical and mineralogical data for that profile are discussed. X-ray diffractogram traces for selected horizons from these profiles are also reproduced. Detailed analytical data are given in Appendix B. In the field, profiles in 12 locations were investigated. However, only seven are discussed in this chapter since four are similar to Site C (an Orthic Humo-Ferric Podzol) and a fifth (a Cryic Fibrisol) reveals little information relevant to this thesis. The data from these five profiles are included in the statistical analyses. Mineralogical data thus consist of 42 cases, 28 of which are directly discussed in the text.

The seven sites, classified using the Canadian (CSSC, 1974) and American (USDA, 1967) taxonomic systems, are listed in Table VI. Five Podzols, one Gleysol and one Brunisol are representative of the major soil types present in the Thor Lake region.

TABLE VI

TAXONOMY OF SOILS AT THOR LAKE

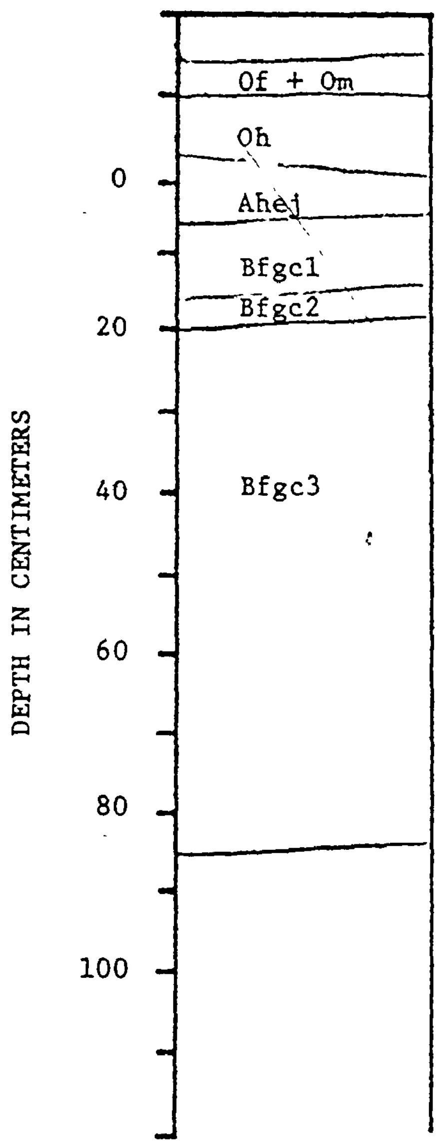
Site	Geomorphic Location*	CSSC (1974) Soil Type	USDA (1967) Soil Type
A	Linear Depression on Drumlin Crest	Placic Humo-Ferric Podzol	Placorthod
B	Drumlin, Mid-crest	Placic Humo-Ferric Podzol	Placorthod
C	Drumlin, Fluted End	Orthic Humo-Ferric Podzol	Typic Cryorthod
D	Kettle on Drumlin Crest	Fragic Humic Podzol	Placohumod
E	Kettle on Drumlin Crest	Fera Gleysol	Sideric Cryaquod
F	Esker	Degraded Dystric Brunisol	Spodic Cryopsamment
G	Relict Channel on Drumlin Slope	Fragic Humo-Ferric Podzol	Placorthod

*Locations are identified on Figure II, Page 28.

Site A: Ice Wedge Depression

On the drumlin 0.5 km northeast of the research area, a linear depression about 300 metres in length, 5-10 metres wide and 1 metre deep has been investigated (Plate II). This depression may have been created by extensive ice wedging. The site has restricted drainage which has resulted in the development of a Placic Humo-Ferric Podzol with an extremely thick Bf horizon (Plate III). This profile is markedly different from an Orthic Humo-Ferric Podzol developed on a well-drained site only 5 metres away.

Thick layers of moss are present at the surface of this profile. Its Aehj horizon has low pH (3.8 $CaCl_2$) and relatively high organic matter content (8.5 %). A water table at 70 cm prevented deep sampling beyond 85 cm. Irregular thin bands and pockets of placic material in the Bfgc are noted. Phosphorus increases with depth while exchangeable magnesium and potassium seem uniformly distributed. The Bfgc3 horizon was investigated mineralogically. Kaolinite (66%) and vermiculite (26%) are the main clay minerals present with minor amounts of chlorite and illite. Large amounts of quartz and feldspar and traces of hornblende and anatase are noted in the <2μ fraction. Clay minerals comprise only 2% of the <2μ fraction in this Bfgc3 horizon.



Profile: A
Classification: Placic Humo-Ferric Podzol
Topography: Within shallow 5 x 200 metre local depression on drumlin crest
Vegetation: Mosses (50%), *Ledum groenlandicum* (20%), *Vaccinium myrtiloides* (10%), lichens (20%) *Picea mariana* (5 m).

15-12	Of	Dense mat of moss, few coarse roots
12-10	Om	Brown (7.5YR 3/2 d) moss fibre; few lateral roots
10-2/0	Oh	Very dark brown (10YR 2/2 d) hu[illegible] Irregular tongues into Ahej
2/0-4	Ahej	Greyish brown (10YR 5/2 w), medium sand, slightly compact; many fine roots
4-15	Bfgc1	Dark reddish brown (5YR 3/3 w) loa[illegible]nd, many iron concretions
15-20	Bfgc2	Dark reddish brown (5YR 3/2 w) medium sand; some charcoal and gravel; reddish stained grains; slightly compact; large 50-70 cm stones, irregular lower boundary
20-85+	Bfgc3	Dark reddish brown (5YR 3/3 w) medium sand and gravel; some mottles; water table at 70 cm

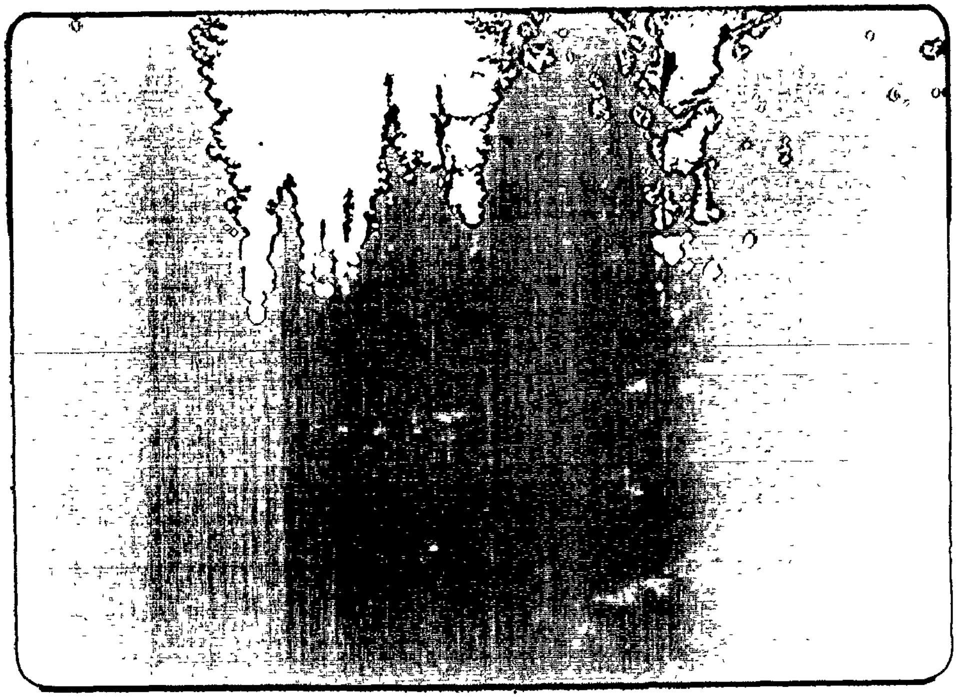


PLATE II: General view of depression at Site A

PLATE III: Plaçic Humo-Ferric Podzol at Site A

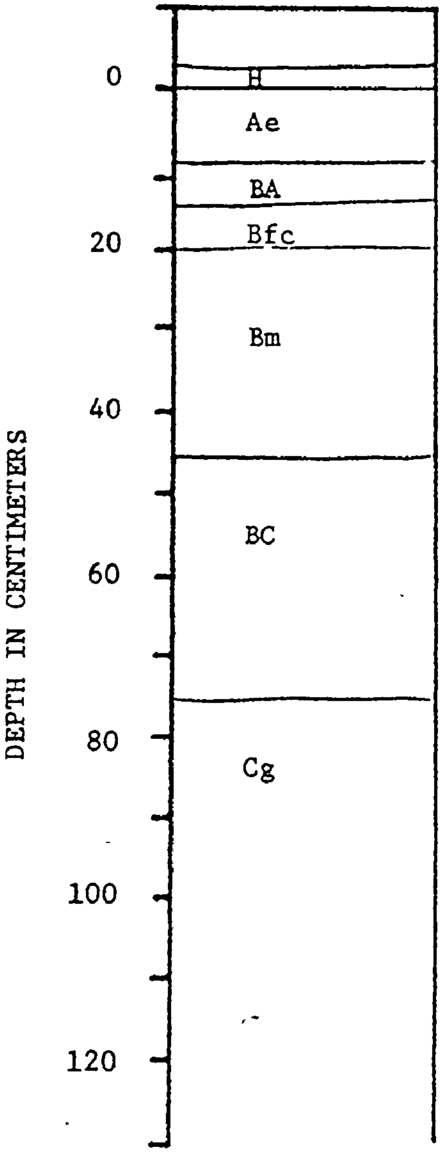
Site B: New Burn Area

In June 1974, an 80 year-old *Picea mariana* forest on this site was felled and burned to establish a test site for climatological measurements. Hence, surface organic horizons were largely destroyed. In samples obtained prior to the burn, organic matter levels in the Ae and Bf mineral horizons range from 1 to 4%. Extensive surface erosion, which occurred during the 1974 and 1975 field seasons at this site, is evident in Plate IV.

The described profile has been classified as a Placic Humo-Ferric Podzol (Plate V). It has a thick, acidic (pH 3.6, $CaCl_2$) Ae horizon and well-developed B horizons, some of placic nature. The Bfc (placic) horizon displays increased bulk density and increased phosphorus (P) content relative to other B horizons. Concentration of phosphorus in the B horizons contrasts with decreased magnesium and potassium in these horizons. The profile has a range of medium to coarse sands of low clay content (maximum fine silt + clay is 0.9%). Less-intense hues and the thickness of the B horizons indicate iron has been largely mobilized downwards in this profile. The relatively low pH of the surface horizons further suggest extensive chemical weathering is active in the Ae and upper B horizons.

Vermiculite is the dominant clay mineral in the surface horizons, ranging from 81 to 91% of the $<2\mu$ fraction. Vermiculite occurrence declines with depth while illite and kaolinite increase, dominating the lower B and C horizons. This pattern suggests that the high acidity and absence of iron in the Ae horizon have resulted in extensive chemical weathering of illite and the formation of vermiculite.

Some mixed-layer vermiculite-illite is noted in the upper C horizon. As in the case of most other profiles at Thor Lake,clay-size quartz and feldspar form a major component of the <2μ material in this soil. In addition, trace amounts of anatase and hornblende are present. Figure III is a reproduction of X-ray diffractograms of the seven samples from this profile. Below the Bf horizon, the decline in intensity of 14 Å peaks, which are characteristic of vermiculite, is most evident in this figure.



Profile: B
Classification: Placic Humo-Ferric Podzol
Topography: Drumlin level crest
Vegetation: Within climatological test burn; sparse lichen cover

1.5-0	H	Black (7.5YR 2/0 d) humus and charcoal; extensive fine roots
0-8	Ae	Pinkish grey (7.5YR 6/2 d) fine sand; compact; extensive fine to medium roots; small stones (5-10 cm)
8-12	BA	Brown (10YR 5/3 d) medium sand; some fine roots; slightly sticky when wet
12-20	Bfc	Strong brown (7.5YR 5/8 d) medium sand; many small (1-5 cm) stones; no roots; compact; pockets of reddish brown (5YR 4/4 d) medium sand of placic nature
20-45	Bm	Reddish yellow (7.5YR 6/6 d) coarse sand; loose; no roots or stones
45-75	BC	Light brown (7.5YR 6/4 d) coarse sand; diffuse boundaries
75-100	Cg1	Light grey (10YR 6/1 d) medium sand; compact; some large stones (20-30 cm)
100-130	Cg21	Grey (10YR 5/1 w, 10YR 7/1 d) fine sand; compact
130-160	Cg22	Light grey medium sand
160+	Cg23	Light grey medium sand

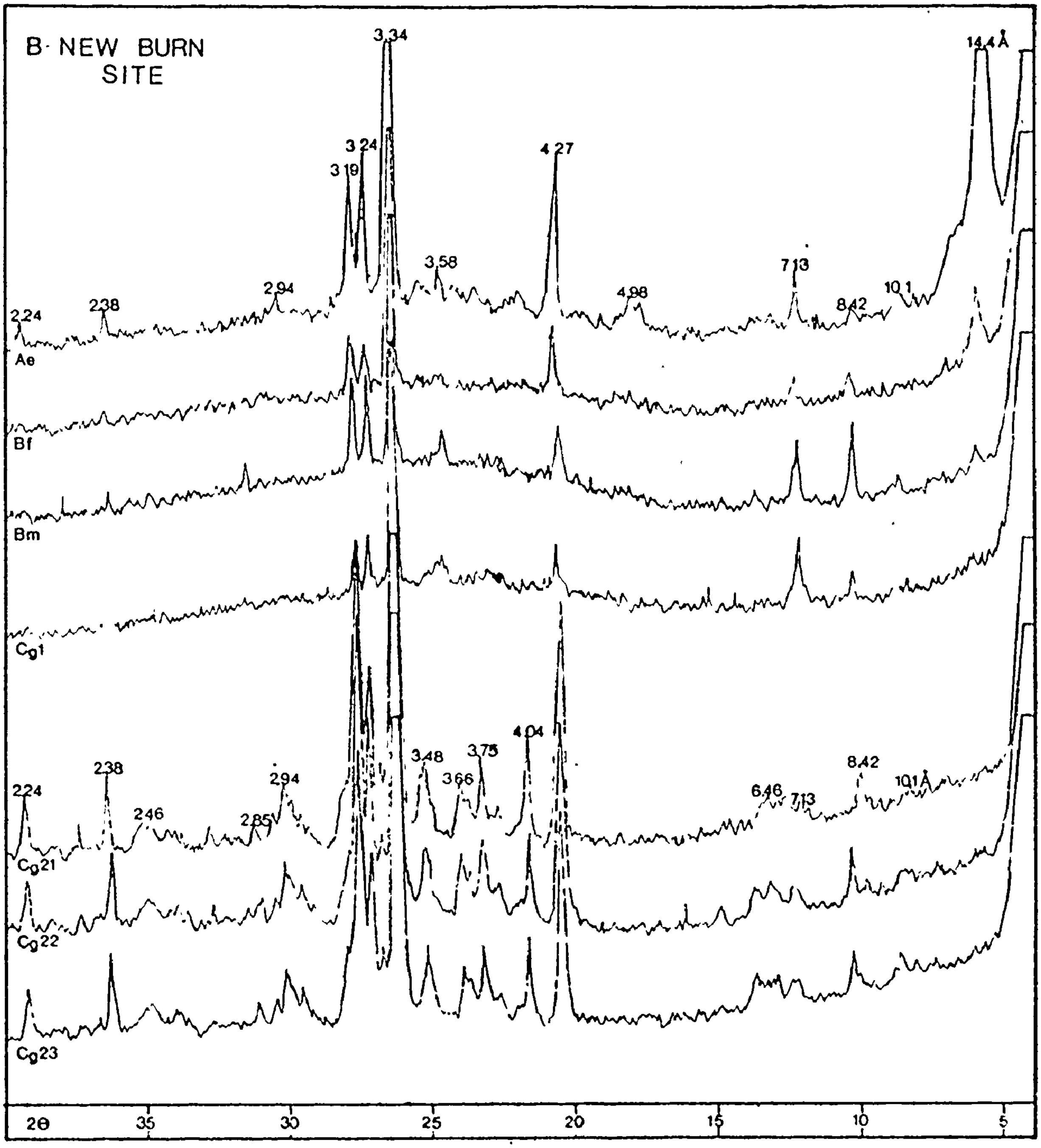


FIGURE III: X-ray diffractograms for Site B soil horizons

PLATE IV: Eroded surface at Site B during 1975 field season

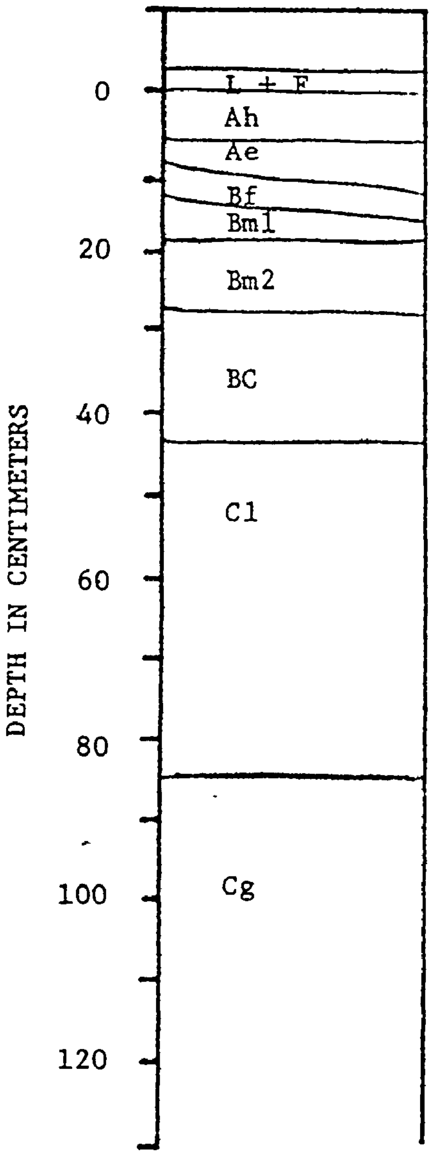
PLATE V: Placic Humo-Ferric Podzol at Site B

Site C: Drumlin Crest Profile

A 125 cm deep pit dug on the crest of a drumlin adjacent to the research site has been studied. It is characterized by a thin Ae (5-7 cm) and a thick but weakly-expressed B horizon. Plate VI is a view of this profile. A sharp pH ($CaCl_2$) gradient is noted in the top 25 cm of this profile ranging from 3.8 in the Ae to 5.4 in the Bm2 horizon. The strong brown hue in the Bf horizon suggests sufficient iron accumulation to classify this soil as an Orthic Humo-Ferric Podzol. A photograph of this site (Plate VII) indicates it is dominated by lichens and *Picea mariana*. Fire-scar dating indicates this site was burned over in 1925.

These loamy sands have uniformly distributed Mg and K and low P content (4-9 ppm) except in the Bf horizon where major P concentration is noted (100 ppm). Organic matter ranges from 2 to 4% in A and B horizons. Clay minerals decrease with depth (from 24 to 2% of the <2μ fraction from Ae to C horizons). Vermiculite comprises 75 to 97% of these clay minerals in A and B horizons but only 12 to 16% in C horizons where illite and kaolinite dominate with small amounts of chlorite (3 to 9%). Large amounts of quartz, feldspar and lesser amounts of hornblende are present with some anatase (1 to 5% of <2μ fraction) in all horizons. Figure IV is a reproduction of X-ray diffractograms for these horizons.

Profile: C
Classification: Orthic Humo-Ferric Podzol
Topography: Drumlin crest
Vegetation: Lichens (80%), *Ledum groenlandicum* (20%)
Picea mariana (3-5 m)



1-0	L+F	Lichen debris
0-5.5	Ah	Very dark brown (10YR 2/2 d) fine sand; many fine roots; undulating lower boundary
5.5-8.5/11	Ae	Pinkish grey (5YR 7/2 d) loamy sand; undulating lower boundary; few vertical roots
8.5/11-10/13	Bf	Strong brown (7.5YR 5/8 w) loamy sandy; slightly sticky but firm when dry; some fine lateral roots
10/13-18	Bm1	Light yellow brown (10YR 6/4 w) loamy sand with some fine gravels; loose dry; medium woody roots; indistinct lower boundary
18-26	Bm2	Reddish yellow (7.5YR 6/6 w) loamy sand; some nodules; glaebules and mottling present
26-42/45	BC	Pinkish grey (7.5YR 7/2 d) loamy sand and gravel; slightly sticky when wet; loose dry; some 8-10 cm stones; many fine vughs
42/45-85	C1	Light brownish grey (10YR 6/2 d) loamy sand and gravel; sticky wet; diffuse lower boundary, few stones
85-125+	Cg	Grey (5YR 5/1 d) loamy sand and gravels; loose

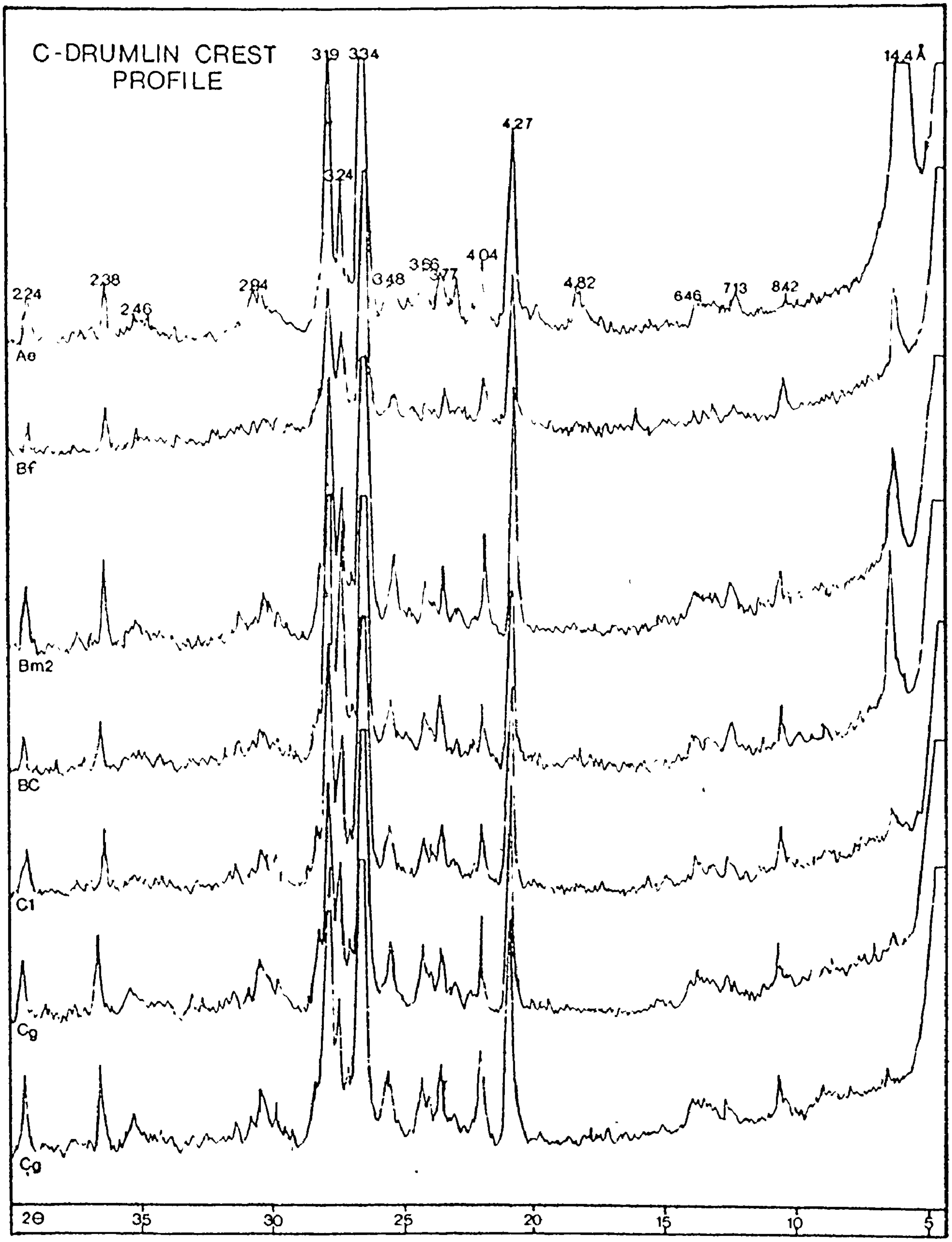
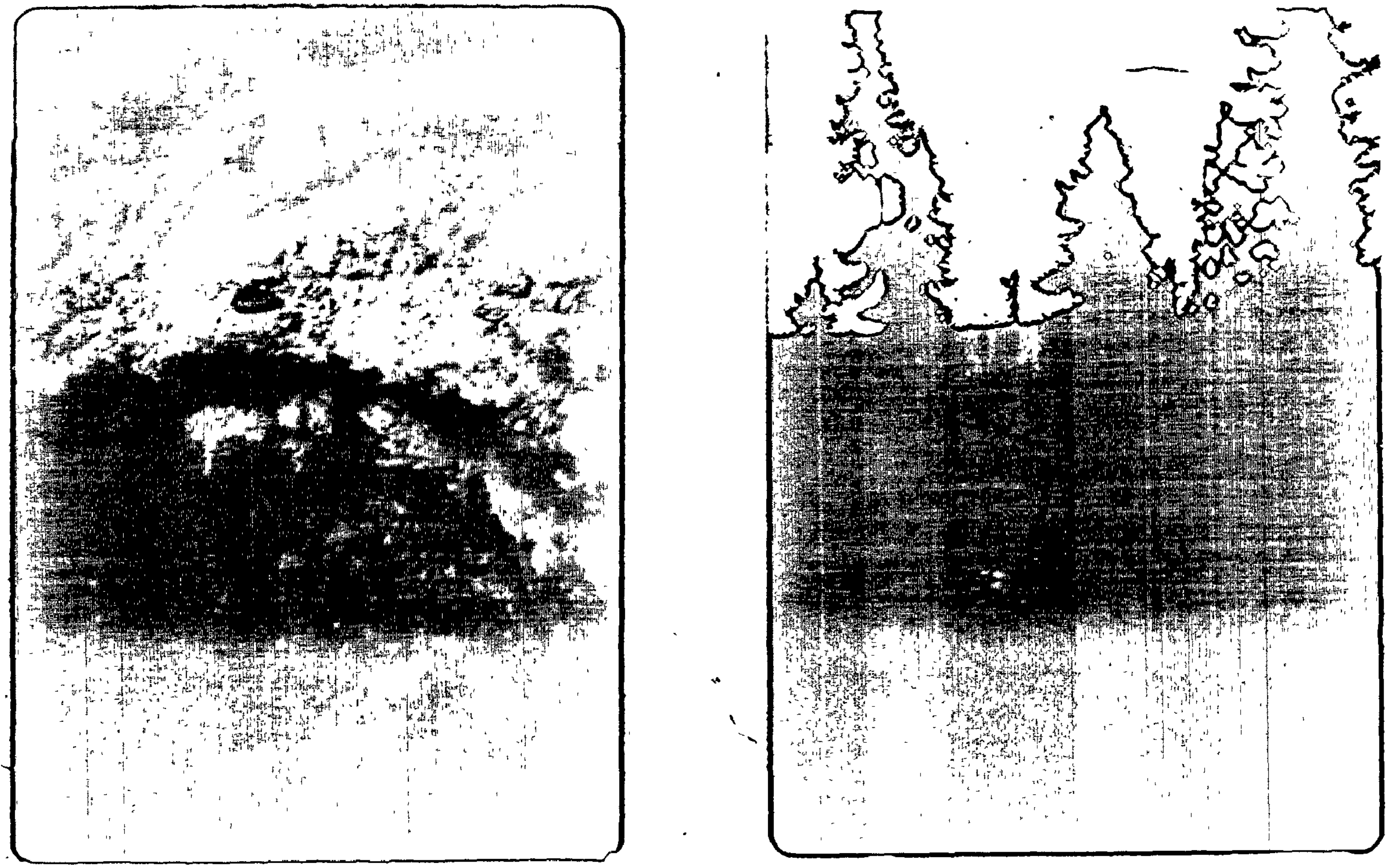


FIGURE IV: X-ray diffractograms for Site C soil horizons



PLA .II: Genera. view of

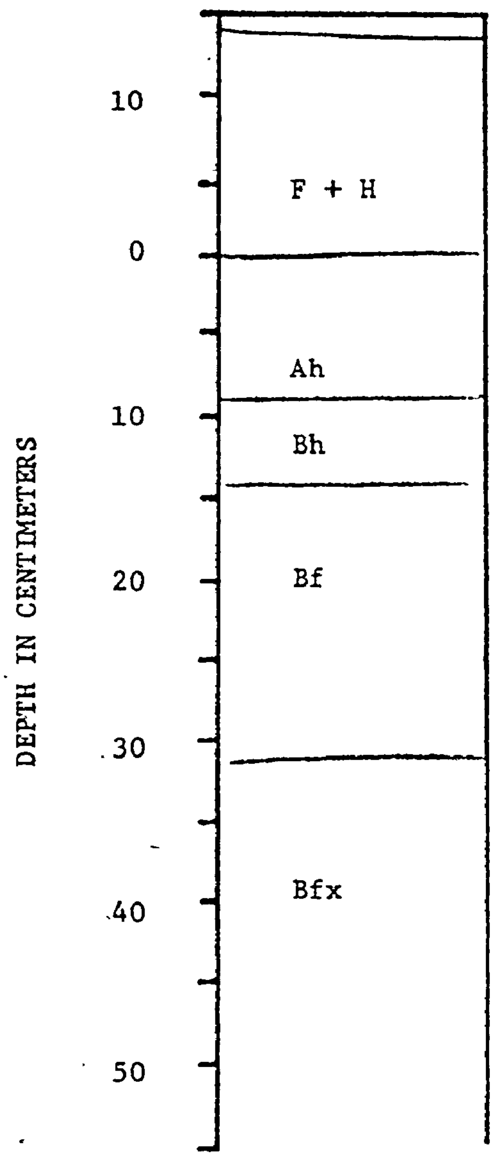
Sites D and E: Kettles

Ponded kettles are observed along crestal areas of drumlins in this area (an aerial view of one is noted on Plate I, page 25). These are believed to develop from collapse of subsurface ice masses. Similar features have been described as "thaw sinks" by Hopkins (1949) and as "thaw depressions" by Black (1969). The kettles in the Thor Lake region collect snow-melt in spring but may dry up completely by August. Plate VII is a view of site D in late summer after such drying had occurred. Soils in two such kettles on adjacent drumlins have been described and sampled.

A Fragic Humic Podzol has developed in the pond bed of Site C, which has been noted to become dry by July both in 1974 and in 1975. Cover comprises sedges and moss underlain by thick humic materials. Mineral horizons include the Ah with 14% organic matter but low phosphorus content (17 ppm). Lower horizons (Bh, Bf) have reduced organic matter (3%) and high phosphorus contents (110 to 120 ppm). A large amount of potassium is noted in the Ah but it declines with depth suggesting intense depotassication. The pond sediments are mainly loamy sand with only minor clay mineral content (3% of the <2μ material in the Bf horizon). Vermiculite and illite dominate the Ah while vermiculite, illite, kaolinite and a trace of mixed vermiculite-illite are noted in the Bf horizon. A fragic Bfx horizon at 32 cm depth, characterized by extreme stoniness, prevented deeper sampling.

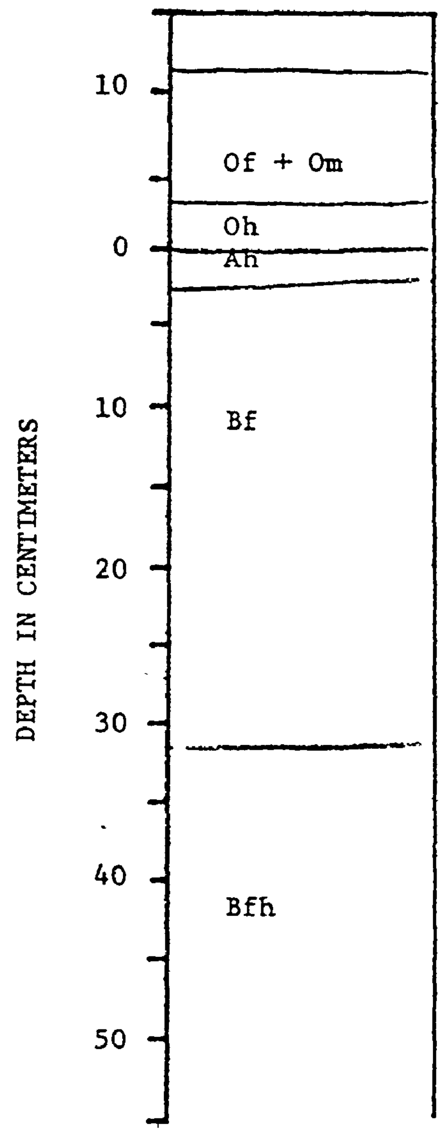
Site E has quite different drainage characteristics compared to Site D. It retains considerable pond water throughout the dry summer period. Plate IX is a view of this site in late July. A Fera Gleysol profile (Plate X) has been described in soil below the spring high water mark in this depression. Sedges and grasses form an extensive covering mat contributing to thick organic horizons over mineral horizons of undetermined depth. The water table present at 32 cm in mid-summer 1974 prevented deeper sampling. A thick Ah horizon of loamy sand has 10% organic matter and extensive amounts of exchangeable P, K and Mg (110, 220, and 102 ppm respectively). Organic matter decreases to 2.5% in the Bf horizon which has deep reddish hues (5YR 3/4) indicating extensive iron accumulation.

Figure V reproduces diffractograms of magnesium and glycol-saturated and heated samples for the Ah horizon of Site D and the Bf horizon of Site E. The Bf of Site E has low clay minerals content (2.4% of the <2μ material) dominated by kaolinite (45%), vermiculite (38%), illite (17%) and chlorite (10%). Extensive clay-size quartz and feldspar and traces of hornblende and anatase are also noted in the horizons studied at Sites D and E. The presence of 4.98 Å peaks on the diffractograms for these samples indicates muscovite is present while biotite is found elsewhere as the major mica form. Muscovite may be a major contributor to the relatively high potassium contents noted in surface horizons of this soil and some others.



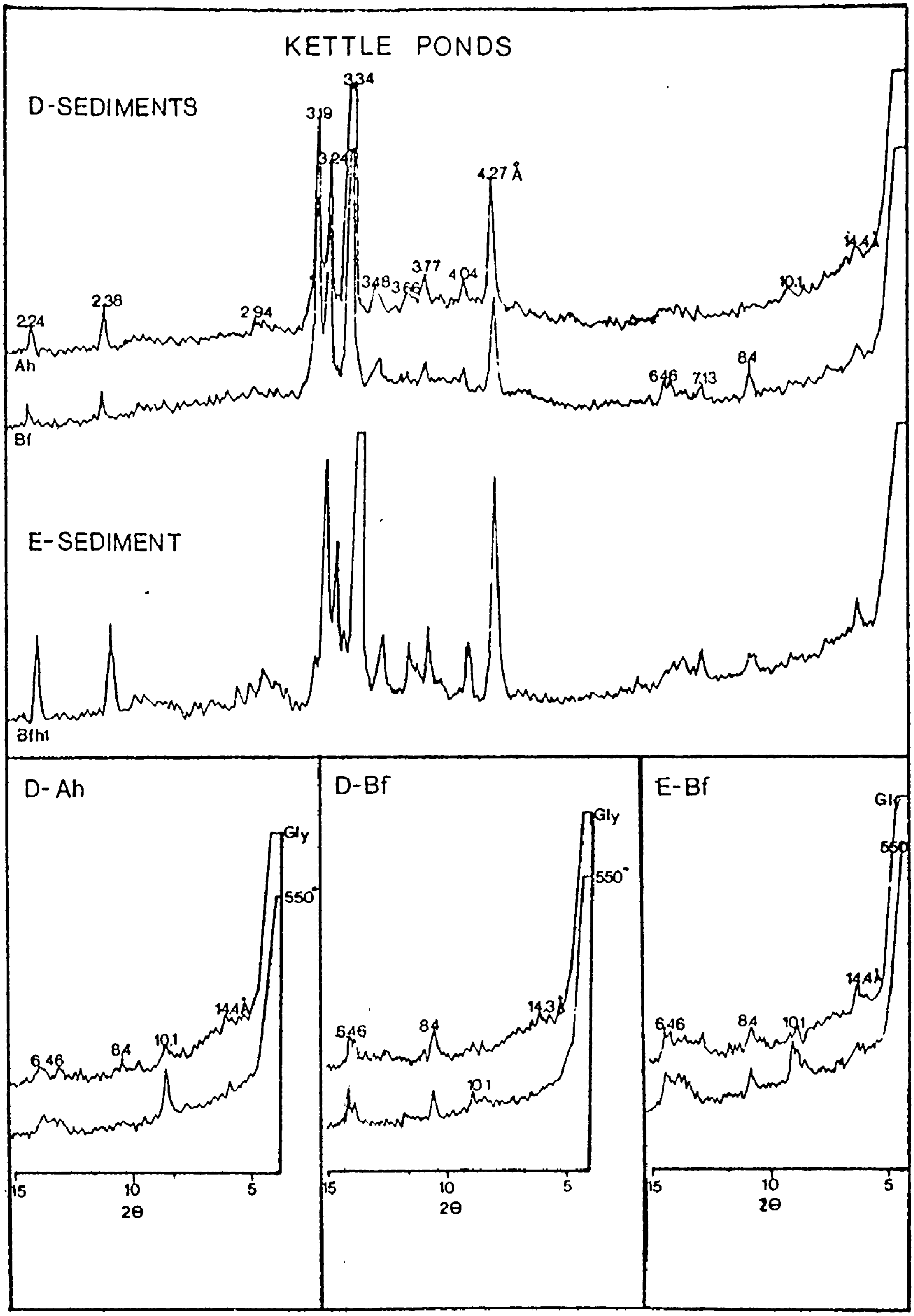
Profile: D
Classification: Fragic Humic Podzol
Topography: Kettle, 10 x 70 m depression on drumlin crest
Vegetation: Mosses and grasses

14-13	F	Moss and grass materials
13-0	H	Black (7.5YR 2/0 w) humic peat; extensive medium and coarse roots; diffuse lower boundary
0-8	Ah	Very dark brown (7.5YR 2/1 w) fine sand; semi-plastic; extensive roots; sharp lower boundary
8-14	Bh	Brown (7.5YR 5/4 w) loamy sand; plastic; extensive roots
14-32	Bf	Dark reddish brown (5YR 3/4 d) loamy sand; loose; few roots diffuse boundaries
32+	Bfx	Dark reddish brown (5YR 3/4 d) fragic coarse sand; no roots; some coarse gravel and 8-10 cm stones



Profile: E
Classification: Fera Gleysol
Topography: Kettle pond near drumlin crest, depression 100 x 150 m
Vegetation: Sedges and grasses

12-10	Of	Grass and sedge materials
10-4	Om	Dark brown (7.5YR 3/2 w) fibres; extensive fine roots
4-0	Oh	Black (7.5YR 2/0 w) humus; sharp boundaries, many roots
0-2	Ah	Black (7.5YR 2/0 w) fine sand; extensive fine to thick roots
2-37	Bf	Reddish brown (5YR 4/4 w) loamy sand; wet; plastic and sticky
37+	Bfh	Very dark brown (7.5YR 3/2 w) sand; sharp upper boundary; water table at 32 cm


KETTLE PONDS
D-SEDIMENTS
3.34
3.19
3.24Å
4.27 Å
14.4Å
10.1
3.48
3.66
3.77
4.04
2.24
2.38
2.94
Ah
6.46
7.13
8.4
Bf
E-SEDIMENT
Bfh1
D-Ah
Gly
550°
14.4Å
10.1
8.4
6.46
15
10
5
2θ
D-Bf
Gly
550°
14.3Å
6.46
8.4
10.1
15
10
5
2θ
E-Bf
Gly
550
14.4Å
6.46
8.4
10.1
15
10
5
2θ

V: [illegible] for [illegible] D and E

PLATE VIII: Kettle Site D in
late summer 1974

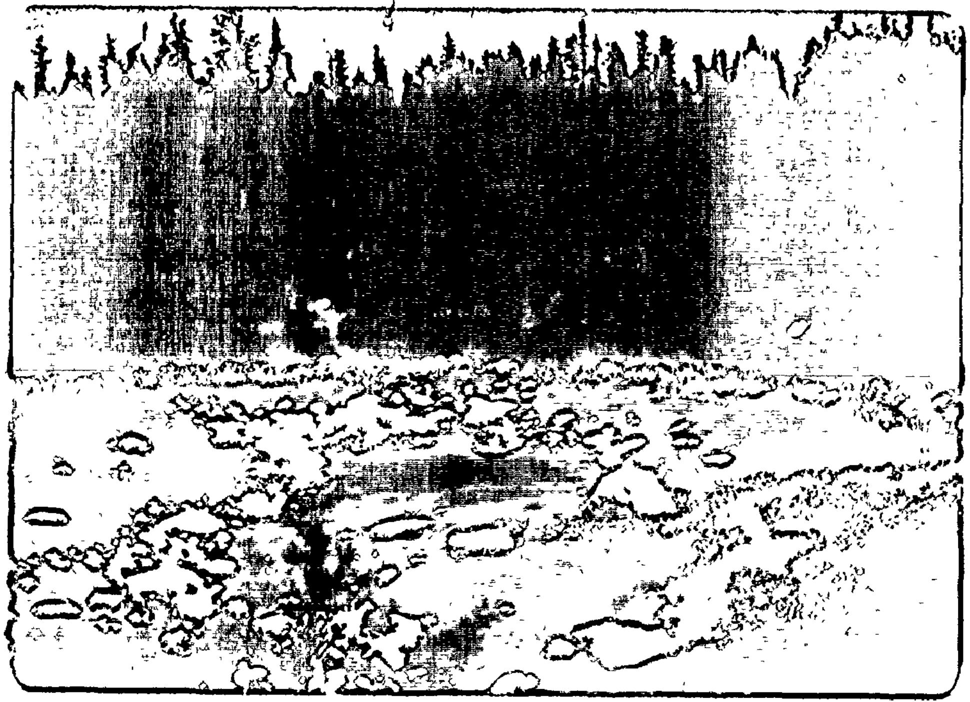


PLATE IX: Ponded kettle at Site E in late summer 1974

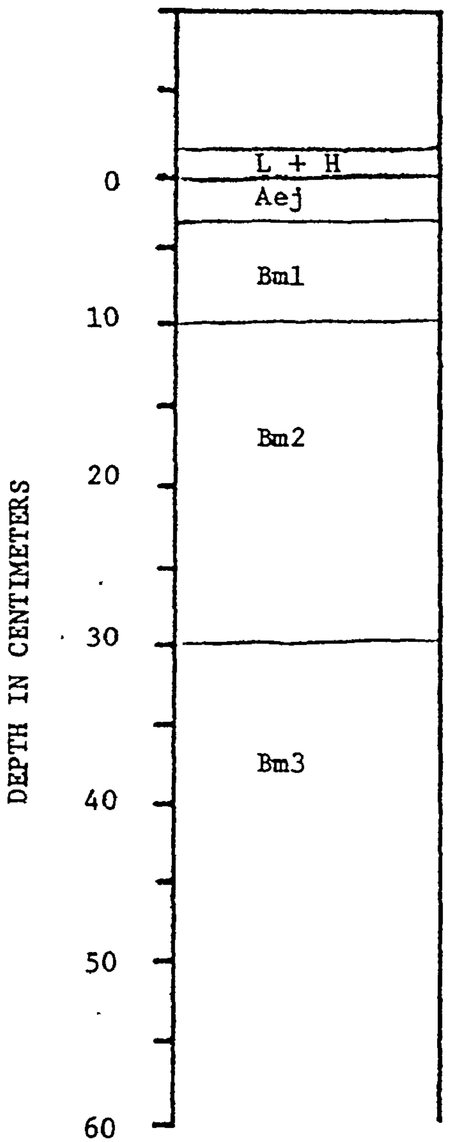
PLATE X: Fera Gleysol profile at Site E

Site F: Esker

A profile developed along the ridge of an esker 8 km to the south of Thor Lake has been described and sampled. Plate XI is a close-up view of this profile while Plate VII is an aerial photograph of the esker. This soil, classified a Degraded Dystric Brunisol, has a thin Aej and a weakly developed, but thick, Bm horizon. The Bm has low organic matter content, low phosphorus and moderate amounts of exchangeable potassium and magnesium. The coarse sandy material in this Bm horizon has moderately low pH (4.8, $CaCl_2$) and a mixture of clay minerals comprising 39% of the <2μ fraction.

Figure VI reproduces three diffractograms obtained in the X-ray analysis of the Bm sample; magnesium and glycol saturation and heating to 550°C. The collapse of the 14.2 Å peak to 10 Å in the 550°C diffractogram is characteristic of vermiculite. The 4-40 2θ diffractogram in Figure VI indiates that the dominate clay minerals in this sample are vermiculite (65%), kaolinite (19%), chlorite (14%), and illite (2%). However, clay-size quartz, feldspar and hornblende form the major component of the <2μ material in this sample.

The soil on this esker has not been extensively affected by weathering. A coarse sand fraction of 68% indicates little physical breakdown of particles has occurred. Moderate pH and weak expression of horizons also suggest that chemical weathering is not intense at this site possibly due to excellent local drainage and the very coarse texture of the deposit.



Profile: F
Classification: Degraded Dystric Brunisol
Topography: Crest of esker
Vegetation: *Vaccinium vitis-idaea* (80%), lichens (20%), *Picea mariana* (5-7 m), *Betula papyrifera* (5-6 m)

1.5-1	L	Lichen debris and twigs
1-0	H	Black (7.5YR 2/0 d) humus, crusty
0-3	Aej	Pale brown (7.5YR 6/3 d) medium sand; very diffuse development
3-10	Bml	Pale yellow brown (10YR 5/3 d) coarse sand; few roots; no stones
10-30	Bm2	Yellowish brown (10YR 5/4 d) coarse sand; compact; extensive roots; many stones (3-5 cm)
30+	Bm3	Yellowish brown (10YR 5/4 d) medium sand; no stones; no roots

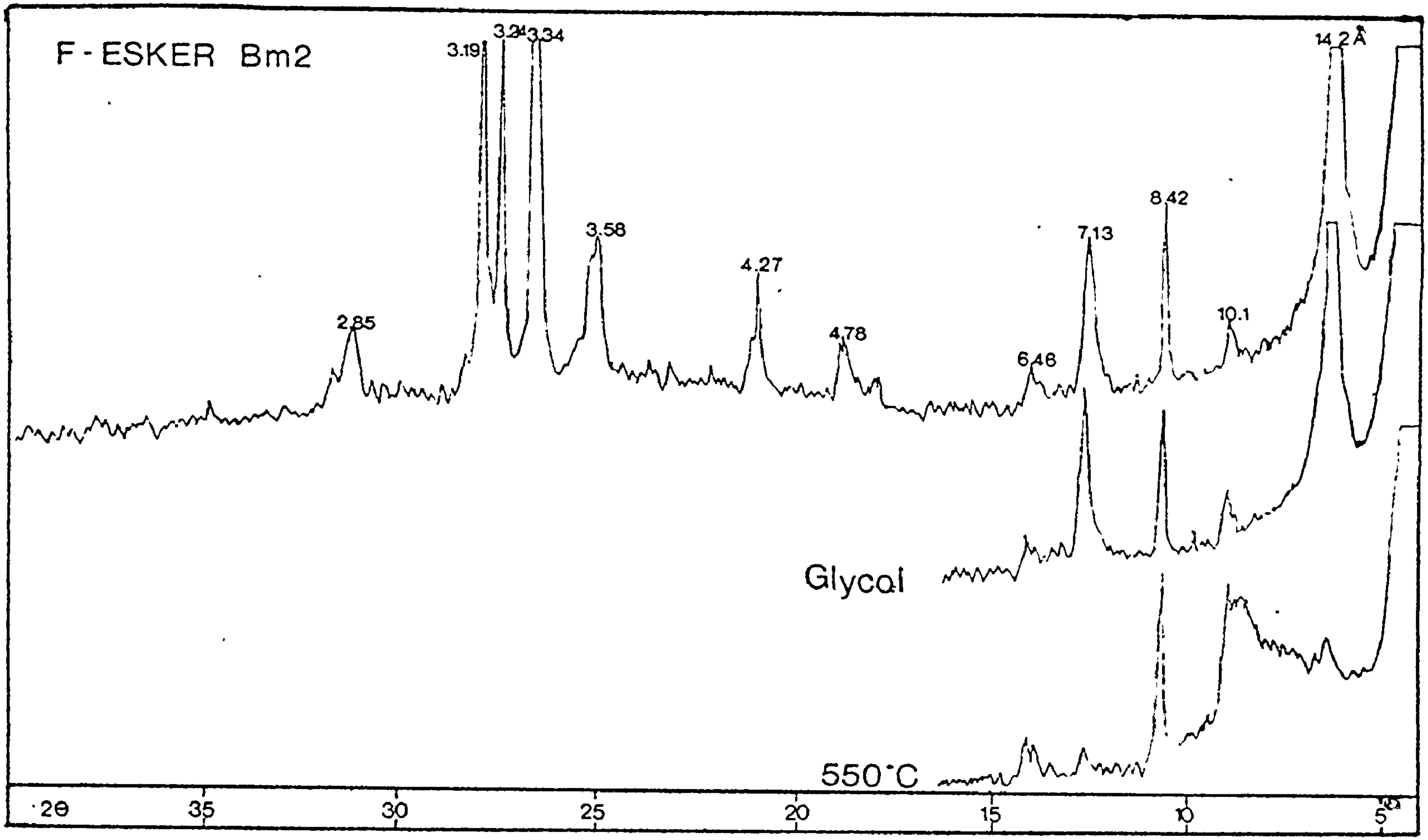


FIGURE VI: X-ray diffractograms for the Bm horizon of esker Site F

PLATE XI: Degraded Dystric Brunisol profile at esker Site F

PLATE XII; Aerial photograph of esker 8 km south of Thor Lake

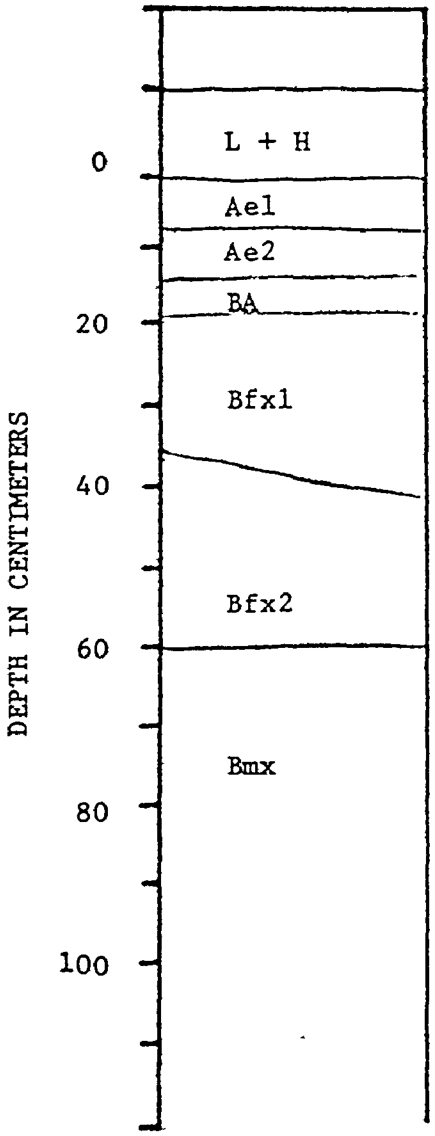
Site G: Relict Drainage Channel

The morphology and mineralogy of soil, in a channel on the north slope of the research drumlin, has been investigated. The sinuous nature and trough-like cross-sectional profile suggest this is a relict, possibly periglacial, drainage channel. Figure VIII is a topographic sketch of the area immediate to this channel. Soil description and sampling of this site were facilitated by the excavation of a 5 metre-long trench. A composite sketch of the numerous profiles described along the trench is presented in Figure VIII. Two such profiles are described (G1 and G2).

Plate XIII shows the area dominated by lichens and *Ledum groenlandicum* around the study trench. Most of the vegetation on this site was destroyed by fire in June 1975. Plate XIV is a close-up of the central area of the trench illustrating the extreme stoniness and difficulties associated with the sampling of complex fragic horizons.

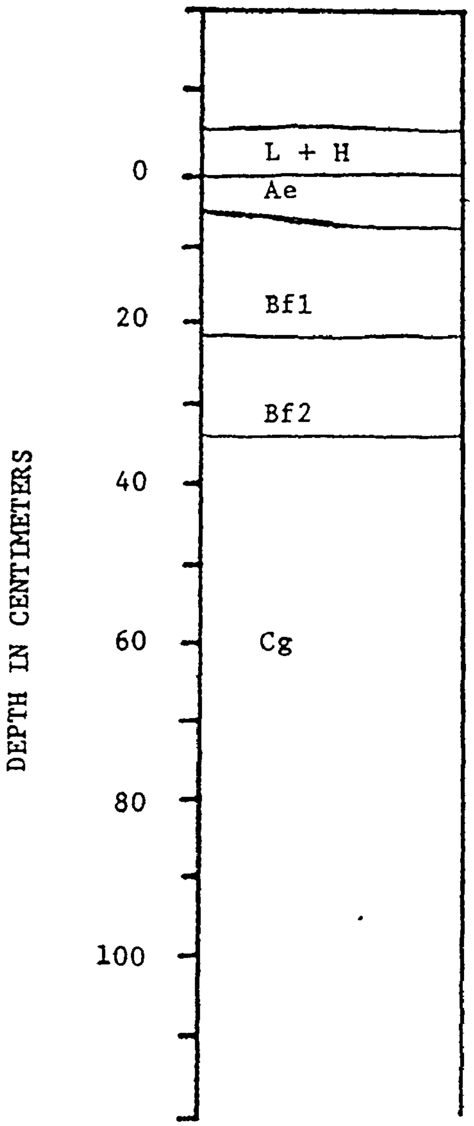
Soil development within this channel has led to a Fragic Humo-Ferric Podzol with thin L, F and H organic horizons; distinct Ae1 and Ae2 horizons; and a thick Bf-Bfx (fragic) horizon overlying glacial parent materials (Cg horizons). Horizons are thicker at the centre of the channel than at the sides. The Bfx has bulk density as high as 2.35 g/cc, extensive induration, reddish-stained coarse sand and rock fragments, and brittleness when wet. Organic matter is at a maximum in the Bfx2 horizon (2.6%). Bf horizons have extensive iron content expressed by deep reddish brown hues (2.5YR 3/6), loamy sand texture and bulk densities (<2.11 g/cc) lower than in Bfx fragic horizons. Acidity decreases with depth with exchangeable phosphorus concentrating in B horizons. Less exchangeable K and Mg are noted deeper in these profiles. These data and particle-size data discussed in Chapter Six indicate that the surface horizons of this site are extensively weathered both chemically and physically (as could be expected in a fluvial channel).

Figure IX reproduces the diffractograms for selected horizons from this site. The variation in 14 Å (vermiculite) and 7.1 Å (kaolinite) peaks down the soil profile is most evident in this figure. Vermiculite dominates the A and B horizons while kaolinite and illite (10 Å) increase with depth dominating the clay mineral fraction in C horizons. Chlorite is noted in the Bf2 and Cg horizons. The only recorded occurrence of montmorillonite in Thor Lake soils is a value of 6.1% of the clay mineral fraction in the Ae1 horizon of this site. This also suggests a highly weathered soil. Clay minerals form a minor component of the <2μ material in all horizons suggesting clay minerals act to indurate this fragic horizon. Quartz and feldspar form major components of the clay size material in all horizons. Traces of hornblende and anatase are also noted.



Profile: G1 at 150 cm on transect
Classification: Fragic Humo-Ferric Podzol
Topography: Possible periglacial drainage channel, north slope of drumlin; in cross-section
Vegetation: Lichens (70%), *Vaccinium vitis-idaea* (20%), *Ledum groenlandicum* (10%), *Picea mariana* (3-5 m)

10-7	L	Lichens and shrub debris
7-10	H	Dark brown (7.5YR 2/2 d) fibres and many fine roots
0-7	Ae1	Pinkish grey (5YR 6/2 d) sandy loam
7-14	Ae2	Pinkish grey (5YR 6/2 d) gravelly sandy loam
14-18	BA	Brown (7.5YR 4/4 d) sandy loam, many small (2-5 cm) stones
18-35/40	Bfx1	Dark reddish brown (2.5YR 3/6 d) fragic coarse sand and gravel; very stoney (5-20 cm)
35/40-60	Bfx2	Dark yellow brown (10YR 4/4 d) fragic coarse sand and gravel; wavy upper boundary
60-88+	Bmx	Fragic coarse sand and stoney gravel with extensive iron staining on grain faces



Profile: G2 at 350 cm on transect
Classification: Humo-Ferric Podzol
Topography and Vegetation as for G1

6–4	L	Lichen debris
4–0	H	Black (7.5YR 2/0 d) humus with extensive fine roots
0–4/6	Ae	Pinkish grey (7.5YR 7/2 d) fine sandy loam; undulating lower boundary
4/6–21	Bf1	Yellowish brown (10YR 5/6 d) sandy loam; some gravels
21–33	Bf2	Light yellowish brown (10YR 5/4 d) medium sand; few fine roots
33–93+	Cg	Light grey (5YR 5/1 d) coarse sand and gravel-till; stoney, compact

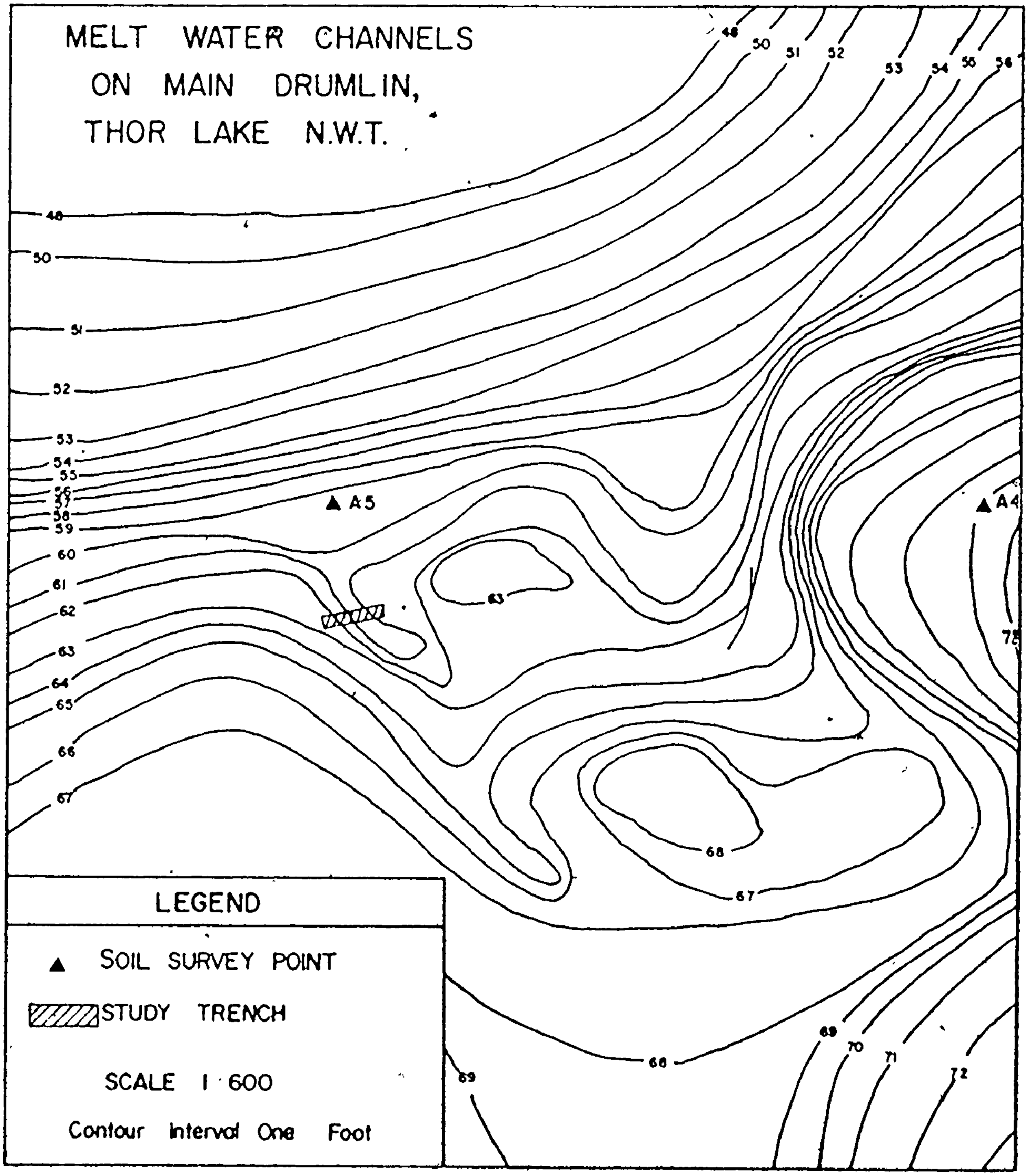


FIGURE VII: Topographic map of Site G area

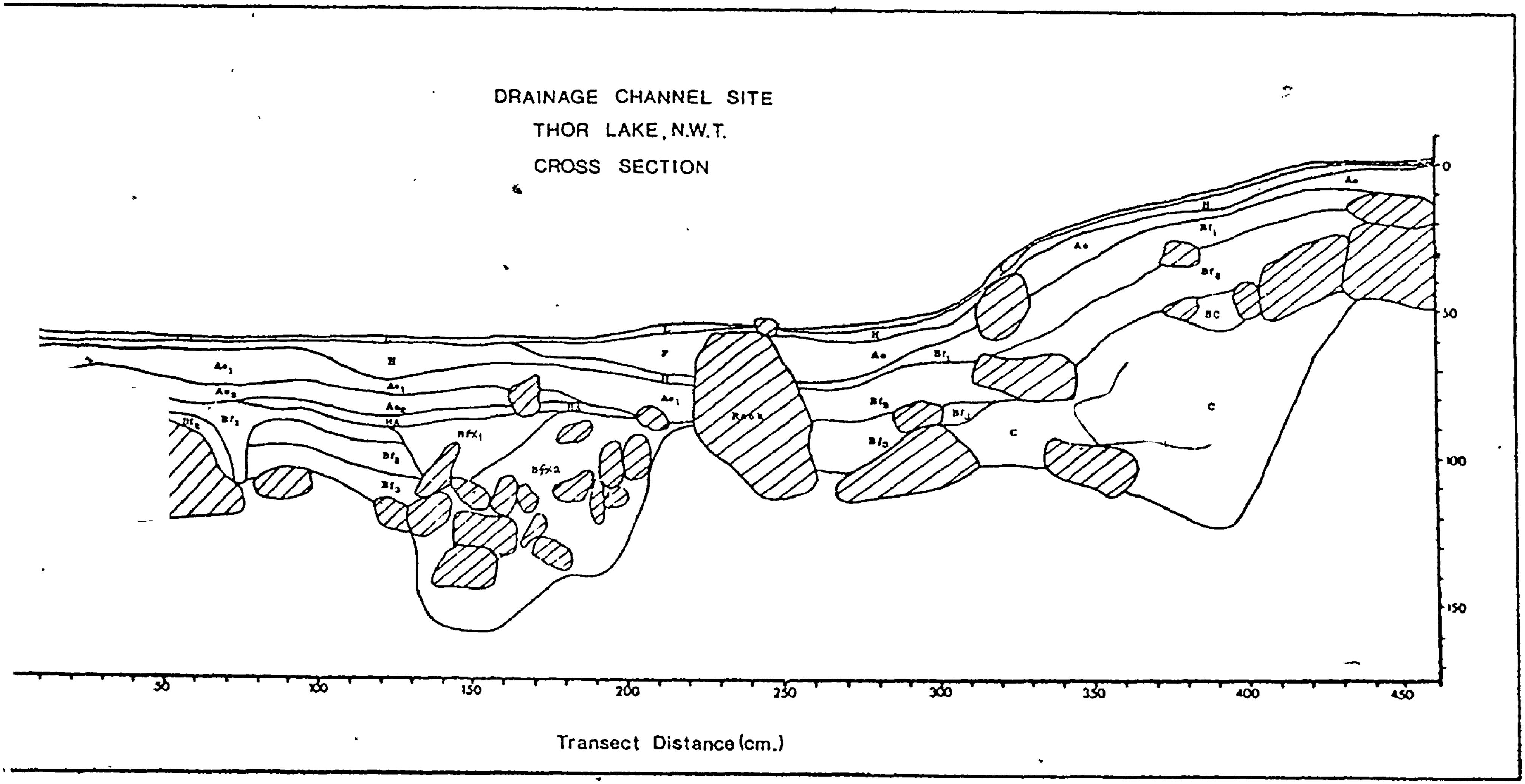
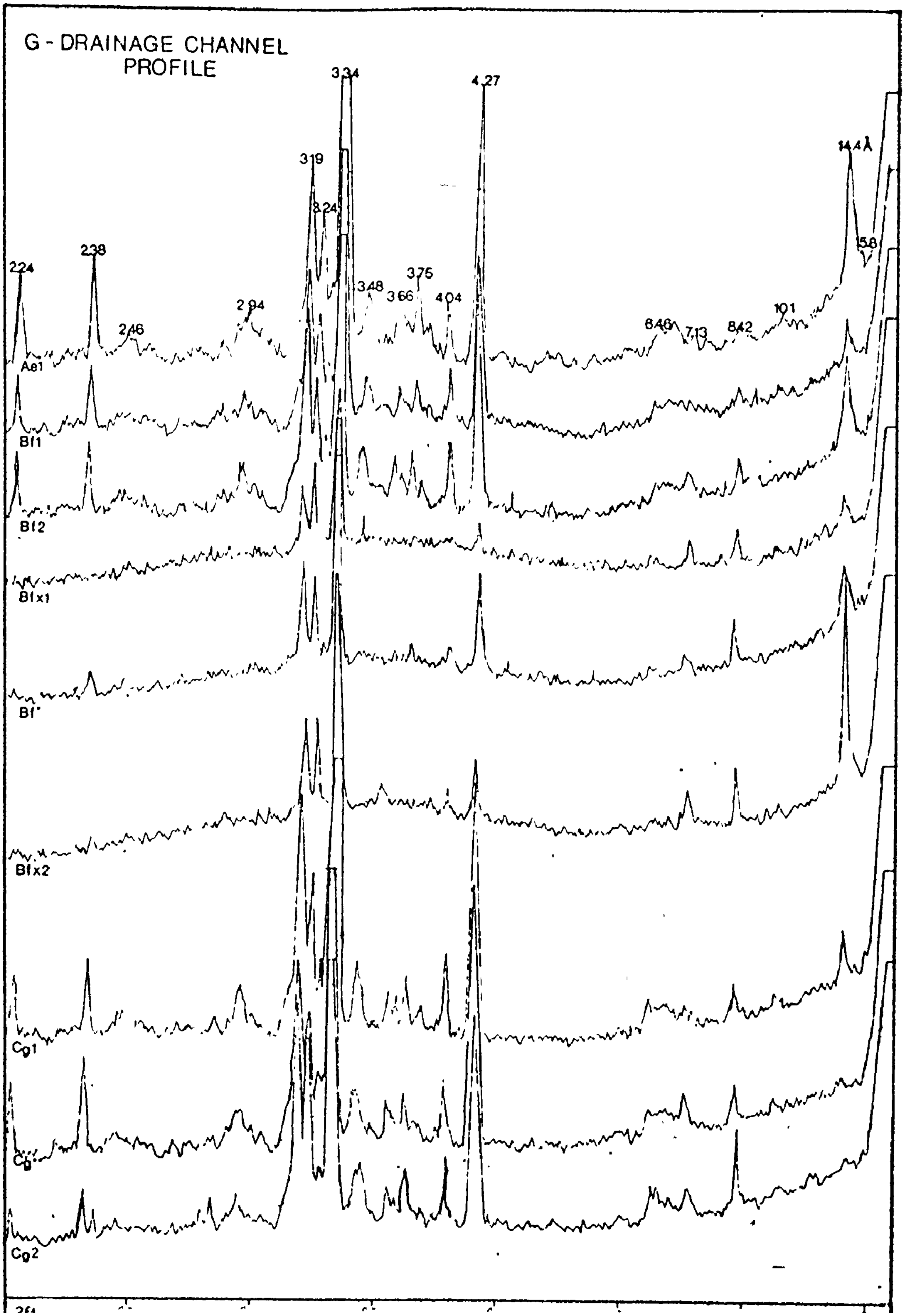


FIGURE VIII: Cross-sectional view of Site G drainage channel


G - DRAINAGE CHANNEL
PROFILE
3.34
4.27
3.19
3.24
14.4Å
15.8
2.24
2.38
3.48
3.75
3.66
4.04
2.94
2.46
6.46
7.13
8.42
10.1
Ae1
Bf1
Bf2
Bfx1
Bf
Bfx2
Cg1
Cg
Cg2

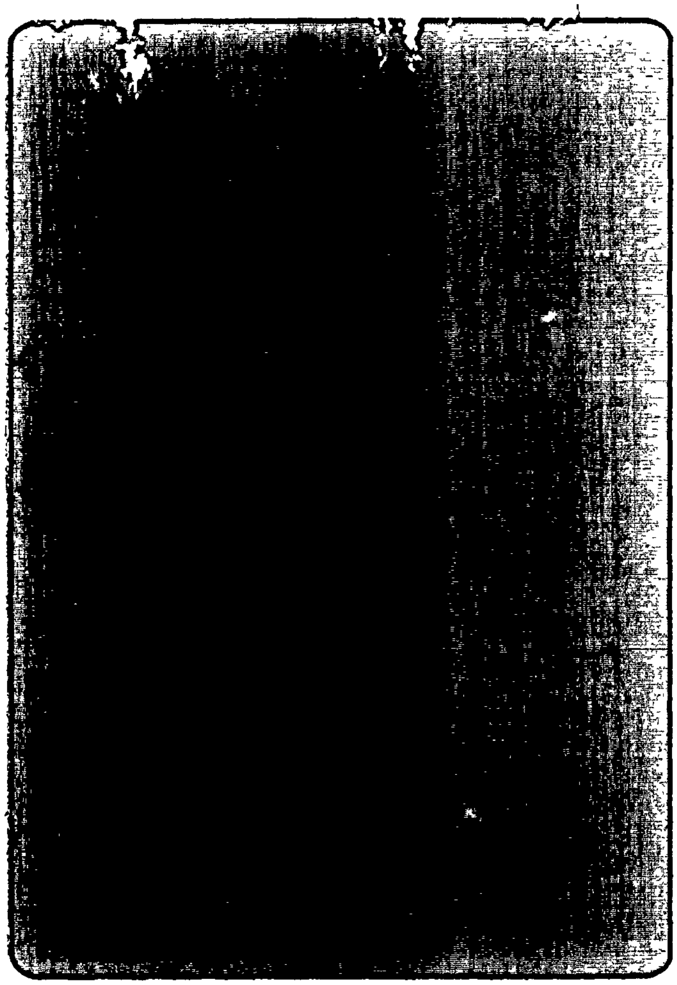


PLATE XIII: Well developed spruce-lichen woodland at Site G

PLATE XIV: Close-up of stony fragic horizon of the Fragic Humo-Ferric Podzol at Site G

CHAPTER SIX

DISCUSSION OF REGRESSION AND FACTOR ANALYSES OF THOR LAKE SOIL PROPERTIES

This chapter examines the main aspects of the soil properties studied and comments on the degree of intercorrelation of variations observed. The relatively large amount of data involved has required the use of statistical techniques. However, numerous non-empirical observations on these data are also made. The discussion of statistical studies centres on three major areas: (1) multiple regressions, (2) factor solutions, and (3) the nature of the variability of associated soil properties and clay mineral assemblages.

A total of 22 variables are utilized in the statistical analyses. A description and the computer mnemonic associated with each variable are outlined in Table VII. In addition, the means, standard deviations and units of measurement for these variables are listed in Table VIII. In each case, mnemonics closely resemble the variable name.

The data in Table VIII indicates that significant soil development in Thor Lake soils is restricted to horizons within 40 cm of the soil surface except in some hydromorphic sites such as kettles (Sites D and E) and channels or depressions (Sites A and G) where thick B horizons extend as deep as 100 cm from the soil surface. The soils at Thor Lake have textures heavily skewed into the coarse sand (CS) range,

TABLE VII

COMPUTER MNEMONICS FOR THOR LAKE SOIL VARIABLES

Variable	Mnemonic
Sample Depth	DEPTH
Acidity in 2:1 Water: Soil Mixture	PH2O
Acidity in 2:1 $CaCl_2$: Soil Mixture	PHCA
Organic Matter	OM
Coarse and Medium Sand (200-177 μ)	CS
Fine Sand (177-53 μ)	FS
Coarse and Medium Silt (53-10 μ)	SILT
Fine Silt and Clay (<10 μ)	VFSC
Available Phosphorus	P
Available Potassium	K
Available Magnesium	MG
Chlorite % of Total Clay Minerals	CHLO
Vermiculite % of Total Clay Minerals	VERM
Mixed Vermiculite-Illite % of Total Clay Minerals	MXVI
Illite % of Total Clay Minerals	ILLT
Kaolinite % of Total Clay Minerals	KAOL
Total Clay Minerals % of <2 μ Fraction	CTOT
Hornblende % of <2 μ Fraction	HORN
Quartz (3.34 Å) % of <2 μ Fraction	QRTZ
Feldspar (3.19 Å) % of <2 μ Fraction	FLDR
Ratio of QRTZ to Feldspar (3.24 Å)	QTOF
Ratio of Feldspar (3.24 Å) to FLDR	FTOF

TABLE VIII

THE MEANS, STANDARD DEVIATIONS AND UNITS OF MEASUREMENT FOR THOR LAKE SOIL VARIABLES

Variable (Mnemonic)	Mean	Standard Deviation	Units of Measurement
DEPTH	38.10	37.78	centimetres
PH2O	5.50	0.76	pH units
PHCA	4.82	0.70	pH units
OM	1.58	2.35	percent by weight
CS	59.82	13.62	percent by weight
FS	24.43	7.47	percent by weight
SILT	14.71	7.70	percent by weight
VFSC	0.65	0.42	percent by weight
P	23.36	34.36	parts per million
K	26.67	16.08	parts per million
MG	21.86	15.65	parts per million
CHLO	5.03	7.94	percent by area
VERM	50.35	32.45	percent by area
MXVI	3.32	7.68	percent by area
ILLT	11.20	15.38	percent by area
KAOL	29.26	23.07	percent by area
CTOT	9.80	10.53	percent by area
HORN	2.26	2.18	percent by area
QRTZ	41.72	8.00	percent by area
FLDR	12.48	4.37	percent by area
QTOF	6.81	3.75	dimensionless
FTOF	0.68	0.36	[illegible]ess

TABLE IX

DEPENDENT AND INDEPENDENT VARIABLES FOR MULTIPLE REGRESSION ANALYSES

	Independent Variables																
Dependent Variable	DEPTH	PHCA	OM	CS	SILT	P,K MG	VERM	CHLO	MXVI	ILLT	KAOL	CTOT	HORN	QRTZ	FLDR	QTOF	FTOF
VERM	X	X	X	X	X	X		X	X	X	X			X	X		
CHLO	X	X	X	X	X	X	X		X	X	X			X	X		
MXVI	X	X	X	X	X	X	X	X		X	X			X	X		
ILLT	X	X	X	X	X	X	X	X	X		X			X	X		
KAOL	X	X	X	X	X	X	X	X	X	X				X	X		
HORN	X	X	X	X	X	X						X		X	X		
QRTZ	X	X	X	X	X	X						X			X		
FLDR	X	X	X	X	X	X						X	X	X			
QTOF	X	X	X	X	X	X						X					
FTOF	X	X	X	X	X	X						X					
OM	X	X		X	X	X	X	X	X	X	X			X			
CS	X	X											X	X	X	X	X
VFSC	X	X	X	X	X	X	X	X		X	X					X	
PH2O	X		X		X	X	X	X		X	X						
PHCA	X		X		X	X	X	X		X	X						

averaging 60% CS material, with very little <10μ (VFSC) fine silt and clay present (averaging <1%). Hence, these soils appear to be only slightly weathered (physically or chemically) in most cases.

Organic matter in most horizons is quite low (<2% on average) except in some depressions such as Sites A, D and E where organic materials, isolated from recurring surface burns, have been able to accumulate. Levels of exchangeable phosphorus average 23 ppm but range as high as 120 ppm in some horizons, usually in association with organic matter. Exchangeable potassium and magnesium average 21-27 ppm in these soils but range as high as 104 ppm in isolated cases.

The major clay minerals observed in Thor Lake soils on average are vermiculite (50%), kaolinite (29%), illite (11%), chlorite (5%) and mixed-layer vermiculite-illite (3%). One case of montmorillonite is also noted. The clay minerals comprise about 10% of the <2μ clay-size fraction in these soils. Clay-size quartz and feldspar form the major components in this fraction with traces of other minerals such as hornblende and anatase.

Multiple Regression Analyses

A total of 15 multiple stepwise regression analyses have been conducted. For each dependent variable, a group of selected variables have been entered as independent variables. Variables with obviously significant intercorrelation to the dependent variable are removed (i.e., PHCA with PH20). Also, only one measure of pH and one of textural variation are entered in any one case. In addition, other selected variables are removed considering which variables would most likely contribute to the occurrence of the dependent variable. Table IX lists the dependent and independent variables entered in each regression analysis.

The multiple regressions are based on a matrix of simple correlations between sets of variables as outlined in Table X. In this matrix, simple correlations exceeding an absolute value of 0.3932 are considered significant at the 1% level for 42 data cases. A summary of the multiple regressions, grouped into those with clay mineral, non-clay mineral and non-mineral dependent variables, comprise Tables XI, XII, and XIII. Only regression multiple R^2 values significant at the 5% level or greater are included in these regression summaries.

Factor Solutions

Factor analysis has been conducted to group variables into discrete factors and to allow the interpretation of the multiple regressions reported in the previous section. The same correlation matrix used in the regression analyses is used here. Two types of factor analysis are utilized: (1) with orthogonal varimax rotation and (2) with oblique rotation. A delta value of zero is used with the oblique solution allowing a moderately correlated solution. Only factors with eigenvalues >1.000 are interpreted.

Table XIV compares the variables loading onto the six factors extracted in each solution. Variables with an absolute loading value <0.500 are considered significant in this case. The original orthogonal varimax factor matrix and the oblique pattern factor matrix make up Tables XV and XVI. A pattern correlation matrix, identifying factors

TABLE X

CORRELATION COEFFICIENTS.

	DEPTH	PH20	PHCA	OM	CS	FS	SILT	VFSC	P	K	MG	CHLO
PH20	.65265											
PHCA	.70057	.83526										
OM	-.37427	-.11406	-.40844									
CS	.03235	-.19992	-.14294	-.04315								
FS	.09437	.16008	.12439	.11550	-.07758							
SILT	-.12175	.17423	.12696	-.03904	-.07429	.56142						
VFSC	-.39825	-.21555	-.34530	.17504	-.44097	.17091	.54031					
P	-.25276	-.12705	-.16964	.38531	.15002	-.23959	-.05367	-.02100				
K	.10057	.21359	-.33555	.07543	-.58492	.14363	-.03416	.17510	.03613			
MG	.20719	.17610	.05064	-.05490	.24703	-.22587	-.24574	.07506	-.11951	.41953		
CHLO	-.02333	.03319	.21510	-.25112	-.03706	.07523	.05350	.34775	-.14864	-.18782	-.24718	
VERM	-.71321	-.49086	-.54487	.18024	-.13365	-.01650	.24308	.30518	.14074	-.14768	-.20455	-.12933
MXVI	-.07353	-.19432	-.18169	-.13460	.15521	-.11302	-.26755	-.01603	-.03533	-.09281	.21101	-.05982
ILLT	.55191	.44527	.36084	.25353	-.12523	.20238	-.05034	-.10143	.00446	.63507	.39055	-.20708
KAOL	.55367	.44942	.31941	-.27843	.26584	-.19072	-.27069	-.37138	-.05471	-.09171	.15891	.02163
HORN	-.03476	-.16253	-.02134	-.13927	.01318	-.41473	-.46731	-.38749	-.03969	-.29401	.03791	.11354
QRTZ	-.03455	.04119	-.03350	.40026	.23114	-.22117	-.25399	-.04925	.19910	.16155	.17064	-.23795
FLDR	.13366	.10721	.20195	-.06098	-.30188	.33555	.34413	-.01073	-.00057	-.05359	-.29019	.20279
QTOF	.25182	.50030	.33276	.01535	-.29944	.19343	.34504	.03730	.00066	.15446	-.04134	-.13554
FTOF	-.33041	-.53914	-.47303	.01939	.57945	-.45560	-.57130	-.20314	.03076	-.20349	.23008	-.17141
CTOT	-.40524	-.43478	-.49757	-.01220	.35768	-.30107	-.24485	-.09856	-.00967	-.13579	-.05142	-.13512

	VERM	MXVI	ILLT	KAOL	HORN	QRTZ	FLDR	QTOF	FTOF
MXVI	-.28307								
ILLT	-.62464	.06164							
KAOL	-.64941	.06232	.28252						
HORN	-.21632	.12775	-.12640	.33785					
QRTZ	-.03207	-.07183	.04203	.10751	.04721				
FLDR	-.14301	-.00601	.21725	-.02720	.15592	-.40667			
QTOF	-.04588	-.32688	.06743	.14382	-.47969	.15623	-.34017		
FTOF	.03024	.45570	-.22386	.03922	.54193	.25261	-.27790	-.51157	
CTOT	.51726	.04321	-.44641	-.30002	-.03393	-.25588	-.44294	-.09130	.29148

TABLE XI

MULTIPLE REGRESSION SUMMARY FOR CLAY MINERAL VARIABLES IN THOR LAKE SOILS

Dependent Variable	Variable Entered	Signif. Level*	Multiple R^2	Constant K	Beta β	Variable Mean	Variable Std. Dev.
VERM**	KAOL	.000	.72150	+83.281	-.9573	29.25	23.07
	ILLT	.000	.88247	"	-.9634	11.20	15.38
	MXVI	.000	.92756	"	-.9375	3.32	7.68
	CHLO	.000	.97480	"	-.9159	5.03	7.94
CHLO	VERM	.023	.26426	+53.660	-.6591	50.35	32.45
	KAOL	.001	.44302	"	-.6080	29.25	23.07
	MXVI	.000	.68541	"	-.6434	3.32	7.68
MXVI	KAOL	.032	.32833	+70.269	-.6211	29.25	23.07
	ILLT	.002	.48698	"	-.5974	11.20	15.38
	CHLO	.000	.68836	"	-.6414	5.03	7.94
ILLT	K	.000	.40332	+61.409	+.1970	26.67	16.08
	VERM	.000	.69162	"	-.7325	50.35	32.45
	KAOL	.000	.76247	"	-.6896	29.25	23.07
	CHLO	.002	.83413	"	-.7581	5.03	7.94
	MXVI	.000	.91428	"	-.6370	3.32	7.68
KAOL	VERM	.000	.72150	+76.129	-.9495	50.35	32.45
	ILLT	.000	.82258	"	-.9018	11.20	15.38
	MXVI	.000	.87898	"	-.8618	3.32	7.68
	CHLO	.000	.95142	"	-.8391	5.03	7.94

*Only relationships significant at the 5% (.050) level or higher are tabulated

**Variable mnemonics are listed in Table VII

TABLE XII

MULTIPLE REGRESSION SUMMARY FOR NON-CLAY MINERAL VARIABLES IN THOR LAKE SOILS

Dependent Variable	Variable Entered	Signif. Level*	Multiple R^2	Constant K	Beta β	Variable Mean	Variable Std. Dev.
HORN**	CS	.001	.26335	-0.332	+.0966	59.82	13.62
	FLDR	.004	.40832	"	+.1001	12.48	4.37
QRTZ	FLDR	.008	.16538	+43.660	-.9966	12.48	4.37
	CTOT	.000	.44728	"	-.5145	9.80	10.53
	OM	.002	.57634	"	+2.6194	1.58	2.35
	CS	.005	.65893	"	+.2066	59.82	13.62
	K	.006	.72437	"	-.2496	26.67	16.08
FLDR	CTOT	.003	.19620	+30.372	-.2852	9.80	10.53
	QRTZ	.000	.51310	"	-.3773	41.72	8.00
	MG	.037	.56634	"	-.0457	21.86	15.64
QTOF	PHCA	.022	.12444	-11.048	+2.0912	4.82	0.70
	SILT	.037	.21752	"	+.2398	14.70	7.70
FTOF	CS	.000	.33577	+1.719	+.0035	59.82	13.62
	PHCA	.001	.49602	"	-.1379	4.82	0.70
	MG	.035	.58090	"	-.0082	21.86	15.64

*Only relationships significant at the 5% (0.050) level or higher are tabulated

**Variable mnemonics are listed in Table VII

TABLE XIII

MULTIPLE REGRESSION SUMMARY FOR NON-MINERAL VARIABLES IN THOR LAKE SOILS

Dependent Variable	Variable Entered	Signif. Level*	Multiple R^2	Constant K	Beta β	Variable Mean	Variable Std. Dev.
OM**	K	.000	.45621	+1.542	+.1065	26.67	16.08
	DEPTH	.000	.61161	"	-.0141	38.10	37.78
	MG	.001	.70510	"	-.0605	21.86	15.64
	QRTZ	.000	.80903	"	+.0859	41.72	8.00
	PHCA	.021	.83574	"	-.7356	4.82	0.70
CS	FTOF	.000	.33577	+82.990	+1.5325	0.68	0.36
	HORN	.008	.45271	"	+2.7632	2.26	2.18
	FLDR	.051	.54882	"	-.15951	12.48	4.37
VFSC	CS	.003	.20158	+2.617	-.0176	59.82	13.62
	PHCA	.002	.37274	"	-.1985	4.82	0.70
PH20	DEPTH	.000	.42596	+3.587	+.0124	38.10	37.78
	SILT	.031	.49129	"	+.0310	14.71	7.70
PHCA	DEPTH	.000	.57846	+3.267	+.0123	38.10	37.78
	CHLO	.021	.63271	"	+.0232	5.03	7.94
					+.0176	14.71	7.70

*Only relationships significant at the 5% (0.05) level or higher are tabulated

**Variables mnemonics are listed in Table VII

2 and 6 in the oblique as having significant intercorrelation, (r = -0.25) is included in Table XVI. An intercorrelation exceeding an absolute value of r = 0.20 is considered significant.

Differences between the two factor solutions are noted. The variables loading on the six factors are rather different in each solution and the last two factors are extracted in opposite order in each solution.

The first factor in each solution has the highest number (7 and 6) of loaded variables and 32.1% of the variance of soil parameters is associated with this factor. In the varimax solution depth, pH (PH2O and PHCA), vermiculite (VERM), illite (ILLT), kaolinite (KAOL) and total clays (CTOT) load with the first factor. The same variables except ILLT load on the first factor of the oblique solution. The loading of these particular variables suggest that the first factor extracted can be attributed mainly to leaching causing the downward movement of materials in these soils.

The four measures of soil texture (CS, FS, SILT, and VFSC) load onto the second factor in each solution with hornblende (HORN) loading onto the second varimax factor as well. This factor in each solution suggests that 26.8% of the variance of parameters in Thor Lake soils can be attributed to the variation of soil texture. HORN is noted to have a significant correlation with CS, FS, and SILT hence its loading here is not surprising. Hornblende is a readily alterable mineral and was used by Cady (1940) as a weathering index in a petrographic study.

TABLE XIV

COMPARISON OF ORTHOGONAL AND OBLIQUE FACTOR SOLUTIONS

Factor Number	Eigenvalue	% Variance Explained	Orthogonal Varimax Variables Loaded (>0.5000)**	Oblique* Variables Loaded (>0.5000)**
1	4.911	32.1	DEPTH, PH20, PHCA, VERM, ILLT, KAOL, CTOT	DEPTH, PH20, PHCA, VERM, KAOL, CTOT
2	4.097	26.8	CS, FS, SILT, VFSC, HORN	CS, FS, SILT, VFSC
3	2.518	16.5	OM, K, ILLT	OM, K, ILLT
4	1.743	11.4	FLDR	FLDR, QTOF
5	1.104	7.2	MXVI, QTOF, FTOF	QRTZ, CTOT
6	.925***	6.0	OM, QRTZ	MXVI, FTOF

*Using Rotated Pattern Matrix

**Variable mnemonics are listed in Table VII, page 74

***The eigenvalue for this factor exceeded 1.000 in the original solution with 22 factors considered

TABLE XV

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
DEPTH	.85684	-.09654	.10949	.00849	.13580	-.20651
PH2O	.74454	.12267	.12770	.65967	.40805	-.04366
PHCA	.82792	.03581	-.11563	-.09948	.34244	-.12276
OM	-.35087	.02117	.69345	-.04781	.14314	.50495
CS	-.01516	-.93770	-.07653	.22954	-.17404	.12264
FS	.00778	.65322	.17073	-.25943	.14407	-.15569
SILT	-.05392	.94876	-.12661	-.13996	.25981	-.04288
VFSC	-.32235	.61173	.02829	.15072	-.10372	.08265
P	-.16769	-.12607	.09816	-.00727	.10979	.30932
K	.06456	.13035	.87049	.16030	.04743	.09245
MG	.25760	-.08382	.32313	.44962	-.38610	-.02959
CHLO	.07637	.05533	-.25905	-.32278	.03516	-.11280
VERM	-.86232	.11251	-.14715	.47225	.29236	.10824
MXVI	.01705	-.08424	.00206	.04357	-.55992	-.11225
ILLT	.55328	.08779	.73169	-.07540	-.09609	-.04280
KAOL	.76640	-.27240	-.12499	.03279	-.11047	.10056
HORN	.09281	-.54378	-.22065	-.30481	-.34793	.12765
QRTZ	.07592	-.14587	.09746	.31744	-.00487	.74444
FLDR	.14285	.22848	.05085	-.63795	-.03811	-.13067
QTOF	.27383	.30759	-.01404	.46119	.60200	.07365
FTOF	-.28128	-.49103	-.11190	.10773	-.70921	.17442
CTOT	-.63013	-.40452	-.04910	.33216	.10142	-.46203

TABLE XVI

OBLIQUE FACTOR PATTERN MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

DELTA = 0.000

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
DEPTH	.85004	.14426	-.13359	-.01804	-.18448	.05665
PH2O	.77277	-.06382	.13714	-.09642	-.03540	.31312
PHCA	.86042	.01000	-.09641	.04351	-.03745	.25529
OM	-.38142	.02544	.68470	.12520	.41908	.21618
CS	.00047	.91439	-.03227	-.18413	.09498	-.07380
FS	.03517	-.69418	.18261	.23957	-.15374	.08706
SILT	-.03392	-.84359	-.14644	.07233	-.01612	.10754
VFSC	-.32737	-.66275	-.00887	-.15375	.09539	-.17419
P	-.16959	.12548	.00655	.02058	.28244	.10355
K	-.00277	-.05632	.57946	-.07522	.01617	.01876
MG	.21193	.01527	.30571	-.36001	-.05302	-.46861
CHLO	.07904	-.04596	-.24298	.28401	-.08555	.05691
VERM	-.81493	-.08976	-.15174	-.11721	-.04465	.35534
MXVI	-.04125	.01683	-.00375	.01234	-.07851	.55773
ILLT	.46372	-.02042	.75601	.15876	-.07112	-.14697
KAOL	.77756	.23274	-.13221	-.02749	.15634	-.15453
HORN	.07346	.49804	-.21137	.33742	.16891	-.24203
QRTZ	.12616	.05647	.03405	-.28361	.74982	-.00614
FLDR	.07345	-.16355	.09762	.24211	-.11704	.02956
QTOF	.36455	-.28127	-.04015	-.53088	.06380	.47706
FTOF	-.32039	.37499	-.13468	-.02931	.20076	-.63227
CTOT	-.61674	.46354	-.01439	-.34774	-.54699	.15517

FACTOR PATTERN CORRELATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
FACTOR 1	1.00000	-.02785	.07525	.07657	-.10233	.00336
FACTOR 2	-.02785	1.00000	-.10845	-.07392	.14212	-.25726
FACTOR 3	.07525	-.10845	1.00000	-.14309	.14424	-.00764
FACTOR 4	.07657	-.07392	-.14309	1.00000	-.06869	-.01908
FACTOR 5	-.10233	.14212	.14424	-.06869	1.00000	-.00318
FACTOR 6	.00336	-.25726	-.00764	-.01908	-.00318	1.00000

The third factor in each solution attributes 16.5% of the variation of soil parameters to three variables: OM, K, and ILLT (organic matter, potassium and illite). The strong relationship (Table X) between K and ILLT (r = +0.635) is discussed in a latter section where potassium is noted to be an integral component of the illite lattice. Potassium and organic matter are also noted to have a strong correlation (r = +0.675). Hence, this third factor can be considered to relate to the role of organic matter in the release of K from mica (illite). The dual loading of illite (ILLT) onto factors 1 and 3 indicates it is poorly associated with either, lying midway between the two factor axes.

The fourth factor extracted in both solutions attributes 11.4% of the variation in parameters investigated to feldspar (FLDR). The oblique factor includes the quartz to feldspar ratio (QTOF) which, as noted in Chapter Two, has been used by Pawluk (1960) as a weathering index in Podzols.

The order in which factors 5 and 6 are extracted in the two solutions is opposite and the variables are loaded somewhat differently. Factor 5(6) loads the "mixed mineral" (MXVI) variable and the ratio of major feldspar peaks (FTOF). Factor 6(5) loads quartz (QRTZ) in each solution with organic matter (OM) in the varimax and total clays (CTOT) in the oblique solution. Factors 5 and 6, in total, account for 13.2% of variance of soil parameters and indicate that the presence of clay-size quartz and feldspar minerals do have a minor, but significant effect on soils at Thor Lake.

Factor analysis suggests that the major components influencing the properties of Thor Lake soils are related to the effects of leaching (factor 1), soil texture (factor 2), and organic matter (factor 3). Factors 4, 5 and 6 are viewed as less important mineral factors relating to the presence of quartz and the weathering of feldspar in these soils. These six factors play major roles in the weathering processes active in the soils at Thor Lake.

Variations in Physical and Chemical Properties

In this section, the information generated by physical and chemical analyses of Thor Lake soils is reviewed. This includes data on soil texture, organic matter, soil reaction and exchangeable ions.

Texture

For statistical analysis, the original seven classes of particle size, as listed in Table V, page 32, have been reduced to four variables. These variables (CS, FS, SILT, and VFSC) with descriptive statistics including mean, standard deviation, range, and measures of kurtosis and skewness are outlined in Table XVII which follows.

Thor Lake soils are observed to be coarse-grained sands and sandy loams (or loamy sands) with very low clay content (less than 2% in all cases). This indicates that little physical weathering has been active to break down or abrade individual coarse grains. The four variables examined are strongly intercorrelated (Table X). Fine silt+clay (VFSC) comprising the <10μ material, is noted to have a significant correlation with depth (r = -.398) indicating this fine material is being illuviated downwards or is forming in these soil

TABLE XVII

DESCRIPTIVE STATISTICS FOR TEXTURAL VARIABLES IN THOR LAKE SOILS

Textural Class and Mnemonics		Particle Sizes (microns)	% Content Mean $\bar{x}$	Standard Deviation s	Range R	Skewness m_3	Kurtosis m_4
CS	Coarse and Medium Sand	2000-177	59.82	13.62	51.40	+1.088	+.109
FS	Fine Sand	177-53	24.43	7.47	30.70	- .910	+.104
SILT	Coarse and Medium Silt	53-10	14.71	7.70	29.60	- .079	-.765
VFSC	Fine Silt and Clay	<10	0.65	0.42	1.80	+ .908	+.587

profiles at depths of 10 to 40 cm.

The four textural variables load onto factor two in both factor solutions. This factor indicates that texture in these soils strongly affects their overall morphology and properties.

An examination of specific size-class data identifies soil horizons in which weathering is most active. Generally, horizons with the lowest coarse sand (CS) and/or highest fine silt+clay (VFSC) fraction are more weathered relative to other horizons. Surface Ae horizons have coarse sand (CS) content of about 10 to 21% as in sites B, C and D. A CS value of 68% noted in the Bm horizon of esker site F indicates relatively unweathered material. A low CS value of 10% in the Ae1 of site G suggests very active weathering. The presence of the highest fine silt+clay content noted (1.9%) and of montmorillonite in this horizon also suggest active chemical and some physical weathering.

Examination of the silt fractions (50-10 microns) reveals that major differences exist between horizons in some profiles. The deep Cg2 horizon of site B is noted to have silt contents of 10 to 12% compared to 1 to 2% in overlying horizons. This suggests that deeper glacial till, as represented by the Cg2 horizon and which is assumed not to have been affected by weathering processes since deposition, must be derived from significantly weathered pre-glacial materials. As shall be discussed, the presence of kaolinite in these soils could be explained in this manner.

Organic Matter (OM)

Factor analysis has also identified organic matter as having a major effect on soil properties at Thor Lake. The organic content in different horizons, especially those near the surface, is largely related to their fire history. Sites subjected to the more recent burns have thinner organic horizons. A direct relationship between organic horizon depth and burn age at Thor Lake, observed by this author, has been reported in Kershaw, et al. (1975).

A significant correlation of organic matter content to sampling depth is not observed on the basis of the entire data matrix. However, it does appear valid in specific profiles (Sites A, C, D and E). In these, a relative decrease from A to B to C horizons is noted. The Humo-Ferric Podzols of Sites B and C display small increases of organic matter in their B horizons. Statistically significant correlations are noted for organic matter with potassium, clay-size quartz, and pH ($CaCl_2$).

Soil Reaction (PHCA, PH20)

The analyses confirm that measurement of soil pH using $CaCl_2$ rather than H_2O is the superior technique. Correlation of PHCA with depth (r = +.761) is higher than that of PH20 with depth (r = +.653). A comparison of multiple correlation R^2 values with a set of identical independent variables (Table XIII) shows that correlations are higher for those variables with PHCA as the dependent variable than with PH20 (Table ~~X~~III, page 82). The role of soil pH in relation to the presence of illite is discussed in a following section. Acidity decreases with depth from A to B to C horizons with pH averaging 3.9, 4.8 and 5.4 ($CaCl_2$) respectively. A comparison of A and B horizons in well-drained and poorly-drained profiles indicates that poorly-drained sites have generally lower pH with average values of 3.8 and 4.5 in A and B horizons. Well-drained sites have higher pH values averaging 3.9 and 4.9 for A and B horizons respectively. This suggests that the hydromorphic condition contributes to increased acidity in Thor Lake soils.

Exchangeable P, K, Mg

Phosphorus appears to occur independently of other variables in these soils. It shows no significant correlation to any other variable and P does not load onto any of the six factors extracted in factor analysis. Phosphorus occurs in concentrations of 19-120 ppm in B horizons but only 17 ppm or less in A and C horizons suggesting a highly mobilizable material which, in most cases, is concentrated in B horizons.

Potassium (K) and magnesium (Mg) occurrence is generally greatest where associated with higher organic matter contents. Potassium shows significant correlations (Table X) with organic matter (r = +.675) and illite (r = +.635). Potassium and magnesium are significantly correlated (r = +.420). Free magnesium which is a critical component of the vermiculite lattice, shows no significant correlation with vermiculite in these data.

Clay Mineral Genesis

This study has revealed considerable evidence concerning the development and alteration of the clay mineral component of soils in the Thor Lake region. In this section, the data concerning each mineral is reviewed and the overall scheme of weathering which appears to be operational in these soils is outlined.

Illite (ILLT)

Illite, which includes biotite and muscovite, forms a group of minerals commonly referred to as the micas. The presence of a 10 Å and a 4.98 Å peak on X-ray diffractograms for soils in kettles at Sites D and E and the esker (Site F) suggest the presence of muscovite in these locations with biotite dominating elsewhere. The amount of these illite minerals in soil horizons increases with depth while vermiculite declines with depth. A strong negative correlation (Table X) of illite with vermiculite ($r = -.625$) suggests that vermiculite is a major weathering product of illite in these soils. Potassium, a major interlayer lattice component of illite, shows a strong correlation to illite ($r = +.675$). Multiple regression (Table XI) indicates that K, MXVI, CHLO, KAOL and VERM have significant R^2 relationships with illite as a dependent variable. This suggests that illite and mixed illite-vermiculite (MXVI) are strongly related. Illite mainly associates with factor 3 in the factor solutions.

In surface horizons, where acidity is generally highest (low pH) it appears that high H+ concentration may encourage the alteration of illite to vermiculite through hydrated magnesium-substitution for potassium at interlayer bonding sites. Pawluk (1961) noted that in northern Alberta, acidity was poorly related to weathering. It appears the opposite is valid at Thor Lake. Illite and pH (H_2O) are significantly correlated in this study ($r = +.445$) indicating that acidity is highest where weathering is most intense. The following genetic process appears active in these soils:

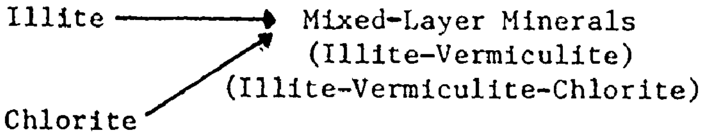
$$\text{Illite} \longrightarrow K^{+} \text{ loss} \longrightarrow \text{Vermiculite}$$

Rates of potassium exchange have been noted to vary inversely with weathering (Ross, 1971; MacLean and Brydon, 1971). This also appears to be valid in Thor Lake soils. The most weathered soil horizons have the lowest potassium and hence lowest unaltered illite content.

Mixed Minerals (MXVI)

Several mixed-layer minerals have been noted in these soils (Table XX, Appendix B). Illite-vermiculite has been noted in nine of the horizons examined, especially B horizons. A mineral similar to illite-vermiculite-chlorite has also been noted in trace amounts in one Ae and the C horizon of Site G. The occurrence of such minerals is difficult to associate with specific conditions. In some cases, minerals classified as vermiculite may in fact be other highly-complicated mixed-layer minerals quite similar in properties to vermiculite. In these few cases, the mineral was noted to dehydrate to only 11-10.3 Å instead of 10 Å upon heating to 550°C as is characteristic of vermiculite. However, vermiculite may rehydrate slightly if cooling proceeds too far prior to X-ray analysis at this stage. Precise identification of complicated minerals would require the use of supplementary techniques such as Differential Thermal Analysis.

Mixed illite-vermiculite, as the name suggests, is an intermediary mineral between illite and vermiculite with a diagnostic basal spacing of 12 Å. The R^2 multiple correlations (Table XI) with illite (0.487) and chlorite (0.688) suggest these minerals are associated with the presence of this mixed-layer mineral. Some minerals designated mixed illite-vermiculite may also have some chloritic character. A mixed illite-vermiculite-chlorite would have a basal spacing of 12.5-13.0 Å and could be readily confused with mixed illite-vermiculite minerals. The data suggest the following genetic sequence:



Vermiculite (VERM)

Vermiculite has been identified as the major weathering product of illite. The correlation of vermiculite and sampling depth (r = -.719) suggests that weathering is most intense in the surface albic horizons. Multiple regression (Table XI) loads chlorite, mixed illite-vermiculite and illite with vermiculite as the dependent variable suggesting these minerals contribute significantly to vermiculite occurrence. Vermiculite loads onto factor one in factor solutions (Table XIV).

Chlorite (CHLO)

The data indicate that chlorite, although only observed in 17 of the 42 samples (Table XX, Appendix B), is present in greatest amounts in B horizons. This mineral is present in one Ae horizon (2.5% of total <2μ clay fraction), in seven B horizons (14.9% average) and in nine C horizons (10.7% average). In some cases, where chlorite may be present, it has not been observed, possibly due to its presence in very low amounts or because of masking by diffraction peaks associated with other minerals. For instance, peaks at 14 Å are difficult to distinguish from vermiculite which also has a 14 Å peak. Peaks at 7.1 and 3.57 Å, attributed in this study to kaolinite, may in some cases correpond to a small chlorite component.

Chlorite displays no significant correlation with other variables in this study. Multiple correlation (Table XI) provides no data indicating vermiculite may be a weathering product of chlorite. However, the few observed cases of chlorite and illite-vermiculite-chlorite suggest the following sequence in B and C horizons:

$$\text{Chlorite} \longrightarrow \text{Vermiculite}$$

Montmorillonite

This mineral has been noted in only one case, in the Ael horizon of the Fragic Humo-Ferric Podzol at site G. Hence, it has not been entered into the statistical analyses. Montmorillonite is generally only present in horizons subject to intense weathering. Its occurrence at Thor Lake is somewhat surprising since weathering processes in this area generally seem weakly expressed. However, this particular horizon is in an unusual location which has resulted in the development of its unusual character. Particle size data indicate that the coarse sand fraction of this sample has been highly weathered (10.5 % CS). The fine silt+clay (VFSC) fraction is the highest noted at Thor Lake (1.9%). The horizon has low organic content for a surface Ae (0.6%) and overlies a deep, well-developed Bfx fragipan. Site G has unusual local microtopography which promotes intense local weathering by channeling surface and sub-surface flows into a limited area. Vermiculite is the dominant mineral in this horizon (85.3% of clay minerals). The montmorillonite present here is attributed to *in situ* weathering of vermiculite:

$$\text{Vermiculite} \longrightarrow \text{Montmorillonite}$$

Kaolinite (KAOL)

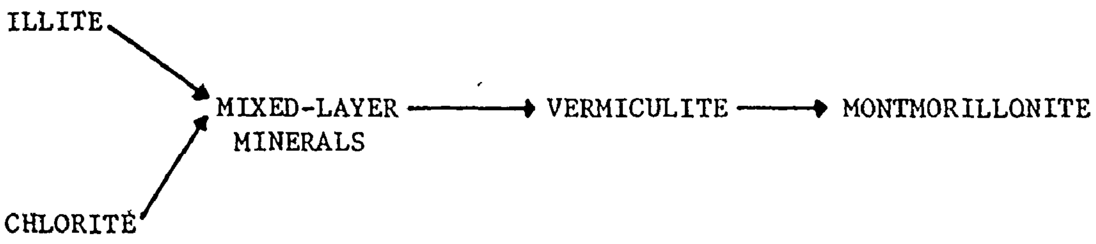
Kaolinite has been observed to be a component of the clay mineral fraction in 41 of the 42 cases studied. Kaolinite increases with depth ($r = +.664$) as does illite. However, a significant correlation between these two minerals is not observed. Illite has been proposed as the major weathering source for vermiculite in these soils. Hence, kaolinite is unlikely to be contributing to vermiculite presence.

Kaolinite is regarded as resistant to weathering and as an advanced component in the processes characteristic of old, highly-weathered landscapes. Gjems (1967) in Norway and Belousova, et al.

(1973) of the Soviet Union attribute the presence of kaolinite, in Podzols developed since glaciation, to preglacial formation. Transported glacial tills are assumed to have been uniformly deposited. Since kaolinite is noted to increase with depth in these soils, either (i) kaolinite was dominant in the parent materials and has been depleted by mechanical washing from surface horizons, or (ii) kaolinite has been concentrated in lower B and C horizons by simple washing downwards in the profile. This is consistent with the suggestion by De Kimpe (1970), that the non-uniform distribution of kaolinite in a Quebec Podzol is due to translocation within the profile.

Clay Mineral Genetic Processes in Thor Lake Soils

In the preceding sections of this chapter, the incidence and weathering of individual clay minerals have been discussed. Compiling this information, a simple scheme for the genesis of clay minerals in Thor Lake soils can be summarized as follows:



The dominant clay minerals in horizons of sites A to G, as listed in order, in Table XVIII, reflect this general genetic sequence. Vermiculite dominates surface horizons (with montmorillonite in one case). Illite and kaolinite increase while vermiculite decreases with

TABLE XVIII

DOMINANT CLAY MINERALS IN THOR LAKE SOILS

Site	Soil Type (CSSC 1974)	Horizon	Dominant Clay Minerals*			
A. Linear Depression Glacial Till	Placic Humo-Ferric Podzol	Bfgc3	Ka	Vm	It	Ch
B. Drumlin Crest, Glacial Till	Placic Humo-Ferric Podzol	Ae	Vm	Ka	It	
		Bf	Vm	Ka		
		Bm	Ka	Vm	It	Vm-It
		Cg1	Ka	Vm	It	
		Cg21	It	Ka		
		Cg22	Ka	It		
		Cg23	Ka	It		
C. Drumlin Crest, Glacial Till	Orthic Humo-Ferric Podzol	Ae	Vm	Ka		
		Bf	Vm	Ka		
		Bm2	Vm	Ka		
		BC	Vm	Ka		
		C1	Ka	It		
		Cg	Ka	Vm-It-Ch	It	Vm Ch
		Cg	Ka	It	Vm	Ch
D. Kettle	Fragic Humic Podzol	Ah	Vm	It		
		Bf	Vm	It	Ka	Vm-It
E. Kettle	Fera Gleysol	Bf	Ka	Vm	It	Ch
F. Esker	Degraded Dystric Brunisol	Bm2	Vm	Ka	Ch	It
G. Relict Channel	Fragic Humo-Ferric Podzol	Ae1	Vm	Mt	Ka	It
		Bf1	Vm	It	Ka	
		Bf2	Vm	Ch	Ka	
		Bfx1	Vm	Ka	It	
		Bf2	Vm	Ka		
		Bfx2	Vm	Ka	It	
		Cg1	Vm	Ka	It	
		Cgtj	Ka	It	Ch	Vm
		Cg2	Ka	It	Vm-It	Ch Vm

*Vm = Vermiculite   Ch = Chlorite   Mt = Montmorillonite   It = Illite   Ka = Kaolinite depth. Chlorite is present in B and C horizons. In addition to these phyllosilicates, minerals such as quartz, feldspar, hornblende and anatase have been noted in most horizons. These are discussed more fully in the next section.

Non-Clay Minerals

Quartz is the most abundant mineral in the <2μ fraction of all the samples ranging from 21-58% of this clay-size material. Surface Ae horizons have slightly less quartz present suggesting minor surficial weathering of this mineral and loss from these horizons. When the values for quartz in each horizon are averaged, the following values are noted: A horizons 39.2%; B horizons 42.4% and C horizons 41.9% of the <2μ fraction. Quartz is significantly correlated to feldspar (FLDR) and organic matter (OM). Quartz loads onto the fifth factor in each factor solution.

Feldspar is another major component mineral in the clay-size fraction, ranging from 5 to 23% of this material. It is noted to increase slightly with depth. The average for A horizons is 10.5%, B horizons 12.8%, and C horizons 13.0%. This suggests minor weathering of feldspar in surface horizons. The identification of feldspar species is a difficult task since feldspars in soils generally are a mixture of several types. Most peaks in the 2.94 to 3.03 Å range are grouped closely to 2.94 Å and numerous peaks are noted in the 3.55 to 3.80 Å range. The major feldspar groups felt by this author to be present in Thor Lake soils are the albite or potassic feldspars (i.e., plagioclase) as suggested by Goodyear and Duffin (1954).

Graham (1949) used plagioclase feldspar peaks as an index to soil weathering. Considerable variation in the heights of the 3.19 and 3.24 Å feldspar peaks has been noted in the diffractograms. A ratio of major feldspar peaks (FTOF) used in this study has not been observed to very significantly from A to B to C horizons (average ratio values are 0.7, 0.8 and 0.6 respectively). The ratio is not felt to reveal useful information concerning mineral species or weathering intensity.

As discussed in Chapter Two, Pawluk (1961) observed that the ratio of quartz to feldspar in Podzols in Alberta is a useful indicator of soil weathering intensity. Surface horizons were noted to have the highest ratio value, decreasing from A to B to C horizons significantly. In this study, the averaged ratios for A, B and C horizons are 6.9, 6.6 and 8.0 respectively, indicating little difference between horizons. The usefulness of the quartz to feldspar ratio (QTOF) seems questionable in light of these data.

Several other minerals are noted in the clay-size fraction of Thor Lake soils. Hornblende is noted in all horizons ranging from 0.8 to 10.7% of the <2μ fraction. This mineral is most likely derived from local amphibolite-schists. Minor traces of anatase (0.6-5.9%) are present in most samples. This is an accessory mineral in igneous and metamorphic rocks and is often found in granite-pegmatite, which is present in the Thor Lake area (Hamilton, et al. 1974). Anatase increases from A to B to C horizons averaging 1.6, 2.1 and 3.3% of the <2μ fraction respectively. Since the diffraction analysis was restricted to the 4-40 2θ range, other minerals may be present in these soils, particularly in the >2μ size fractions.

Mineralogy of Fragic and Placic Horizons Examined

The presence of fragic and placic horizons in Thor Lake soils is of considerable interest. They are noted to have high bulk density, and display characteristic brittleness when wet and induration when dry. For instance, the fragic Bfx1 horizon of site G has a bulk density of 2.35 g/cc compared to a value of 2.11 g/cc in a nearby Bf2 horizon at the same depth. The incidence of these horizons seems directly related to localized drainage conditions. In two cases, fragic horizons are noted where topography restricts drainage (Site G in a sinuous slope channel and Site D in a kettle depression).

Clay mineral data suggest that placic and fragic horizons, in some cases, have decreased clay content relative to other horizons. The Bfc placic horizon at Site B has no fine silt+clay fraction whereas horizons above and below have from 0.1 to 0.9% in this size-class. Horizon Bfx1 of Site G has less 14 Å clays relative to other horizons as demonstrated by reduced 14 Å peaks on the diffractograms (Figure IX, page 71). The increase of kaolinite in this Bfx1 fragic horizon suggests it acts to impede the downward translocation of this mineral. While the total clay content is less in fragic horizons it also seems that fragic horizons have more true clay minerals on a relative basis in this clay-size fraction, regardless of its total amount. The Bfx horizons of Site G have 11.2% and 34.0% of the total <2μ fraction represented by clay minerals whereas the non-fragic Bf horizons have a maximum of 7.3% of the clay-size material in the form of clay minerals.

Placic horizons at Sites A and B have been described in Chapter Five. The linear depression of Site A has restricted drainage but Site B on a drumlin crest, does not. The mineralogy of horizon Bfgc3 of the Placic Humo-Ferric Podzol at Site A is described in Table XIX of Appendix B. It is noted to have large kaolinite and vermiculite components but a very low relative clay mineral fraction (2% of the total <2μ materials).

All fragic and placic horizons are generally found where the concentration of total Fe+Al appears to be large. Analytical data on iron mobilization in a catena of soils at Thor Lake has been described by Fox (1975). The occurrence of fragipans in association with iron and aluminum concentration is well established in the literature (Wang, et al. 1974; Grossman and Carlisle, 1969). Some placic horizons (notably at Site A) are characterized by extensive orstein mineral occurrence. Positive identification of the minerals contributing to the induration of placic and fragic horizons (and the processes may be entirely different) is not possible with the data available from this project. Extensive pyrophosphate, dithionite and oxalate extractions for Fe, Al and Mn would be necessary to elucidate the problem. In addition X-ray Fluorescence Analysis (as conducted by Fox,1975) might reveal further information, as could the Scanning ~~Eleetron~~ Electron Microscopy approach of Wang, et al. (1974). It is evident that total clay minerals seem to increase in these placic and fragic horizons. This is consistent with the view of Wang, et al. (1974)

that the binding agents are a function of this total clay mineral (phyllosilicate) fraction present in the soil.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

In Chapter Five seven soil profiles are described, corresponding to the major types of soils present in the Thor Lake region. Most importantly these include Humo-Ferric Podzols, Degraded Dystric Brunisols, Gleysols and Sphagno-Fibrisols. The major criteria for distinguishing these soils are outlined by the Canada System for Soil Classification (CSSC,1974). While these soils have obvious morphological differences, the system by which they are classified suggests that they are the product of significantly different genetic processes. The present study suggests that in the case of Podzols and Degraded Brunisols in this area, the genetic processes active in these soils are of a common nature. The morphological differences between these soils are reflections of variation in the intensity of these processes.

Fox (1975) has noted the presence of Brunisols and Podzols in close proximity in a catena of soils at Thor Lake, as does this study. Significant variation in the intensity of weathering with sites of different topographic and drainage characteristics has resulted in different soil types being developed from originally uniform parent materials. The processes operational are the same, only the intensity with which they occur varies. It would seem illogical then to classify such soils into different soil Orders.

The present study supports the view that the CSSC system of soil classification is in need of review to allow proper classification of soils in the southern part of the District of Mackenzie. An improved system of classification would remove the Degraded Brunisol subgroup (including both Eutric and Dystric subgroups) completely and incorporate these as new subgroups in the Podzolic Order. The so-called Brunisols in the Thor Lake region have definite podzolic character and should be classified as such.

The major criterion used to separate soils in these groups is presently the definition of a Bf horizon. It is clear that the chemical criteria for separation of a Bf and a Bm soil horizon (and hence a Podzol versus a Brunisol) is entirely inadequate in this region. Soils with an Ae or Aej horizon and strongly or weakly expressed illuvial B horizons with iron and/or aluminum concentration must be considered genetically similar soils in this region.

Review of Hypotheses

It was hypothesized that there exist differences in the clay minerals present in the different soil types of the area. The data suggest that this is not a valid hypothesis. Significant differences in the expression of clay mineral suites in these soil profiles are not observed. The scheme of soil genesis in these soils appears uniform for all the soils examined. A statistical analysis of a large number of soil profiles for this region would be desirable to assess whether there exist significant differences in the data between sites. In this study, only differences between individual cases have been statistically analyzed. The sample size of soil profiles in this study is too small for inter-site analysis. Such analysis would more precisely identify whether the differences in mineralogy, morphology, and chemical and physical properties of these soils, differently classified, are really significant. Work by this author and Fox (1975) suggest they are not.

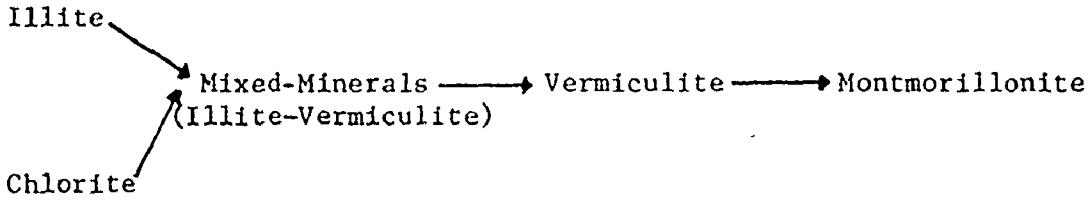
Three other hypotheses are made in Chapter One. All three are felt to be valid based on the data presented. The clay minerals chlorite and illite as well as quartz, feldspar, hornblende and anatase reflect the parent rocks reported in the literature for this region. Chemical weathering is active in surface horizons resulting in the alteration of chlorite and illite to vermiculite. Where weathering is very intense, vermiculite may alter to montmorillonite. Limited weathering of some alkali feldspar (plagioclase) is suggested in some surface horizons.

Chemical and physical properties do seem to contribute to the existence of specific clay minerals in these soils. Acidity, texture, potassium and organic matter have been discussed with reference to specific minerals.

The scheme proposed for clay mineral genesis in Thor Lake Podzols is similar to those discussed in Chapter Two. This supports the hypothesis that the genesis of soils in this area is similar to that in Norway, the north-central parts of the Soviet Union and other boreal areas of Canada. The morphology of the soils in this subarctic spruce-lichen woodland resembles that observed in similar environments in Canada and elsewhere (e.g., by Moore, 1974). The presence of soils with fragic and placic horizons in this region is an unusual occurrence rarely reported in the literature for Canadian subarctic soils. Of the four hypotheses made in Chapter One (page 7), the first, third and fourth are felt by this author to be valid while the second hypothesis is not.

Summary

Investigation of soils at Thor Lake, Northwest Territories indicates an environment characterized by weak chemical weathering restricted mainly to surface horizons. A uniform suite of clay minerals is associated with these soils derived from glacially-transported tills. A sequence of clay mineral genesis in these mainly Podzolic soils, similar to that observed in other areas of Canada and elsewhere, is described. In surface horizons, vermiculite is the major weathering product of illite and chlorite. Under conditions of sufficient intensity, vermiculite may weather to montmorillonite in these soils. The following sequence is in operation in these soils:



The presence of kaolinite in these soils is attributed to preglacial formation. Significant downward washing of this mineral in these soil profiles is noted. Other minerals in the <2μ clay-size fraction of the parent glacial till reflect the bedrock minerals noted in the literature for this region. These include quartz, feldspar (mainly plagioclase), hornblende and anatase. Quartz and feldspars form the major components in the clay-size materials in these soils. There is some evidence that clay-size quartz is being removed from the A horizons of these soils.

The major soil types observed in this area are Humo-Ferric Podzols and Degraded Dystric Brunisols. Classification of these soils into two Orders is questioned and suggestions are made for alteration of the Canadian System of Soil Classification. The morphology of these soils is similar to soils formed in similar environments reported in the literature. Variable Ae horizons overlie weakly to strongly developed illuvial B horizons in which iron and aluminum oxides have been concentrated. The existence of fragic and placic horizons in these soils is reported.

Statistical analyses indicate that the variation of soil properties at this location can be mainly attributed to six soil factors: (1) downward percolation or leaching of materials, (2) textural differences between horizons, (3) the amount and history of organic matter occurrence in soil horizons, (4,5) the influence of such minerals as quartz and feldspar and (6) the intensity of weathering as expressed by the chemical properties of diagnostic clay minerals.

APPENDIX A

APPENDIX A

X-RAY ANALYSIS

PRETREATMENT PROCEDURES

The following procedures are adapted for use in the McMaster University Pedology Laboratory from a method of analysis set up by Professor G. K. Rutherford of Queen's University, Kingston, Ontario using procedures of Mehra and Jackson (1960) and Gjems (1967).

1. Separation of Clay Size Soil Fractions

(a) Each 500 ml dessicator bottle is filled to its outlet with a small amount of water. Make two marks on the bottles stating "6 hours" and "4 hours" at $7^{1}/2$ and 5 cm respectively above this water level. Particles remaining in suspension after these times up to these levels will be clay-size.

(b) Weigh out roughly 20 gm of <2 mm air (not oven) dry soil from each sample into a 500 ml beaker. Use only 5-10 g for soils with high clay contents. Just cover soil with Calgon solution.

(c) Place beakers (12 beakers should fit at one time if desired) in shaker box and secure. Shake gently for 24 hours.

(d) When a dessicator bottle is available, wash the shaken sample into it. Be sure to scrape any deposits off the beaker walls. Fill with water to the 6 hour mark, shake briskly by hand and allow solution to settle. Make sure rubber hoses are clamped and corks firmly secured.

(e) Should the suspension clear quickly, this is an indication of excess $CaCO_3$. Pour the suspension into a 500 ml beaker and add an equal amount amount of sodium acetate ($C_2H_3NaO_2$) at pH 5.0 and boil in the water bath for two hours. Decant the clear liquid, fill with distilled water, rewarm to 90°C and redecant. Continue until the suspension no longer settles out. Pour the suspension back into the dessicator bottle.

(f) After 6 hours the rubber tube is unclamped and first 5 ml is allowed to run into a waste beaker. The rest of the suspended material is run into a labelled 500 ml beaker. A second beaker for each sample will also be required.

(g) Refill the bottles with distilled water to the four hour mark and repeat the settling and drainage procedure. Do this four times or until shaken solution is clear after four hours. Twice may be sufficient for clay marine sediments.

(h) Using a pipette add 5 ml of acidified Magnesium Acetate ($C_2H_3MgO_2$) to the collection beakers ($2^1/2$ to each). This precipitates clay particles and dissolves any phosphate remains from the Calgon treatment. Leave the beakers overnight.

(i) The next day, decant the clear liquid from the beakers (in some samples the solution will be coloured but basically particle free). If the particles have not precipitated completely, use the 100 ml centrifuge to do this. Transfer the clay size fractions to 15 ml centrifuge tubes. It will be necessary to decant several times. If some sand has gotten into the collection beakers do not wash this material into the centrifuge tubes. Label tubes clearly and stopper.

2. Removal of Organic Matter

(a) Decant the clear liquid. A maximum of 1 gm of clay is required in the tube. Add 10 ml of 10% Hydrogen Peroxide (H_2O_2). When effervescence stops add 2 ml more.

(b) Place in drying oven at 55°C overnight, unstoppered.

(c) Next day centrifuge for 15 minutes at highest speeds (about 2200 rpm). This centrifuge takes four 15 ml tubes. Do not use the centrifuge designed for six 10 ml tubes as 15 ml tubes will break at higher speeds.

(d) Decant, add distilled water and place on vortex mixer for one minute. This will shake the particles and wash them removing all the Hydrogen Peroxide. Recentrifuge and decant (if you are not proceding leave aboug 5 ml in the beaker to prevent drying out).

(e) If the suspension does not clear on centrifuging add a few drops of Magnesium Acetate; centrifuge and decant.

3. Removal of Calcium Carbonate ($CaCO_3$)

Only if suspended $CaCO_3$ is suspected:

(a) Add 10 ml 1 N Sodium Acetate at pH 5.0 to the centrifuge tube. Heat in water bath at 100°C for 3 minutes. Shake on vortex mixer.

(b) Centrifuge suspension, and decant until supernatant is just not quite clear.

4. Removal of iron and aluminum oxides

(a) Decant off all liquid and add 5 ml of the Citrate solution and 0.6 ml. Sodium Bicarbonate from a burette. Heat to 80°C and add about 0.2 g Sodium Dithionite ($Na_2S_2O_4$) from the tip of a spatula. Shake several times during heating which should continue for one hour.

(b) Centrifuge, decant, wash (add 10 ml distilled water and shake) until the clay is precipitated with difficulty. This will usually involve repeating three or four times.

(c) Add 5 ml 1 M Magnesium Acetate, shake and let stand for one hour. This saturates the clay particles with Mg.

(d) Centrifuge, decant and wash until clays precipitate with difficulty (three to four times).

(e) Decant all but 4-5 ml of the clear liquid.

(g) Prepare a glass slide.

5. Preparation of Glass Slides

(a) Shake suspension for one minute. Using a small syringe draw about 2 ml of suspension and place on top-half of slide. Do not touch the glass with the syringe tip. Try to distribute suspension evenly starting at one end and working toward you. Avoid putting suspension on at the center and spreading outwards as this will concentrate particles at that point.

(b) Use petroscopic slides (27 x 46^1/2 mm) or cut regular micro-slides to size.

(c) Scribe a number on the clear end of the slide in such a way as to be able to replace the slide in the Diffractometer bracket in the same orientation repeatedly.

6. Diffraction Analysis

(a) The regular sample is run from 4° to 40° 2θ for clay minerals or 4° to 65° for all major minerals.

(b) The glass slide is removed from the diffractometer and placed in a dessicator for 48 hours. A dish filled with Ethylene Glycol is also placed in the dessicator. This "glycolates" the clays causing expansion of certain mineral lattices.

(c) Remove from dessicator and make a new diffraction curve from 4° to 15° 2θ immediately. Make sure slide is placed in same orientation as in part 6(a).

(d) Remove slide and carefully place in an ignition oven for one hour at 550°C. Remove and cool in a dessicator. After a short while when slide is still warm make a third diffraction curve with this same slide from 4° to 15° 2θ.

(e) Peaks on the diffractograms are analyzed and the various minerals identified. Qualitative and quantitative analysis may also be done if desired.

(f) If the presence of kaolinite is suspected proceed with part 7.

7. Testing for Kaolinite

(a) To the remaining sample in the centrifuge tube add 10 ml 5 N Hydrochloric Acid (HCl). Heat to the boiling point in the water bath for one hour. Shake occasionally.

(b) Centrifuge and decant twice.

(c) Prepare a new glass slide and run a diffraction curve from 4° to 15°. This technique should destroy all other minerals except kaolinite. If it is present, its characteristic peak will remain.

Reagents and Equipment

Calgon: 32 g of reagent grade $NaPO_3$, Sodium Metaphosphate or "Calgon" water softener mixed with 8 g of sodium carbonate.

Citrate Solution: (i) 0.6 M Citric Acid = 126 g/l; (ii) 1.8 M NaOH = 72 g/l; (iii) 0.3 M Sodium Citrate = 88 g/l. Mix equal volumes of (i)+(ii) and (iii). For 500 ml solution mix 12 g (i); 9g (ii); 2 g (iii) amd 500 ml distilled water.

Concentrated HCl: 5 N reagent grade.

Hydrogen Peroxide 10%: A 3:1 dilution of reagent 30% H_2O_2. Do not store in unvented laboratory refrigerators. Note precautions concerning use.

Sodium Bicarbonate: Use 0.6 M $NaHCO_3$, Sodium Hydrogen Carbonate = 50.4 g/l.

Sodium Acetate: 1 N $C_2H_3NaO_2$ at pH 5.0 is a mixture of 82 g $C_2H_3NaO_2$ plus 27 ml Acetic Acid added to one liter of distilled water. Adjust to pH 5 by adding small amounts of one or the other.

Magnesium Acetate: 1 M $Mg(C_2H_3O_2)_4H_2O$ = 214 g/l.

Acidified Magnesium Acetate: A 1:1 mixture of 1 N HCl and 1 M $Mg(C_2H_3O_2)\cdot 4H_2O$.

Sodium Dithionite: $Na_2S_2O_4$. Gives off irritating fumes.

Glycol: Ethylene Glycol is recommended, as glycerine or glycerol require heating to provide proper saturation of specimens.

Dessicator Bottles: Use 500 ml bottles, with 25 cm rubber transfer hoses and two strong clamps.

Glass Slides: Petrographic 27 x $46^1/2$ mm.

Centrifuge Tubes: Graduated 15 ml.

APPENDIX B

APPENDIX B

CHEMICAL, PHYSICAL AND MINERALOGICAL DATA SUMMARIES FOR THOR LAKE SOILS

TABLE XIX

CHEMICAL AND PHYSICAL DATA SUMMARY FOR THOR LAKE SOILS

Site and Soil Type	Horizon	Field Ref. No.	Depth (cm)	pH H_2O	pH $CaCl_2$	%O.M.	Particle Size (microns)					P (ppm)	K (ppm)	Mg (ppm)	B.D. (g/cc)	P.D. (g/cc)
							2000-500	500-177	177-53	53-10	<10					
A. Placic Humo-Ferric Podzol	Ahej	197A	4	5.5	3.8	8.5	25.5	34.2	26.4	13.5	0.6	12	16	12		
	Bfgc1	197	10	5.3	4.5	2.5	22.1	24.6	31.5	21.3	0.5	45	24	12		
	Bfgc3	198	30	5.4	4.4	2.7	33.6	29.9	24.0	12.1	0.4	59	24	12		
B. Placic Humo-Ferric Podzol	Ae	72	2	4.1	3.6	3.1	18.8	38.9	31.2	10.2	0.9	4	36	46		2.40
	Bf	73	12	5.4	4.4	4.4	17.7	62.2	17.0	2.5	0.6	51	36	40		2.41
	Bfc	78	19	4.9	4.8	0.9	10.7	53.1	33.6	2.6	0.0	28	16	8	2.15	
	Bfc	74	20	4.9	4.5	1.3	20.8	59.4	18.5	1.3	0.0	52	16	8	2.31	2.52
	Bm	75	36	5.7	4.8	2.7	23.3	64.0	12.0	0.6	0.1	8	16	36	2.06	2.53
	BC	76	50	5.5	4.7	0.1	19.8	78.0	2.1	0.2	0.0	6	12	8		2.54
	Cg1	77	75	5.8	5.1	0.0	18.5	74.0	7.3	0.2	0.1	6	20	36		2.55
	Cg21	95	100	6.7	6.0	0.0	28.2	27.5	32.8	11.3	0.2	5	48	46		
	Cg22	96	130	6.7	6.0	0.0	33.7	27.3	26.5	12.1	0.4	5	44	50		
	Cg23	97	160	6.6	5.7	0.0	33.1	27.9	28.6	10.2	0.2	5	44	50		
C. Orthic Humo-Ferric Podzol	Ae	156	7	5.9	3.8	4.1	19.0	26.5	28.1	25.1	1.3	9	32	16		
	Bf	157	12	6.2	4.9	4.3	24.2	28.2	29.9	16.8	0.8	100	20	8		
	Bm2	158	25	6.5	5.4	2.6	23.3	27.7	27.9	20.8	0.3	10	26	12		
	BC	159	45	6.6	5.7	2.5	23.3	26.0	28.8	21.6	0.3	8	32	12		
	Cl	160	65	6.6	5.7	2.4	21.2	26.7	31.7	20.1	0.3	8	20	8		
	Cg	161	90	6.5	5.9	0.5	16.3	24.7	37.9	20.7	0.4	5	16	12		
	Cg	162	105	6.3	6.0	0.2	19.2	24.6	30.1	25.7	0.4	4	26	20		
D. Fragic Humic Podzol	Ah	200	5	4.9	3.6	13.9	20.6	33.1	32.6	12.6	1.1	17	104	24		
	Bh	201	10	4.6	4.1	3.2	20.6	26.1	36.4	22.7	0.9	110	32	16		
	Bf	202	20	4.7	4.2	3.8	24.3	30.5	24.7	14.9	0.6	120	24	12		
E. Fera Glysol	Ah	203	2	5.4	4.5	10.8	21.1	32.4	32.7	13.6	0.2	110	220	102		
	Bf	204	8	4.9	4.5	2.5	20.9	27.3	27.1	23.5	1.2	120	32	16		
F. Degraded Dystric Brunisol	Bm2	98	12	5.0	4.8	0.4	68.0	20.5	7.2	3.9	0.4	4	32	20		

Table XIX Continued...

Table XIX Continued...

Site and Soil Type	Horizon	Field Ref. No.	Depth (cm)	pH H_2O	pH $CaCl_2$	%O.M.	Particle Size (microns) 2000-500	500-177	177-53	53-10	<10	P (ppm)	K (ppm)	Mg (ppm)	B.D. (g/cc)	P.D. (g/cc)
G. Fragic Humo-Ferric Podzol	Ae1	2	2	5.1	4.2	0.6	10.5	35.4	22.4	29.8	1.9	6	28	36	1.39	2.45
	Ae1	1	5	5.0	4.3	0.8	21.7	26.5	28.6	21.7	1.5	6	20	12		
	Ae2	3	8	5.4	4.2	0.1	22.9	44.2	22.7	9.3	0.9	6	16	12		
	Bf1	4	13	6.1	5.1	1.4	26.9	24.7	19.9	27.8	0.7	65	40	40		2.43
	Bf1	5	15	5.4	5.1	2.1	20.4	24.0	18.2	36.2	1.2	6	24	12		2.25
	BA	21	15	4.5	3.9	1.4	13.2	28.4	25.5	31.3	1.6	19	16	12		
	Bf2	6	22	6.0	5.4	0.7	25.8	25.0	22.0	25.6	1.6	22	28	36		2.56
	Bfx1	7	25	4.9	4.8	1.2	33.2	40.7	21.5	4.6	0.0	48	12	8		
	Bfx1	8	30	5.5	4.8	1.5	26.6	58.7	11.6	2.8	0.3	70	20	32		
	Bf2	9	30	4.6	4.6	0.9	28.0	50.4	14.9	6.1	0.4	21	12	8		
	Bf2	10	35	5.5	5.0	1.2	45.9	47.0	5.6	0.9	0.6	44	20	12	2.11	
	Bfx2	11	40	5.8	5.1	1.0	18.4	20.6	16.3	43.7	1.0	6	24	12		
	Bfx2	12	36	5.0	4.4	2.6	61.7	27.7	7.4	3.1	0.1	120	28	12		2.55
	Bfc	22	40	5.4	4.7	0.7	17.4	52.3	27.0	3.2	0.1	21	16	12		2.50
	Bfc	13	45	5.6	4.6	0.9	28.0	54.2	15.0	2.6	0.2	77	16	12	2.35	
	Bfx2	14	55	5.4	5.0	0.6	55.1	41.6	2.3	0.8	0.2	42	12	8		
	Bf2	20	58	5.5	4.5	0.1	58.2	31.6	7.9	2.2	0.1	8	16	8		
	Cg1	15	60	6.3	5.7	0.5	24.0	26.7	25.3	23.1	0.8	9	32	12		
	Cgtj	16	65	6.1	4.9	1.3	35.3	30.2	18.9	14.5	1.1	8	20	12		
	Cgtj	17	90	6.5	5.5	0.0	28.4	27.7	20.3	22.7	0.9	6	20	8		
	Cg2	18	100	5.5	5.1	0.5	35.2	36.9	18.3	9.0	0.6	5	24	12		
	Cg2	19	105	5.8	4.9	0.1	56.2	34.2	8.5	1.0	0.1	7	12	8		

TABLE XX

X-RAY IDENTIFICATION OF MINERALS IN THE CLAY FRACTION OF THOR LAKE SOILS
(PERCENTAGE OF TOTAL PEAK AREA)

Site	Horizon	Feldspar Peaks in Å												Anatase		Hornblende	QTCF* Ratio	FTCF* Ratio
		2.81	2.85	2.90	2.94	3.00	3.19	3.24	3.66	3.77	3.85	4.04	6.46	2.38	3.51Å	8.42Å		
A	Bfg3	--	0.8	0.7	1.5	0.5	10.1	3.7	1.7	1.3	0.8	2.7	1.2	2.7	2.8	1.2	13.1	0.4
B	Ae	--	--	--	0.5	--	4.9	5.7	0.8	0.5	--	0.5	0.6	0.9	0.6	0.4	7.1	1.2
	Bf	--	--	--	--	--	5.1	4.4	--	--	--	--	--	--	--	2.0	14.6	0.9
	Bm	1.8	--	--	--	--	7.3	10.1	--	--	--	--	1.2	--	--	10.7	4.8	1.4
	Cg1	--	--	--	--	--	5.2	7.5	--	--	--	--	--	--	--	2.4	7.7	1.4
	Cg21	--	0.5	--	4.8	--	17.5	5.0	3.4	1.9	1.4	4.6	--	2.4	3.4	1.4	7.1	0.3
	Cg22	--	0.5	0.5	2.0	1.5	13.3	5.1	0.7	3.5	1.1	2.8	1.2	1.7	4.9	1.7	7.4	0.4
	Cg23		0.6	0.6	2.0	0.9	14.5	4.6	2.9	2.1	1.0	3.1	1.0	2.2	3.1	1.4	8.3	0.4
C	Ae	--	--	1.2	1.5	--	16.8	4.0	1.5	0.9	0.9	2.5	0.6	1.1	1.2	0.2	8.1	0.2
	Bf	--	--	--	0.6	--	13.2	5.4	0.4	1.3	--	3.4	0.4	1.7	1.6	1.3	8.7	0.4
	Bm2	--	0.5	--	1.1	0.5	14.0	3.9	1.1	1.6	0.6	2.6	0.9	3.2	3.2	0.6	10.3	0.3
	BC	--	0.6	--	0.7	0.3	17.8	5.7	1.9	1.4	0.3	2.3	0.7	1.6	1.6	1.5	6.7	0.3
	C1	--	0.7	0.2	1.1	1.0	14.8	4.8	1.2	1.8	--	3.2	1.1	2.0	2.0	1.4	9.0	0.3
	Cg	--	0.4	0.4	2.1	0.6	10.1	3.5	1.5	2.0	0.9	3.7	1.2	2.8	4.4	1.0	12.6	0.4
	Cg	--	0.4	0.4	1.7	1.0	14.1	3.8	1.6	3.2	0.4	3.9	1.9	2.9	5.0	1.8	9.1	0.3
D	Ah	--	--	0.5	0.5	--	12.6	9.9	1.4	1.5	0.6	1.5	--	1.9	2.4	--	5.9	0.8
	Bf	--	--	--	--	--	19.5	20.5	0.4	1.1	--	0.6	1.3	0.8	2.4	1.6	2.0	1.1
E	Bf	--	0.9	0.7	2.0	1.5	14.0	5.0	2.3	2.2	0.9	2.3	0.7	3.6	3.6	0.8	6.7	0.5
F	Bm2	0.5	1.5	--	--	--	10.9	8.4	--	0.4	0.5	--	0.8	--	--	3.2	2.5	0.8
G	Ae1	--	0.7	--	2.7	0.9	9.7	5.9	1.9	2.5	0.9	2.1	1.0	1.1	2.3	0.5	6.3	0.6
	Bf1	--	--	1.1	0.4	--	9.7	5.5	1.2	1.3	0.7	3.0	--	2.3	2.0	0.8	9.6	0.6
	Bf2	--	0.7	--	1.5	0.5	11.6	3.9	1.3	1.6	0.7	2.6	1.2	2.1	2.6	0.9	11.1	0.3
	Bfx1	--	--	--	--	--	12.4	13.7	--	--	--	--	1.1	--	5.9	7.3	3.2	1.1
	Bf2	--	--	--	--	--	9.8	8.0	0.6	1.0	--	1.6	0.9	--	--	3.1	6.6	0.8
	Bfx2	--	0.9	--	--	--	6.4	5.2	--	--	--	--	--	--	--	2.6	8.4	0.8
	Cg1	--	--	0.5	2.2	0.6	11.0	2.0	1.0	1.5	1.3	3.0	0.8	2.0	3.3	0.8	20.9	0.2
	Cg1	--	--	--	1.9	1.3	8.6	5.2	2.0	1.4	0.8	3.1	1.0	2.8	3.0	1.5	9.0	0.6
	Cg2	0.3	1.2	--	1.2	--	17.4	10.3	1.0	1.5	0.4	1.9	1.2	2.1	4.1	2.2	3.6	0.6

*QTOF, FTOF are mnemonics defined in Table VII, Page 74

TABLE XX (Cont'd...)

X-RAY IDENTIFICATION OF MINERALS IN THE CLAY FRACTION OF THOR LAKE SOILS
(PERCENTAGE TOTAL PEAK AREA)

Site	Horizon	Field Ref. No.	Vm,Ch*Ch		Vm-It	Vm-It-Ch	Illite		Kaolinite			Mt	Quartz			
			14.4Å	4.78Å	12Å	13Å	10.1	4.98	7.1	3.57	2.38	15.5	4.27	3.34	2.46	2.24Å
A	Bfgc3	198	(0.6)	--	--	--	0.1	--	1.3	--	--	--	11.7	43.5	0.4	2.2
B	Ae	72	29.6	--	--	--	0.5	0.9	2.3	1.1	0.9	--	7.8	40.5	--	0.9
	Bf	73	8.5	--	--	--	--	--	2.0	1.4	1.0	--	11.2	64.4	--	--
	Bm	75	1.5	--	0.8	--	1.2	--	9.2	2.3	--	--	4.4	48.6	--	--
	Cg1	77	(0.7)	--	0.6	--	0.5	--	16.2	4.9	--	--	5.5	57.6	0.1	--
	Cg21	95	--	--	--	--	0.7	--	0.3	--	--	--	12.5	35.5	0.9	0.4
	Cg22	96	--	--	--	--	0.8	--	1.0	--	--	--	9.9	37.9	1.1	1.2
	Cg23	97	--	--	--	--	0.6	--	1.0	--	--	--	14.3	38.3	1.2	1.0
C	Ae	156	23.1	1.2	--	--	0.3	--	0.6	--	--	--	7.3	32.2	--	1.3
	Bf	157	5.1	--	--	--	0.3	--	0.7	0.4	--	--	13.4	47.2	--	1.5
	Bm2	158	6.7	--	--	--	0.3	--	1.3	0.3	--	--	12.3	40.2	0.6	2.3
	BC	159	(10.6)	--	--	--	0.3	--	1.0	0.5	--	--	10.7	37.9	--	0.9
	C1	160	(0.7)	--	--	--	0.9	--	1.1	--	--	--	13.8	43.3	--	2.0
	Cg	161	(0.3)	--	--	0.3	0.3	--	0.9	--	--	--	13.3	44.1	0.7	2.0
	Cg	162	(0.3)	--	--	--	0.2	--	1.0	--	--	--	14.8	34.4	1.7	2.7
D	Ah	200	0.6	--	--	--	0.6	0.6	--	--	--	--	9.7	58.3	--	0.8
	Bf	202	0.8	--	0.4	--	0.6	0.6	0.5	--	--	--	7.9	41.1	--	0.8
E	Bf	204	(0.9)	--	--	--	0.4	0.4	1.1	--	--	--	16.4	33.4	--	3.5
F	Bm2	98	(30.8)	1.4	--	--	0.8	0.3	7.3	8.0	--	--	3.7	21.2	0.3	--
G	Ae1	2	5.5	--	--	--	0.2	--	0.3	--	--	0.4	17.7	37.1	--	3.0
	Bf1	4	2.6	--	--	--	0.5	--	0.4	0.3	--	--	11.3	52.9	--	3.0
	Bf2	6	(6.3)	--	--	--	--	--	1.0	--	--	--	4.6	43.3	0.9	2.1
	Bfx1	8	5.6	--	--	--	1.1	--	4.5	--	--	--	4.5	44.3	--	--
	Bf2	9	5.9	--	--	--	--	--	0.9	--	2.6	--	10.4	52.8	0.4	0.4
	Bfx2	12	29.8	--	--	--	0.5	--	3.7	1.1	0.5	--	4.7	43.7	--	0.7
	Cg1	15	1.9	--	--	--	0.3	--	1.3	1.1	--	--	17.7	41.8	0.3	2.4
	Cgtj	16	(0.2)	--	--	--	0.2	--	0.9	0.6	--	--	8.3	46.8	0.5	2.2
	Cg2	18	(0.3)	--	0.5	--	0.5	--	1.5	--	--	--	12.4	37.3	--	1.5

*Figures in brackets represent the sum of Vermiculite and Chlorite, those without are Vermiculite only.

Vm = Vermiculite
Ch = Chlorite
It = Illite
Mt = Montmorillonite

TABLE XXI

CLAY MINERALS PRESENT IN THE <2μ FRACTION OF THOR LAKE SOILS EXPRESSED AS 100% OF TOTAL

Site	Horizon	% Clay Min. of Total <2μ Fraction	% Vm*	% Ch	% It	% Ka	% Mt	% Vm-It	% Vm-It-Ch
A	Bfgc3	2.0	26.0	3.2	5.0	65.7	--	--	--
B	Ae	31.4	91.3	--	1.6	7.1	--	--	--
	Bf	10.5	80.7	--	--	19.3	--	--	--
	Bm	11.9	11.6	--	9.2	72.9	--	6.2	--
	Cg1	18.0	3.7	--	3.7	88.8	--	3.7	--
	Cg21	1.0	--	--	66.7	33.3	--	--	--
	Cg22	1.8	--	--	43.9	56.1	--	--	--
	Cg23	1.6	--	--	38.4	61.6	--	--	--
C	Ae	24.0	96.9	--	0.6	2.5	--	--	--
	Bf	6.1	82.1	--	6.3	11.6	--	--	--
	Bm2	8.3	80.8	--	3.8	15.4	--	--	--
	BC	11.9	75.3	9.1	2.8	12.8	--	--	--
	C1	2.7	16.3	8.5	34.1	41.1	--	--	--
	Cg	1.8	12.4	5.5	15.3	48.6	--	--	18.2
	Cg	1.5	15.4	3.4	16.1	65.1	--	--	--
D	Ah	1.2	50.0	--	50.0	--	--	--	--
	Bf	2.3	34.9	--	26.0	21.8	--	17.4	--
E	Bf	2.4	37.8	10.2	16.9	45.1	--	--	--
F	Bm2	38.9	64.8	14.3	1.9	19.0	--	--	--
G	Ae1	6.4	85.3	--	3.5	5.1	6.1	--	--
	Bf1	3.5	65.0	--	20.0	15.0	--	--	---
	Bf2	7.3	65.9	20.8	—	13.3	—	--	--
	Bfx1	11.2	50.0	--	10.0	40.0	--	--	--
	Bf2	6.8	96.1	--	--	3.9	--	--	--
	Bfx2	34.0	87.8	--	1.4	10.8	--	--	--
	Cg1	4.5	55.0	--	8.3	36.6	—	--	--
	Cgtj	1.3	6.3	9.3	15.3	69.0	—	--	--
	Cg2	2.8	4.5	5.9	18.7	52.3	—	--	--

*Vm = Vermiculite Ch = Chlorite Mt = Montmorillonite It = Illite Ka = Kaolinite

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