SOIL-WATER CHEMISTRY RELATIONSHIPS AND CHARACTERIZATION OF THE PHYSICAL ENVIRONMENT - INTERMITTENT PERMAFROST ZONE, MACKENZIE VALLEY, N.W.T.

by

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ABSTRACT

A discussion is presented to illustrate the relationships among landform, soil, vegetation and water chemistry in the intermittent permafrost zone of the Mackenzie Valley, Northwest Territories. Two study areas were examined in this region, one in the vicinity of Wrigley and the other in the vicinity of Fort Simpson, N.W.T. A catenary sequence of soils and vegetation occurring as a transect on five distinctive landforms were examined in the Wrigley area. The transect extended from 1170 m above sea level downslope to 500 m above sea level. The five landforms were: an alpine meadow, an area of stone stripe and stone ring formation, a colluvial slope, a coalescing fan and an area of polygonal bog formation. Information on chemical water quality is presented for each of these areas for the parameters pH, O_2, Ca, Mg, Na, K, Cl, F and NO_3. Chemical water quality presented for the Fort Simpson study area allows for the differentiation of different types of organic terrain based on the dissolved load of the saturated organic materials. The polygonal bog landform initially examined in the Wrigley area formed one of the differentiated types of organic terrain. The results are discussed with reference to organic terrain morphology and the distribution of permafrost in the study area.

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INTRODUCTION

Historically, land has been defined as the solid part of the earth's surface as distinguished from the sea and has been recognized as being composed of different types in terms of quality and location. The concept that there are different types of land in relation to quality or more specifically productivity, has led investigators to derive various techniques for the classification of land. Land classification schemes, the arrangement of land units into various categories based on the properties of the land or its suitability for some particular purpose, have taken several different forms during the evolution of this concept but generally have been firmly rooted in the geological, pedological and climatological sciences. Various investigators have attempted to integrate the botanical sciences into land classification schemes with varying degrees of success. In order to facilitate a knowledge of the interrelationships between various landscape parts in terms of natural features such as fields, hills, forests and water that distinguish one part of the earth's surface from another part, an understanding of the environment is required. In the last few years, investigators have realized that environment can not be totally understood, for example, by only such factors as radiant energy and chemical compounds, but must include a description of the form and structure of the landscape. In a genetic sense landform, including surface form and geologic substratum, determines the landscape. It is strongly influential and shapes the structure and function of terrestrial and aquatic ecosystems. Landform controls the microclimate and selects the plants and animals that can survive there. In turn, the biotic communities determine the kinds of soils that form in the surficial materials on the landform. Derivative from landform is vegetation and when landform and vegetation interact a characteristic soil is developed. In relation, material dissolved in the water associated with the particular landform or environment is a function of the geologic substratum and integrates the effects of climate, vegetation and pedogenic processes on the landform. Vegetation, soils and water chemistry are therefore useful as indicators of particular environments. The manner and degree expressed by each of these parameters will determine the extent to which one or combination of these factors will exhibit control and hence define the ecosystem. In this manner, each parameter is a function of several others and as a result is a measurable indicator of the environment. For example, though vegetation influences landform by controlling rates of erosion, and soil influences vegetation through the development of material suitable for rooting, the degree of both is reflected by the dissolved chemical load in the subsequent waters.

With the above in mind, studies were conducted to illustrate the relationships between these parameters in a particular geographic area and climatic regime. The area in question is located within the northern part of the Interior Plains containing the Mackenzie Plain, east of the Mackenzie Mountains. Climatically, the study area is north of the summer limit of permafrost and has a climate that is considered subarctic, typified by cool, short summers with temperatures above 10°C. The long, cold winters have led to considerable ice buildup in parts of the area.

Characteristic of this portion of Canada, extensive areas of organic terrain are common throughout this region.

Two study areas were examined in this region. One at Wrigley, N.W.T. and another at Fort Simpson, N.W.T. upriver from Wrigley. Both hamlets are situated on the banks of the Mackenzie River. Chapters 1 and 2 describe a catenary sequence of landform and soil patterns established at the Wrigley study site where a total of five landforms were defined. An intensive examination of each landform included the sampling of soil material for subsequent physical and chemical analysis and a description of the land in terms of relief, drainage, elevation and soil parent materials. The characteristic vegetative species of each site were also described. Water chemical parameters were also examined by in situ techniques as well as laboratory analysis for waters associated with some of the defined landforms.

Since muskeg or organic terrain is extensive in this region, an understanding of this particular terrain type is important in terms of land use implications. A particular expression of muskeg, the polygonal bog landform, formed one of the landforms discussed in the Wrigley study area. As a result of this, Chapter 3 describes a study conducted in the Fort Simpson area directed toward the elucidation of the various terrain types associated with land defined broadly as organic terrain. Water chemical,pedological and vegetative parameters were used to distinguish two quite distinct types of landforms; the bog and the fen. The initial parameter mentioned, water chemistry, is indicated as being an extremely useful tool in defining these landforms. This is no doubt caused by the fact that water is present in very large quantities in this environment, frequently composing as much as 90% of the total volume of organic soils developed in this area.

The results demonstrate that various water chemical parameters can be used as indicators of particular terrain types in the intermittent permafrost zone of the Boreal Forest as soil and vegetation have. Just as soils are a function of particular environmental factors, so is the chemical composition of water, namely climate, geology, topography, vegetation and time. Since the chemical composition of water is also a function of pedological processes, this, in combination with the other environmental factors mentioned above, indicates that water chemistry is perhaps a means of integrating environmental effects on the land.

C H A P T E R 1

LANDFORM - SOIL - VEGETATION - WATER CHEMISTRY RELATIONSHIPS; WRIGLEY AREA, N.W.T.: I. MORPHOLOGY, CLASSIFICATION AND SITE DESCRIPTION.

ABSTRACT

Five landforms occurring in the intermittent permafrost region of the Mackenzie Valley are described. The five landforms, consisting of distinct soil and vegetative characteristics occur on a transect from the 1170 m ASL (above sea level) position at the summit of Cap Mountain, Wrigley area, N.W.T. to approximately 500 m ASL at the base of the slope. Two soils meet the requirements of the Organic order. Dark surface mineral horizons qualified one of the groups of soils as belonging to the Alpine supgroup. An area of stone stripe and stone ring formation was encountered at approximately 1000 m ASL and an extensive area of lichen covered polygonal bogs occurred at approximately 500 m ASL. The soils are described in relation to environmental factors and the processes of cryoturbation causing intermittent horizons are discussed.

INTRODUCTION

Although it is often reported that there is a dearth of knowledge with respect to northern development especially concerning environmental factors, much information is available regarding environmental factors in the Boreal Forest regions of Canada [Roberts-Pichette, 1972]. Much of this information, however, is indirect for much of northern Canada as it is often extrapolated from areas not directly within the areas of concern, e.g. the Mackenzie Valley. In this light, a study was conducted to illustrate the relationships between soil, vegetation, landform and water chemistry in the intermittent permafrost region of the Mackenzie Valley by means of a transect from the 1170 m ASL of Cap Mountain, to the 500 m ASL position at the base of the mountain.

The study area is located within the northern part of the Interior Plains containing the Mackenzie Plain, east of the Mackenzie Mountains (Figure 1). Climatically, the study area is north of the summer limit of permafrost [Brown, 1970]. The area has a climate that is considered subarctic [Brandon, 1965], typified by cool, short summers with temperatures above 10°C. The long, cold winters have led to considerable ice buildup in some of the different terrain types in the Wrigley area. Table 1 presents a summary of the climatic parameters. A ten year average is given for the mean maximum and minimum temperatures whereas a twenty-five year average is given for the remaining parameters. The geology of the area has been documented by the publications of

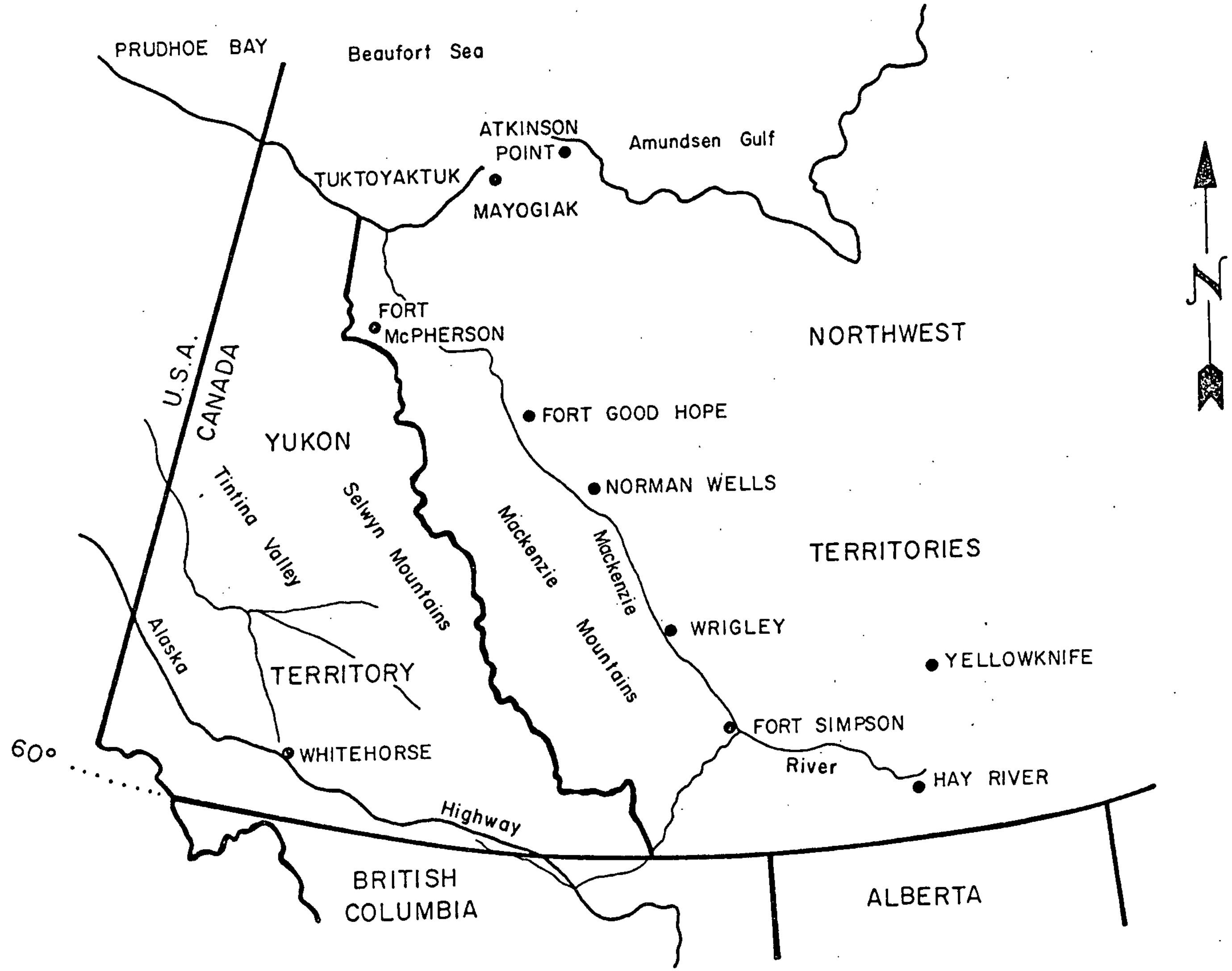

Figure 1. Geographic location of study area, Wrigley N.W.T.

Table 1. Selected climatic data of the Wrigley area

	TEMPERATURE (°C)					PRECIPITATION (CM)		
Month	Mean Maximum	Mean Minimum	Maximum	Minimum	No. of days with freezing temperature	Total	No. of days with 0.01 or more	Snowfall
January	-27.0	-34.8	- 9.9	-45.1	31	1.95	10.9	19.5
February	-20.2	-29.8	- 7.4	-43.1	28	1.25	8.6	12.5
March	-11.3	-23.1	3.3	-36.7	31	0.98	7.6	10.0
April	3.2	9.9	13.3	-23.0	27	1.52	6.8	13.5
May		0.6	23.7	7.0	14	2.30	7.0	4.8
June	13.6	7.1	28.7	- 0.3	1	3.60	9.1	0.0
July	20.6	9.6	30.8	1.8	0.3	5.03	10.7	0.0
August	22.5	7.0	28.3	- 1.1	1.6	4.78	9.3	0.0
September	20.2	0.3	20.3	6.0	10	3.32	8.4	3.5
October	11.3	- 5.8	12.6	-18.6	28	2.70	9.2	20.8
November	0.9	-22.2	- 1.8	-35.2	30	2.12	10.7	22.5
December	-21.8	-26.3	-10.8	-42.4	31	2.10	9.3	20.0

Craig [1965], Hume [1954], Stott [1960] and Douglas and Norris [1960]. The entire lowland area has been covered by a continuous mantle of glacial and post-glacial deposits. Extensive areas of organic terrain are common throughout this region [Lavkulich, 1970; 1971; 1972).

The study area is located on the south-east slope of Cap Mountain, a dominant physiographic feature of the landscape in the Wrigley area. Geographically, the transect extended from a semi-flat alpine meadow area at the top of Cap Mountain (1170 m ASL) to an area of stone stripe and stone ring formation at approximately 1000 m ASL which further extended into a rocky area consisting mainly of broken rock fragments and colluvium at 800 m ASL. From this area, the transect extended to the foot of the slope which consisted of an extensive area of coalescing fans, dissected in certain locations by erosional drainage channels flowing down the mountain slope. The coalescing fan area located between 700 and 550 m ASL, gently extended into a small forest of stunted Picea mariana which abruptly merged with an area of lichen covered polygonal bogs at approximately 500 m ASL (see Appendix for list of common and scientific names for vegetative species described in the text).

For each of the five landforms outlined above, a description of the dominant soils was recorded as well as a complete list of the vegetation present. Chapter 2 presents physical and chemical data in an attempt to illustrate the relationship between terrain type (i.e. land-form and soils) and water chemistry.

SOIL SITES

The pedons were examined in the field using standard techniques. Bulk samples were taken of each major horizon and returned to the laboratory for processing and analyses. Depths and horizonations are those recorded in the field description.

I. Alpine Meadow Area; Cryic Mesisol

This very poorly drained soil occurs on a 2% slope. The regolith is a calcareous glacial till and loess mixture. Bedrock in the area is dominantly sandstone and quartzite.

Horizon	Depth (cm)	Description
Of	0-11	Dark brown (10 YR 4/3, moist); pH 3.0
Om1	11-23	Dark brown (7.5 YR 3/2, moist); pH 4.3
Om2	23+	Very dark grayish brown (10 YR 3/2 moist); pH 4.3

II. Stone Stripe Area; Alpine Eutric Brunisol

These moderately well drained soils occur on 10% to 15% slopes on gently undulating colluvial fans. The regolith is a mixture of calcareous loamy glacial till and colluvium. Each of the four sample sites on this landform is described consecutively below (see Figure 3).

Site 1

Horizon	Depth (cm)	Description
Ah	0-3	Black(5 Y 2/2, moist; 7.5 YR 3/2 dry); sandy clay; weak granular structure; very turfy; pH 5.1; clear smooth boundary.
Bm1	3-23	Brown (10 YR 5/3, moist); clay loam; moderate fine subangular blocky structure; friable; pH 6.3; gradual irregular boundary.
Bm2	23-38	Grayish brown (10 YR 5/2, moist); clay loam; moderate coarse blocky structure; friable; pH 5.6; gradual wavy boundary.
Bm3	38-48	Grayish brown(2.5 Y 5/2, moist); clay loam; moderate very coarse subangular blocky breaking to moderate fine subangular blocky structure; friable; pH 5.9; gradual wavy boundary.
C	48+	Dark brown (10 YR 3/3, moist); clay loam; coarse subangular blocky structure; firm; pH 6.8; clear wavy boundary.

Site 2

Horizon	Depth (cm)	Description
Ah	0-4	Dark reddish brown (5 YR 2/2, moist); sandy clay loam; weak granular structure; turfy; pH 5.9; clear wavy boundary.
Ob	4-12	Dark brown (7.5 YR 3/2, moist); pH 6.4; gradual irregular boundary.
Bm1	12-22	Brown (10 YR 5/3, moist); clay loam; moderate fine subangular blocky structure; friable; pH 6.3; clear smooth boundary.

Bm2	12-22	Brown (10 YR 5/3, moist); clay loam; moderate coarse subangular blocky structure; firm; pH 5.8; gradual wavy boundary.
C	47+	Olive gray (5 Y 5/2 moist); clay loam; moderate fine subangular blocky structure; firm; pH 7.1; abrupt, smooth boundary.

Site 3

Horizon	Depth (cm)	Description
Ah	0-10	Grayish brown (2.5 Y 5/2, moist); clay loam; weak granular structure; turfy; pH 5.6; clear smooth boundary.
Bm1	10-20	Grayish brown (2.5 Y 5/2, moist); clay; moderate fine subangular blocky structure; firm; pH 5.8; gradual irregular boundary.
Bm2	20-29	Grayish brown (2.5 Y 5/2, moist); clay loam; moderate coarse blocky structure; friable; pH 5.8; gradual wavy boundary.
C	29+	Olive brown (2.5 Y 4/4, moist); clay loam; coarse subangular blocky structure; firm; pH 6.2; clear wavy boundary.

Site 4

Horizon	Depth (cm)	Description
Ah	0-3	Dark reddish brown (5 YR 3/2, moist); sandy clay loam; weak granular structure; turfy; pH 4.7; clear smooth boundary.
Bm1	3-13	Dark brown (10 YR 3/3, moist); clay loam; weak fine blocky structure; friable; pH 5.1; gradual wavy boundary.

Bm2	13-23	Dark grayish brown (10 YR 4/2, moist); clay loam; moderate medium blocky structure; friable; pH 5.2; gradual wavy boundary.
C	23+	Grayish brown (10 YR 5/2, moist); clay loam; fine subangular blocky structure; firm; pH 6.4; clear wavy boundary.

III. <u>Colluvial Slope Area; Lithic Alpine Eutric Brunisol</u>

This moderately well drained soil occurs on a 25% to 38% slope of the undulating colluvial slope east and down slope of the stone stripe area. The underlying regolith is a mixture of coarse textured colluvial material and calcareous loamy glacial till overlying non-calcareous shale bedrock.

Horizon	Depth (cm)	Description
LFH	2-0	Dark Brown (7.5 YR 3/2, moist); pH 6.4.
Ah	0-4	Very dark brown (10 YR 2/2, moist); sandy loam; weak granular structure; pH 6.2; clear smooth boundary.
Ahb	4-6	Very dark grayish brown (10 YR 3/2, moist); sandy clay loam; weak granular structure; pH 6.2; gradual wavy boundary.
Bm	6-16	Grayish brown (2.5 YR 5/2, moist); clay loam; moderate fine subangular blocky structure;friable; pH 6.8; gradual irregular boundary.
C	16-24	Grayish brown (2.5 Y 5/2, moist); clay loam; coarse subangular blocky structure; firm; pH 6.6; clear wavy boundary.
R	24+	non-calcareous shale bedrock

IV. Coalescing Fan Area; Orthic Gleysol

This poorly drained soil occurs on a 7% slope of the gently undulating coalescing fan south of the stone stripe area. The regolith consists of a mixture of colluvial and alluvial material composed of shattered noncalcareous shale bedrock.

Horizon	Depth (cm)	Description
LFH	20-0	Very dark brown (10 YR 2/2, moist); pH 5.9
Bg	0-11	Brown (10 YR 5/3, moist); sandy loam; fine subangular blocky structure; slightly sticky; pH 6.4; diffuse irregular boundary.
BC	11-19	Reddish brown (5 YR 4/3, moist); loamy sand; structureless; nonsticky; pH 6.6; diffuse irregular boundary.
C	19+	Dark reddish gray (5 YR 4/2, moist); loamy sand; structurless; nonsticky; pH 6.4; diffuse irregular boundary.

V. Polygonal Bog Area; Cryic Fibrisol

This very poorly drained soil occurs on nearly level land with slopes of 0% to 2%. The regolith is composed of sphagnum moss species at different stages of decomposition, frozen at 35 cm.

Horizon	Depth (cm)	Description
Of1	0-20	Dark brown (7.5 YR 4/4, moist); pH 2.6
Of2	20-35	Dark brown (7.5 YR 4/2, moist); pH 2.5
Ofz	35+	Same as above but frozen.

RESULTS AND DISCUSSION

The study area is schematically presented in Figure 2 and an oblique photograph of the area is given in Figure 3. The entire transect is illustrated, beginning at the top of Cap Mountain at the alpine meadow area down through the stone stripe area and colluvial slope area into the coalescing fan unit and finally into the area of polygonal bog formation. Due to the remoteness of the area, no data was available regarding soil temperatures or air movement patterns. From site observations, it is believed that windswept conditions prevail on the sites at the summit of the mountain as well as on the slope. This has the effect of causing the soil to freeze early in the fall at these sites and warm fairly rapidly in the spring. As a result this area was locally more arid than the other sites, with soil temperatures closely paralleling air temperature patterns. The coalescing fan area at the base of the slope is believed to be less windswept and covered by a considerable depth of snow in winter, as indicated by numerous examples of krummholz vegetation. This has the effect of causing the mean soil temperatures to be higher during the winter months than the corresponding air temperature. Depending on the duration of the snow-pack in this area, the mean soil temperatures will remain lower than mean air temperatures during the spring months. Similar to the areas at the top of the mountain, the polygonal bog area is considered to be generally windswept with the exception that large drifts of snow will accumulate within the scattered clumps of trees dotting the landscape

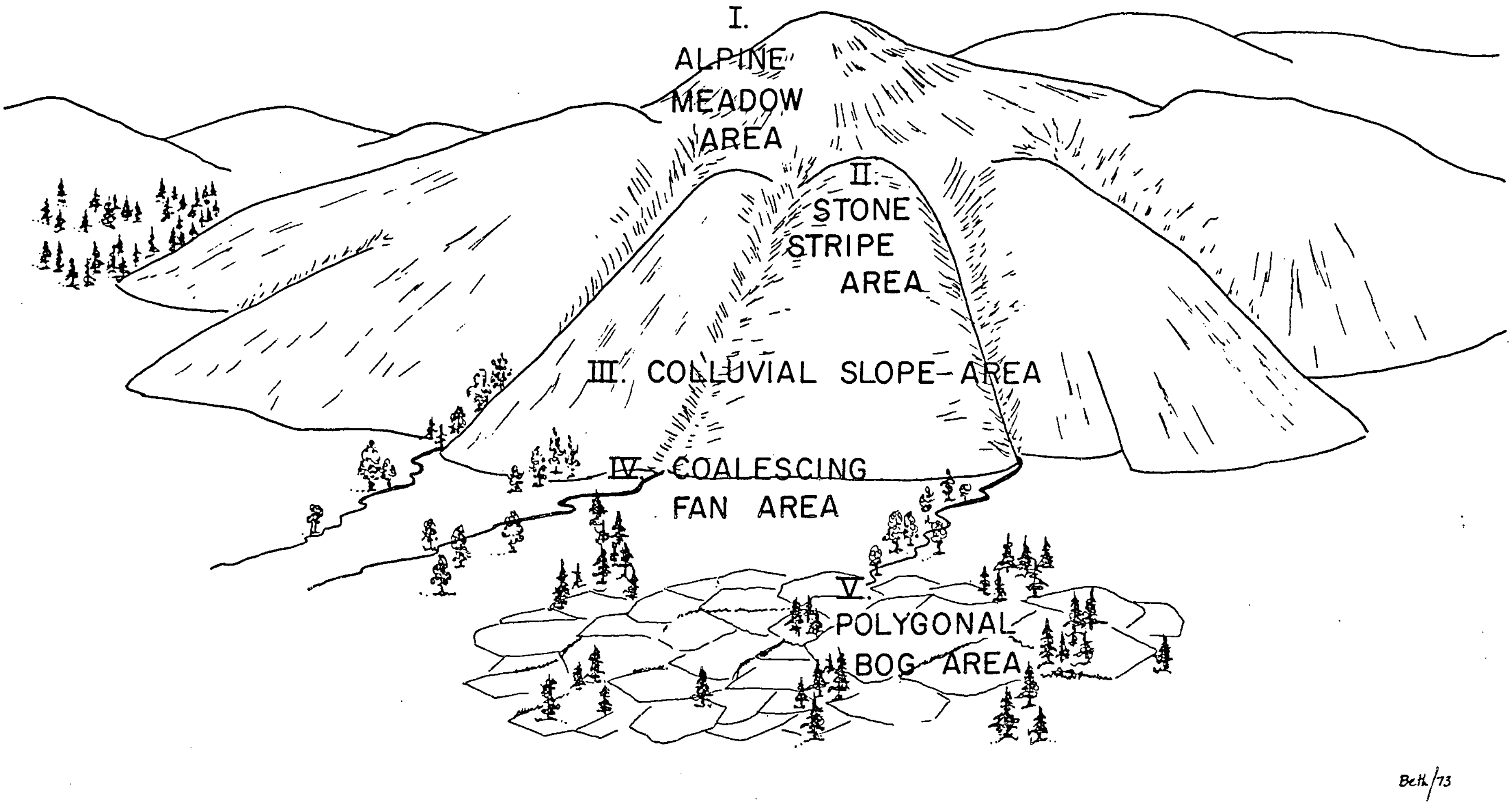

Figure 2. Physiographic relationships of study sites, Cap Mountain.

Figure 3: Oblique photograph of study area; Cap Mountain in the background.

in this area. As mentioned above, this will result in a rapid cooling of the ground as winter approaches and subsequently a rapid warming during the spring. The presence of a thick, insulating mat of organic material on this landform coupled with these climatic characteristics is considered condusive for polygonal ground formation [Britton, 1957].

The alpine meadow unit located at the top of Cap Mountain consisted mainly of a very poorly drained area surrounding a small alpine lake (tarn). Figure 4 illustrates the area. The organic material, frozen at approximately 30 cm was dissected by drainage lines forming a polygonal pattern, resultant from the windswept and locally arid nature of this area. An organic soil has developed in this environment with the dominant soil in the area being classified as a Cryic Mesisol according to the Canadian System of Soil Classification [1970]. Ecologically, the area was typified by a well developed shrub layer consisting of Betula glandulosa, Salix spp., Salix reticulata and Potentilla fruticosa. The predominant species in the rich herb layer were Dryas sp., Lupinus arcticus, Anemone parviflora, Pedicularis kanei, Saxifraga bronchialis, Aconitum columbianum and Arnica sp. Feathermosses (Hylocomium splendens, Pleurozium schreberi and Ptilium crista-castrensis) and lichens (Cetraria cuculata and Alectoria octocruka) were abundant.

The stone stripe and stone ring area, occurring downslope from the alpine meadow area, generally had slopes ranging from ten to fifteen percent (Figure 5). An Ah horizon had developed in this environment formed from the accumulation and decomposition of shrubs and

Figure 4: Alpine meadow area.

Figure 5: Stone stripe and stone ring area.

herbs. The soils from the four sampling sites described for this area were classified as Alpine Eutric Brunisols. Due to the variability present in the developed soils in this area, a cross-sectional profile through a stone ring is presented in Figure 6. Ground frost had caused a large amount of mixing and convoluting of the soil horizons. Figure 6 illustrates two areas in the solum where organic material has been incorporated into the profile, described as Ob horizons. Both of these areas are located on either side of the stone ring, indicating a downward as well as inward movement of material under the stone ring area with a subsequent upward movement of coarser material. Inspection of the soils developed in this area indicated some differences in the morphology of the soils developed under the stone rings and the soils developed under the depressions between the stone rings. The Ah horizon developed under the stone ring had a low organic matter content compared with the Ah horizons developed in the areas between the stone rings. Such a situation is indicative of both a more intensive biological activity in the area between the stone rings as well as greater cryoturbation under the stone ring area, causing a considerable movement of mineral material into this zone. An indication of the depth to which the most extensive amount of cryoturbation may be effective is given by the location of the Bml horizon. Just as the depth of the Ob horizons were approximately 5 to 10 cm below the surface of the depressions between the stone rings, the Bml horizon was at approximately the same depth. This suggests a depth of approximately 15 cm for the maximum zone of extensive cryoturbation.

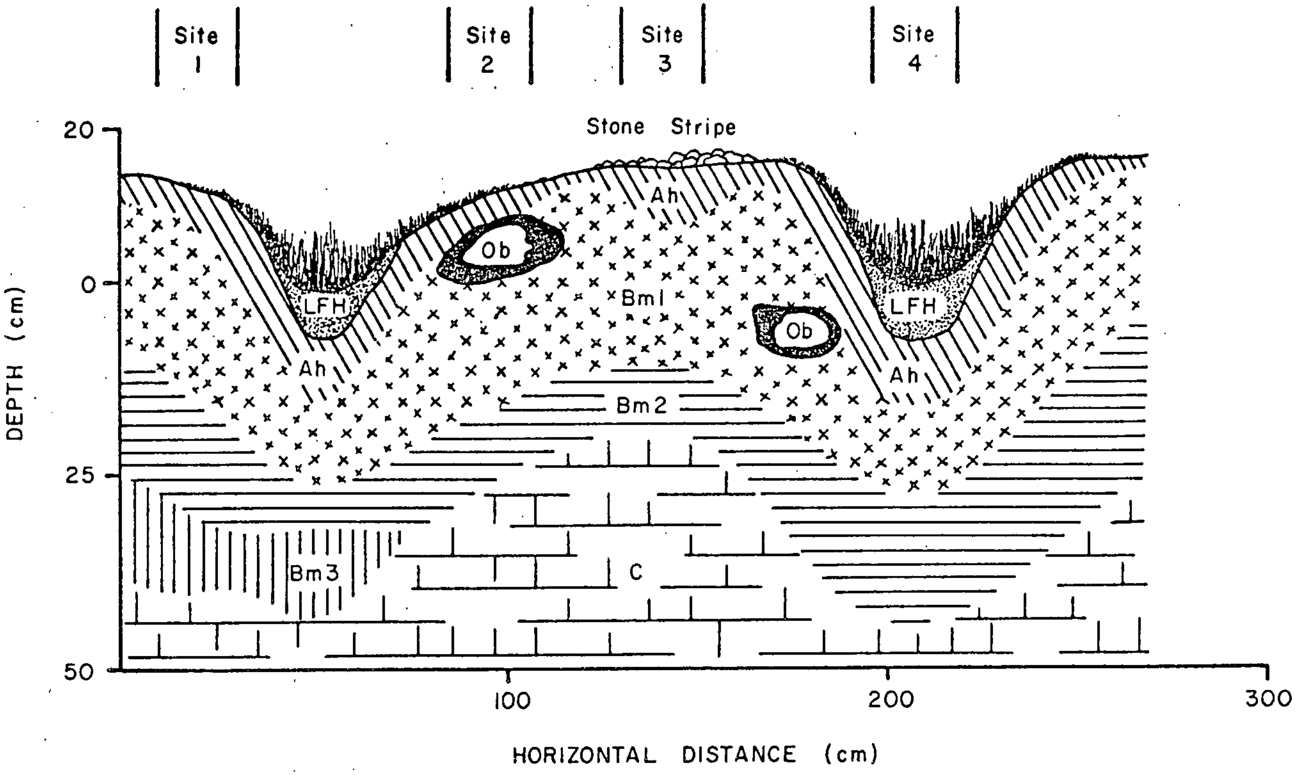

Figure 6. Cross-sectional profile through stone stripe area, illustrating sampling sites.

The dominant vegetation on the stone rings and the stone stripes which run parallel to the slope was somewhat different in comparison to the meadow unit discussed previously. In this area Vaccinium sp. was dominant whereas Betula glandulosa was dominant in the meadow unit. The stone stripes and stone rings had abundant Dryas sp. and generally the same herbs as the lush meadow unit but with less ground coverage.

On much steeper terrain (25 to 30%) downslope from the stone ring area, the third unit of study occurred. This area consisted mainly of coarse textured colluvial material and was generally rocky or stony at the surface (Figure 7).

With the exception of extensive cryoturbic processes, the soil developed on this landform is similar to that of the stone stripe area. An Ah horizon had also developed and the soil was classified as a Lythic Alpine Eutric Brunisol. Continual downslope movement of shattered bedrock and unconsolidated material in this environment has altered the profile in a certain manner. The presence of a buried Ah horizon (Ahb) is indicative of the large amount of downslope movement typical of this area. Such gravitational processes have also resulted in shallow profile development in comparison to the soils developed in the stone stripe area.

Ecologically, the rocky units were dry areas which were being invaded by Dryas sp., Lupinus arcticus, Oxytropis Maydelliana, Saxifraga bronchialis, Polytrichum juniperinum, Cetraria cuculata and Cetraria tilesii.

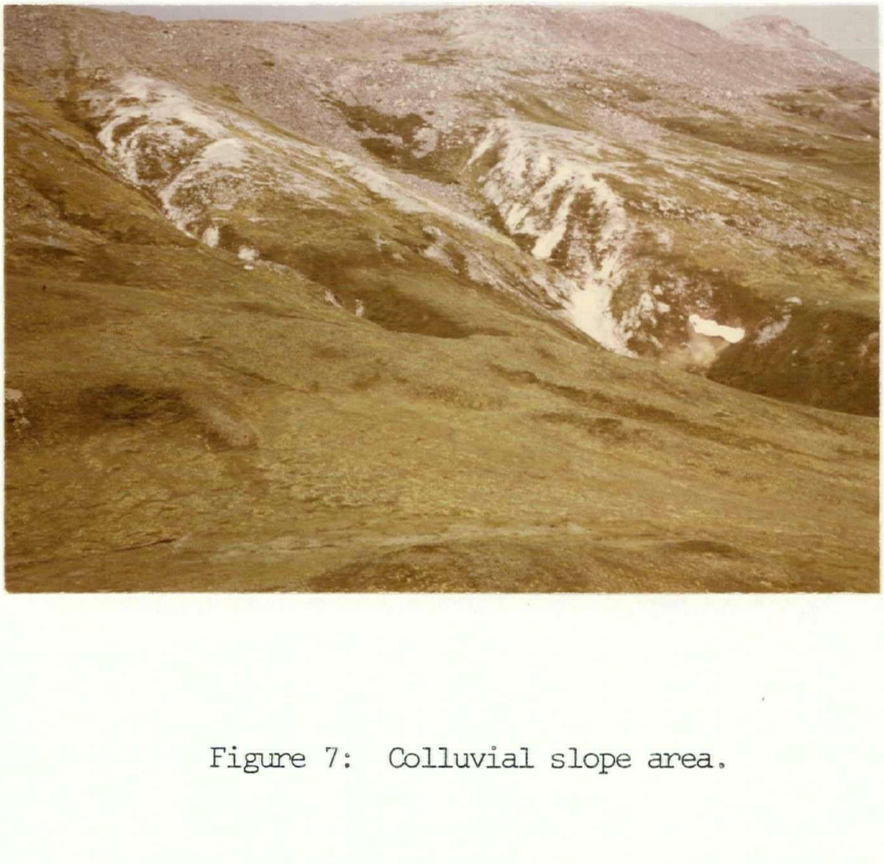

Figure 7: Colluvial slope area.

At the foot of the slope, approximately the 800 m level, the coalescing fan landform occurs. Pedologically, the area was characterized by Orthic Gleysol soils in the more depressional areas and by organic soils, developed on the hummocks of the slightly undulating topography. Geomorphically, the area consisted of large coalescing colluvial fans extending from the base of the mountain (Figure 8). The slope of the land varied from 5% to 10% and in aerial extent ranged from approximately 8 to 10 km in length and 1 to 2 km in width. As a result of the finely bedded red shale bedrock of the slope area, the material is under constant movement during the summer and fall months. The finely broken shale material, being flat and non-cohesive, offers little resistance to gravitational forces. Physical and chemical weathering of the shale material has produced a finer texture for the developed soils in comparison to the soils developed in the rocky unit upslope from this area. Shale material is known to weather quickly and completely to material of clay size. As a result, the area is quite unstable in terms of engineering uses such as road or pipeline construction.

The dominant vegetation of this area was visually striking as a result of the vast expanse of krummholz trees and low shrub vegetation. The author believes this area is to be inundated with a large amount of snow during the winter months, blowing off from the nearby mountains and slopes. Consequently, the trees in the area were extremely stunted or krummholtz in nature, caused by the weight of the deep snow. Dominantly, the vegetation consisted of scattered,

Figure 8: Coalescing fan area.

krummholz Picea glauca with a shrub layer consisting of Betula glandulosa, Vaccinium sp., Salix reticulata, Salix spp., Rhododendron lapponicum, Vaccinium vitis-idaea and Arctostaphylos rubra. Typical herbs were Dryas sp., Tofieldia sp., Lupinus arcticus, and Pedicularis kanei. The feathermosses Hylocomium splendens, Dicranum sp., Tomenthypnum nitens and Dicranum undulatum were abundant, with the lichens Cladina arbuscula and Cetraria cuculata present.

Extending east from the coalescing fan area described above was a small forest of stunted Picea mariana which abruptly bordered on an extensive lichen covered bog or peat polygon [Tarnocai, 1970] area. This type of terrain had polygonal cracks outlined in the bogs with polygons 15-20 m in diameter. These were outlined by fissures of variable width (1-3 m) and sunk about 0.5 m below the surrounding terrain. An aerial view of the polygonal bog is presented in Figure 9. These hummocky surfaced bogs had Cryic Fibrisols as the dominant soils. These soils consisted of 30 cm of black, moderately decomposed organic matter over raw undecomposed sphagnum derived peat with ice at 35 cm.

Vegetatively, the area was characterized by a shrub layer of less than 1 m in height. The species consisted of Betula glandulosa, Ledum decumbens, Andromeda polifolia, Vaccinium vitis-idaea, and Rubus chamaemorus. The dominant sphagna was Sphagnum fuscum while approximately 80% of the ground was covered by lichen species consisting of Cladina alpestrus, Cetraria cuculata, Cladina rangiferina and Cladina mitis.

In summary, the five landforms described appeared distinctly different pedologically as well as ecologically but when considered collectively were component ecosystems forming a part of the major

Figure 9: Polygonal bog area.

ecosystem characteristic of this part of the Boreal Forest region of Canada [Rowe, 1959]. Gross climatic regimes dominate the characteristics of the physical environment in this region. The cold temperatures associated with each of the five landforms caused not only a limited biological breakdown of organic matter but also increased the physical weathering of rock material due to intense freeze and thaw cycles. Soil formation on mineral sites was shallow and highly retarded by mixing of soil horizons as a result of cryoturbation. The subangular blocky structures and friable consistencies reflected the high permeability and low clay mineral contents of these soils illustrating the low level of chemical weathering. Organic matter had accumulated to variable depths at certain locations in this region and tended to modify the effect of climate. The organic material accumulated in the alpine meadow study area was at a higher stage of decomposition than was the organic material located on the polygon bog study area. The elevation of the sites and the distribution of snow has affected the distribution of permafrost and the types of vegatative species. Each of these factors has contributed to a higher degree of biological activity at the alpine meadow site.

APPENDIX

Common Names	Scientific Names
Trees	
Black spruce	*Picea mariana*
White spruce	*Picea glauca*
Shrubs	
Moorwart	*Andromeda polifolia*
Kinnickinnick	*Arctostaphylos rubra*
Bog birch	*Betula glandulosa*
Arctic labrador tea	*Ledum decumbens*
Shrubby cinquefoil	*Potentilla fruticosa*
Purple rhododendron	*Rhododendron lapponicum*
Baked appleberry	*Rubus chamaemorus*
Willow	*Salix reticulata*
	Salix spp.
Cowberry	*Vaccinium vitis-idaea*
	Vaccinium sp.
Herbs	
Monkshood	*Aconitum columbianum*
Anemone	*Anemone parviflora*

Common Names	Scientific Names
Arnica	*Arnica sp.*
Dryas	*Dryas sp.*
Arctic lupine	*Lupinus arcticus*
Locoweed	*Oxytropis maydelliana*
Louse wort	*Pedicularis kanei*
Spotted saxifrage	*Saxifraga bronchialis*
Tofieldia	*Tofieldia sp.*
Sphagna	
Sphagnum	*Sphagnum fuscum*
Mosses	
Wavy dicranum	*Dicranum undulatum*
Ribbed bog moss	*Dicranum sp.*
Feather moss	*Hylocomium splendens*
Schrebers moss	*Pleurozium schreberi*
Hair cap moss	*Ptilium crista-castrensis*
	Polytrichum juniperinum
Liver wort	*Tomenthypnum nitens*
Lichens	
Reindeer mosses	*Alectoria octocruka*
	Cetraria cuculata

Common Names	Scientific Names
Reindeer mosses	_Cetraria tilesii_
	Cladina alpestrus
	Cladina arbuscula
	Cladina mitis
	Cladina rangiferina

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CHAPTER 2

LANDFORM - SOIL - VEGETATION - WATER CHEMISTRY RELATIONSHIPS; WRIGLEY AREA, N.W.T.: II. CHEMICAL, PHYSICAL AND MINERALOGICAL DETERMINATIONS AND RELATIONSHIPS

ABSTRACT

A discussion is presented on the results of selected chemical, physical and mineralogical analyses carried out on soil samples collected from catenary sequences from five landforms in the intermittent permafrost region of the Mackenzie Valley, N.W.T. The five landforms are an alpine meadow, an area of stone stripe and stone ring formation, a colluvial slope, a coalescing fan and an area of polygonal bog formation. Information on chemical water quality is also presented for each of these areas for the parameters pH, O_2, Ca, Mg, Na, K, Cl, F and NO_3. Relationships are discussed in terms of the environmental controls that occur on the five landforms. An attempt is made to show the relationships between the four parameters; landform, soil, vegetation, and water chemistry. Also, an indication is given of the usefulness of this data as environmental indicators for the definition of particular terrain types.

INTRODUCTION

The results of chemical, physical and mineralogical determinations performed on soils from five distinct landforms occurring on a transect down a mountain slope in the Mackenzie Valley, N.W.T. are presented. In Chapter 1 of the study the soils were described and classified. Relationships are discussed between water chemical data and various pedologic and geologic characteristics of the landforms.

MATERIAL AND METHODS

Laboratory analysis of the sampled soils was performed on the less than 2 mm material. Particle size analysis was accomplished by treatment of the sample with H_2O_2 for removal of organic matter followed by hydrometer analysis as described by Day [1950].

Organic matter was estimated by determination of total carbon with a Leco induction furnace and carbon analyzer [Allison, _et al_.; 1965].

Total nitrogen was determined by semi-micro Kjeldahl methods [Bremner, 1965].

Cation exchange capacity and exchangeable cations were determined by neutral, normal NH_4OAc leaching, followed by semi-micro Kjeldahl determination of absorbed ammonium and atomic absorption spectrophotometric procedures for exchangeable cations, as developed in the University of British Columbia, Department of Soil Science laboratory.

The determination of pH was carried out on 1:1 mineral material: water and 1:2 mineral material: 0.01 M $CaCl_2$ slurries. Due to their high moisture holding capacity, 1:2 organic material: water and 1:4 organic material: 0.01 M $CaCl_2$ slurries were used for the organic soils.

Free iron and aluminum were extracted by the ammonium oxalate procedure of McKeague and Day [1966].

Analysis of water samples was performed both _in situ_ and in the laboratory. The parameters pH and dissolved oxygen were determined _in situ_ at the site while NO_3, F and Cl were analyzed within a few hours at the field camp with the aid of specific ion electrodes. Samples were taken at the site in plastic bottles and delivered to the laboratory where analysis for Na, Ca, Mg and K was performed by atomic absorption spectrophotometric procedures. The specific ion electrodes employed were solid state Cl and F electrodes and a liquid junction NO_3 ion electrode. A single junction reference electrode (Orion Model 90-01; Orion Research Inc., Cambridge, Massachusetts) was used with the NO_3 ion electrode with saturated KCl as the filling solution. A double junction (Orion Model 90-02) reference electrode was used with the chloride electrode to minimize the liquid junction potential and avoid sample contamination. The F ion electrode is a combination type, having a built in reference electrode, using saturated KCl as the reference solution. A combination pH electrode employing saturated KCl as the reference filling solution was used for the measurement of hydrogen ion activity. Dissolved oxygen was determined with a Y.S.I. Model 54 oxygen meter (Yellow Springs Instrument Co. Inc., Yellow Springs, Ohio). This meter in conjunction with an oxygen electrode is capable of determining the dissolved oxygen concentration of liquids within the range of 0.0 to 20.0 ppm [Walmsley and Lavkulich, 1973].

Soil samples collected for clay mineral identification were air-dried, crushed and fractionated by sieving and centrifuge techniques. The clay sized material ($< 2\mu m$) was separated using a laboratory model supercentrifuge (Sharples Co., Philadelphia, Pa.) following the procedure outlined by Jackson [1956]. The clay size separates were then treated to make the following parallel oriented slides: Mg-saturated, Mg-saturated and glycol solvated, K-saturated, K-saturated and heated to 300C, and K-saturated and heated to 500C following the procedure outlined by Jackson [1956].

The parallel oriented clay mineral slides were subjected to Ni filtered CuKα radiation using a Phillips X-ray diffractometer. The resultant diffractograms were interpreted according to standard methods [Jackson, 1964; Whittig, 1965] and the relative quantities of each clay mineral present were expressed as a function of peak intensity and peak area.

RESULTS AND DISCUSSION

Physical and Chemical Analyses of Soils

To facilitate a knowledge of the interrelationships between various landscape parts, an understanding of the environment is required. Environment can not be totally understood by only such factors as radiant energy and chemical and physical composition but must also include a description of the form and structure of the landscape. In a genetic sense, landform, including surface form and geologic substratum, determines the landscape. It in conjunction with elevation, is strongly influential and shapes the structure and function of terrestrial and aquatic ecosystems. Landform and elevation control the micro-climate within a climatic region and select the plants and animals that can survive there. In turn, the biotic communities determine the kinds of soils that form in the surficial materials on the landform. Derivative from landform is vegetation and when landform and vegetation interact, a characteristic soil profile is developed. Chemical water quality in relation, is a function of the geologic substratum and integrates the effect of climate, vegetation and pedogenic processes on the landform. Vegetation, soils and chemical water quality are therefore useful as indicators of particular environments rather than as definers of it. The manner and degree expressed by each of these parameters will determine the extent to which one or a combination of these factors will exhibit control and hence define the ecosystem. In this manner, each parameter is a function of several others and as a result is a

Table 1

Some Selected Chemical and Physical Properties of Sampled Soils

Site	Horizon	Depth (cm)	Coarse Fragments (%)	Sand (%)	Silt (%)	Clay (%)	N (%)	OM (%)	C/N	pH H_2O	pH $CaCl_2$	Exchangeable Cations Ca (me/100 g)	Mg (me/100 g)	Na (me/100 g)	K (me/100 g)	CEC (me/100 g)	Oxalate Extractable Fe (%)	Oxalate Extractable Al (%)
I. Alpine Meadow Area	Of	0-11					0.68	69.1	58.3	3.9	3.0	8.81	8.13	1.96	1.55	126.22		
	Om1	11-23					1.78	44.0	14.2	5.1	4.3	15.21	8.44	1.89	0.38	99.45		
	Om2	23+					1.72	42.0	12.0	5.1	4.3	12.50	7.81	1.95	0.29	82.87		
II. Stone Stripe Area																		
Site 1	Ah	0-3	24.7	44.4	15.2	40.4	0.46	14.4	18.0	5.6	5.1	12.88	6.88	8.75	0.34	40.16		
	Bm1	3-23	36.1	39.0	32.4	28.6	0.14	3.4	13.8	6.6	6.3	5.00	6.06	0.63	0.29	29.89	0.20	0.20
	Bm2	23-30	4.7	32.4	27.3	40.3	0.08	1.9	13.7	6.2	5.6	13.13	6.44	0.69	0.24	27.47	0.19	0.19
	Bm3	38-48	21.3	29.2	29.8	41.0	0.09	1.9	12.2	6.5	5.9	15.00	7.88	0.69	0.22	29.25	0.17	0.18
	C	48+	30.8	33.2	30.9	35.9	0.08	0.3	16.4	7.3	6.8	15.00	8.06	0.63	0.18	25.17	0.19	0.14
Site 2	Ah	0-4	10.7	48.7	25.5	25.8	0.80	19.2	13.7	6.4	5.9	46.88	4.13	3.13	0.48	58.45		
	Ob	4-12					0.70	18.1	14.9	6.9	6.4	33.75	5.00	1.25	0.17	52.78		
	Bm1	12-22	29.8	37.9	32.9	29.2	0.17	3.8	12.9	7.0	6.3	18.13	4.75	0.63	0.16	31.29	0.17	0.20
	Bm2	22-47	1.0	41.2	27.2	31.6	0.08	1.8	13.0	6.6	5.8	13.75	5.50	0.63	0.19	26.32	0.18	0.18
	C	47+	24.2	28.8	35.9	35.3	0.08	0.5	25.4	7.7	7.1	15.00	7.06	0.56	0.13	26.57	0.24	0.12
Site 3	Ah	0-10	13.4	32.2	35.5	32.3	0.13	2.6	11.6	6.6	5.6	13.13	6.06	0.69	0.20	29.63		
	Bm1	10-20	20.2	25.5	29.5	45.0	0.07	1.8	15.1	6.9	5.8	14.38	8.94	0.69	0.36	26.70	0.28	0.21
	Bm2	20-21	18.2	23.4	32.5	44.1	0.07	1.7	13.7	6.6	5.8	13.75	9.44	0.69	0.29	28.23	0.25	0.20
	C	29+	19.8	35.6	28.0	36.4	0.08	1.7	12.0	6.9	6.2	15.00	8.38	0.69	0.22	28.87	0.31	0.18
Site 4	Ah	0-3	18.6	51.2	23.7	25.1	0.47	15.1	18.5	5.4	4.7	9.38	4.63	1.38	0.33	30.60		
	Bm1	3-13	8.2	41.2	30.5	28.3	0.37	6.5	10.0	5.9	5.1	9.38	3.00	1.25	0.20	27.79		
	Bm2	13-23	17.2	32.5	30.5	37.0	0.09	2.2	13.9	6.9	5.8	13.75	7.19	0.56	0.18	26.83	0.27	0.19
	C	23+	9.5	33.0	33.0	34.0	0.08	2.0	14.7	7.1	6.4	13.75	9.31	0.39	0.26	26.96	0.26	0.16
III. Colluvial Slope Area	LFH	0-2					0.52	15.4	17.0	6.7	6.4	1.15	9.13	0.05	0.50	39.01		
	Ah	2-6	4.1	66.8	12.9	20.3	0.51	11.4	12.8	6.7	6.2	25.00	8.69	0.02	0.19	39.78		
	Ahb	6-8	4.0	50.0	26.5	25.5	0.42	8.2	11.2	6.7	6.2	23.75	9.25	0.02	0.18	36.85		
	Bm	8-18	44.1	34.2	36.6	29.2	0.09	4.2	26.6	7.4	6.8	13.13	7.38	0.02	0.20	25.43	0.29	0.13
	C	18+	29.0	44.6	27.8	26.6	0.08	4.7	33.6	7.4	6.6	13.31	7.75	0.20	0.20	25.30	0.27	0.14
IV. Coalescing Fan Area	LFH	0-20					2.13	65.2	17.6	6.4	5.9	4.13	30.94	0.10	1.06	158.74		
	Bg	20-31	49.2	70.2	20.8	9.0	0.16	5.9	21.0	6.9	6.4	17.50	7.06	0.03	0.17	29.31	0.34	0.14
	BC	31-39	59.0	80.0	18.4	1.6	0.04	4.7	66.7	7.2	6.6	7.90	4.00	0.02	0.15	22.50	0.12	0.08
	C	39+	26.8	82.2	15.1	2.7	0.04	2.7	38.2	7.2	6.4	8.03	3.75	0.02	0.14	22.50	0.20	0.08
V. Polygonal Bog Area	Of1	0-20					0.71	72.9	60.0	3.4	2.6	4.38	0.81	0.04	0.08	34.42		
	Of2	20-35					0.82	70.4	50.0	3.4	2.5	1.25	3.75	0.15	0.28	56.82		
	Ofz	35+																

measurable indicator of the environment. For example, though vegetation influences landform by controlling rates of erosion, and soil influences vegetation through the development of material suitable for rooting and nutrition, the degree of both is reflected by the dissolved chemical load of the draining waters.

In this particular study, five landforms were defined and described in terms of soil, vegetation and water chemistry parameters. The study area is schematically presented as a cross-sectional diagram in Figure 1. The developed soils are also figuratively drawn in an attempt to show the catenary sequence in terms of soil genesis. Elevation above sea level is given by a scale on the right side of the diagram.

The first landform, the alpine meadow unit, was distinct in terms of surface form and geologic substratum. Topographically, the area was flat to very gently sloping. Poor internal drainage and climatic factors affecting biological decomposition resulted in the buildup of organic material on the soil which was frozen at approximately 30 cm. Chemical data (Table 1) indicated the soil is extremely to very strongly acid. The values tend to be low at the surface and increase with depth. Organic matter decreased with depth and is in good agreement with cation exchange capacity values which also decreased with depth. The decrease in C/N ratios with depth is indicative of increased decomposition perhaps being a function of increased microbial activity with depth. The exchangeable cations in order of abundance are Ca, Mg, Na and K, considered typical for this soil type. Relatively high levels of total N are indicative of a relatively high level of decomposition, reflecting warm soil temperatures during the summer months. In this sense, elevation and landform have tended to modify the micro-climate and keep this area windswept and relatively clear of snow. The geographical occurrence of this landform as a receiving site for moisture from surrounding slopes and its close proximity to standing water have also determined the expression of this landform in terms of vegetation and soils. Shallow depth to bedrock had resulted in impeding water flow through the soil material which was also reflected by the presence of a rich herb layer of vegetation and the development of an organic soil.

The stone stripe and stone ring area occurring downslope from the alpine weadow unit was another distinctive landform in terms of surface form as modified by climate. Ground frost had caused mixing and convoluting of the surficial material and hence the soil horizons. Reference to Table 1 for the four soils sampled on this landform indicate that there were differences between the soils developed under the stone rings and the soils developed under the depressions between the stone rings. The Ah horizon developed under the stone ring showed a significantly lower organic matter content (2.6%) compared with the Ah horizons developed in the areas between the stone rings (15.1%). The interaction of elevation (climate) and landform has resulted in a more intensive level of biological activity in the area between the stone rings as well as greater cryoturbation under the stone rings causing a considerable movement of mineral material into this zone. The gently undulating form of the landscape in this area and the elevation have caused windswept conditions to prevail resulting in very cold soils during the winter and a substantial difference between

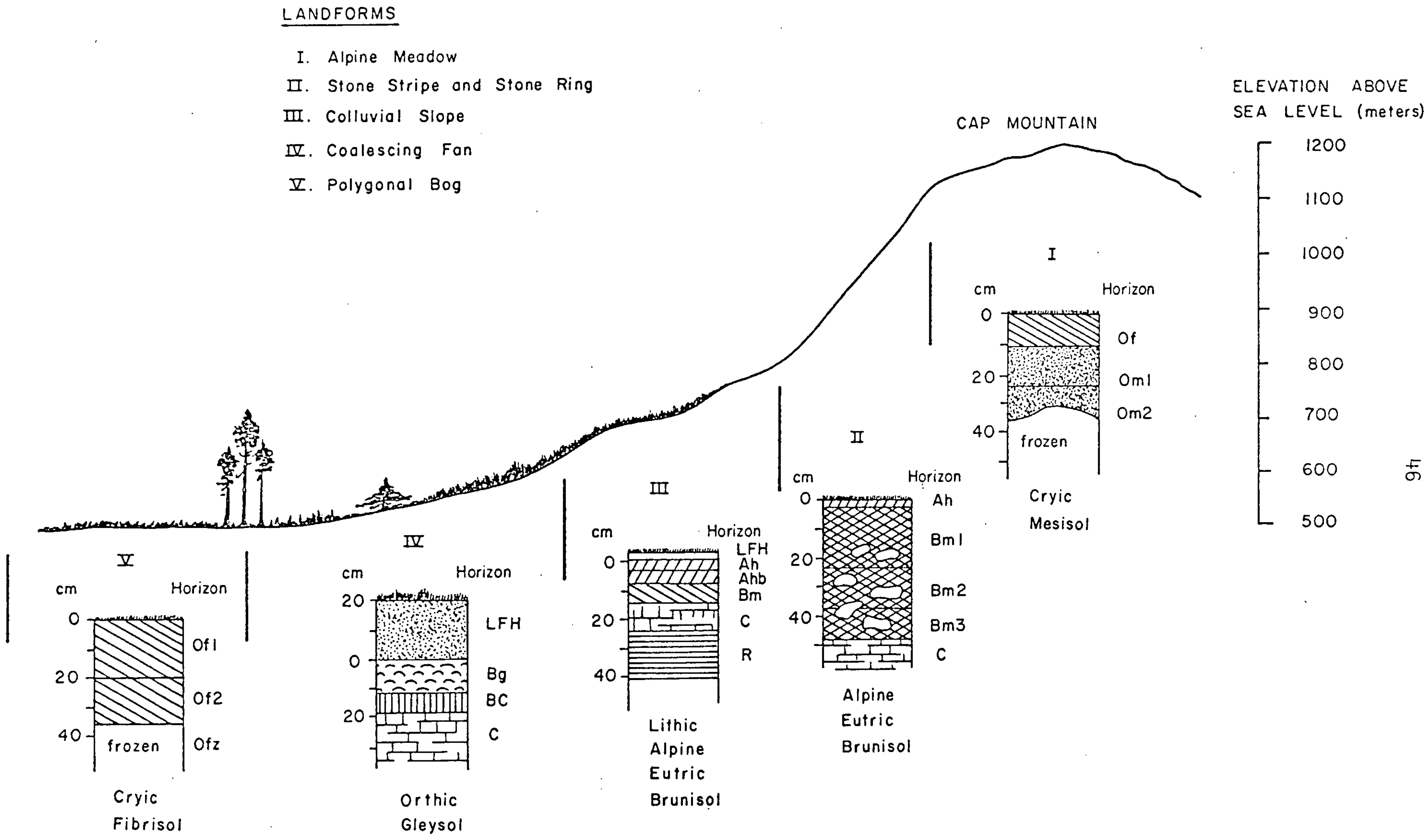

Figure 1. Schematic representation of a toposequence of soils and the relationships to the landform units in the Wrigley area, N.W.T.

summer and winter soil temperatures. The geologic material comprising the substratum, having a relatively loose structure and a clay loam texture, provides an environment conducive for cryoturbic processes to act. The sparse amount of vegetation is indicative of an area of disturbance and also maintains the natural regime by not providing an insulating layer [Flint, 1963]. For similar reasons both the Ah and Bml horizons under the stone ring area had a considerably lower nitrogen level (0.13% and 0.07% respectively) relative to the same horizons developed under the area between the stone rings (0.47% and 0.37% respectively). Just as the depth of the Ob horizons were approximately 5 to 10 cm below the surface of the depressions, the Bml horizon was at approximately the same depth. A depth of approximately 15 cm is suggested for the maximum depth of extensive cryoturbation. Particle size analysis illustrated that these soils had relatively high silt and clay contents. Frost action was considered to be largely responsible for this heterogenity as reported for other soils in similar environments [Sneddon, et al., 1972]. Sites 1, 2 and 4 have a lower silt content in the surface mineral horizon in comparison to the other mineral horizons whereas the converse is true for site 3 (15.2%, 25.5% and 23.7% for sites 1, 2 and 4 respectively and 35.5% for site 3). This was considered to be the result of sites 1, 2 and 4 being more windswept causing removal of fines from the surface while site 3 is located on a stone stripe area and is thus protected from the wind. Evidence of clay translocation at site 3 is illustrated by the distribution of clay in the profile although no clay skins were observed on field examination. Since this material is directly beneath the stone stripe it is considered to be subject to the greatest amount of frost penetration producing the deepest weathering. Also, vertical sorting is pronounced in this zone resulting in a downward migration of fine material. Percent organic matter tended to decrease with depth at all sites. Although no indication was given that organic matter translocation had taken place, the cation exchange capacity values and carbon to nitrogen ratios indicated that organic matter may become more humified with depth. In this region of northern Canada, extremely low temperatures prevailing for most of the year result in the accumulation of organic material due to the low level of microbial activity. Cation exchange capacity decreased with depth as did total nitrogen content and appeared not as much a function of clay distribution as organic matter content. The increase in the Ob horizon for site 2 was a result of the buried organic material incorporated into the solum by cryoturbic processes. The pH values show the soils are slightly acid to neutral, inhibiting the mobilization of Fe and Al. This observation is supported by the data for acid ammonium oxalate extrable Fe and Al which, although illustrating generally more Fe present than Al, indicate no horizons of sesquioxide accumulation are present.

The third unit of study occurred downslope from the stone stripe area on much steeper terrain (25% to 30%). The landform, called the colluvial slope area, was typified by coarse textured material, generally rocky at the surface with many protrusions of bedrock outcrops. The same general chemical trends held for this soil in comparison with the stone stripe area in terms of decreasing organic matter and nitrogen contents with depth. The main differences stemmed from the fact that the surficial material in this area is moving downslope almost continuously as indicated by the presence of the Ahb horizon. Organic material has become incorporated into this pedon by these solifluction and gravitational processes. This has resulted in a relatively higher organic matter content (4.7%) and C:N ratio (33.6) for the soil parent material (C horizon) as compared to the stone ring area (approximately 2% and 14.0 respectively). Also, physical analyses illustrated a coarser texture as well as a higher coarse fragment content in comparison to the stone ring unit. Vegetation has provided little influence on the stability of the material as reflected by the sparse occurrence of herbs and lichens. Pedogenic processes in terms of gravitational and physical weathering acting on the geologic material in this environment have produced the expression of this landform and hence determined the makeup of the ecosystem. The condition of the geologic substratum in terms of its coarse texture and convoluted nature and the sparse vegetation are indicative of the instability of this area.

The coalescing fan landform, occurred at approximately the 800 m level and extended from the foot of the slope for a distance of approximately one kilometer. The landform was characterized by a vast expanse of krummholz life-forms consisting mainly of Picea glauca and various herbs. Due to the nature of the surficial material comprising this landform, it is believed that the area is under constant movement due to gravitational and solifluction processes. Groundwater appear to be constantly flowing through this material during the frost free months with the resultant poorly drained conditions and the production of a Gleysolic order for the dominant soil. Particle size analysis illustrated the coarse texture of these soils with large amounts of sand being characteristic. Low levels of clay and silt in the solum were considered indicative of internal water movement removing fine material from the soil. Constant movement of the geologic material had tended to maintain a pedogenically youthful soil. There was no evidence of extensive clay translocation provided by field inspection or laboratory analysis. Basically, similar trends were present for this soil in comparison to the store stripe area and the colluvial slope area. Organic matter content tended to decrease with depth as did total N and cation exchange capacity. Chemically, the main difference between this landform and the colluvial slope area and stone stripe area was the higher level of humification indicated for the LFH horizon. Organic matter, total N and cation exchange capacity values indicated a higher level of microbial decomposition for the surface layer of organic material. This situation is considered to be resultant from the position of this landform on the landscape. Not only is the landform at a lower elevation than those in the preceding discussion and hence not subject to as harsh a climate but snow accumulation is considered to be large due to drifts blowing off nearby mountains and slopes. Such a situation maintains soil temperatures at a level higher than the prevailing air temperature during the winter months by providing an insulating layer. This landform provided an excellent example for the statement given in the introduction; that vegetation and soils are useful as indicators of a particular environment and not necessarily definers of it. Ecologically, this landform closely approximates the schneetalchen semi-terrestrial habitat commonly found in alpine and subalpine areas of more southern latitudes characterized by soil and vegetation development limited by late snow-lie and a cold usually water saturated root environment [Krajina and Brooke, 1970].

The fifth landform designated on this transect consisted of an extensive lichen covered bog containing cracks and fissures delineating a polygonal structure to the surface. Polygonal ground is defined as ground with a polygonal surface pattern caused by the subsidence of the surface over ground-ice arranged in a polygonal network [Black, 1952]. As in the stone stripe landform, climate is operating in conjunction with a unique array of substrate and surface characteristics [Britton, 1957]. It is the distribution of relief of this landform that causes differences in distribution of ground water and hence vegetative types. Similar to the alpine meadow area an organic soil has developed on this landform. Due to climatic and vegetative differences, the soil material is not as well decomposed as that of the alpine meadow area. Levels of total N are lower in this soil due to decreased microbial activity. Lower total cation exchange capacity and levels of exchangeable cations also reflect the nature of the environment. The pH measurements indicated more acidic conditions for this soil in relation to the soil developed on the alpine meadow landform. Waksman and Stevens [1929] illustrated that acidity has an over-riding influence on the chemical composition of peat due to its effect on vegetation and the rates and products of decomposition. For example, highly acidic sites indicated slow decomposition rates, low levels of microorganism activities and the presence of certain celluloses and hemicelluloses. Less acidic sites normally show a higher rate of decomposition of cellulose and hemicellulose with an accumulation of lignin, proteins and minerals [Walmsley, 1973].

Mineralogical Analyses

The results of selected mineralogical analyses are presented in Table 2.

The clay mineralogy of the soil samples demonstrated that vermiculite was the dominant clay mineral found in the stone stripe landform whereas illite was dominant in the coalescing fan landform. Kaolinite was the next most significant clay mineral. Montmorillonite and chlorite were found only sporadically and in less abundance than the previously mentioned clay minerals. This was indicative of little active weathering and a subdued pedogenic regime. Interstratified minerals such as vermiculite-illite occurring in the material on the stone stripe landform, although in low abundance, indicate slightly more weathering in relation to the other landforms, conceivably the result of cryic processes. Fine grained quartz appeared in all samples.

In general, the clay minerals are little weathered and appear to reflect the original geologic material from which the deposits have been derived.

TABLE 2

X-Ray Identification of Minerals Present in the Clay Fraction

Landform	Horizon	Depth (cm)	Dominant Minerals in Clay Fraction*
Stone stripe and stone ring area	Bm1	12-22	Vm Kt It Qtz Vm-It
	Bm2	22-47	Vm Kt It Mt Cht Qtz Vm-It
	C	47+	Vm Kt It Cht Qtz Vm-It
Colluvial slope area	Bm	8-18	It Kt Qtz
	C	18+	Vm It Kt Qtz
Coalescing fan area	Bg	20-31	It Kt Qtz
	C	39+	It Kt Qtz

*Listed in decreasing order of abundance

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

Water Chemical Analyses

The chemical water data presented in Table 3 indicated a higher dissolved chemical load for the creek flowing into the coalescing fan area as compared to the other sampling sites. A significant increase in dissolved Ca, Mg and K illustrated the use of water chemistry information as an ecological indicator. The increase in dissolved load is due in part to the finer grain size of the materials in the coalescing fan area as well as the greater erosive capacity of the water as it flows down the slope. In this sense, a particular terrain type (landform and soils) is characterized. Differences in bedrock may also be indicated by the data. In terms of soil genesis, the water chemistry data illustrated that the relatively high exchangeable Ca in all horizons of the soil developed on the coalescing fan landform is reflected by the relatively high amount of dissolved Ca in the stream water in this area. Values of approximately 62.0 me/100 gm exchangeable Ca were measured for the soil parent material in this area and 10.4 ppm dissolved Ca were measured for the creek flowing into and through the area. This is in comparison to values of 13.1 me/100 gm exchangeable Ca for the parent material of the dominant soil developed on the colluvial slope landform and 3.1 ppm dissolved Ca in the alpine lake at the top of Cap Mountain. A higher value of dissolved oxygen for the coalescing fan stream as compared with the alpine lake and lake near the polygonal bog area was considered typical due to the mixing and stirring of the stream water as it flows down slope.

The water chemical data also indicated that steady state conditions existed in the alpine lake and the lake near the polygonal

TABLE 3

Results of Water Chemical Analysis

Location	pH*	Dissolved Oxygen*	Ca*	Mg**	Na*	K**	Cl*	F*	NO_3*
			ppm						
Alpine Lake (tarn)	8.1	7.5	3.1	1.4	0.1	0.2	1.3	0.0	3.0
Creek flowing into fan area	7.8	10.6	10.4	5.1	0.2	0.5	1.4	0.6	1.1
Lake; peat polygon area	8.0	8.1	3.5	1.3	0.1	0.1	1.0	0.0	2.8
Polygonal Bog	5.7	1.7	3.6	0.5	0.2	0.4	2.6	0.0	2.6

* *in situ* analysis

** laboratory analysis

bog area. Values obtained for the dissolved chemical load were quite similar for these two bodies of standing water. As well as the water flowing in the creek through the coalescing fan area, water chemical analysis indicated a non-steady state environment for the polygonal bog landform. Water samples examined in the peat polygon area itself were relatively low in dissolved material. Quite acidic conditions (pH 5.7) are typical of bog landforms in this environment, due in large part to microbial activity and an essentially closed environment [Walmsley and Lavkulich, 1973]. Values for dissolved oxygen (1.7 ppm O_2) were also indicative of a closed environment, the bog receiving most of its water in the form of precipitation.

Analysis for the parameters pH, dissolved oxygen, Ca, Na, Cl, F and NO_3 were performed by in situ techniques whereas the parameters Mg and K were analyzed for in the laboratory using an atomic absorption spectrophotometer on water samples collected in the field. A duplicate analysis for Ca and Na performed on the collected samples using atomic absorption techniques provided results compatable with the in situ specific ion electrode analysis.

CONCLUSIONS

The objective of this study was to illustrate the relationships between soil, vegetation, landform and water chemistry in the intermittent permafrost zone of the Boreal Forest. Information presented on soil chemical and physical characteristics indicated considerable cryoturbation in the stone stripe area. Quite sparse or areas often barren of vegetation illustrated considerable downslope movement of material. In the coalescing fan landform, water chemistry data indicated an increase in dissolved chemical load, due to an increase in slope as well as a decrease in the grain size of the material. Clay mineral analyses also indicated the somewhat different pedogenic regimes occurring on each of these landforms firstly by a decrease in the abundance and distribution of clay minerals from the stone stripe to the coalescing fan area and secondly by a difference in the kind of clay minerals present. Just as water chemistry information indicated areas affected by harsh conditions produced, for example, by slope or climate, mineralogical analyses also identified such areas through an indication of the kind and amount of clay minerals present. Both soil and vegetation provided useful indicators of the polygonal bog environment. The developed soil, due to its frozen nature, is undecomposed relative to the organic soil in the alpine landform. As an example, the dense lichen cover is often considered useful as an indicator of the presence of permafrost [Korpijaakko and Radforth, 1966] in peatlands. Brown [1968] however, disagreed with this concept, as he points out, lichens proliferate in many peat landforms where no permafrost exists as well as being absent from many areas where permafrost occurs. This contradiction points to the necessity of interpreting all three factors; soil, vegetation and landform to facilitate a thorough understanding of the ecosystem. Water chemical data has also proven beneficial as an environmental indicator by several examples. An indication is given of steady state conditions by both the alpine lake and polygonal bog lake sample sites. The increased chemical load in the coalescing fan creek illustrates the greater competency of the water as well as greater mixing and stirring as indicated by the higher dissolved oxygen concentration. Water chemical analysis also characterizes the polygonal bog landform by indicating the increased acidity and the oxygen concentration of the water, typical of a partially closed environment in this region.

In general, an indication is given of the value of coupling information on soil, landform, vegetation and water chemical relationships in order to better understand the complex interactions in each environment. It is suggested that a thorough analysis of these four parameters, in relation to each other, will provide a working framework for any land use or management of a particular environment.

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CHAPTER 3

IN SITU MEASUREMENT OF DISSOLVED MATERIALS AS AN INDICATOR OF ORGANIC TERRAIN TYPE

ABSTRACT

Portable equipment has been used to measure selected environmental parameters in situ A battery operated potentiometer used in conjunction with several specific ion electrodes, a platinum redox electrode and a combination pH electrode were used to obtain ion activity, pH and Eh measurements of natural systems. In addition, dissolved oxygen concentration was measured using an oxygen electrode and battery operated meter. Results from the analysis of several streams is presented to illustrate the application of the technique to field measurements of streams as an indicator of environmental disturbance. Information collected also allowed for the differentiation of different types of organic terrain based on the dissolved load of the saturated organic materials. The terrain type referred to as fen had a higher activity of Na, Cl and Ca, a higher pH value and a lower concentration of oxygen than the bog terrain type. These results are explained with reference to organic terrain morphology and the distribution of permafrost in the study area.

INTRODUCTION

In view of the importance of water in every facet of the physical environment, it is surprising to note that few accurate and reliable methods exist for the *in situ* measurement of the dissolved chemical load of water in the natural environment. Often, water quality studies are either not oriented towards integration with the natural physical environmental parameters or the analysis is carried out by sampling the water, with subsequent storage prior to analysis, with little regard to the changes in the chemistry of the sample during the storage process.

Often, streams carry more dissolved matter than they do solid particles [Morisawa, 1968]. The proportions of suspended and dissolved loads depends in part upon the relative contributions of groundwater and surface runoff to stream discharge. When the flow results primarily from groundwater flow, the concentration of dissolved material is generally high. This concentration of dissolved salts is usually lower when surface runoff contributes most to stream flow. Also, the biological balance of the stream will affect the chemical balance. Certain dissolved material can be taken up by organisms that live in the stream and be subsequently released, often in a different form, at death. It has been suggested that the environmental factors which determine the chemical composition of river water are climate, geology, topography, vegetation and time [Gorham, 1961].

As a relatively mobile component of nature, water responds quickly to the influences of the environment as can be appreciated by relatively recent interests in water quality studies as indicators of environmental quality and pollution [McGriff, 1972]. Studies have recognized the fact that water is affected and effects every part of the physical environment and is thus a useful agent to monitor. Hence, in some areas, it is possible to use this information to define terrain units since the water will have a dissolved chemical load that is a direct function of the type of geologic material with which it has come in contact.

The objectives of this study were to illustrate the use of portable equipment and specific ion electrodes as an aid in obtaining water quality measurements in areas where costly monitoring equipment is not justified and also to demonstrate the usefulness of the approach in relating water chemistry to terrain and soil indices. Relationships between landform, soil, vegetation and water chemistry that were investigated in Chapter I are further elucidated with specific reference to organic landforms in this region of the Boreal Forest. Organic terrain or muskeg covers extensive areas in this region and hence an understanding and its makeup is important in terms of its use characteristics.

MATERIALS AND METHODS

The two areas of study were in the vicinity of Watson Lake, Yukon Territory and Fort Simpson, North West Territories. Soils in the Watson Lake area are developed essentially from coarse textured glacial fluvial outwash and glacial till material which were derived from a variety of bedrock materials. The streams draining this area, therefore, reflect variable geologic and soil-landform conditions. In the Fort Simpson area, the soils studied were exclusively organics. The underlying mineral material was generally medium to fine textured glacial till deposits. In some areas, a shallow layer of lacustrine material covered the glacial till. Results of the laboratory analysis of two organic soils are given in Table 1.

Analytical Methods

The potentiometer used in conjunction with the specific ion electrodes was the Orion Model 407 Ionalyzer (Orion Research Inc., Mass.). It is a transistorized, battery operated potentiometer which may be used with monovalent or divalent cation or anion electrodes and with pH and redox electrodes. A special scale permits direct readout of ion concentrations in several concentration units. The specific ion electrodes employed were solid state Cl, Na and F ion electrodes and liquid junction Ca and NO_3 ion electrodes. Redox measurements were taken with a combination platinum electrode using saturated KCl as the reference filling solution. A combination pH electrode employing saturated KCl as the reference filling solution was used for the measurement of hydrogen ion activity.

Two standard solutions of each ion measured that encompassed the range of activity values expected, were used to standardize the potentiometer to allow direct readout of the activity value on the logarithmic scale. These standard solutions were contained in plastic bottles and replaced every few days with a fresh portion to decrease the chance of contamination and deterioration. Great care was employed in rinsing the electrode with distilled water and wiping dry prior to placing it in the standard solutions. Buffer solutions of a certain pH value were also employed to standardize the meter for pH determinations. These solutions were prepared fresh every few days from the dry chemical to ensure a reliable standard.

A single junction reference electrode (Orion Model 90-01) was used with the NO_3 and Ca specific electrodes. Saturated KCl was used as the filling solution. The sleeve-type construction of this electrode eliminates the problems associated with the frit and fibre-type junctions, but does not eliminate the liquid junction potential. A double junction (Orion Model 90-02) reference electrode was used with the Cl electrode to minimize the liquid junction potential and avoid sample contamination. The choice of reference electrode, as well as a sensitive potentiometer, is of prime importance in obtaining accuracy with specific ion electrodes.

The response of specific ion electrodes is Nernstian in nature and, therefore, similar in operation to pH electrodes. Since some specific ion electrodes will respond to a certain extent to ions other than the one it was designed to measure, there is an additive term in the normal Nernst equation. Equation [1] is the modified form of the Nernst equation.

$$E = E_a - \frac{RT}{n_x F} \ln [A_x + K_y (A_y)^{1/n_y}] \qquad (1)$$

where

E = the measured total potential of the system

E_a = the portion of the total potential due to the choice of the reference electrode and internal solution

R = universal gas constant (8.314 joule $^oK^{-1}$)

T = temperature in degrees absolute

n_x = number of electrons transferred in half-reaction of ion to be measured

F = Faraday constant (9.65×10^4 coulomb mole^{-1})

A_x = activity of the ion to be measured

K_y = selectivity constant for the interfering ion

A_y = activity of the interfering ion

n_y = number of electrons transferred in half-reaction of interfering ion.

This additive term is made up of three parameters, namely the charge on the interfering ion, the activity of the interfering ion and the selectivity constant for the interfering ion. Selectivity constants are usually determined by the manufacturer of the electrode. Normally, selectively constant values are given for several species.

By using a ratio of this additive term to the term for the activity of the ion one wishes to measure, a percentage interference on percentage error can be defined. This allows a better understanding of the accuracy of the measurement if the activity levels of the highly interfering ions are known [Mack and Sanderson, 1970].

Similar to the specific ion meter is the Y.S.I. Model 54 oxygen meter (Yellow Springs Instrument Co. Inc., Ohio). This meter, in conjunction with an oxygen electrode is capable of determining the dissolved oxygen concentration of liquids within the range of 0.0 to 20.0 ppm. The technique employed by the electrode is polarography or, more specifically, voltammetry. Dissolved oxygen is reduced at the polarized electrode and the meter is designed to indicate the concentration of dissolved oxygen in parts per million. Standardization is accomplished by reference to a table of oxygen concentrations in the atmosphere at a particular barometric pressure and at a certain temperature. For this purpose, a sensitive barometer is required. Temperature measurement is achieved with a temperature probe that is an integral part of the electrode. The meter has a scale that permits temperature readout. The maximum error is stated by the manufacturer to be $\pm$ 0.59 ppm O_2 at 20°C.

In the laboratory analysis of the organic soils (Table 1), the determination of pH was carried out in 1:4 organic material-water and in 1:8 organic material 0.01M $CaCl_2$ slurries. Organic matter was estimated by determination of total carbon with a Leco induction furnace and carbon analyzer [Allison _et al._, 1965]. Total nitrogen was determined by Kjeldahl methods [Bremner, 1965]. Cation exchange capacity and exchangeable cations were determined by neutral, normal NH_4OAc leaching, followed by micro-Kjeldahl determination of absorbed ammonium and atomic absorption spectrophotometric procedures for exchangeable cations, as developed in the U.B.C. Department of Soil Science laboratory.

Field Application

Due to the remoteness of the study sites, small aircraft were used exclusively to achieve access to the areas. With this type of transportation, a protective device for the instruments is required that is both convenient for carrying the equipment and sturdy enough to withstand repeated shock. A rigid box, mounted on a packboard frame proved to be reasonably satisfactory for this purpose.

Great care must be exercised when using this type of equipment in the field. The meters must not be jarred too severely or exposed to high-humidity for long periods of time. None of the electrodes should be forced into mineral soil or have their membrance touched by any rough surface. Precautions that may become lax in the laboratory must be rigidly followed in the field.

TABLE 1

Selected Chemical Properties of Two Organic Soils

Soil	Horizon	Depth	pH		O.M.	N	Exchangeable Cations				C.E.C.
			H_2O	$CaCl_2$	%	%	Ca	Mg	Na	K	
							me/100g				
Cryic Fibrisol	Of_1	0 - 7.5	4.0	3.5	75.92	0.89	25.00	5.38	0.18	1.50	118.95
	Of_2	7.5 - 32.5	4.1	3.5	78.23	1.40	28.38	5.63	0.24	0.50	158.94
	O_z										
Cryic Mesisol	Om_1	0 - 15.0	6.5	6.3	65.73	1.88	81.25	34.00	5.50	0.50	166.27
	Om_2	15.0 - 30.0	5.5	5.1	77.56	1.46	42.50	19.25	1.50	2.63	93.30
	O_z										

RESULTS AND DISCUSSION

Results of the in situ analysis in the Watson Lake area (Table 2) indicate that with the exception of a few minor differences, the six streams studied have essentially the same chemical status with respect to the parameters analyzed. The values obtained correspond with values obtained previously by other methods in different parts of North America [Morisawa, 1968]. Ca activities ranged from 2.4 ppm to 22.2 ppm and Na activities from 1.0 to 2.3 ppm. Oxygen concentrations of 10.2 ppm to 10.6 ppm and Eh values of 256.4 mV to 316.4 mV were found. The minor chemical differences among these rivers may be attributed to the fact that each is located in a slightly different environment. For example, the amount of oxygen dissolved in water is a function of the temperature of the water and the barometric pressure at the time of measurement. Hence, the concentrations may change slightly from river to river strictly because of climatic differences.

Values for the parameters above and below the mining operation indicate that there is a substantial change in the chemical status of the river. The change from an oxidizing to a reducing state may be of extreme importance. Not only may aquatic life be altered but any engineering application, such as bridge or pipeline construction, could be adversely affected. The increase in F activity below the mining operation illustrates that the chemical analysis of water can be used as an indicator of terrain disturbance.

Mainly because of differences associated with respect to permafrost, there has arisen a need for a more strict definition as

Table 2. Chemical composition of some river waters in the Watson Lake area, Yukon Territory

Location	Ca^{++}	Cl^-	NO_3^-	F^-	Na^+	O_2	Eh*
	ppm						mV
Little Rancheria	11.2	1.8	1.3	5.5	2.3	10.4	286.4
Big Creek	22.2	1.3	-	2.3	1.5	10.4	256.4
Canyon Creek	4.8	1.7	-	0.7	1.0	10.3	256.4
Upper Rancheria	4.0	2.5	1.4	1.7	1.1	10.1	266.4
Swift River	7.4	1.6	-	2.0	1.3	10.2	316.4
Seagull River	2.4	6.1	1.5	2.1	1.1	10.6	266.4
Above Mining Operation	10.6	1.4	1.6	1.0	0.5	11.1	296.4
Below Mining Operation	12.6	3.3	1.7	5.2	1.6	10.7	156.4

*$Eh = E_{measured} + Eh_{reference\ electrode}$

$Eh_{reference\ electrode} = 246.4$ mV

well as a better understanding of the different segments that make up extensive areas of organic soils. Figure 1 illustrates the relationship of some organic soils in Northern Canada. These organic terrain types may be divided into two parts, namely bog [Drury, 1956] and fen [Sjors, 1963]. The fen is open to the inflow of mineral rich water from rivers and ground water, while the bog is enclosed by a peat plateau [Radforth, 1955]. The peat plateau is essentially composed of frozen peat which restricts the inflow of groundwater and limits the bog to precipitation as a source of water. The spatial relationship between the bog and peat plateau as viewed from the ground is presented in Figure 2. An oblique photograph taken from an aircraft of a peat plateau area that had been partially burnt is presented in Figure 3. The bogs appear as lighter blotches within the reddish peat plateau matrix. Figure 4 illustrates a fen typical of the region around Fort Simpson. The effect of groundwater flowing through the area is to produce the darker network of lines within the light green area. These drainage lines are distinct because of the different vegetation supported by the mineral rich ground water.

Activity values for the measured ionic species (Table 3) illustrates the chemical differences between these two terrain types. There is a general increase in Na, Cl, Ca and NO_3 activity in the fen compared to the bog. The two transitions between these terrain types are also in line with the reasoning that the fen is minerotrophic (associated with water from mineral soil) while the bog is ombotrophic (less influenced by soil water than by direct precipitation). Selected

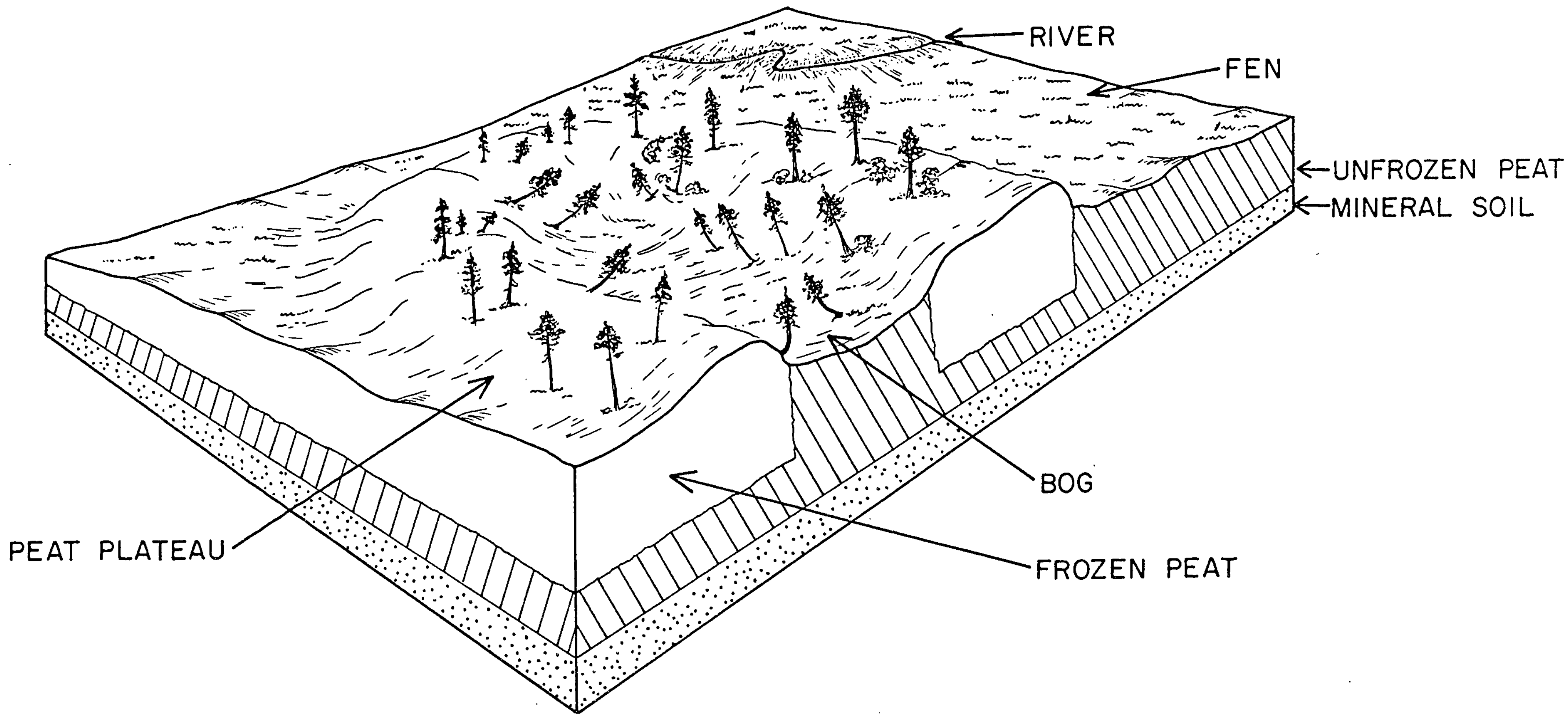

Figure 1. Schematic diagram of a dominantly organic landscape.

Figure 2: Bog area surrounded by peat plateau.

Figure 3: Oblique photograph of partially burnt peat plateau area.

Figure 4: Fen area illustrating ground water flow along network of drainage lines.

Table 3. *In situ* measurement of selected chemical parameters associated with organic terrain types

Variable	Bog	Transitional Bog	Transitional Fen	Fen
pH	3.8	4.4	4.8	6.5
Na^+ (ppm)	0.6	9.7	14.5	47.7
NO_3^- (ppm)	3.4	2.7	6.3	6.5
Cl^- (ppm)	4.1	3.4	19.0	70.0
Ca^{++} (ppm)	7.2	99.0	100.0	140.0
O_2 (ppm)	6.1	5.1	2.0	1.8

chemical properties (Table 1) of the soil developed on the bog (Cryic Fibrisol) and on the fen (Cryic Mesisol) also indicate the effect of groundwater on these two terrain types. Pictorial examples of a Cryic Fibrisol and a Cryic Mesisol typical of those sampled are given in Figures 5 and 6 respectively. The Cryic Mesisol has a higher pH value and N content. The exchangeable cations show a significant increase in the Cryic Mesisol compared to the Cryic Fibrisol. Higher pH values in the fen are also indicative of the inflow of nutrient rich waters. Although one might expect the dissolved oxygen concentration to be higher in the fen, it is believed that due to the higher activities of nutrients in the fen water, vegetative species are supported that reduce the dissolved oxygen level. Since the oxygen level is low, bacteria that normally use dissolved oxygen will extract it from a variety of compounds dissolved in the water. For example, the reduction of sulphate to hydrogen sulphide produces the required oxygen for the bacteria and also the characteristic 'rotten egg' odor of the fen [Stanier et al., 1965].

The results obtained indicate the usefulness of specific ion electrodes and related portable equipment for the *in situ* measurement of dissolved materials in water and soil solution. The methodology has application in relating water chemistry to terrain type as well as an indicator of modification of the physical environment. With water samples and saturated soils the methodology appears to be precise and useful for characterization without the need for costly permanent installations. It is believed that this technique could be applied for the determination of selected dissolved parameters, such as oxygen,

Figure 5: Cryic Fibrisol soil, frozen at 30 cm.

Figure 6: Cryic Mesisol soil, frozen at 25 cm.

in attempting to characterize soil drainage, provided there exists enough groundwater at the sites for measurement. It must be emphasized, however, that certain problems exist in the application of this methodology to natural systems, such as soils. Problems associated with electrodes being coated by dissolved materials and the extent of interference from other substances require further study and elucidation. Problems associated with disruption of the natural equilibrium during the measurements of dissolved materials are still probable, especially with considerations of redox potential and dissolved oxygen. It is felt, nevertheless, that the methodology, if carried out with care, yields more reliable data than conventional methods of sampling and storage followed by laboratory analysis.

Due to the climate in the area it is believed that the sampling and analysis of water associated with these landforms in this area should be performed during July and early August in order to obtain near equilibrium conditions between the ground water, the atmosphere and the soil materials after the spring thaw period. In order to understand the inherent variability associated with this analysis it is believed a minimum of three and perhaps five years of sampling is required.

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SUMMARY

In summary, methodology developed for the use of specific ion electrodes and other portable equipment for the determination of *in situ* water chemical parameters proved beneficial for the collection of data illustrating the relationships between terrain types in terms of landform, soil and vegetation and chemical water quality. The catenary sequence of landform, soil and vegetative types in the Wrigley area, N.W.T. provided information on the characterization of the physical environment in the region of the Boreal Forest and provided a physical base upon which a discussion of the relationship between these parameters and the dissolved chemical load of the water associated with the various units can be integrated. Physical and chemical information presented for the soils sampled from each of the units indicated areas of extensive cryoturbation characteristic of northern climates as well as areas of instability, essentially devoid of vegetation. Special emphasis is placed on the strongly influential effect that landform, in conjunction with elevation, plays in shaping the structure and function of ecosystems. Vegetation, soils and water chemistry are illustrated as useful indicators of particular environments as they are a function of landform as influenced by elevation in a particular climatic regime. The definition of the two organic terrain types, bog and fen, illustrates this principle by using water chemistry as a definitive criteria. Soil, vegetation and organic terrain morphology also provide a basis for the distinction of these two terrain types. Specifically, information is presented on the value of coupling data on soil, landform, vegetation and water chemical relationships in order to better understand the

complex interactions in each environment. It is suggested that an integrated analysis of these four parameters within a particular climatic region will provide a working framework for any land use operation or management of a particular environment.