

GEOCHEMICAL WEATHERING IN A
TOPOSEQUENCE AT THOR LAKE, N.W.T.

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THE INTENSITY OF GEOCHEMICAL WEATHERING
IN A TOPOSEQUENCE FORCED ON GRANITIC TILL
AT THOR LAKE, NORTHWEST TERRITORIES

by

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ABSTRACT

From standard cell data and a principal component analysis, the intensity of geochemical weathering in the toposequence developed at Thor Lake, Northwest Territories was determined as follows: Degraded Dystric Brunisols formed on the dry crestal sites were weakly weathered; the Orthic Humo-Ferric Podzol found on moist terrace and slope sites as well as the Gleyed Humic Podzol situated adjacent to the thaw pond were moderately weathered in relation to the other soils; whereas the Gleyed Humo-Ferric Podzol located in the moist linear depressions revealed the maximum intensity of geochemical weathering, that is, the maximum removal of mobile ions and the greatest alteration from a stable parent material.

It was established that the iron-magnesium bearing minerals were initially weathered from the parent-material; calcium, sodium, and then potassium were removed by the soil solution from the A horizon; iron, aluminum, and phosphorus were the prime depositional cations in the B horizon with silicon increasing as a residual cation in the A horizon.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

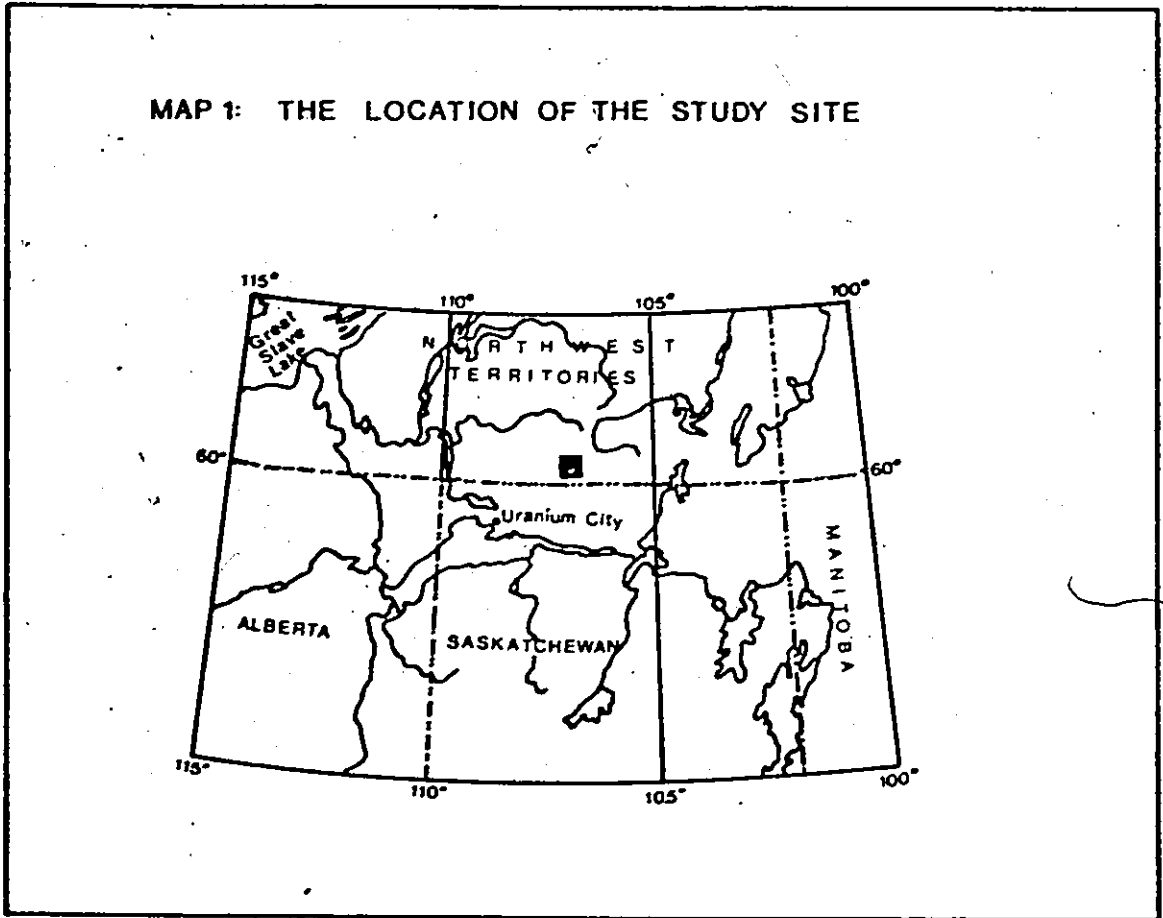
Geochemical weathering is primarily the inorganic alteration of the mineral constituents in the soil profile. The effectiveness of geochemical weathering depends on the climate, biological activity, parent material, topography, and time (Carroll, 1970). The resulting chemical alterations of the constituent minerals are due to chemical reactions occurring between the parent material and the soil environment. A geochemical analysis or total chemical composition of the soil involves the determination of the ten most common oxides found in the earth's crust, namely, silicon, SiO_2 ; aluminum, Al_2O_3 ; iron, Fe_2O_3 ; magnesium, MgO ; calcium, CaO ; potassium, K_2O ; sodium, Na_2O ; manganese, MnO ; titanium, TiO_2 , and phosphorus, P_2O_5 .

This thesis proposes to investigate the intensity of geochemical weathering in a toposequence of soils formed on granitic glacial till, located at Thor Lake, Northwest Territories ($106^\circ 53' 58''\text{W}$, $60^\circ 20' 4''\text{N}$) approximately eighty-five miles northeast of Uranium City, Saskatchewan (Map 1).

No Canadian study could be found in the literature which specifically examined the geochemical composition of soils developed in the Subarctic¹ area of the Precambrian Shield. Many of the available studies are concentrated in the MacKenzie River Valley on primarily calcareous alluvial soils and tend to discuss only the physical and chemical

¹ Region defined by soil climate in The National Atlas of Canada.

MAP 1: THE LOCATION OF THE STUDY SITE



properties as well as the development of peatlands: Wright, Leahey, and Rice (1959); Pawluk (1960); Day and Rice (1964); Tarnocai (1973); Pettapiece (1974); Pettapiece and Zoltai (1974); Walmsley and Lavkulich (1975a, 1975b); Zoltai and Tarnocai (1975). However, the procedures and conclusions reported in some of these investigations have a direct relationship to the proposed problem.

Wright et al. (1959) sampled an Alluvial (youngest), Brown Wooded, and Grey Wooded (oldest) soil developed on calcareous alluvium at Hay River, Northwest Territories (116° W, 61° N). Obtaining the total geochemical analyses of the various mineral horizons and then calculating molecular ratios, the relative translocation of the elements within the soil could be discussed in terms of soil formation. The following conclusions were obtained:

1. A greater loss of silica than sesquioxides ($Al_2O_3 + Fe_2O_3$) in the earlier stages of development took place at the same time as the removal of carbonates.
2. Calcium was removed about twice as rapidly as magnesium from the parent materials during development of the solum.
3. A loss of bases especially calcium after the removal of carbonates was accompanied by a decrease in pH and a loss of organic matter.
4. Marked eluviation of clay and accelerated leaching of iron and aluminum with respect to silica resulted in a distinct siliceous eluviated layer (A_2) underlain by a clay- and sesquioxide-enriched layer (B).

Wright et al. (1959) p. 43.

Pawluk (1960), in a region just south of the Subarctic, at Fort McMurray, Alberta, incorporated a geochemical analysis into his investigation of the soils developed on glacial and glacial-fluvial materials. He found that free silica had the highest concentrations in the Ae horizon; while, iron and aluminum oxides had well-defined accumulations and highest concentrations in the Bir horizons.

T.R. Moore (1974) stated that the development of podzolic features is a function of the release of iron and aluminum from minerals, and the ability of organic compounds to translocate the iron and aluminum oxides and hydroxides. Wicklund and Whiteside (1959) studied the degree of podzolization in the Caribou catena, a toposequence of soils located in Northeastern New Brunswick on Paleozoic calcareous shales and slates, by comparing the differences in silica and sesquioxide contents between the A, B, and C horizons. Despite differences in environmental conditions, observations based on geochemical data were similar to those found by Wright et al. (1959) and Pawluk (1960). It was established that concentration of silica and losses of sesquioxides occurred in the A₂ horizons of well-drained soils; whereas, the B horizons showed relative decreases in silica content and concentrations of sesquioxides, especially aluminum. Phosphorus was slightly higher in the B horizons than in the A or C horizons. McKeague (1965) examined the total chemical composition of the Uplands Catena -- three soils with marked moisture differences located on sandy deposits near Ottawa. Data revealed relative losses of Al₂O₃, Fe₂O₃, MnO, CaO, MgO, and P₂O₅ from the Ae horizons of the Podzols and relative gains in SiO₂. In relationship to the A and C horizons, a maximum of free iron oxide (Fe₂O₃) was noted in the B horizons with the total iron maxima occurring specifically in the Bh_f and Bg horizons of the Gleyed Orthic Podzol and Orthic Gleysol. Similarly, Russian soil scientists, Sokolova (1964), Sokolova and Smirnova (1965), Belousova et al. (1973), and Pshenichnikov (1974) in studies with podzolic soils report an accumulation of silica in the eluvial horizon (Ae) with a corresponding accumulation of iron and aluminum in the illuvial horizon (B).

G.G. Beckmann (1975) utilizes Barth's (1948) standard cell concept to determine the relative gains and losses of the elements during soil formation. The standard cell concept is based on the fact that in most rocks oxygen makes up 92%

of the volume and the metal cations and silicon account for the remaining 8% (Carroll, 1970; Beckmann, 1975). Therefore, a standard cell of 160 oxygen ions could be taken as the basis of comparison since the chemical composition of most silicate rocks is associated with 100 cations. These 100 cations associated with a cell of 160 oxygen ions have the same mathematical order as the determined weight percentages for the oxides which have a base of 100. Consequently, recalculating the weight percentages of the ten oxides obtained for each horizon in terms of the constituent cations (that is, eliminating the effect of oxygen) the A and B horizon of the soil could be assessed in relationship to the C horizon for relative gains and losses of cations. Furthermore, Beckmann states that inferences could be obtained from "the changes in the number of 'cations', whether they have come from relative enrichment within particular layers or by some form of absolute accumulation by transport within the profile" (Beckmann, 1975, p. 303).

In one of the soils investigated by Beckmann, a Lithosol-podzolic intergrade developed on granite, there was a removal of the more mobile bases, Na and Ca, but slight alteration from the parent material to soil was apparent because of nearly constant amounts of K, Mg, Ti, Si and Al throughout the solum. Using the calculations of the number of cations per standard cell for the soil horizons developed on granodiorite, Beckmann distinguished four distinct zones within the weathering column: an A horizon, B horizon, B transitional horizon, and a C horizon. He noted the following conclusions regarding the distribution of cations:

- a) Uniform distribution of the cations from the parent material through the C horizon, and into the transitional B horizon suggests a continuity of weathering through one uniform mass of material.
- b) Relatively low numbers of sodium and calcium ions in the B horizon may reflect the varying stability in different weathering environments; that is, the type of minerals

- present and the particle size of the soil material.
- c) Aluminum, iron and silicon contents in the A and B horizons correspond to observed changes in the quantity of silicate clays and iron oxides in these horizons.

(Beckmann, 1975, p.309)

Further investigation using principal component analysis with the standard cell data demonstrated the degree of similarity between the horizons and indicated relationships between the cations. The first and second principal component respectively accounted for 47% and 24% of the variation (Beckmann, 1975, p. 312). The first component designated as a mineral assemblage axis reflected differences in parent material since the profiles studied were developed on basalt, andesite, granodiorite and granite. The second component distinguished general trends in soil development; that is, the relationships of the horizon structure -- A horizon then the B horizon followed by the parent material of the C horizon. When individual cations were considered, the second component was interpreted as reflecting a weathering trend because of the contrast between the hydroxyl ions (OH) and the more mobile ions Na, Ca, and Mg.

From the literature reported, some cations appear more prevalent than others, and as a result show significant losses or gains in the soil profile. This phenomena is related first to the initial composition of the parent material itself and second to the relative mobilities of the individual ions. The following list of some minerals usually found in granites is arranged in increasing order of stability according to the sequences reported by Brewer (1964): apatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$; hornblende $(\text{Na}, \text{K})_{0-1}\text{Ca}_2(\text{Mg}, \text{Fe}^{+2}, \text{Fe}^{+3}, \text{Al})_5[\text{Si}_{6-7}\text{Al}_{2-1}\text{O}_{22}](\text{OH}, \text{F})_2$; biotite $\text{K}_2(\text{Mg}, \text{Fe}^{+2})_{6-4}(\text{Fe}^{+3}, \text{Al}, \text{Ti})_{0-2}[\text{Si}_{6-5}\text{Al}_{2-3}\text{O}_{20}](\text{OH}, \text{F})_4$; muscovite $\text{K}_2\text{Al}_4[\text{Si}_6\text{Al}_2\text{O}_{20}](\text{OH}, \text{F})_4$; plagioclase feldspars $\text{Na}[\text{AlSi}_3\text{O}_8] - \text{Ca}[\text{Al}_2\text{Si}_2\text{O}_8]$; alkali feldspars $(\text{K}, \text{Na})[\text{AlSi}_3\text{O}_8]$; quartz SiO_2 . When these minerals are subjected to weathering processes, the constituent ions are released according to their relative ionic mobilities.

Several sequences of ion mobilities have been established:

Ca > Na > Mg > K > Si > Al = Fe	Polynov (1937)
Na(K) > Mg > Ca > Fe > Al > Si	Mason (1966)
Na ⁺ = Mg ⁺⁺ = Ca ⁺⁺ > K ⁺ > Fe ⁺⁺ > Si ⁴⁺ > Fe ³⁺ > Al ³⁺	Loughnan (1969)

In general, the most mobile ions are the basic cations Ca, Na, Mg, and K; whereas, Si, Fe, and Al ions are the least mobile. The precise order in the above sequences for the basic cations cannot be fixed since the relative mobility for each ion depends on the weathering environment present as well as the stability of the mineral sources. Chesworth (1973) emphasizes that the relatively immobile oxides of SiO₂, Al₂O₃, and Fe₂O₃ will be concentrated in the weathered products (residua) that are derived from the parent material.

Therefore, it is proposed that by determining the geochemical composition of each soil horizon, the relative intensity of weathering can be assessed in soil profiles by delineating horizons which show the maximum removal of mobile ions and the greatest alteration from a stable parent material.

CHAPTER 2

PHYSICAL DESCRIPTION OF THE STUDY AREA

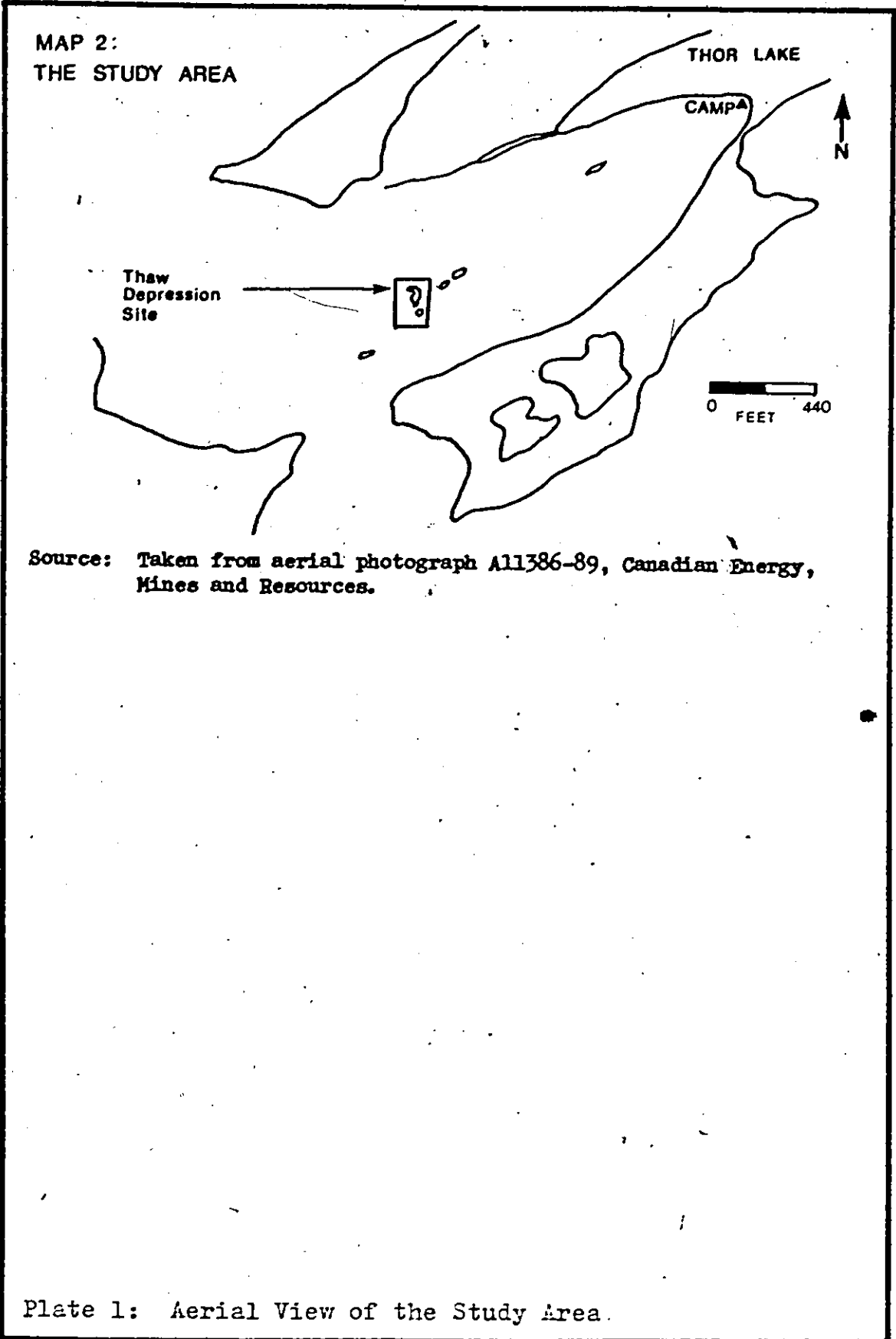
1. Soil Climate

The study area is located in the Subarctic region with a mean annual soil temperature -6.6°C to 2.7°C (20°F to 36°F) and a mean summer soil temperature 5°C to 8.3°C (41°F to 47°F). A short growing season exists with less than 120 days over 5°C (41°F). The average annual precipitation is less than 30.5 cm (12 inches). The soil moisture regime is classified as subaquic; that is, the soil is saturated for short periods of the year (less than 120 days). (National Atlas of Canada, 1974, p. 44.)

2. Geology and Geomorphology

The site exists within the Kazan Region (Churchill Province) of the Canadian Shield consisting primarily of migmatic and granitic gneiss dating to Archean age (2500 million years before present, m.y.b.p.) that has undergone Kenoran (2300 m.y.b.p.) and Hudsonian (1700 m.y.b.p.) orogenies (National Atlas of Canada, p. 30.)

Hoadley (1955) conducting a preliminary geologic survey of the Abitau Lake Region which included the Thor Lake study site found outcrops of grey, pink, and white quartz feldspar gneiss together with massive pink granite, quartz-biotite gneiss, granodiorite and quartz monzonite. These rocks constitute the source materials for the glacial drift deposited approximately 9000 years ago (GSC, 1970) which covered at least 90 per cent of the area in an interlocking



network of drumlins and drumlinoid forms (Hoadley, 1955).

The study area is located at a thaw depression situated on the crest of one of the northeast-southwest trending drumlins as shown in Map 2.

3. Vegetation and Soil Humus

The drumlin crests are characterized by open woodland vegetation -- a dense lichen floor interrupted by black spruce, tamarack, and labrador tea shrubs. Vegetation in the depressions varies according to the moisture regime. Drier sites tend to have a lichen cover while wetter areas are populated with sedges and moss.

Periodic fires have maintained the open woodland climax. Depending on the intensity of the fire, the accumulated humus will be partially or completely destroyed. The soil humus layers on the crestal sites are very thin (less than 2 cm) because of the following interacting factors: the actual lichen biomass available for decomposition is low; the sites tend to be dry; severe climate with low temperatures and short growing season retards significant additions through biochemical degradation, and periodic fires have removed previous accumulations. In contrast to the crestal areas, the saturated depressions have thick L-F-H horizons (maximum 30 to 40 cm). Some reasons for this difference are the following: mosses and sedges add greater biomass upon decomposition; saturated conditions during the growing season would favour decomposition as well as continual growth; fire rarely removes the vegetative cover because of the moisture present.

The actual plant species are listed in Chapter 4 with each soil profile description. A glossary is provided in Appendix II.

CHAPTER 3

METHODOLOGY: INVESTIGATIONAL TECHNIQUES

Selected soil physical and chemical properties were determined on the sampled horizons for the following two reasons:

- a) To classify the soil profiles according to the terminology adopted by the Ninth Meeting of Canada Soil Survey Committee, Saskatoon, 1973.
- b) To establish a basis of information for the formulation of an hypothesis regarding the intensity of weathering occurring in the soil profiles. The validity of this hypothesis would then be tested using geochemical data.

1. Physical Characteristics

The soil profiles were described during the June 1974 field season according to the terminology outlined in The System of Soil Classification for Canada, 1970

Colour, under moist and dry conditions was assessed with the Munsell Soil Chart.

A 50 gram portion of each sample collected was oven dried at 110°C, passed through a 2mm sieve, and treated with 30% H₂O₂ (Hydrogen peroxide) to remove organic matter in preparation for texture analysis -- the percentage of sand, silt, and clay sized fractions. A Ro-Tap shaker (Department of Geology) was used for the coarse to fine sand fractions (2mm to 0.105mm) and the Sonic Sifter (Department of Geography) for the very fine sand to medium silt and clay fractions (0.105mm to 0.02mm). Pipette analysis was not undertaken because the clay sized fraction (<0.002mm) for the weathered horizons was minimal (<1%).

2. Chemical Characteristics

The pH of each soil horizon was determined as follows:

- a) The pH in water 1:2.5 (20 grams of soil in 50ml water) using the Orion pH meter;
- b) The pH in 0.01M CaCl₂ (calcium chloride) following procedures outlined in the Tentative Manual on Soil Sampling and Methods of Analysis (CSSC) and the readings taken with the Fisher pH meter.

Organic carbon (%) was evaluated according to the Walkley-Black method (Soil Survey Laboratory Methods, USDA, p. 22).

Sodium pyrophosphate extractable Fe and Al provided a measure of the organic-complexed iron and aluminum. The extracts were prepared following the Tentative Manual procedures and then evaluated using a Perkin-Elmer 303 Atomic Absorption Spectrophotometer (Department of Geology). To obtain an estimate of amorphous forms of iron and crystalline iron oxides, Dithionite-extractable Fe was determined using colorimetric methods developed by Mehra and Jackson (1960) and cited in the Tentative Manual.

3. Geochemical Data

In preparation for X-ray fluorescence analysis, a 10 gram sample less than 250 mesh (0.063mm) was subjected to loss on ignition (the soil heated to 875°C for 1.5 hours) in order to remove the organic matter and the water of constitution (water held within the mineral structure). The pellets required for the Philips PW-1450 Spectrometer (X-ray fluorescence unit) were prepared according to the methods outlined by the McMaster University, Department of Geology with slight modifications for use with the soils being investigated. Briefly the steps are as follows:

1. Three grams of soil less than 250 mesh sieve size (fine silt and clay) are weighed into plastic beakers.
2. Approximately 4 to 6 drops of 2% Moviol solution are added to the soil and mixed very thoroughly to distribute the

moisture evenly.

3. The mixture is then poured into the apparatus -- aluminum barrel, metal discs -- and shaped with the plastic plunger to form a circular pellet or disc.
4. Boric Acid crystals (Fisher Chemical Baker Analysed Reagent: 0084), approximately 5 grams are added on top of the pellet.
5. The apparatus is then placed on a hydraulic press and subjected to 10 tons pressure per square inch (psi) for nearly 60 seconds. The pressure must be slowly released in order to prevent breakage.
6. The pellet is removed from the apparatus and is ready for analysis in the spectrometer.

Since standard soil pellets were not available, standard rock pellets obtained from the Department of Geology were evaluated with the prepared soil pellets during X-ray analysis in order to calculate the weight percentages of the ten major elements. The calculation of the weight percentages was accomplished by the computer programs referred to in Brown et al. (1973) and modified by Michael Marchand (1974, McMaster University) for the X-ray fluorescence unit.

4. Analytical Procedures

The weight percentages and calculated molecular ratios for each soil horizon were examined for patterns of gains and losses in the soil profile.

Following computational procedures outlined by Beckmann (1975), the number of individual cations per standard cell were plotted on semi-logarithmic paper in order to delineate zones of gains or losses of cations within the soil solum in relationship to the C horizon.

Comparison of the soil profiles in terms of relative weathering intensity was accomplished by principal component analysis (BMD OLM).

CHAPTER 4

SOIL PROFILE DESCRIPTIONS

The actual sampling sites, alphabetically recorded as Soil A, B, C, D, and E are shown on Map 3.

The sites chosen are representative of the following topographic features found at the study area: Soils A and D, the dry crestal areas of the drumlins; Soil B, the relatively moist intermediate slopes and terraces of the drumlins; Soil C, the hydromorphic environment adjacent to the thaw depressions which frequently occur on the drumlins, and Soil E, the linear depressions between drumlinoid forms.

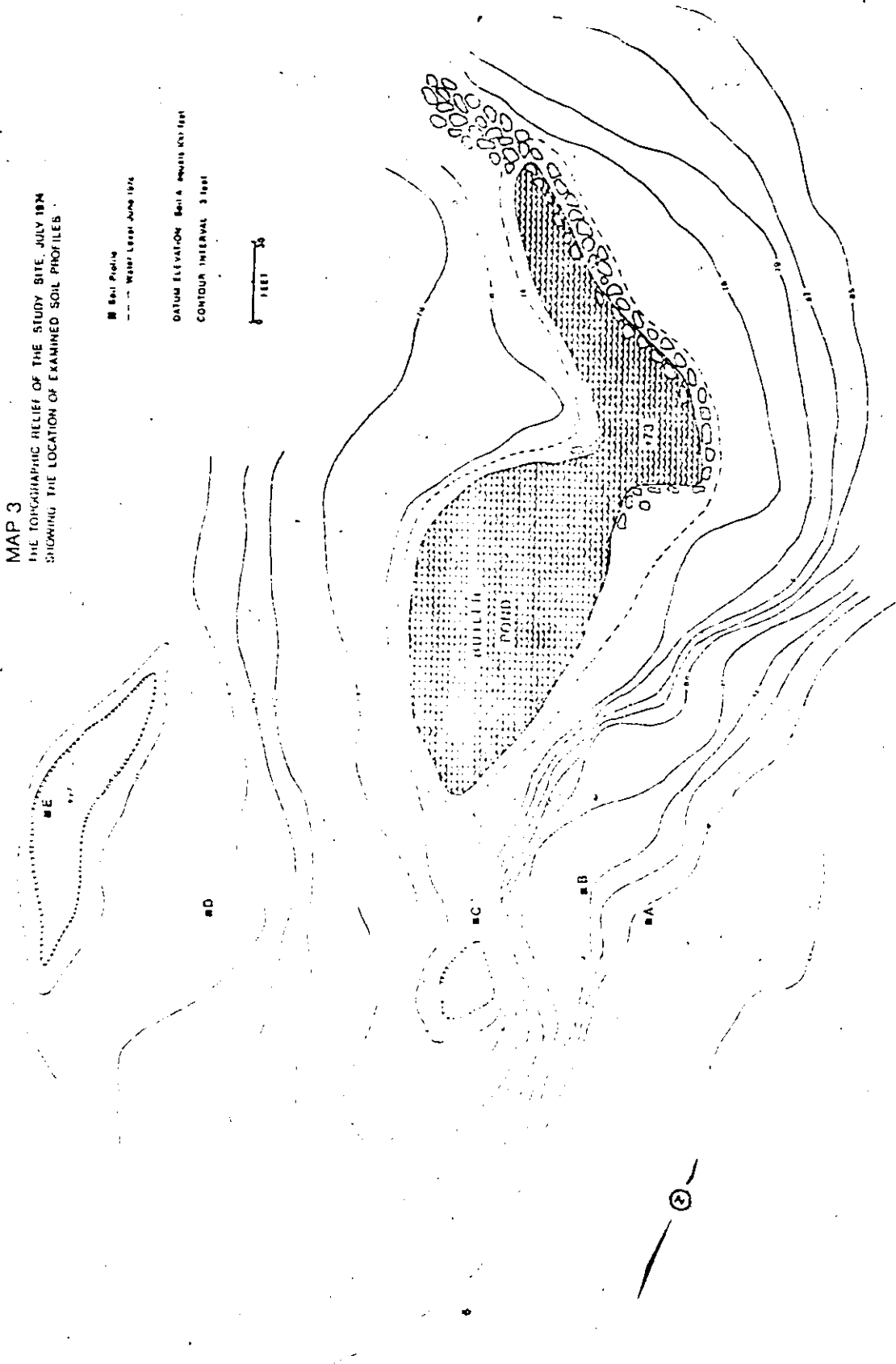
The soil profile descriptions are given on individual pages together with photographs of the surrounding vegetation and soil horizons. A glossary for the vegetative species is provided in Appendix II.

MAP 3
THE TOPOGRAPHIC RELIEF OF THE STUDY SITE, JULY 1974
SHOWING THE LOCATION OF EXAMINED SOIL PROFILES

■ Soil Profile
--- Water Level June 1974

DATUM ELEVATION: Sea Level
CONTOUR INTERVAL: 3 FEET

0 10 20 30
FEET



SOIL A

Topography: Crest of drumlin, dry, well-drained.

Surrounding Vegetation: *Picea mariana*, *Ledum groenlandicum*, *Vaccinium myrtilloides*, *Vaccinium uliginosum*, *Polytrichum piliferum*, *Cladonia crispata*, *Cladonia coccifera*, *Cladonia uncialis*, *Cetraria nivalis*, *Stereocaulon paschale*

Classification: Degraded Dystric Brunisol

Horizon	Depth (cm)	Description
L-F	2-0	Lichens, moss. Very dark grey (5YR 3/1 d) dense, compact; incorporated mineral grains.
Ae	0-1/2	Pinkish grey (7.5YR 6/2 m), light grey (10YR 7/1 d) loamy sand; granitic gravels; loose, friable; numerous lateral roots; wavy boundary; pH 4.5.
Ba ₁	1/2-4/6	Dark brown (7.5YR 4/4 m), very pale brown (10YR 7/3 d), loamy sand; granitic fragments; loose, very friable; few fine roots, numerous root channels often lined with organic matter; clear, slightly wavy boundary; pH 5.0.
Ba ₂	4/6-9/10	Brownish yellow (10YR 6/6 m), pale yellow (2.5Y 7/4 d) loamy sand; granitic gravels; loose, very friable; some root channels, fine roots; clear, slightly wavy boundary; pH 5.5.
BC	9/10-19/20	Light yellow brown (10YR 6/4 m), pale yellow (2.5Y 8/4 d), loamy sand; loose, very friable; root channels, some fine roots; diffuse, irregular boundary; pH 5.6.
C	19/20-27	Pale brown (10YR 6/3 m), white (10YR 8/1 d), loamy sand contains silt coated granitic gravel fragments; loose, very friable; clear irregular boundary; pH 5.9.
IIC	27-52+	Light brownish grey (2.5YR 6/2 m), white (10YR 8/1 d), silt loam; slightly plastic; large stones; pH 5.9.

SOIL A: DEGRADED DYSTRIC BRUNISOL

Surrounding Vegetation

SOIL B

Topography: Drumlin terrace, moist, well-drained.

Surrounding Vegetation: *Picea mariana*, *Betula* sp., *Ledum groenlandicum*, *Vaccinium vitis-idea*, *Vaccinium myrtilloides*, *Empetrum hermaphroditum*, *Cladonia coccifera*, *C. uncialis*, *C. gonecha*, *C. gracilis*, *Cetraria islandica*, *Cetraria nivalis*, *Stereocaulon paschale*.

Classification: Orthic Humo-Ferric Podzol

Horizon	Depth (cm)	Description
L-F	4-0	Dark reddish brown (5YR 2/2 d); dense lichen growth, large black spruce roots both lateral and horizontal; abundant fine roots, compact; some charcoal, some incorporated mineral grains; clear boundary.
Ae	0-5/7	Pinkish grey (5YR 6/2 m), light grey (10YR 7/1 d) sand; washed quartz grains, granitic fragments; very friable; abundant fine roots, few coarse roots; abrupt wavy boundary caused by roots; pH 4.9.
BA	5/7-5/9	Yellow brown (10YR 5/4 m) sand; friable; very discontinuous often non-existent, undulating boundary caused by stones and roots. (Not sampled)
Bf	5/9-10/12	Dark reddish brown (2.5YR 2.5/4 m), yellowish brown (10YR 5/6 d) sand; very friable; abundant fine roots; irregular, broken, discontinuous boundary; pH 5.4.
Bm	10/12-15	Strong brown (7.5YR 5/6 m), olive yellow (2.5Y 6/6 d) sand; very friable, abundant fine roots, channels lined with organic matter; clear slightly irregular boundary; pH 5.4.
BC	15-24	Yellow brown (10YR 5/4 m), pale yellow (2.5Y 7/4 d) loamy sand; very friable; some organic matter coating root channels; smooth boundary; pH 5.4.
C ₁	24-31	Pale brown (10YR 6/3 m), white (2.5Y 8/2 d) loamy sand; very friable; granitic fragments silt coated; gradual smooth boundary; pH 5.7.
C ₂	31+	Light brown grey (10YR 6/2 m), white (10YR 8/1 d) loamy sand; very friable; slightly plastic; granitic fragments and gravels coated on upper surface with silt; pH 5.9.

SOIL B: ORTHIC HUMO-FERRIC PODZOL

Surrounding Vegetation

SOIL C

Topography: Base of thaw depression feature on boulder ridge separating two ponds; poorly drained; saturated for most of summer period.

Surrounding Vegetation: *Picea mariana*, *Salix* sp., *Vaccinium uliginosum*, *Polytrichum commune*, *Carex saxatilis*.

Classification: Gleyed Humic Podzol

Horizon	Depth (cm)	Description
L-F	31-26	Weak red (10R 4/3 d), mosses and sedges; fibrous; abundant roots.
H	26-0	Black (10R 2/1 m), slightly fibrous, abundant roots; dense; irregular broken boundary.
Bh	0/9-11	Dark red brown (5YR 3/3 m), brown (10YR 5/3 d) coarse sand, grains stained; loose; very friable; abundant fine roots, root channels contain organic matter; upper boundary tongues into the H horizon, lower is diffuse; pH 4.9.
Bhgj	11-27 +	Dark reddish brown (2.5YR 3/4 m) with patches reddish brown (5YR 4/4 m), yellowish brown (10YR 5/4 d) sand, some gravel, abundant decomposing lithorelics (some form clay masses, others very coarse sand to gravel pockets, visible quantities of micas), sand grains stained reddish brown; granitic fragments show silt coating on upper surfaces; roots form a mat on upper surface of boulders; pH 4.9.
C	27 +	Unable to determine a C horizon because of the vertical extent of the reddish brown B horizon, massive boulders and high water table at the time of sampling.

SOIL C: GLEYED HUMIC PODZOL

Surrounding Vegetation

SOIL D

Topography: Crest of drumlin, dry, well-drained.

Surrounding Vegetation: *Picea mariana*, *Larix laricina*, *Ledum groenlandicum*, *Vaccinium vitis-idea*, *Empetrum hermaphroditum*, *Polytrichum piliferum*, *Cladonia coccifera*, *Cladonia uncialis*, *Cladonia macroptera*.

Classification: Degraded Dystric Brunisol

Horizon	Depth (cm)	Description
L-F	2.5-0	Black (5YR 2/1 d), dense lichen cover; very fibrous, compact, some mineral incorporation; irregular, sharp boundary.
Ae }	0/1.5-1.5/3	Pinkish grey (7.5YR 6/2 m), light grey (10YR 7/1 d) sand; loose, friable; gravel, granitic fragments coated with fine silt, abundant fine to medium roots; abrupt, wavy boundary; horizon discontinuous or completely absent in sections; pH 5.5.
Bm	1.5/3-7	Strong brown (7.5YR 5/6 m), yellow (10YR 7/6 d) loamy sand, gravelly; very friable; abundant fine to coarse roots; clear boundary; pH 5.5.
BC	7-17/19	Light yellow brown (10YR 6/4 m), light grey (2.5Y 7/2 d) loamy sand, gravel; loose, very friable; wavy clear boundary; pH 5.5.
C	17/19-23/30	Pale brown (10YR 6/3 m), light grey (2.5Y 7/2 d) loamy sand; granitic fragments have coatings of silt; loose; very irregular boundary; pH 5.5.
IIC	23/30 +	Light brown grey (10YR 6/2 m), white (10YR 8/1 d) loam; contains gravels; friable; plastic; pH 5.5.

SOIL D: DEGRADED DYSTRIC BRUNISOL

Surrounding Vegetation

SOIL E

Topography: Linear depression between drumlinoid features; imperfectly drained, saturated in early spring and periodically during the summer.

Surrounding Vegetation: *Picea mariana*, *Ledum groenlandicum*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Dicranum undulatum*, *Polytrichum piliferum*, *Cladonia uncialis*, *C. gonecha*, *C. rangiferina*, *C. amourocraea*, *C. crispata*, *Nephroma arcticum*, *Stereocaulon paschale*.

Classification: Gleyed Humo-Ferric Podzol

Horizon	Depth (cm)	Description
L-H	1.5-0	Dark brown (7.5YR 3/2 d) lichen, black spruce needles, <i>V. vitis-idaea</i> leaves, moss <i>P. piliferum</i> ; dense; black spruce roots form deeper organic matter pockets.
Ahe	0-1.5/2	Pinkish grey (5YR 6/2 m), light grey (10YR 7/1 d) sand; very friable; abundant coarse roots; slightly wavy boundary; pH 4.2.
Ae	1.5/2-8/10	Light brown (7.5YR 6/4 m), light grey (10YR 7/2 d) loamy sand; loose; lithofragments have silt coatings; abundant fine roots, root channels; abrupt wavy boundary; pH 4.4.
Bhf	8/10-16	Very dusky red (10R 2.5/2 m), dark yellowish brown (10YR 3/4 d) loamy sand; compact, hard; abrupt irregular boundary; pH 4.5.
Bf	16-24	Dark reddish brown (2.5YR 3/4 m), yellowish brown (10YR 5/8 d) loamy sand, few coarse roots, irregular gradual boundary; pH 4.5.
BC	24-33/36	Strong brown (7.5YR 5/6 m), pale yellow (2.5Y 7/4 d) loamy sand, gravels; abundant medium to coarse roots; diffuse boundary; pH 4.9.
Cg	33/36-61 +	Strong brown (7.5YR 5/6 m), pale yellow (2.5Y 7/4 d), loamy sand, distinct mottling, large mottles reddish yellow (7.5YR 7/6 m), coarse sand; grains and gravel fragments coated with silt; pH 5.5.

SOIL E: GLEYED HUMO-FERRIC PODZOL

Surrounding Vegetation,

CHAPTER 5

ANALYTICAL OBSERVATIONS AND DISCUSSION

1. Physical and Chemical Characteristics

The physical and chemical characteristics of the soil horizons, shown in Table 1, were evaluated in order to first classify the soil and second to deduce the general patterns of weathering in the toposequence.

A. Crestal Locations

Profiles A and D, classified as Degraded Dystric Brunisols, are located on the dry crests of the drumlin features which surround the thaw depression. These soil profiles are weakly developed since each fails to completely satisfy all the chemical and morphological criteria³ necessary for a podzolic B horizon. However, the designation of a Bm horizon indicates that evidence for soil mineral alteration does exist. The colour in the Bm horizon has stronger chromas and hues than (a) the underlying BC horizon in Soil D; that is, from a strong brown 7.5YR 5/6 in the Bm horizon to light yellowish brown 10YR 6/4 in the BC, and (b) the underlying Bm₂ horizon in Profile A -- from a dark brown 7.5YR 4/4 in Bm₁ to brownish yellow 10YR 6/6. This difference in intensity of colour in the B horizon tends to suggest that in relationship to Soil D, Soil A has been subjected to a greater removal from the A horizon of soil materials such as

³ The criteria necessary to classify podzolic B horizons are stated in Appendix I.

TABLE I : PHYSICAL AND CHEMICAL CHARACTERISTICS

HORIZON	DEPTH (cm)	pH (0.01M CaCl ₂)	I Coarse Sand (%)	Medium Sand (%)	I Fine Sand (%)	I Very Fine Sand (%)	I Coarse Silt (%)	Medium Silt and Clay < 20μ (%)	Organic Carbon (%)	Pyrophosphate Extractable		Dichromate Extractable	
										Fe (%)	Al (%)	Fe (%)	Al (%)
SOIL A : DEGRADED DYSTRIC BRUNISOL													
Aa	0-1/2	3.6	17.2	21.1	22.9	22.7	15.0	1.0	0.76	0.04	0.04	0.18	0.18
Bm1	1/2-4/6	4.5	22.9	18.5	21.3	17.3	17.5	2.5	1.38	0.06	0.31	0.69	0.69
Bm2	4/6-9/10	4.8	22.2	18.7	20.8	18.6	16.0	3.7	0.69	0.04	0.16	0.48	0.48
Bc	9/10-19/20	5.2	19.3	17.3	20.1	17.6	20.4	5.8	0.41	0.02	0.13	0.32	0.32
C	19/20-40	5.4	17.0	17.4	19.5	20.5	22.2	3.4	0.14	0.01	0.06	0.23	0.23
IIC	40+	5.4	4.3	5.7	10.7	18.3	49.4	11.6	0.10	-	0.11	0.30	0.30
SOIL D : DEGRADED DYSTRIC BRUNISOL													
Aa	0/1.5-1.5/3	3.5	14.2	21.2	31.3	22.3	9.2	1.8	0.83	0.07	0.05	0.13	0.13
Bm	1.5/3-7	4.5	22.1	18.4	20.3	16.6	18.7	3.9	1.52	0.08	0.31	0.94	0.94
Bc	7-17/19	4.8	18.4	17.9	21.1	17.0	22.3	3.3	0.48	0.05	0.15	0.30	0.30
C	17/19-23/30	4.8	18.8	18.2	20.2	18.6	20.5	4.1	0.28	0.04	0.13	0.24	0.24
IIC	23/30+	4.8	7.8	9.4	13.9	17.2	41.7	10.0	0.24	0.02	0.13	0.28	0.28
SOIL B : ORTHIC HUMO-FERRIC PODZOL													
Aa	0-5/7	3.6	24.7	21.5	22.5	16.6	13.5	1.2	0.55	0.04	0.04	0.19	0.19
Ba	5/7-5/9	Not Sampled											
Bc	5/9-10/12	4.5	24.7	19.7	21.0	18.6	13.9	1.9	2.34	0.17	0.46	1.09	1.09
Bm	10/12-15	4.7	23.9	20.5	21.1	20.8	11.0	2.6	0.89	0.02	0.18	0.56	0.56
Bc	15-24	4.9	21.7	20.2	22.7	19.6	13.2	2.7	0.43	0.01	0.15	0.34	0.34
C1	24-31	5.1	22.1	18.4	17.7	17.9	20.9	3.0	0.31	0.01	0.15	0.25	0.25
C2	31+	5.2	19.2	16.7	19.7	18.6	23.2	2.6	0.07	0.01	0.05	0.24	0.24
SOIL E : GLAYED HUMO-FERRIC PODZOL													
Aba	0-1.5/2	3.3	28.8	20.0	20.3	14.7	13.3	2.6	1.58	0.03	0.05	0.02	0.02
Aa	1.5/2-8/10	3.7	20.1	18.6	20.2	18.0	20.5	2.5	0.68	0.05	0.04	0.01	0.01
Baf	8/10-16	4.2	23.7	19.7	21.4	17.9	14.1	3.2	7.39	0.36	1.96	0.23	0.23
Bf	16-24	4.4	21.5	17.7	20.4	18.3	19.3	2.8	3.03	0.05	0.75	0.16	0.16
Bc	24-33/36	4.8	19.5	16.7	19.6	18.4	21.5	4.3	0.89	0.03	0.28	0.21	0.21
Cg	33/36+	5.5	23.6	18.5	19.9	15.2	20.7	1.9	0.38	0.02	0.11	0.48	0.48
SOIL C : GLAYED HUMIC PODZOL													
Ed	0/9-11	4.2	31.7	18.8	19.4	14.8	13.4	1.8	3.03	0.06	0.53	0.06	0.06
Edj	11-27+	4.4	24.9	14.4	14.2	22.8	20.4	3.2	2.00	0.05	0.45	0.06	0.06

organic carbon, iron and aluminum oxides which have subsequently deposited in the Bm horizon. Such a migration of soil materials has taken place from the Ae to the Bm horizon. Organic carbon has accumulated in the Bm horizon -- Soil A, 1.38% and Soil D, 1.52%. Associated with this increase of organic carbon in the Bm horizon is an accumulation of iron and aluminum. In Soil A, sodium pyrophosphate-extractable Fe and Al is 0.37% in the Bm horizon in contrast to 0.08% in the Ae horizon; in Soil D, the Bm has 0.39% with 0.12% determined in the Ae horizon. The amounts for dithionite-extractable - Fe further support the fact that the leaching of metallic oxides from the Ae horizon has occurred: Soil A shows 0.18% in the Ae horizon and 0.69% in the Bm₁ horizon; Soil D has 0.13% in the Ae and 0.94% in the Bm horizon; whereas the parent material for both soils reveals approximately 0.3% thus showing distinct leaching in the Ae and accumulation in the Bm horizon.

From an examination of the results from textural analysis, a greater proportion of coarse silt exists in the IIC horizon indicating a discontinuity is present in the parent material. This increased siltiness is also apparent in the field with a plastic consistence when wet, loamy texture, and silt accumulations on the surface of the gravel fragments. Possible explanations for the existence of this unconformity are as follows: the existence of former permafrost conditions where, upon thawing, the silt size particles tended to accumulate on the surfaces of the larger gravel fragments and collect in voids; translocation of the finer soil material from the upper horizons by vertical drainage of water, and third, the initial deposition of the glacial till in this horizon contained a greater percentage of silt size materials. The Ae horizons are dominated by 80% sand of which 45% is fine to very fine sand. The Bm horizons show slightly more accumulation of silt and clay sized particles than the Ae horizon suggesting a translocation of the finer fractions into the B horizon.

The pH (0.01M CaCl₂) shows that a very acidic soil environment is present. The pH in both soils is 3.5 - 3.6 in the Ae horizon which increases to 4.5 in the Bm horizon and to 4.8 - 5.4 in the C horizons.

B. Terrace Site

Soil B is classified as an Orthic Humo-Ferric Podzol. The Bf podzolic horizon has an accumulation of 2.34% organic carbon, 0.63% organic-complexed Fe and Al, and 1.09% amorphous and crystalline iron forms. It is at least 5cm thick in many parts of the profile despite interruptions from stones and root channels.

There is a slight decrease in the sand content of the C horizons (74-76%) from the amount present in the A and Bf horizons (84%). A corresponding increase of coarse silt from 13% in the Ae and Bf horizons to 23% in the lower C horizon suggests that downward movement of particles is taking place. This increased siltiness of the C horizon is evident in the field with marked accumulations of silt-sized particles on the upper surface of the granitic fragments. The medium silt and clay fraction shows a slight loss in the Ae and Bf horizons (1.2 and 2.0% respectively) when compared to the BC and C horizon (2.6 to 3.0%).

The soil profile is very acidic with pH values (CaCl₂) ranging from 3.6 in the A horizon to 4.5 in the Bf to 5.2 in the C₂ horizon. The location of Soil B in an acidic, moist (in contrast to the dry crestral sites), well-drained site suggests a greater potential for leaching and the subsequent decomposition of minerals. The existence of a podzolic Bf horizon in Soil B with increased accumulations of organic carbon, sodium pyrophosphate-extractable iron and aluminum as well as dithionite-extractable Fe shows a soil profile exhibiting more development than Soils A and D, the Degraded Dystric Brunisols on the dry crestral regions.

C. Depression Sites

i) Linear depression between drumlinoid features

Soil E, classified as a Gleyed Humo-Ferric Podzol is imperfectly drained.

The accumulated organic matter is very thin (1.5 cm); yet, the thickness of the developing A horizon is greatest in this soil profile (10 cm). The following reasons can be suggested:

1. According to Viro (1974) thinning of the humus layer by fire improves the thermal conditions of the soil which in turn usually benefits the fertility of the site. Hence, the removal of the insulating mosses, Dicranum undulatum and Polytrichum piliferum, at Soil E produced a rise in the soil temperatures with depth causing increased biogeochemical degradation of the soil minerals allowing the release of nutrient cations.
2. The establishment of a lichen dominated vegetative cover with extensive spruce needle incorporation has formed a very strong acidic soil environment. Of the five soils in the toposequence, the Ahe horizon of Soil E is the most acidic with a pH in CaCl_2 of 3.3. Therefore the increased temperature and acidic conditions would enhance the potential for weathering within the mineral constituents.
3. The maintenance of water in the depression from spring meltwaters and surface run-off from severe rainstorms would ensure saturated to continually moist conditions during the summer months. Consequently, because of the continual presence of an acidic soil solution, there exists a greater tendency for the removal of organic materials, complexed organo-metallic forms and weathered cations from the A horizon.

The Ahe horizon contains a maximum of sand (84%) indicating that the finer fractions have been leached downward since a slight increase in medium silt and clay occurs in the Bhf horizon (2.6% in the Ahe, 2.5% in the Ae, and 3.2% in the

Bhf). The most significant indications for the translocation of soil materials from the A to Bhf horizon are the organic carbon contents (1.58% in the Ahe, 0.68% in the Ae, and 7.39% in the Bhf), the sodium pyrophosphate-extractable Fe (0.03% in the Ahe, 0.05% in the Ae, and 0.36% in the Bhf), and the sodium pyrophosphate-extractable Al (0.05% Ahe; 0.04% Ae; 1.96% Bhf). This accumulation has produced in the field a compact, hard Bhf horizon implying that these materials act as a cementing agent for the sand-sized particles.

Although imperfectly drained, oxidizing conditions exist in the lower horizons as evidenced by distinct reddish yellow (7.5YR 7/6 m) mottles in the Cg horizon. Corresponding with this mottling is an increase in the per cent dithionite-extractable iron confirming that an addition in the amount of crystalline iron oxides and amorphous forms has taken place in the Cg horizon. This mottled horizon also suggests that differences exist with regards to the geochemical weathering of the mineral constituents.

ii) Base of the thaw depression

Soil C, a Gleyed Humic Podzol, has developed on a ridge of large boulders separating Butler Pond and a small depression. During May and most of June the site is submerged by meltwaters; but, with warmer conditions and subsurface drainage within the thaw depression, the upper horizons are above the water table for the latter part of the growing season. The solum contains 31 cm of peat and sedges, mainly Polytrichum commune and Carex saxatilis, above the mineral horizons. Extreme downward leaching and weathering is believed to be taking place in the strongly acid soil environment; pH in CaCl₂ is 4.2 - 4.4. In the Bhgj horizon, several lithorelicts have decomposed forming homogeneous pockets of coarse gravel to very fine sand lenses.

The horizons contain a high proportion of coarse sands (31.7% in the Bh and 24.9% in the Bhgj) which indicates either the severe removal of the finer fractions or the

extremely coarse grained parent material in this profile. In the field a red staining was found on the sand particles which produced a dark reddish brown (2.5YR 3/4 m) profile under moist conditions. The depth of this staining could not be determined because of massive boulders and a high water table. However, the extent of colour with depth would suggest that oxidizing conditions for the iron bearing minerals and free drainage of subsurface water are present. Analysis for sodium pyrophosphate Fe reveals that a low content of iron is complexed with the organic matter. Also the dithionite-extractable Fe is extremely low (0.06%). It appears that either the iron is inorganically held within the mineral structures or that the iron has already been strongly leached from the soil material. Because of the low content of iron that is complexed with the organic matter, there arises the question of the source for the red staining that exists on the soil particles in the B horizon. Three possibilities can be considered as follows: an inorganic complexed oxide of iron and aluminum, an organic matter coating, or an organometallic complex has deposited on the mineral grains. The sodium pyrophosphate-extractable aluminum shows higher amounts (0.55% in the Bh and 0.45% in the Bhgj) than the pyrophosphate extractable Fe (0.06% in the Bh and Bhgj) indicating that aluminum may have been initially more abundant or alternatively less mobile than iron. These suggestions as well as the three possibilities for the red staining on the soil particles will be examined more extensively with geochemical data.

2. Formulation and Testing of Hypothesis

From the discussion of the physical and chemical characteristics of each soil, the following hypothesis is postulated:

Soils A and D, Degraded Dystric Brunisols, which have formed on the dry crestal sites are weakly developed in terms of geochemical weathering; Soil C, the Gleyed Humic Podzol, located at the base of the thaw depression has undergone severe leaching; while, Soil B, an Orthic Humo-Ferric Podzol, and Soil E, a Gleyed Humo-Ferric Podzol are in intermediate stages of weathering with Soil E more weathered than Soil B.

In order to test the above hypothesis which will essentially delineate the intensity of weathering that has taken place in each soil, the chemical composition of the soil horizons will be discussed in terms of (a) weight percentage and calculated molecular ratios of the major oxides and (b) cations determined according to the standard cell concept reported by G.G. Beckmann (1975).

A. Geochemical Compositions of the Soil Profiles

The weight percentage and molecular ratios are recorded in Table 2 and 3 respectively. Weight percentages provide an indication of the relative changes and trends of the elements in the soil (Birkeland, 1974). The calculated molecular ratios are used to express several of the analytical values (weight per cent) into a single number which is then calculated further to express in relative terms the differences that exist between the parent material, C horizon, and a particular soil horizon. Wright (1959) states that by using the ratios the effects of gains in organic matter is eliminated and the detection of relative translocation of elements is possible.

TABLE 2: WEIGHT PERCENTAGE (WT. % OF LIGHTED MATERIAL)

HORIZON	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Mn ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅
SOIL A : DEGRADED DYSTIC HUMUSOL										
A _s	79.50	11.23	1.22	0.38	1.77	3.07	2.44	0.30	0.02	0.06
B _{m1}	73.49	15.77	3.20	0.50	1.66	2.27	2.23	0.36	0.03	0.48
B _{m2}	76.96	12.81	2.17	0.50	1.93	2.78	2.33	0.27	0.02	0.22
BC	77.73	12.12	2.04	0.50	1.90	2.83	2.37	0.28	0.03	0.20
C	78.28	11.30	1.91	0.52	2.07	2.98	2.43	0.29	0.03	0.20
IIC	78.23	11.20	2.02	0.55	2.15	2.96	2.34	0.36	0.03	0.17
SOIL D : DEGRADED DYSTIC HUMUSOL										
A _s	78.08	12.00	1.31	0.48	1.83	3.31	2.57	0.35	0.02	0.05
B _m	75.66	13.76	3.06	0.53	1.61	2.34	2.38	0.38	0.03	0.25
BC	77.72	12.13	2.04	0.52	1.90	2.79	2.39	0.29	0.03	0.19
C	78.00	11.86	1.91	0.49	1.97	2.89	2.39	0.27	0.02	0.20
IIC	77.84	11.40	2.13	0.57	2.12	2.95	2.37	0.40	0.03	0.19
SOIL B : ORTHIC HUMO-FERRIC PODZOL										
A _s	60.58	10.88	1.04	0.29	1.43	2.75	2.58	0.36	0.02	0.05
EA	NOT SAMPLED									
BE	69.49	17.84	4.31	0.55	1.81	2.24	2.13	0.37	0.03	1.23
B _m	75.31	14.04	2.58	0.50	1.94	2.63	2.28	0.30	0.02	0.41
BC	77.77	12.13	1.95	0.47	1.97	2.92	2.33	0.25	0.03	0.19
C ₁	78.23	11.44	1.92	0.51	2.05	2.97	2.39	0.29	0.03	0.17
C ₂	78.13	11.28	1.93	0.53	2.17	3.02	2.42	0.29	0.02	0.20
SOIL E : CLAYED HUMO-FERRIC PODZOL										
A _{bs}	82.02	10.35	0.40	0.18	1.19	2.60	2.66	0.52	0.02	0.07
A _s	81.08	10.62	0.60	0.26	1.47	2.73	2.76	0.41	0.02	0.06
B _{h1}	67.47	22.58	1.66	0.43	1.54	2.07	2.04	0.43	0.02	1.75
BE	72.36	18.40	1.43	0.47	1.74	2.36	2.15	0.35	0.03	0.71
BC	74.03	16.01	1.96	0.60	1.73	2.41	2.32	0.38	0.03	0.52
C _B	77.03	12.55	2.52	0.53	1.66	2.57	2.46	0.40	0.03	0.26
SOIL C : CLAYED HUMIC PODZOL										
B _h	78.96	12.17	1.13	0.58	1.31	2.26	2.77	0.43	0.02	0.37
B _{h1}	79.27	11.86	0.96	0.44	1.66	2.64	2.52	0.28	0.02	0.35
Average C horizon	78.16	11.47	1.92	0.51	2.06	2.96	2.41	0.29	0.03	0.19

TABLE 3.1. MOLECULAR AND CALCULATED RELATIVE MOLECULAR RATIOS

HORIZON	$\frac{SiO_2}{Al_2O_3}$		$\frac{SiO_2}{Fe_2O_3}$		$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$		$\frac{K_2O+Na_2O+CaO+MgO}{Al_2O_3}$		$\frac{K_2O}{H_2O}$	
	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.
SOIL A : DEGRADED DYSTRIC HUMUSOL										
Ae	12.03	1.02	169.00	1.89	11.31	1.07	1.05	0.92	0.53	1.02
Bw1	7.89	0.67	61.15	0.61	7.79	0.74	0.66	0.58	0.65	1.25
Bw2	10.17	0.86	91.50	0.92	9.15	0.86	0.92	0.81	0.56	1.07
BC	10.87	0.92	99.54	0.99	9.80	0.93	0.99	0.87	0.54	1.04
C	11.74	0.99	108.58	1.08	10.59	1.00	1.12	0.98	0.54	1.04
TIC	11.84	1.00	100.15	1.00	10.59	1.00	1.14	1.00	0.52	1.00
SOIL D : DEGRADED DYSTRIC HUMUSOL										
Ae	11.00	0.95	162.38	1.63	10.31	0.99	1.06	1.14	0.51	0.96
Bw	9.33	0.81	66.26	0.66	8.18	0.79	0.78	0.84	0.66	1.24
BC	10.87	0.94	99.46	0.99	9.79	0.93	0.98	1.06	0.56	1.04
C	11.19	0.97	108.17	1.09	10.14	0.98	1.03	1.11	0.53	1.00
TIC	11.57	1.00	99.69	1.00	10.37	1.00	0.93	1.00	0.53	1.00
SOIL B : ORTHIC HUMO-FERRIC PODZOL										
Ae	12.53	1.07	223.50	2.06	11.87	1.12	0.96	0.84	0.61	1.15
BA	NOT SAMPLED									
Bf	6.61	0.56	42.81	0.40	5.72	0.54	0.60	0.52	0.64	1.20
Bw	9.08	0.78	78.31	0.72	8.14	0.77	0.81	0.71	0.57	1.08
BC	10.87	0.93	107.83	0.99	9.88	0.94	1.00	0.87	0.53	1.00
C1	11.63	0.99	108.50	1.00	10.50	0.99	1.10	0.96	0.52	0.98
C2	11.71	1.00	108.33	1.00	10.57	1.00	1.14	1.00	0.53	1.00
SOIL E : CLAYED HUMO-FERRIC PODZOL										
Abs	13.38	1.28	455.00	5.68	13.00	1.41	0.93	1.05	0.67	1.05
Ae	12.97	1.24	337.25	4.21	12.49	1.35	1.01	1.14	0.66	1.04
Bw1	5.08	0.48	112.90	1.40	4.86	0.53	0.42	0.48	0.99	1.56
Bf	6.69	0.64	133.78	1.67	6.37	0.69	0.58	0.65	0.61	0.95
BC	7.65	0.75	102.66	1.28	7.29	0.79	0.70	0.79	0.64	1.01
Cg	10.42	1.00	80.13	1.00	9.22	1.00	0.89	1.00	0.63	1.00
SOIL C : CLAYED HUMIC PODZOL										
Bw	11.03	0.97	187.57	0.85	10.4	0.96	0.86	0.90	0.81	1.29
Bw1	11.37	1.00	219.84	1.00	10.8	1.00	0.95	1.00	0.63	1.00

1) Degraded Dystric Brunisols -- Soil A and Soil D

Referring to Table 2, there is an increase of SiO_2 , CaO , Na_2O and K_2O in the Ae horizon and a decrease of Al_2O_3 , Fe_2O_3^* , and MgO . The Bm horizons show increases of Al_2O_3 , Fe_2O_3 and P_2O_5 when the weight percentages are compared to the A and C horizons.

Although the texture analysis showed a discontinuity in IIC, the geochemical composition for the C horizon and the IIC horizon is very similar suggesting that marked differences in the mineral constituents do not exist in the parent material.

From Table 3, the molecular ratios substantiate the fact that SiO_2 has accumulated in the Ae horizon and that Al_2O_3 and Fe_2O_3 have deposited in the Bm horizon. The basic materials $\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO} + \text{MgO}$ are greater in the Ae horizon (1.05% Soil A; 1.06% Soil D) than in the Bm horizon (0.66% Soil A; 0.78% Soil D) indicating the following possibilities:

- a) There is an accumulation of these basic oxides from in situ weathering of the surface minerals.
- b) Additions to the thin Ae horizon has occurred from the decomposition of the surface organic matter.
- c) The intensity of leaching required to remove these soluble ions is very weak in the upper horizons.
- d) The increase in the Ae horizon of basic materials reflects a loss in aluminum to the Bm horizon.

Comparing the ranges of molecular ratios for the basic materials, the values recorded are very similar in the A, B and C horizons. The molecular ratios calculated with SiO_2 are analogous in the B transition and C horizon. These two observations illustrate that a uniform soil material exists throughout the soil profile with regard to the cations.

*Note: Experimental method determines total Fe; for this study the Fe content is assumed to be Fe_2O_3 after Chesworth, 1973 and Beckmann, 1975. Deposition incorporates fact that in situ weathering is present plus Fe in the parent material. Excess over parent material represents in situ weathering and translocated iron oxides.

Evidence for the removal of the soluble cations is reflected by the molecular ratios of the upper horizons of Soil A and D. Soil A shows a slight increase in relationship to Soil D with regards to the accumulation of SiO_2 in the A horizon and deposition of iron and aluminum in the B horizon. Soil A also shows an increased loss of basic cations in the upper horizons when compared to Soil D suggesting that more intense leaching is taking place in Soil A.

ii) Orthic Humo-Ferric Podzol -- Soil B

Comparing the weight percentages of the Bf horizon with the Ae and C horizons, there is a decrease in SiO_2 , Na_2O , and K_2O but an increase in Al_2O_3 , Fe_2O_3 , and P_2O_5 . A marked decrease of CaO , MgO , and P_2O_5 is apparent in the Ae horizon. The quantity of Al_2O_3 and Fe_2O_3 present in the Ae in relationship to the parent material shows that leaching has occurred but the degree is relatively little as evidenced from the differences between the horizons (0.40% Al_2O_3 and 0.89% Fe_2O_3). Yet, appreciable amounts of these two oxides have deposited in the Bf horizon (in reference to the C horizon: 6.56% Al_2O_3 ; 2.38% Fe_2O_3) that is not accounted for by the Ae horizon. This would indicate that lateral movement of cations is taking place. Such an hypothesis is reasonable because of the location of Soil B on a terrace midway between two slopes through which the subsurface water would drain (See Map 3).

The molecular ratios $\text{SiO}_2/\text{Al}_2\text{O}_3$; $\text{SiO}_2/(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$; $\text{SiO}_2/\text{Fe}_2\text{O}_3$ show a decrease in the Bf horizon in relation to the A horizon reflecting the accumulation of aluminum and iron oxides in the B horizon. The ratio of basic materials reveals a decrease of sodium in relation to potassium in the Ae and Bf horizons which indicates that sodium is being leached from the minerals of the solum. There is also an increase of aluminum related to all basic materials in the Bf horizon which implies that aluminum has been deposited in this horizon.

iii) Gleyed Humo-Ferric Podzol -- Soil E

Prominent additions of aluminum, 22.58% and phosphorus, 1.75% occur in the Bhf horizon of Soil E. Iron is markedly removed from the Ahe (0.4%) and Ae (0.6%) horizons with subsequent increases in both the Bhf (1.66%) and Bf (1.43%) horizons indicating deposition. But, in the Cg horizon, the higher iron reading (2.52%) reflects in part the oxidizing conditions of the soil environment whereby prominent iron oxide mottles have formed as well as the iron content of the parent material. The relatively low amount of iron together with a high per cent of aluminum that occurs in the podzolic B horizons of Soil E may be the result of vertical and lateral removal of iron by the soil solution which has left the least mobile element, aluminum, to accumulate along with carbon in the Bhf and Bf horizons. Examining the relative ratios of $\text{SiO}_2/\text{Al}_2\text{O}_3$ and $\text{SiO}_2/\text{Fe}_2\text{O}_3$, there has been approximately five times as much iron as aluminum removed from the A horizons in relation to the C horizon. Phosphorus (1.75%) has also accumulated in the Bhf horizon.

MgO and CaO are being leached from the solum; only slight accumulations of sodium and potassium oxides occur in the Ahe and Ae horizons. The molecular ratio $\text{K}_2\text{O}/\text{Na}_2\text{O}$ shows a decrease of sodium to potassium in the upper horizons. The molecular ratios with SiO_2 reflect the extreme accumulation of silicon oxide in the Ahe and Ae in relationship to the lower horizons indicating that strong leaching of the more soluble ions has resulted in the upper horizons.

iv) Gleyed Humic Podzol -- Soil C

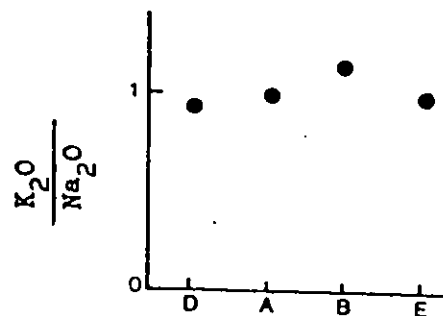
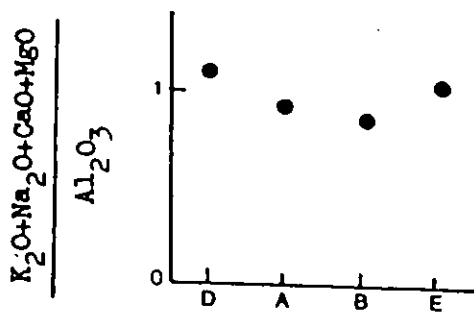
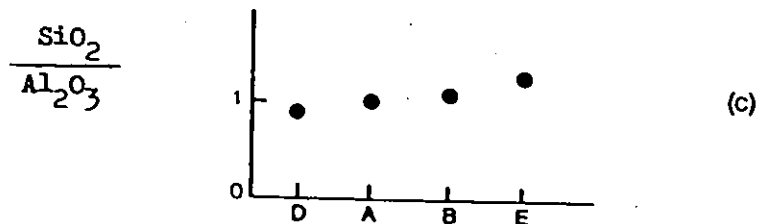
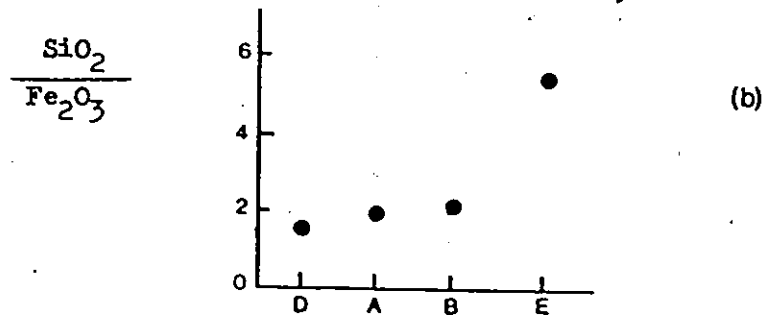
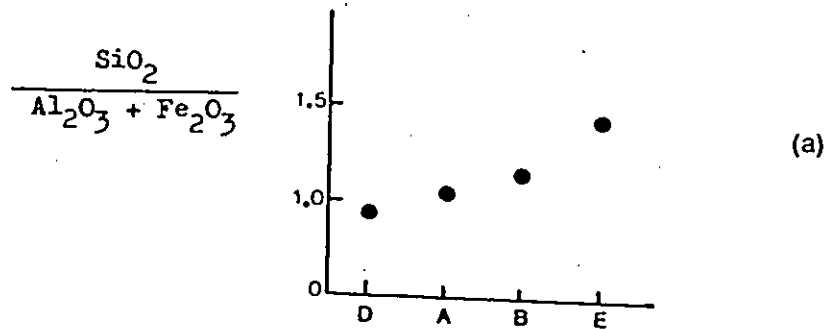
This soil poses a dilemma with regards to the comparison of horizons in that an Ae horizon is absent and no C horizon could be determined in the field. Thus, the weight percentages for the podzolic Bh horizon and the underlying gleyed Bhgj cannot be used to determine if accumulation or leaching of soil materials has occurred. The only alternative that remains is a comparison based on the assumption that the

parent material in which this soil formed is equivalent to the other soils examined in the toposequence. Therefore, in order to establish a basis of comparison, the C horizon of the Orthic Humic Podzol and Degraded Dystric Brunisol were averaged (Table 2). The C horizon was chosen because of the absence of mottling and the negligible effects of weathering. Using the "average C horizon" for comparison, it was established that CaO , Na_2O , and Fe_2O_3 have been removed from the profile; P_2O_5 has been deposited in the B horizon; Al_2O_3 , K_2O and TiO_2 show greater amounts in the upper Bh horizon. This slight increase of aluminum was also evident in the sodium pyrophosphate extractable aluminum.

The conclusions regarding Soil C are as follows:

1. The profile contains a low amount of iron which has either been removed by extreme leaching or was initially absent in the mineral constituents of the glacial material.
2. Sodium and calcium have been leached from the solum.
3. The B horizon weight percentages differ very little from those in the calculated average C horizon with regards to Al_2O_3 and SiO_2 suggesting that removal of these oxides from the profile is limited. An explanation for this decreased mobility could be attributed to the coating that surrounds the sand particles thus inhibiting the effects of weathering in the acidic soil environment. Also, the coarse texture of the profile implies the presence of a large percentage of primary minerals that have not undergone alteration by physical or chemical processes.

FIGURE 1: Comparison of Relative Molecular Ratios for the A horizon of Soils A, B, D, and E.



(d)

(e)

B. Comparison of Weathering Trends

To test the formulated hypothesis, the A horizon was examined since it is defined as "a mineral horizon formed at or near the surface in the zone of the removal of materials in solution and suspension, or a maximum in situ accumulation of organic matter, or both." (Soil Classification for Canada, 1974, p.21.) Next, relative values of the molecular ratios (Table 3) were calculated for the A horizon in terms of the C horizon which was assigned a ratio of one, and then graphed according to the profile order proposed in the hypothesis: Soil D, Soil A, Soil B, Soil E, and Soil C. However, such a ranking of increasing intensity of weathering by using the A horizon does not apply to Soil C which has no A horizon. Therefore, only the remaining soil profiles could be adequately assessed for an estimate of the intensity of weathering as shown in Figure 1(a) to 1(e).

The increasing trend from Soil D to Soil E in Figure 1(a) represents an increase of SiO_2 over the sesquioxides indicating the greatest removal of aluminum and iron occurs in Soil E. Figure 1(b) shows the extreme removal of iron from the Ae horizon of Soil E. The leaching of aluminum ($\text{SiO}_2/\text{Al}_2\text{O}_3$ in Figure 1(c)) is not as pronounced as for iron which may be a reflection of the low mobility of aluminum ions in these soils. With regards to basic oxides in relationship to the quantity of Al_2O_3 present, Figure 1(d), Soils A and B have a greater proportion of aluminum; whereas, Soils D and E show an increase of bases over aluminum. Since these pairs of soil profiles are located on opposite sides of the thaw depression, the increase of basic material may be indicative of differences in vegetation; a shorter time period since fire added basic elements from vegetative ash to the upper solum; an increase in the basic minerals present in the parent material; or to differences in the relative mobilities of the basic cations. In Figure 1(e), the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios show that sodium has been removed slightly more in Soil B than in the other three soils suggesting that

TABLE 4 : CALCULATED STANDARD CELL DATA

HORIZON	Si	Al	Fe	Mg	Cs	Mn	K	Ti	Nb	P	Total Cations
SOIL A : DEGRADED DYSTRIC ENTISOL											
As	67.72	11.28	0.78	0.48	1.62	5.07	2.65	0.19	0.02	0.04	89.85
Bm1	63.16	15.97	2.07	0.52	1.53	3.78	2.44	0.23	0.02	0.35	90.07
Bm2	65.88	12.92	1.39	0.64	1.77	4.61	2.55	0.17	0.02	0.15	90.10
Bc	66.47	12.21	1.31	0.64	1.74	4.69	2.58	0.18	0.02	0.14	89.98
C	66.97	11.39	1.23	0.66	1.89	4.95	2.65	0.19	0.02	0.14	90.09
IIC	66.96	11.30	1.30	0.69	1.97	4.91	2.55	0.23	0.02	0.12	90.05
SOIL D : DEGRADED DYSTRIC ENTISOL											
As	66.79	12.09	0.85	0.61	1.67	5.48	2.80	0.22	0.01	0.03	90.55
Bm	64.89	13.90	1.99	0.68	1.48	3.89	2.60	0.24	0.02	0.18	89.87
Bc	66.46	12.22	1.32	0.66	1.73	4.62	2.60	0.18	0.02	0.13	89.94
C	66.67	11.95	1.24	0.62	1.80	4.78	2.60	0.17	0.01	0.14	89.98
IIC	66.68	11.51	1.39	0.72	1.94	4.90	2.59	0.25	0.02	0.13	90.13
SOIL B : ORTHIC HEMO-FERRIC PODZOL											
As	68.39	10.88	0.66	0.37	1.30	4.52	2.79	0.23	0.01	0.04	89.19
EA	NOT SAMPLED										
Bf	60.13	18.19	2.84	0.71	1.67	3.76	2.35	0.24	0.02	0.90	90.81
Bm	64.59	14.19	1.69	0.64	1.78	4.37	2.49	0.19	0.01	0.30	90.66
Bc	66.49	12.22	1.27	0.59	1.80	4.84	2.54	0.16	0.02	0.14	90.07
C1	66.92	11.53	1.25	0.65	1.87	4.92	2.60	0.18	0.02	0.12	90.06
C2	66.90	11.38	1.25	0.67	1.99	5.01	2.64	0.18	0.01	0.14	90.17
SOIL E : CLAYED HEMO-FERRIC PODZOL											
Abw	69.25	10.30	0.25	0.22	1.07	4.25	2.86	0.33	0.01	0.04	88.58
As	68.73	10.61	0.38	0.32	1.33	4.48	2.98	0.26	0.01	0.04	89.14
Bhf	57.81	22.80	1.08	0.57	1.41	3.43	2.23	0.27	0.01	1.28	90.89
Bf	61.86	18.54	0.93	0.60	1.59	3.91	2.34	0.22	0.02	0.51	90.52
Bc	63.39	16.15	1.27	0.76	1.58	3.99	2.53	0.24	0.02	0.37	90.30
Ce	65.94	12.66	1.64	0.67	1.52	4.26	2.68	0.26	0.02	0.18	89.83
SOIL G : CLAYED MERIC PODZOL											
Bw	66.70	12.18	0.73	0.73	1.19	3.72	3.00	0.27	0.01	0.26	88.79
Bwhj	67.33	11.87	0.62	0.55	1.51	4.34	2.73	0.18	0.01	0.25	89.39

the soil solution in Soil B is more effective with regards to the removal of this soluble ion or that the removal of sodium in Soils D, A, and E is overshadowed by increases from the decomposition of organic matter.

Assessment of the intensity of weathering based only on the A horizon is inadequate since soils without this horizon are excluded. Therefore, a more precise method which takes into account the whole profile as well as the relative movement of the cations is required. In response to this conclusion, the soil profiles will be examined using the techniques outlined by G.G. Beckmann (1975). The first procedure recalculates the weight percentage data in terms of Barth's (1948) standard cell concept based on a cell containing 160 oxygen ions. The results are presented in Table 4 and plotted according to horizon depth on semi-logarithmic paper, Figures 2 to 6, in order to examine each cation for relative gains and losses between the soil horizons. The logarithmic scale allows sufficient range for the graphing of all cations.

C. Standard Cell Data

With the standard cell concept, the individual cations instead of the oxides are considered in terms of gains or losses between the profile horizons. Because the method of calculation is based on weight percentages, similar trends result for the soil profiles. For instance, there is an increase in aluminum and iron in the B horizon and a decrease in silicon; phosphorus has deposited in the B horizon with greater accumulations in Soil B and E; the A horizon shows losses of aluminum, iron, phosphorus and gains of silicon; the basic cations tend to vary in the individual profiles.

In Figures 2 to 6, the distinct weathering zones determined by Beckmann (1975) in relation to the C horizon are apparent for each soil except for Soil C which contains no A horizon or defined C horizon. Consequently, in the other four profiles, an A horizon (zone of weathering),

TABLES 5 : RELATIVE GAINS, LOSSES AND STABILITY OF CATIONS IN THE ZONES OF WEATHERING

ZONE	SOIL A	SOIL D	SOIL B	SOIL E	SOIL C+
Weathering					
Gain	K, Na, Si	K, Na, Si	K, Si, Ti	K, Si, Ti	
Loss	Al, Fe, Ca, Mg, P, Ti	Al, Fe, Ca, Mg, Mn, P, Ti	Al, Fe, Ca, Na, Mg, P Mn	Al, Fe, Ca, Na, Mg, Mn, P	
Stable	Mn	-	Mn	-	
Accumulation					
Gain	Al, Fe, P, Ti (upper B)	Al, Fe, P	Al, Fe, Mg, Mn, Ti, P	Al, Fe*, Mg*, P, Ti	Al, Fe, K, Mg, P, Ti
Loss	Ca, K, Mg, Na, Si, Ti (Lower B)	Ca, Mg, Na, Si, Ti	Ca, K, Na, Si	Ca, Fe, Mg, K, Mn, Na, Si	Ca, Na, Si
Stable	Mn	Mn, K	-	(Unconformity)	Mn
Transition					
Gain	Al, P	Al	Al, Mn	Al, Mg, P	
Loss	Ca, Fe, Mg, Na, Ti	Ca, Fe, Mg, Na, Ti	Ca, Mg, P, Ti	Fe, Na, Si	
Stable	K, Mn, Si	K, Mn, P, Si	Fe, K, Na, Si	Ca, K, Mn, Ti	

+ Soil C changes of cations assessed between B horizons

* Soil E cation gains in zone of accumulation in relationship to A horizon. All other zone evaluations in terms of C-horizon (zone of stability). Note unconformity in Soil E since Cg horizon is not stable.

B horizon (zone of accumulation or translocation), B transitional horizon (zone of slight alteration), and the C horizon (zone of stability or no change) are discernible. These zones are indicated in Figures 2 to 5. Table 5 was constructed by assessing the cations in the A, B, and B transitional horizons for relative gains, losses or stability in reference to the cations in the C horizon.

i) Observations

The Degraded Dystric Brunisols formed on the dry crestral sites show a very weakly developed profile as evidenced by the transition zone occurring before 10 cm depth. The zone of weathering or removal of cations with their subsequent deposition takes place within 5 cm from the surface. Referring to the zone of accumulation, the patterns displayed by the graphs for the following cations are similar for both Soil A and Soil D, the Degraded Dystric Brunisols, in Figures 2 and 3 respectively:

1. Fe, Al, and P show gains in the Bm horizon and losses in the Ae horizon.
2. Na, K, and Si reveal losses in the Bm horizon and gains in the Ae horizon.
3. Mg shows a loss in the upper solum of both soils. Below 10 cm the curves for Mg, Ti and Fe show similar patterns.
4. Ca in relation to the C horizon exhibits losses in the upper solum (above 10 cm) and then tends to remain fairly stable.
5. Mn is present in very minute quantities (0.01 and 0.02 cations).

Similarly, examining the moist profiles, Soil B, the Orthic Humo-Ferric Podzol, and Soil E, the Gleyed Humo-Ferric Podzol, the following trends were observed from Figures 4 and 5:

1. Generally, P, Mg, Fe, and Al revealed gains in the B horizon and losses in the Ae horizon. There is in Soil B a close parallelism of the shape of the curves for each of these cations especially P, Fe, Al, and to a lesser degree Mg and

FIGURE 4:

CHANGES OF NUMBERS OF INDIVIDUAL CATIONS PER "STANDARD CELL" IN SOIL B: Orthic Humo-Ferric Podzol

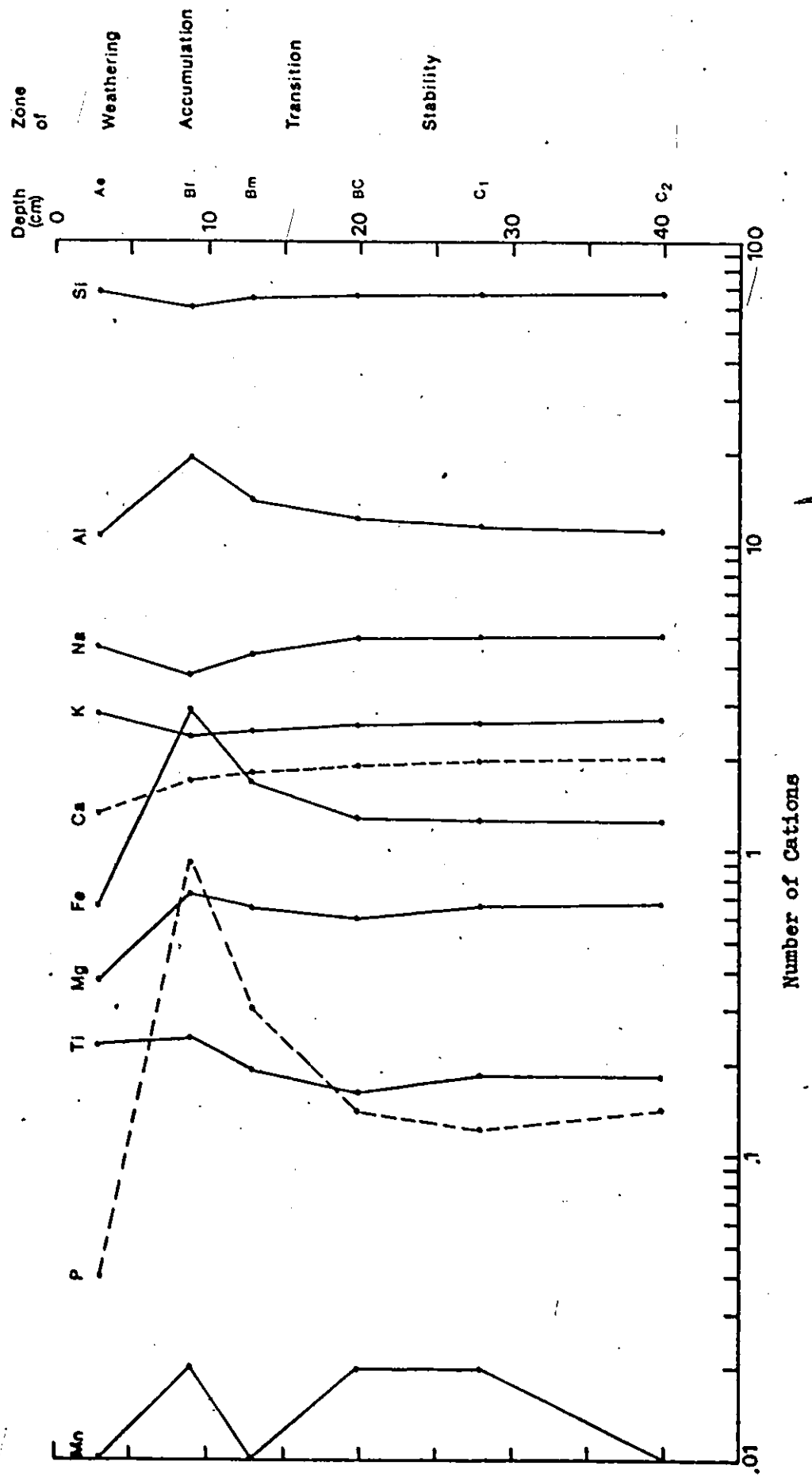
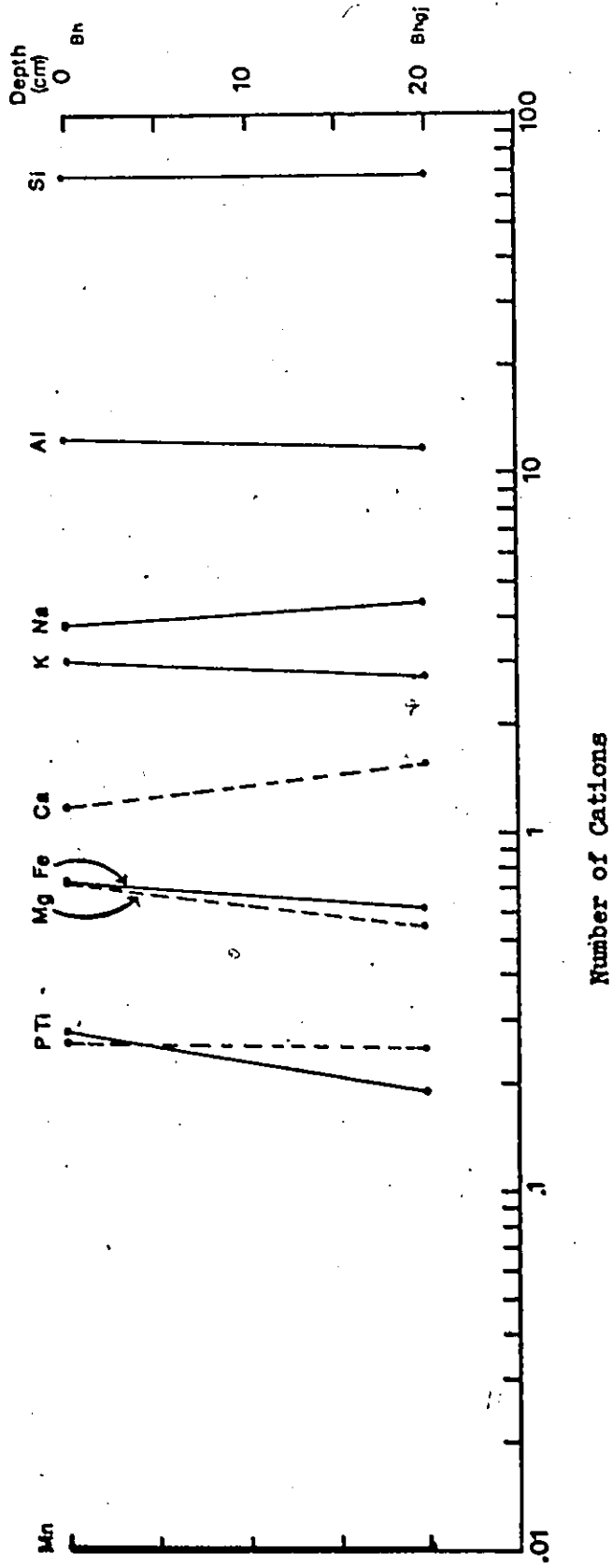


FIGURE 6:

CHANGES OF NUMBERS OF INDIVIDUAL CATIONS PER "STANDARD CELL" IN SOIL C: Gleyed Humic Podzol



- Ti. In Soil E, close similarity exists between (a) the Mg and Fe curves, and (b) P and Al.
2. Na and K graphs in Soil E are parallel to each other showing extreme stability in the parent material and zone of transition; in Soil B, although showing marked similarity Na is not as stable as K in the transition zone.
 3. Ca shows a loss in the upper solum of Soils B and E.
 4. Si shows gains in the A horizon and losses in the B horizon.
 5. Gains of Ti occur in the upper sola.
 6. Mn is present in minute quantities.
 7. The depth of the zone of weathering in Soil B extends to approximately 6 cm whereas in Soil E, the boundary is at 10 cm.

In the wettest site, the Gleyed Humic Podzol, Soil C, located next to Butler Pond, the relative gains and losses of cations were assessed between the Bh and Bhgj horizons. The outstanding features from Figure 6 are the close similarity of the Mg and Fe curves, the marked loss of Ca, and the very slight changes of Al, Si, P, and Mn in the B horizon.

ii) Conclusions

Sodium, potassium and silicon are the residual cations in the Degraded Dystric Brunisols. In the Orthic Humo-Ferric Podzol and Gleyed Humo-Ferric Podzol, potassium, silicon and titanium remain in the zone of weathering. This removal of sodium indicates a greater intensity of geochemical weathering has taken place in Soil B and Soil E in order to remove this soluble ion.

In the zone of accumulation for Soils A, D, B, and E, phosphorus, aluminum and iron are the prime depositional cations. The close similarity of the graphs for these cations suggests that similar chemical processes exist within the soil horizons of these soils.

The close correspondence of the Mg and Fe curves suggests that the ferro-magnesium minerals (biotite and hornblende) are weathered first from the soil solum.

The Mg, Fe, and Ti curves tend to be unstable in the BC transition horizon and the C horizon of these soils; while, at the same time the graphs for Na, Ca, and K (contained primarily in feldspars) show negligible alterations by chemical processes indicating that a primary stage of geochemical weathering exists since the basic cations appear to be unaltered. To illustrate this, in Soil E, marked increases of Mg and Fe occur in the Cg horizon; whereas, the basic cations show stability throughout the BC and Cg horizon. Therefore, the prominent reddish-yellow mottles observed in the field in the Cg horizon indicate the oxidation of the iron-magnesium bearing minerals. Furthermore, in the A horizon of Soil E, losses of Fe and Mg have occurred with deposition in the B horizon. But in relation to the C horizon possible losses of Fe and Mg have also taken place in the B horizon. Therefore, in Soil E, a geochemical unconformity exists which differentiates two processes -- removal of cations from the A horizon to the B horizon and the oxidation of minerals in situ in the Cg horizon.

In all five soils of the toposequence, calcium shows a loss in the solum, thus reflecting its greater solubility in relationship to the other basic cations. In the Degraded Dystric Brunisols, the cations, Na and K, remain; but, in the Orthic Humo-Ferric and Gleyed Humo-Ferric Podzols, the least soluble basic cation, K, is left in the weathered horizon.

Losses of basic cations in the B horizon of all profiles may be from the following sources: 1) Leaching of these more mobile cations by periodic high water table and/or 2) the cations move into empty lattice spaces in the mineral structures to form clay minerals and amorphous materials in the podzolic horizons.

Soil C, the Gleyed Humic Podzol, was assessed by comparing the two B horizons in the profile -- the upper Bh in terms of the lower Bhgj for gains or losses of cations. But, this method still compares two horizons in which changes are taking place. Therefore, a principal component analysis discussed by Beckmann (1975) will be implemented because the

TABLE 6: COMPUTED LOADINGS FOR THE FIRST AND SECOND PRINCIPAL COMPONENTS

FIRST COMPONENT		SECOND COMPONENT	
Loading	Horizon	Loading	Horizon
5.352	E Bhf	4.235	E Ahe
4.895	B Bf	3.397	E Bhf
2.700	E Bf	2.566	C Bh
2.237	A Bm ₁	2.560	E Ae
1.899	E BC	1.874	B Ae
1.197	D Bm	0.706	C Bhgj
0.908	B Bm	0.691	E Bf
0.246	E Cg	0.543	A Bm ₁
0.145	A Bm ₂	0.196	E BC
-0.210	D BC	0.177	E Cg
-0.233	A BC	0.155	D Bm
-0.255	D IIC	0.008	B Bf
-0.340	B BC	-0.328	D Ae
-0.373	A IIC	-0.480	B Bm
-0.602	B C ₁	-0.728	A Ae
-0.715	A C ₁	-0.968	D C ₁
-0.789	D C ₁	-1.376	D BC
-0.991	B C ₂	-1.401	A BC
-1.051	C Bh	-1.518	A Bm ₂
-1.329	C Bhgj	-1.522	D IIC
-1.706	A Ae	-1.579	B C ₂
-2.044	D Ae	-1.738	B BC
-2.501	B Ae	-1.753	A IIC
-3.218	E Ahe	-1.821	A C ₁
-3.220	E Ae	-1.894	B C ₁

Slight Alteration Podzolic
 ↑
 CATIONS GAINED
 ↓
 Transition horizons and
 parent material
 Leached horizons
 ↓
 INTENSITY

Cations gained and/or lost
 ↑
 INCREASING INTENSITY
 ↓
 Relative stability of cations

Source: Computed Output (END OLM)

soil horizons can be compared and grouped by using the cations as parameters for assessing the weathering intensity between the soils of the toposequence. This essentially enables the horizons of Soil C to be examined in relation to each horizon present in the other soils of the toposequence in order to comparatively establish the intensity of weathering.

D. Principal Component Analysis

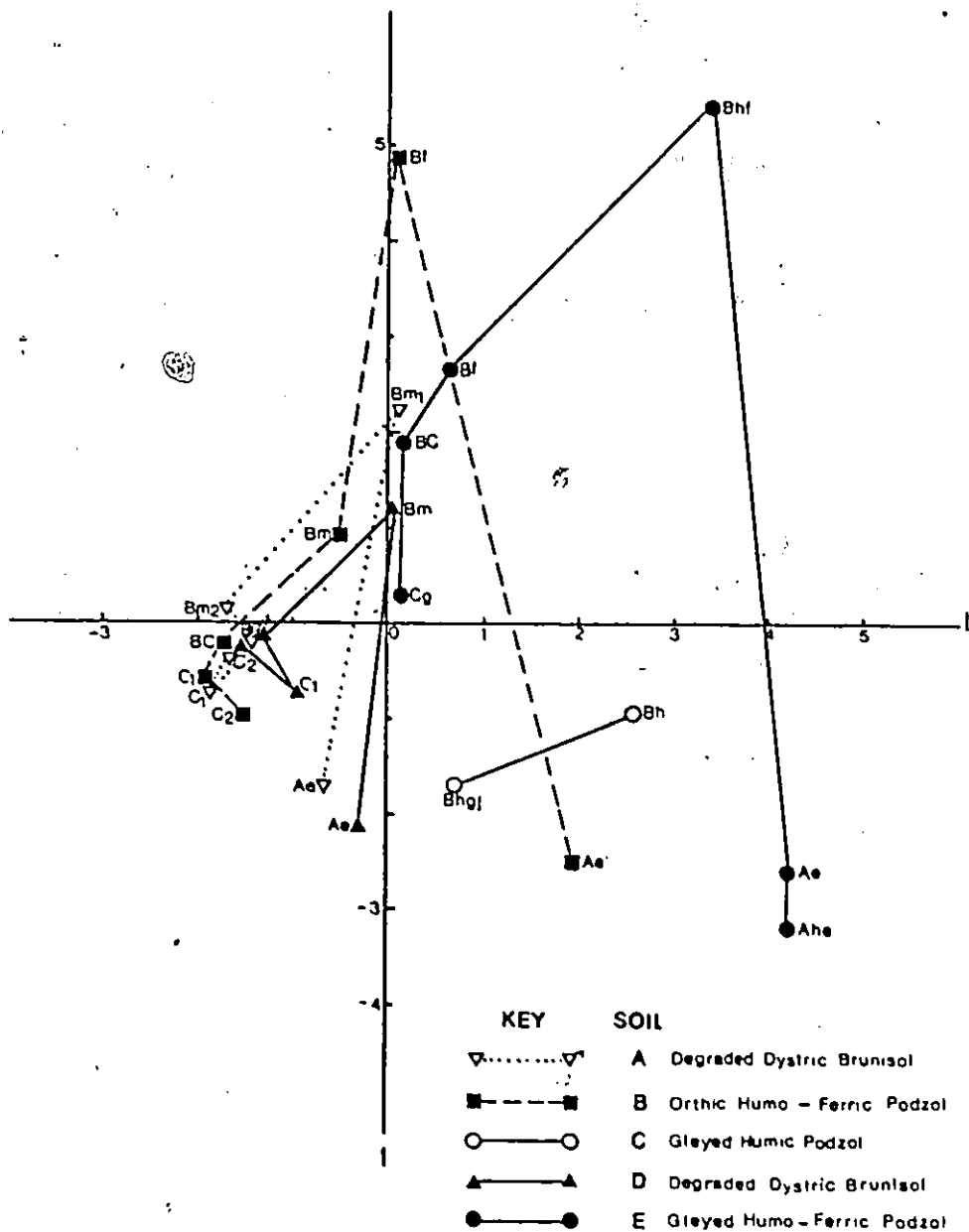
Principal component analysis (BMD OLM) differentiated two significant components (significant if computed eigenvalues are greater than 1.0). The first component accounted for 46 per cent of the variance in the data, and the second component added an additional 31 per cent to the explanation of the variance. Thus, the two components accounted for 77 per cent of the variance in the data. The computed loadings for the first and second components are shown in Table 6.

The first component separated the horizons according to the content of iron, aluminum and silicon cations. High positive loadings occurred on the podzolic horizons: E-Bh; B-Bh; E-Bf; thus, reflecting depositional environments. In contrast, high negative loadings are computed for the Ae horizons and the horizons of Soil C indicating leached soil environments. In between, with low loadings on the first component, are the BC and C horizons. Thus, the first principal component also separates the profiles into three fundamental zones -- the B horizons (podzolic); the BC transition and C horizons, and third the Ae horizons.

The second principal component separated the horizons according to (a) horizons in which cations are being removed and/or added and (b) horizons that reflect the relative stability of cations, that is, slight or no alteration of the original glacial material.

Graph 1 is a plot of the loadings given to each horizon by the two principal components. Component I reflects

GRAPH 1: Plot of the First and Second Principal Component Loadings



Source: Computer output (BMD OLM)

horizons with additions of iron while Component II represents the parent material. The resulting graphs for Soils A and D show marked parallelism suggesting comparable weathering intensities. The horizons in Soils B and E show a greater degree of separation of the B horizon from the A horizon with Soil E reflecting the maximum change. A grouping of the Ae horizons occurs in the third and fourth quadrants; for the most part, the B podzolic horizons are centered about the first component axis, and the BC and C horizons are found about the second component. The Bh horizon of Soil E is located high in the first quadrant indicating that other factors are influential. From previous analyses, this horizon contains significant gains in organic carbon, and aluminum, but the addition of iron is fairly low. The location of A-Ae and D-Ae near the first component axis shows that the removal of cations has occurred only slightly; thus, proving the Degraded Dystric Brunisols to be geochemically weakly weathered soils. The A horizon of the Gleyed Humo-Ferric Podzol, Soil E, is the furthest from the first and second component axes, thus reflecting the maximum change from the parent material as well as the maximum removal of cations. Soil B, the Orthic Humo-Ferric Podzol, has an intermediate position between the weakly weathered Degraded Dystric Brunisols of Soils A and D and the strongly leached Gleyed Humo-Ferric Podzol of Soil E. The plot for Soil C also occurs close to these A horizons, indicating that the Bh and Bhgj horizons of this Gleyed Humic Podzol are moderately leached when compared to the other soil profiles in the toposequence. There has been a distinct alteration of the parent material as well as substantial losses of cations especially iron, aluminum, and silicon.

Thus, the statement in the initial hypothesis that Soil C is the strongest geochemically weathered profile in the toposequence is not valid. Consequently, the following conclusion regarding the intensity of geochemical weathering can be put forward:

Soil A and Soil D, the Degraded Dystric Brunisols, on the dry crestral sites are weakly weathered; Soil B, the Orthic Humo-Ferric Podzol, on the terrace site and Soil C, the Gleyed Humic Podzol, adjacent to the thaw depression are moderately weathered; while, Soil E, the Gleyed Humo-Ferric Podzol, in the linear depression shows the maximum geochemical weathering of the five soil profiles examined in the toposequence.

E. Sequence of Geochemical Weathering

Principal component analysis has established the order of geochemical weathering within the toposequence and together with the examination of the individual cations with a semi-logarithmic plot, a sequence of geochemical weathering can be discussed for the soils.

1. The iron-magnesium bearing minerals are initially weathered from the parent material releasing Mg, Fe, Ti and basic cations.
2. Calcium is then removed from the sola of all profiles, then sodium followed by potassium. Additional sources for these basic cations are the feldspar minerals. This sequence is revealed with Na and K remaining as residual cations in the weakly weathered Degraded Dystric Brunisols and only K left in the moderately weathered Orthic Humo-Ferric Podzol and the strongly leached Gleyed Humo-Ferric Podzol.
3. Iron, aluminum and phosphorus are deposited in the B horizon with silicon increasing as a residual cation in the Ae horizon.

CHAPTER 6

SUMMARY

A. The Geochemical Investigation

Geochemical data has been used to determine the intensity of weathering occurring in a toposequence of soils developed on granitic glacial till in the Canadian Subarctic at Thor Lake, Northwest Territories. Physical and chemical data was determined to first classify the soils according to the Canadian system of soil classification and second to formulate an hypothesis in terms of the relative degree of soil weathering that had taken place in the five soils examined. The hypothesis was stated as follows: Soil A and D, Degraded Dystric Brunisols, which have formed on the dry crestral sites are weakly developed in terms of geochemical weathering; Soil C, the Gleyed Humic Podzol, located at the base of the thaw depression has undergone severe leaching; while, Soil B, an Orthic Humo-Ferric Podzol and Soil E, a Gleyed Humo-Ferric Podzol are in intermediate stages of weathering with Soil E more weathered than Soil B. Evaluation of this hypothesis was accomplished with geochemical data obtained from X-ray fluorescence procedures. Comparing the resultant weight percentages and molecular ratios of the oxides proved inadequate for Soil C which had no Ae or defined C horizon. Hence, a more precise method which took into account the whole profile as well as the relative movement of the cations was required.

Adopting the techniques outlined by G.G. Beckmann (1975), the weight percentages were recalculated in terms of Barth's (1948) standard cell concept based on a cell containing 160 oxygen ions. The results for the individual

cations were plotted according to horizon depth on semi-logarithmic paper in order to assess the relative gains and losses of cations in the weathering zones. Sodium, potassium and silicon were the residual cations in the Ae horizons of the Degraded Dystric Brunisols; whereas, potassium, silicon and titanium were left in the Ae horizons of the Orthic Humo-Ferric and Gleyed Humo-Ferric Podzol. In the zone of accumulation, phosphorus, aluminum, and iron were the prime depositional cations. The close correspondence of the iron and magnesium curves and the minimal removal of basic cations in the transition and C horizon suggested that the iron-magnesium bearing minerals were weathered initially from the glacial material. Soil C, a Gleyed Humic Podzol, could not be evaluated in relation to the C horizon by using standard cell data because this profile had no defined C horizon.

Therefore a principal component analysis used by Beckmann (1975) to distinguish soils developed on several parent materials was adapted to delineate soil horizons formed on one parent material in this case glacial granitic till. The soil horizons were compared and grouped by using the cations as variables for assessing the weathering intensity between the soils of the toposequence. This enabled the horizons of Soil C to be examined in relation to each horizon present in the other soil profiles in order to comparatively establish the intensity of geochemical weathering.

The first component described the addition of cations, especially iron, and separated the profiles according to podzolic horizons, transition and C horizons, as well as Ae horizons. The second component reflected the parent material and separated the horizons into two groups: horizons in which cations were gained, or lost, and horizons in which cations remained fairly stable. The first component accounted for 46 per cent of the variance and the second component explained a further 31 per cent of the variance in the data.

Graphing of the two components determined the intensity of geochemical weathering which had taken place in each soil profile. The B horizons in which significant additions of iron and aluminum had occurred were centered positively about the first component axis; transition horizons and C horizons were negatively grouped about the second component axis. The Ae horizons showed a gradation away from the first and second component axes according to the degree of removal of cations and alteration from the parent material. In this region that indicated significant weathering of cations, the horizons of Soil C were located.

The final evaluation for the intensity of weathering evident in the toposequence was as follows: Degraded Dystric Brunisols formed on the dry-crestal sites were weakly weathered; the Orthic Humo-Ferric Podzol found on the moist terrace sites and the Gleyed Humic Podzol situated adjacent to the thaw pond were moderately weathered in terms of the other soil profiles; while, the Gleyed Humo-Ferric Podzol located in the linear depressions showed the maximum intensity of geochemical weathering of the five soils examined.

A sequence of geochemical weathering of the cations in the parent material was established from an assessment of the semi-logarithmic plots and the profile order of intensity of weathering.

B. Further Areas of Investigation

- 1) Determination of the actual weathered products, for instance the types of clay minerals, and the alteration products of feldspars, micas, and ferro-magnesium minerals would enable the formulation of a model to predict the residual products of the granitic tills.
- 2) Extensive testing of the proposed model with geochemical data obtained from other soils developed on glacial granitic tills in different environments would establish if similar trends existed with regard to weathering intensity.

- 3) Detailed micromorphological examination of the thin section for each soil horizon is required to describe the effects of degrees of weathering in the soil matrix.
 - 4) Additional high power magnification with the transmission and scanning electron microscope could locate actual sites on the constituent minerals where the release of cations has occurred.
- U.

APPENDIX I
LIMITS FOR THE PODZOLIC ORDER

Soils of the Podzolic order meet the following limits:

A. Morphological

1. The B horizon, at least 5 cm thick, has moist crushed colours as follows:
 - a) The hue is 7.5 YR or redder, or it is 10YR near the upper boundary and becomes yellower with depth, and
 - b) The chroma is higher than 3 or the value is 3 or less, and
2. Accumulation of amorphous material in a B horizon at least 5 cm thick is indicated by:
 - a) Brown to black coatings on some minerals grains or brown to black microaggregates, and
 - b) A silty feel when rubbed wet unless the material is cemented.
3. The texture of the podzolic B horizon is coarser than clay.
4. The soil either has no Bt horizon, or the Bt horizon occurs below 75 cm, or a weakly-expressed Bt horizon occurs below 50 cm. (A weakly expressed Bt horizon lacks both strong structure and obvious clay films and just meets the clay increase specified for a Bt horizon).

B. Chemical

Either 1. They have a B subhorizon (Bh) at least 10 cm thick that contains:

- a) More than 1% organic C, and
- b) Less than 0.3% pyrophosphate-extractable Fe, and
- c) That has a ratio of organic C to pyrophosphate-extractable Fe of 20 or more.

Or 2. They have a B subhorizon (Bf or Bhf) at least 5 cm thick that:

- a) Contains 0.6% or more pyrophosphate-extractable Al+Fe in textures finer than sand and 0.4% or more in sands (coarse sand, sand, fine sand and very fine sand).
- b) Has a ratio of pyrophosphate-extractable Al+Fe to clay (2mm) of more than 0.05, and
- c) Has an organic C content of more than 0.5%.

APPENDIX II

VEGETATION SPECIES AT THE SAMPLING SITES

Trees:

Picea mariana

Black Spruce

Larix laricina

Tamarack

Shrubs:

Betula sp.

Shrub Birch, specie

Empetrum hermaphroditum

Crowberry

Ledum groenlandicum

Labrador Tea

Salix sp.

Shrub Willow specie

Vaccinium myrtilloides

Blueberry

Vaccinium uliginosum

Alpine Blueberry

Vaccinium vitis-idaea

Lingonberry

Sedges:

Carex saxatilis

Bryophytes (Mosses):

Dicranum undulatumPolytrichum communePolytrichum piliferum

Lichens:

Cetraria islandicaCladonia gracilisCetraria nivalisCladonia macropteraCladonia amourocraeaCladonia rangiferinaCladonia cocciferaCladonia uncialisCladonia crispataNephroma arcticumCladonia gonechaStereocaulon paschale

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